UNIVERSIDAD NACIONAL DE INGENIERÍA

FACULTAD DE INGENIERÍA CIVIL

ESTUDIO DEL COMPORTAMIENTO DEL CONCRETO DE MEDIANA A ALTA RESISTENCIA, CON LA INCORPORACIÓN DE FIBRAS DE ACERO Y CEMENTO PÓRTLAND TIPO I ANDINO

TESIS

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DEDICATORIA

A Dios por darme vida
y una familia maravillosa

En memoria de mi padre Ángel, cuyo amor eterno me acompaña y guía mis pasos, como el siempre nos replicaba: hoy mejor que ayer y mañana mucho mejor, asumo sus enseñanzas para cada día ir superándome.

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INTRODUCCION

Dentro de las nuevas tecnologías y materiales que van apareciendo para hacer frente al desarrollo de la construcción, los hormigones con fibras especialmente con fibras de acero, han venido a mejorar alguna de las propiedades que en el hormigón tradicional no tenían, que le exigían determinadas aplicaciones. Así nos encontramos que las fibras de acero dispersas en le masa del hormigón y presentando una distribución uniforme, aparte de conferir al material una homogeneidad y una isotropía, ejercen una acción reforzante muy eficaz en la respuesta a acciones como la tensión, impacto etc.

No es de extrañar que ante la mejora que la incorporación de fibras de acero produce en los hormigones, éstos hayan encontrado una gran aceptación en muchas de las aplicaciones debido a que mejora sus propiedades, como es el caso de los pavimentos de hormigón en carreteras, en aeropuertos; igualmente su aplicación es importante en gunitados de túneles, canales y taludes, fabricación de tubos etc.

Nuestro país cuenta con una variedad de climas donde se realizan obras de minería, civil y subterránea de gran envergadura, en la cual se hace uso de concreto con fibras de acero debido a que se incrementa la resistencia al fisuramiento, ductilidad y tenacidad.

La presente tesis de investigación tratara sobre el comportamiento de un concreto sin fibras (patrón) y de un concreto con adición de fibras. Las relaciones de agua/cemento a estudiar son 0.40, 0.45, 0.50 y las dosificaciones de fibra de acero INSONEX serán de 30, 40, 50 Kg/m^3 de concreto; para cada relación de a/c. Cabe resaltar que la fibra de acero Insonex a utilizar en la presente investigación es de producción nacional fabricada por la empresa INSOMIN.

Los ensayos a realizarse serán efectuados sobre el concreto para estudiar sus propiedades principales, visto desde el aspecto practico de colocación y compactación asi como el diseño. En el ESTADO FRESCO se abordara los ensayos de: asentamiento, fluidez, peso unitario compactado, tiempo de fraguado, contenido de aire, exudación , y en el ESTADO ENDURECIDO se realizaran los ensayos de: compresión, tracción por compresión diametral, modulo elástico estático, flexión, impacto. Estos ensayos se realizaron en el Laboratorio de Ensayo de Materiales (LEM) de la Universidad Nacional de Ingeniería.

Actualmente en la Universidad Nacional de Ingeniería se han realizado y vienen realizándose investigaciones sobre concretos con adición de fibras de acero, que a continuación indicamos: " Estudio de las propiedades del concreto utilizando fibras de refuerzo de acero", " Estudio del comportamiento del concreto de mediana a baja resistencia con la incorporación de fibras de acero" etc.

Este programa de trabajo, se emana en un estudio mas amplio sobre el comportamiento del concreto con fibras de acero, que contribuirá al conocimiento y difusión de técnicas modernas que son fuertemente utilizadas en otros países.

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CAPITULO 01

EL CEMENTO

1.1 GENERALIDADES

El cemento es un producto artificial, que se obtiene de la transformación de una materia prima, que puede estar compuesta de una mezcla de calizas, arcillas y otros minerales. Esta materia prima finamente molida y homogenizada, es llevada a altas temperaturas, a través de un horno, (rotativo o vertical), de donde se obtiene un producto intermedio denominado Clinker, del cual, al molerse finamente con alrededor de 5% de yeso, se obtiene el cemento.

Este cemento obtenido así, esta constituido por sales minerales anhidras inestables (en particular Silicatos y Aluminatos de cal) que con el agua, forman una pasta capaz por "Hidratación" de fraguar y endurecer progresivamente, adquiriendo propiedades resistentes y adherentes.

1.2 DEFINICIONES

1.2.1 Clinker.- Es un producto obtenido por cocción hasta la fusión parcial (clinkerización) de la materia prima (debidamente proporcionada y homogenizada, que debe contener como elementos principales al Calcio, el Silicio, el Aluminio y el Fierro).

Estos elementos principales, que se encuentran en forma de óxidos: la cal (CaO), sílice (SiO_2) y alumina (Al_2O_3), se obtiene en general a partir de productos naturales de cantera (caliza como aportadora del Calcio, arcilla para el Silicio y el Aluminio, la Pirita o hematita para el fierro, etc.).

En el proceso de clinkerizacion, se producen cuatro nuevos compuestos mineralógicos principales en el clinker:

El Silicato Tricalcico	(C_3S),
El Silicato Bicalcico	(C_2S)
El Aluminato Tricalcico	(C_3A)
El Ferro-Aluminato Tetracalcico	(C_4AF)

Ellos son, los que le dan las características de comportamiento, al clinker obtenido de las materias primas que se utilizan en cada fabrica de cemento.

Este clinker, una vez triturado, con la adición del sulfato de sodio (yeso natural) de alrededor de 5% (que juega el papel regulador), se convierte en “ Pórtland ” y confiere a los cementos de este grupo sus propiedades características.

1.2.2 Cemento Pórtland.- Es un producto obtenido por la pulverización del Clinker, con la adición eventual del sulfato de calcio. Excepcionalmente se admite adiciones, las cuales no deben exceder del 1% de los otros materiales, que pueden ser molidos conjuntamente con el Clinker, siempre que dichas adiciones hayan mostrado no ser dañinas.

El cemento Pórtland normal se clasifica en cinco tipos diferentes, de acuerdo a las proporciones relativas de los cuatro compuestos principales y que responden a diferentes requerimientos constructivos.

1.3 CLASIFICACIÓN DE LOS CEMENTOS

De acuerdo a las normas NTP y a las Internacionales ASTM, los cementos están clasificados en dos grandes grupos:

1.3.1 CEMENTO PÓRTLAND

Tipo I	De uso general donde no se requieren propiedades especiales.
Tipo II	De moderada resistencia a los sulfatos y moderado calor de hidratación. Para emplearse en estructuras con ambientes agresivos y/o en vaciados masivos.
Tipo III	Desarrollo rápido de resistencia con elevado calor de hidratación. Para uso en climas fríos o en los casos en que se necesita adelantar la puesta en servicio de las estructuras.
Tipo IV	De bajo calor de hidratación. Para concreto masivo.
Tipo V	Alta resistencia a los sulfatos. Para ambientes muy agresivos. Cuando a los tres primeros tipos de cemento se les agrega el sufijo A (p.e Tipo IA) significa que son cementos a los que se les a añadido incorporadores de aire en su composición, manteniéndose las propiedades originales.

1.3.2 CEMENTO PÓRTLAND ADICIONADOS

Son cementos obtenidos por la mezcla del Clinker Pórtland con los materiales de adición y yeso, dentro de los limites especificados por las normas. La particularidad de reemplazar parte del cemento por estos materiales, estriba en cambiar algunas de sus propiedades, como son el retrasar y/o disminuir el desarrollo de resistencia en el tiempo, incrementar la permeabilidad, mayor capacidad para retener agua, mayor cohesividad, incremento de los requerimientos de agua para formar la pasta, menor calor de hidratación y mejor comportamiento frente a la agresividad química.

Ellos se dividen en dos tipos principales:

- Cemento Pórtland de Escorias y
- Cemento Pórtland Puzolanicos.

Cemento Pórtland Puzolanico de Escoria Tipo IS

Cemento al que se ha añadido entre un 25% a 70% de escoria. Es para los mismos usos del cemento Pórtland Tipo I, y especialmente para las obras de concreto armado subterráneo, todo tipo de aguas agresivas (en particular agua de mar) y todo tipo de obras hidráulicas. Su empleo es también conveniente en ciertos pavimentos y estabilización de suelos. Uso limitado en revoques enlucidos, obras de pequeño espesor. Fue fabricado por Cementos Pacasmayo.

Cemento Pórtland Puzolanico Tipo IP

Cemento al que se ha añadido puzolana en un porcentaje que oscila entre el 15% y 40% del peso total. Son para uso general en la construcción, especialmente para obras de grandes masas de concreto y obras que requieren resistencia a las aguas agresivas (agua de mar, aguas negras, etc.).

CUADRO N° 1.1

COMPONENTES DE LOS CEMENTOS ADICIONADOS EN (%)

TIPO	CLINKER	ESCORIA	PUZOLANA
IS	75-35	25 – 65	-----
ISM	> 75	< 25	-----
IP	85-55	----	15 – 40
IPM	> 85	----	< 15

1.4 CARATERÍSTICAS FÍSICAS DEL CEMENTO

1.4.1 PESO ESPECÍFICO

Se define como la relación de la masa de un volumen unitario de un material a una temperatura determinada, a la misma masa del mismo volumen de agua destilada libre de aire.

Su determinación es importante en el control y diseño de mezclas.

La norma NTP 334.005, establece el método de ensayo por medio de un frasco volumétrico de Le Chatelier para determinar el Peso Especifico.

1.4.2 CONSISTENCIA NORMAL

Se considera que una pasta tiene una consistencia normal cuando, para un porcentaje dado de agua se obtiene una penetración de 10mm. En 10 seg. Con la varilla de Vicat.
Se determina de acuerdo a la Norma NTP 334.006

1.4.3 FRAGUADO

Es el paso del estado fluido al estado sólido. Se entiende que la pasta de cemento ha fraguado cuando esta lo suficientemente rígida como para soportar una presión arbitraria definida.

El tiempo de fraguado se puede determinar con la aguja de Vicat o de Gillmore. El método de la norma es utilizando el aparato de Vicat.

Se determina de acuerdo a la Norma NTP 334.006

1.4.4 RESISTENCIA A LA COMPRESIÓN

Es la propiedad física que define la capacidad del cemento para soportar esfuerzo sin falla. La velocidad del desarrollo de la resistencia es mayor durante el periodo inicial de endurecimiento y tiende a disminuir gradualmente en el tiempo.

El ensayo se hace en cubos de mortero de proporciones prefijadas de arena standard, de acuerdo a la norma NTP 334.051. El valor de la resistencia a los 28 días, se considera como la resistencia del cemento.

1.4.5 SUPERFICIE ESPECÍFICA

La superficie especifica es el índice de fineza del cemento, es decir, de su grado de molienda. Cada tipo de molienda produce una composición granulométrica diferente y por ende una superficie especifica diferente.

Influye sobre la trabajabilidad y los requisitos de agua en la mezcla. Aumentando a fineza del cemento mejora su calidad, hay mayor rapidez y eficacia en la reacción con el agua, ya que aumenta la superficie de contacto agua-cemento, quedando menores cantidades de cemento sin hidratar.

SUPERFICIE ESPECIFICA MEDIANTE EL ENSAYO DE PERMEABILIDAD AL AIRE DE BLAINE (Norma NTP 334.002)

Los valores Blaine se calculan a partir de la permeabilidad al aire de una capa de cemento de peso determinado compactados en condiciones dadas. Esta capa de cemento opone al paso de aire una resistencia que es, tanto mayor cuanto más elevada es la superficie especifica del cemento.

1.4.6 ESTABILIDAD DE VOLUMEN

Es la medida de la expansión potencial, que indica la existencia de agentes expansivos en el cemento, generalmente debido a la cal libre no determinadas en el análisis químico.

El ensayo se realiza, de acuerdo al Norma NTP 334.004

1.5 CARACTERÍSTICAS QUÍMICAS DEL CEMENTO

Por medio del análisis químico del cemento se encuentran sus óxidos principales.

El cálculo de los compuestos del cemento, se hace sobre la base de los óxidos principales que son:

- CAL	(CaO)
- SÍLICE	(SiO2)
- ALUMINA	(AL2O3)
- HIERRO	(FeO3)

El método para calcular los compuestos mas generalizados es el del químico Bogue; según este método los compuestos principales del cemento son las que se muestran en el cuadro N° 1.2.

CUADRO N° 1.2

COMPUESTOS PRINCIPALES DEL CEMENTO PÓRTLAND

COMPUESTOS PRINCIPALES	FORMULA	ABREV.	%
Silicato Tricalcico	3CaO.SiO2	C3S	40-65%
Silicato Dicalcico	2CaO.SiO2	C2S	10-30%
Aluminato Tricalcico	3CaO.Al2O3	C3A	7-15%
Aluminato-Ferrito Tetracalcico	4CaO.Al2O3.Fe2O3	C4AF	4-5%

Por ser ellos, los compuestos que le dan las características de comportamiento al Clinker, y por ende definen el comportamiento del cemento hidratado, pasaremos a describir brevemente sus características individuales.

1.5.1 Silicato Tricalcico (C_3S).- Su contenido general en el Clinker, puede variar entre el 40 y 65%; cuando es más alto, se obtiene un más rápido desarrollo de las resistencias iniciales (en la primera semana), incrementándose el calor de hidratación.

1.5.2 Silicato Dicálcico (C_2S).- Este silicato de calcio, que con el anterior son los dos compuestos mayoritarios y principales del Clinker, y que determinan las características de comportamiento de las resistencias a compresión, se encuentra entre el 10 y el 30% del total de la composición. A diferencia del silicato Tricalcico, su desarrollo de resistencias es lento en las edades iniciales, y por lo tanto es menor su calor de hidratación. La suma de ambos silicatos debe ser de alrededor de 70 a 75% del total de la composición del Clinker.

1.5.3 Aluminato Tricálcico (C_3A).- Su composición en el Clinker puede variar entre 7 y 15%. Aisladamente no tiene trascendencia en la resistencia, pero con los silicatos condiciona el fraguado violento actuando como catalizador, por lo que es necesario añadir yeso en el proceso (3% - 6%) para controlarlo. Es responsable de la resistencia del cemento a los sulfatos ya que al reaccionar con estos produce Sulfoaluminatos con propiedades expansivas, por lo que hay que limitar su contenido.

1.5.4 Aluminito-Ferrito Tetracálcico (C_4AF).- Su presencia es de menor importancia en comparación a la de los anteriores compuestos mencionados. Puede llegar a estar entre el 4 al 15% en la composición del Clinker. Tiene trascendencia en la velocidad de hidratación y secundariamente en el calor de hidratación.

Nota.- Cuando se menciona " resistencias" se refiere a la resistencia mecánica a la compresión, que no es la única, ni la más importante de todas las características del cemento y concreto, pero sí la más usual. (ACI 211.1-3)

Además de los compuestos principales, para completar el análisis se incluyen los llamados compuestos secundarios:

CUADRO N° 1.3

COMPUESTOS SECUNDARIOS DEL CEMENTO PÓRTLAND

COMPUESTO SECUNDARIO	FORMULA	ABREV.
Oxido de Magnesio	MgO	
Óxidos de Potasio y Sodio	$K2O.Na2O$	
Óxidos de Manganeso y Titanio	$Mn2O3.TiO2$	
Perdida por calcinación		PC
Residuo insoluble		IR

Las variaciones de los compuestos son muy grandes, por ejemplo el ASTM para el cemento de uso general, no da limites de compuestos, o sea considera que, si en cemento pasa las pruebas físicas y esta dentro de los requerimientos químicos, sus óxidos principales y sus compuestos pueden tener cualquier valor; en caso de otros tipos de cemento da ciertos limites en algunos óxidos y compuestos.

1.6 CONCEPTOS IMPORTANTES REFERENTE A LAS PROPIEDADES FÍSICAS DEL CEMENTO:

1.6.1 Mecanismo de Hidratación

Se denomina hidratación al conjunto de reacciones químicas entre el agua y los componentes del cemento que llevan consigo el cambio del estado plástico al endurecido, con las propiedades inherentes a los nuevos productos formados. Los componentes ya mencionados anteriormente, al reaccionar con el agua forman hidróxidos e hidratos de Calcio complejos.

Dependiendo de la temperatura, el tiempo y la relación entre la cantidad del agua y el cemento que reaccionan se pueden definir los siguientes estados:

1.6.1.1 Plástico

Unión del agua y el polvo de cemento formando una pasta moldeable. Cuanto menor es la relación agua/cemento, mayor es la concentración de partículas de cemento en la pasta compactada y por ende la estructura de los productos de hidratación es mucho más resistente.

El primer elemento en reaccionar es el C_3A, y posteriormente los silicatos y el C_4AF, caracterizándose el proceso por la dispersión de cada grano de cemento en millones de partículas. La acción del yeso contrarresta la velocidad de las reacciones y en este estado se produce lo que se denomina el periodo latente o de reposo en que las reacciones se atenúan, y dura entre 40 y 120 minutos dependiendo de la temperatura de ambiente y el cemento en particular.

1.6.1.2 Fraguado Inicial

Condición de la pasta de cemento en que se aceleran las reacciones químicas, empieza el endurecimiento y la pérdida de la plasticidad, midiéndose en términos de la resistencia a deformarse. Es la etapa en la que se evidencia el proceso exotérmico donde se genera el denominado calor de hidratación, que es consecuencia de las reacciones químicas mencionadas.

Se forma una estructura porosa llamada gel de Hidratación de Silicatos de Calcio (CHS ó Torbemorita), con consistencia coloidal intermedia entre sólido y liquido que van rigidizándose cada vez en la medida que se siguen hidratando los silicatos.

Este periodo dura alrededor de tres horas y se producen una serie de reacciones químicas que van haciendo más estable con el tiempo al gel CHS.

En esta etapa la pasta puede remezclar sin producirse deformaciones permanentes ni alteraciones en la estructura que aun esta en formación.

1.6.1.3 Fraguado Final

Se obtiene al termino de la etapa de fraguado inicial, caracterizándose por el endurecimiento significativo y deformaciones permanentes. La estructura del gel esta constituida por el ensamble definido de sus partículas endurecidas.

1.6.1.4 Endurecimiento

Se produce a partir del fraguado final y es el estado en el que se mantiene e incrementa con el tiempo las características resistentes.

La reacción predominante es la hidratación permanente de los silicatos de calcio, y en teoría continúan de manera indefinida.

Es el estado final de la pasta, en que se evidencia totalmente las influencias de la composición del cemento.

Durante el proceso de hidratación, el volumen externo de la pasta se mantiene relativamente constante, sin embargo internamente el volumen de sólidos se incrementa constantemente con el tiempo, causando la reducción de porosidades, que esta relacionada de manera inversa con la resistencia de la pasta endurecida y en forma directa con la permeabilidad.

Para que se produzca la hidratación completa se necesita la cantidad suficiente de agua, la temperatura adecuada y el tiempo, y de aquí se desprende el concepto fundamental del curado, que consiste en esencia en procurar estos tres elementos para que el proceso se complete.

Un concepto básico que nos permitirá entender el comportamiento del concreto, reside en el que el volumen de los productos de hidratación siempre es menor que la suma de los volúmenes de agua y cemento que los origina debido a que por combinación química el volumen de agua disminuye en alrededor de un 25%, lo que trae como consecuencia la contracción de la pasta endurecida.

Otro concepto que hay que tomar en cuenta es que esta demostrado que la relación agua/cemento mínima para que se produzca hidratación completa del cemento es del orden de 0.35 a 0.40 en peso dependiendo de cada caso particular.

En los cuadros a continuación se presenta las características Físicas y Químicas, para el Cemento Pórtland Tipo I - Sol, proporcionadas por el fabricante así como también las Normas ASTM y de NTP.

En la presente tesis de investigación se utilizo el CEMENTO PÓRTLAND TIPO I ANDINO que a continuación detallamos.

1.7 CEMENTO PÓRTLAND TIPO I - ANDINO.

Este producto es fabricado por CEMENTO ANDINO S.A., ubicada en la localidad de Crancha en la provincia de Tarma. Esta sujeto a un estricto control de calidad, de acuerdo a la norma norteamericana ASTM C150 y la norma nacional NTP 334.009. Este tipo de cemento es para uso general, es el adecuado para todos los usos en que no se requieren de propiedades especiales.

Se usa donde el concreto no esta sujeto al ataque de factores específicos como a los sulfatos del suelo o del agua, o elevaciones perjudiciales de temperatura, debido al calor generado en la hidratación. Entre sus usos se incluyen pavimentos, edificios de concreto reforzado, puentes tanques y depósitos, alcantarillas, tuberías para agua etc.

1.7.1 COMPOSICIÓN QUIMICA DEL CEMENTO PÓRTLAND TIPO I ANDINO

Cuantitativamente el componente mas importante del cemento es la cal, siguiendo a gran distancia la sílice, a esta la alumina y finalmente el oxido de hierro, a continuación mostramos el análisis químico de los elementos que participan en el cemento Pórtland tipo I andino.

CUADRO N° 1.4

ANÁLISIS QUIMICO DEL CEMENTO PÓRTLAND TIPO I ANDINO

COMPUESTO	SIMBOLO	%	NORMA NTP 333.009
Oxido de Calcio	CaO	64.18	-
Oxido de Silicio	SiO_2	21.86	-
Oxido de Aluminio	Al_2O_3	4.81	-
Oxido de Fierro	Fe_2O_3	3.23	-
Oxido de Potasio	K_2O	0.65	-
Oxido de Sodio	Na_2O	0.15	-
Oxido de Azufre	SO_3	2.41	max 3.5%
Oxido de Magnesio	MgO	0.96	max 5.0%
Silicato Tricalcico	C_3S	51.33	-
Silicato Bicalcico	C_2S	23.95	-
Aluminato Tricalcico	C_3A	7.28	-
Ferroaluminato Tetracalcico	C_4AF	9.82	-
Cal Libre	-	0.59	-
Perdida por Ignición	P.I	1.24	max 3.0%
Residuos Solubles	R.I	0.42	max 1.0%

1.7.2 CARACTERISTICAS FISICAS DEL CEMENTO PORTLAND TIPO I ANDINO.

A continuación mostramos un cuadro en el cual se especifica las características físicas de cemento Pórtland tipo I andino, y el intervalo permisible de acuerdo a las normas ASTM.

CUADRO N° 1.5

PROPIEDADES FÍSICAS DEL CEMENTO PÓRTLAND TIPO I ANDINO

PROPIEDADES FISICAS MECANICAS	UNIDAD	VALOR DE ENSAYO	LIMITES ASTM C150
Peso Específico	gr/cm^3	3.11	
Consistencia Normal	%	22.15	
Tiempo de Fraguado			
Fragua Inicial	h:m	1:58 - 2:24	Min 0:45
Fragua Final	h:m	3:08 - 3:45	Max 6:45
Superficie Especifica	cm^2/gr	3210 - 3340	Min 2800
Calor de Hidratación	cal/gr	64.93	
Resistencia a la Compresión			
03 Días	kg/cm^2	195 - 200	Min 122
07 Días	kg/cm^2	250 - 270	Min 2194
28 Días	kg/cm^2	340	Min 280
Estabilidad de Volumen	%	0.00 - 0.07	

CAPITULO 02

FIBRAS DE ACERO

2.1 GENERALIDADES.

Reforzar una matriz con fibras es muy antiguo, siendo el adobe su manifestación clásica en que agregando paja a una matriz se logra una estructura capaz de asumir esfuerzos de tracción y reducir la fisuración.

Dentro de las nuevas tecnologías y materiales que van apareciendo para hacer frente al desarrollo de la construcción, los hormigones con fibras, especialmente con fibras de acero, mejora algunas de las propiedades que en el hormigón tradicional no tenían la entidad que le exigían determinadas aplicaciones y así nos encontramos que las fibras de acero dispersas en la masa del hormigón y presentando una distribución uniforme, aparte a conferir al material una homogeneidad e isotropía, ejercen una acción reforzante muy eficaz en la respuesta a determinadas acciones.

2.2 LAS FIBRAS.

El empleo de las fibras para mejorar la isotropía de un material no es algo desconocido. Los adobes de barro cocidos al sol y armados con paja ya se empleaban hace mucho tiempo, hasta hace poco hemos visto utilizar pelos de cabra o de caballo para armar el yeso; el fibrocemento no es otra cosa que el una pasta de cemento a la que se a añadido del 8% al 16% de fibras de asbesto para incrementar la resistencia a la flexotracción de 2 a 4 veces la de la matriz. Al mismo hormigón armado podríamos considerarlo, en el limite, como un hormigón de gruesas fibras orientadas.

Las fibras empleadas en el hormigón reforzado son discontinuos, presentando una distribución discreta y uniforme que confiere al material una gran isotropía y homogeneidad. La efectividad de la acción reforzante y la eficacia en la transmisión de tensiones depende de muchos factores pero, depende de muchos factores pero, especialmente, de la naturaleza y del tipo de fibra empleado.

2.3 TIPOS DE FIBRAS

Las fibras actualmente empleadas pueden ser minerales, Orgánicas y Metálicas.

2.3.1 FIBRAS MINERALES.

Cabe distinguir las de asbesto y las de vidrio. Las fibras de asbesto o amianto empleadas en el fibrocemento tienen el inconveniente de absorber grandes cantidades de agua, con lo cual al aumentar la relación agua/cemento exigen gran cantidad de fibras y de cemento para obtener resistencias apreciables; la distribución uniforme de las fibras es difícil de conseguir. No todos los países poseen asbesto. Las fibras de Vidrio están sustituyendo, en sus aplicaciones, al Asbesto; Sin embargo, estas fibras tienen el inconveniente de ser atacadas por los álcalis del cemento, lo que da lugar a una degradación con el tiempo de la resistencias, este inconveniente se evita mediante el revestimiento de las fibras con resinas tipo epóxico ó con el empleo de fibras especiales con oxido de zirconio. Ambos sistemas encarecen las fibras.

USOS

El cemento reforzado con fibras de vidrio se emplea para paneles decorativos prefabricados (planos o con forma) y para fachadas con propósitos arquitectónicos o de revestimiento. El asbesto cemento es mas barato y puede usarse para producir hojas planas, paneles resistentes al fuego y tubos .La fibra de polipropileno se usa para formar el encofrado exterior de pilotes de concreto reforzado hincados convencionalmente.

2.3.2 FIBRAS ORGÁNICAS

Pueden ser de Algodón, rayón, poliéster, polipropileno, polietileno, y nylon. Las tres primeras hay que desecharlas, ya que son atacables por el álcalis. Las mas empleadas son las de nylon, polietileno, polipropileno; sin embargo debido al bajo modulo de elasticidad que poseen, no tienen interés en los hormigones reforzados debido a la gran deformabilidad que les confiere y a no aumentar sensiblemente la resistencia a la tracción por fallar la adherencia con la pasta de cemento.

USOS

No obstante, algunas veces se utilizan para mejorar la resistencia al impacto de hormigones.

La fibra de polipropileno se usa para formar el encofrado exterior de pilotes de concreto reforzado hincados convencionalmente

2.3.3 FIBRAS METÁLICAS

Fibras Metálicas concretamente las de Acero, son las que mas se emplean en el refuerzo de hormigones por ser las mas eficaces y económicas. El acero posee un modulo de elasticidad diez veces superior al del hormigón; las fibras de acero presentan una buena adherencia a la pasta, alto alargamiento a la rotura y fáciles de mezclar.

Las fibras de acero pueden obtenerse por diferentes métodos; el mas común consiste en fabricarlas por corte de alambre trefilado, de acero, de bajo contenido de carbono. El diámetro de los alambres están contenidos entre 0.25 a 0.80 mm. La longitud de las fibras puede ser muy variable, oscilando entre 10 y 75 mm.

A efectos de comparación de unas fibras, con respecto a otras, se a establecido un parámetro numérico denominado "Aspecto". El aspecto o esbeltez de una fibra es la relación que existe entre la longitud de la misma y su diámetro equivalente, es decir, el diámetro del circulo cuya secciona es equivalente a la superficie de la fibra. Los aspectos normales oscilan entre 30 y 150.

Los principales efectos que trae consigo la incorporación de fibras de acero a los hormigones podemos resumirlos en los siguientes:

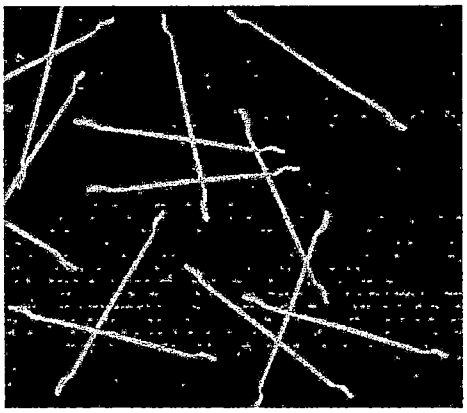
- MEJORA EL COMPORTAMIENTO A FLEXO TRACCION.
- INCREMENTO DE LA RESISTENCIA A LA ROTURA.
- REDUCCION DE LA DEFORMACION BAJO CARGAS MANTENIDAS.
- AUMENTO DE LA RESISTENCIA A LA TRACCION.

- FUERTE INCREMENTO EN LA RESISTENCIA AL IMPACTO Y CHOQUE
- GRAN RESISTENCIA A LA FATIGA DINAMICA.
- FISURACION CONTROLADA.
- AUMENTO DE DUCTILIDAD.

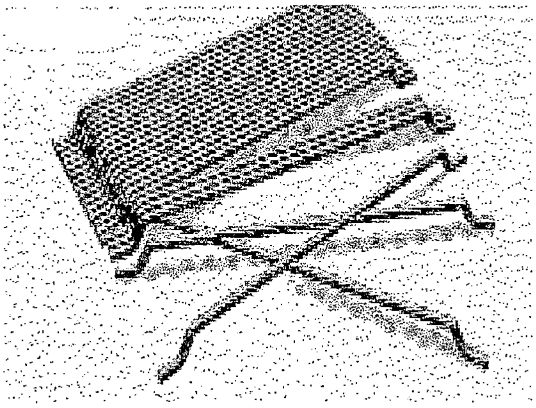
TIPOS DE FIBRA DE ACERO

FIGURAS N° 2.1

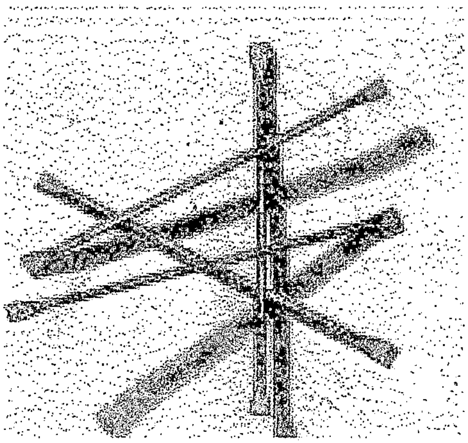
LISA (a)



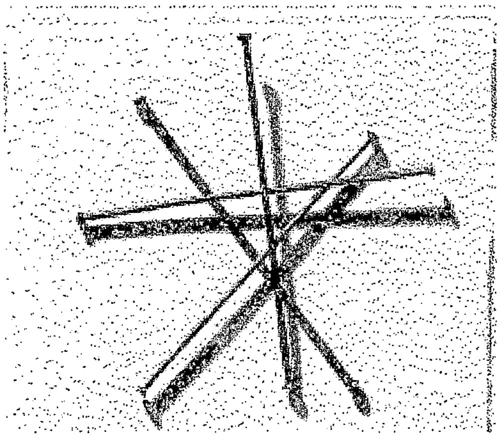
LISA (b)



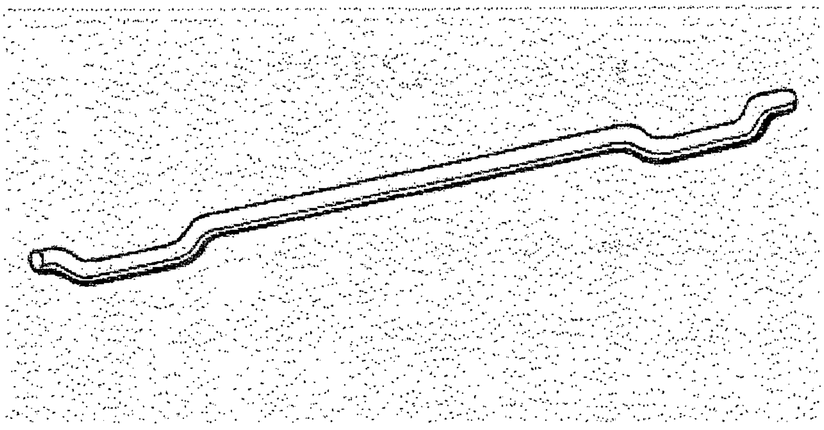
LISA (c)



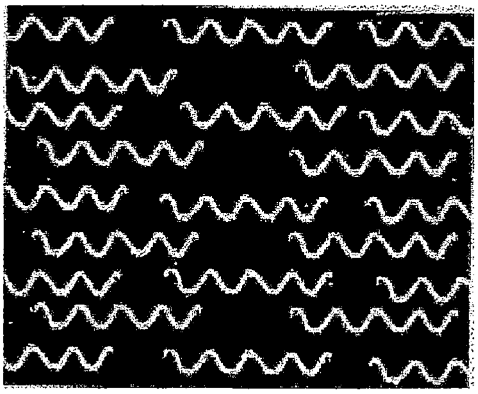
LISA (d)



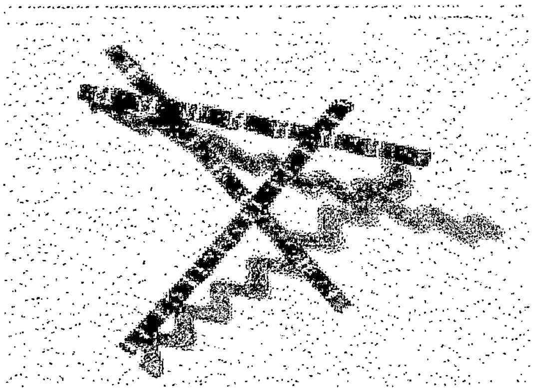
LISA (e)



ONDULADA (a)



ONDULADA (b)



Para el uso de las fibras de acero se realizan añadiendo al concreto en consecuencia definiremos el concepto de concreto.

2.3.3.1 EL CONCRETO SIN FIBRA METÁLICA

El concreto es un material heterogéneo, el cual esta compuesto por un material aglutinante (como el cemento Pórtland) , material de relleno (Agregados naturales o artificiales), el agua, aire naturalmente atrapado o intencionalmente incorporado y eventualmente aditivos o adiciones, presentando cada uno de estos componentes propiedades y características que tienen que ser evaluadas así como aquellas que pueden aparecer cuando se combinan desde el momento de mezclado.

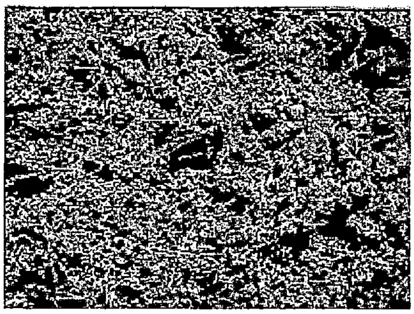
2.3.3.2 FORTALEZA Y DUCTILIDAD DEL CONCRETO CON FIBRA DE ACERO

Cuando un concreto es sometido a cargas de esfuerzos de tensión y cargas de impacto, este se torna muy frágil por tal razón siempre a sido necesario reforzar el concreto utilizando varillas de acero o malla para compensar esta falta de ductilidad.

Sin embargo, mediante el uso de fibra de acero INSONEX se logra tener un concreto mas flexible y dúctil, aumentando la resistencia a la tensión en toda la masa y todas las direcciones.

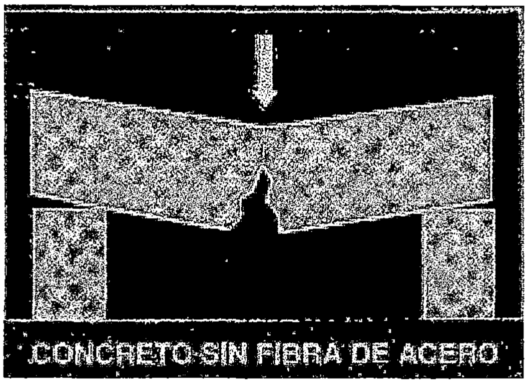
CONCRETO CON FIBRA

FIGURA N° 2.2



DUCTILIDAD DEL CONCRETO CON FIBRA

FIGURAS N° 2.3



2.3.3.3 DOSIFICACIÓN, AMAZADO Y PUESTA EN OBRA

Los hormigones reforzados con fibras de acero están formados, esencialmente, por un conglomerante hidráulico, áridos finos y gruesos, agua, fibras discontinuas cuya misión es contribuir a mejorar determinadas características de los hormigones.

Las fibras en una mezcla de hormigón actúan como inclusiones rígidas con una gran área superficial y una geometría diferente a la de los áridos.

Para que cada fibra sea efectiva precisa estar completamente embebida dentro de la mezcla; esto obliga a que la proporción de elementos finos a gruesos tenga que ser la adecuada, generalmente con, con , mayor proporción de finos que en un hormigón convencional. Los hormigones convencionales requieren entre 25% y el 35% de pasta con respecto al volumen total, mientras que un hormigón armado con fibras precisa del 35% al 45% dependiendo del aspecto y volumen de fibras empleado.

Es absolutamente imprescindible cualquiera que sea el método utilizado, obtener una dispersión uniforme de las fibras y eliminar los peligros de segregación y la formación de bolsas ó erizos de fibras. La segregación y formación de bolsas están relacionadas con muchos parámetros, principalmente con el aspecto, el porcentaje de fibras, tamaño máximo del árido, granulometría, relación agua cemento y sistema de mezclado.

La buena docilidad de las mezclas y la eliminación de la formación de la formación de bolas aconsejan no usar áridos de tamaño superior a 20mm, lo cual no es un grave inconveniente, ya que para muchas aplicaciones este es un tamaño ideal .

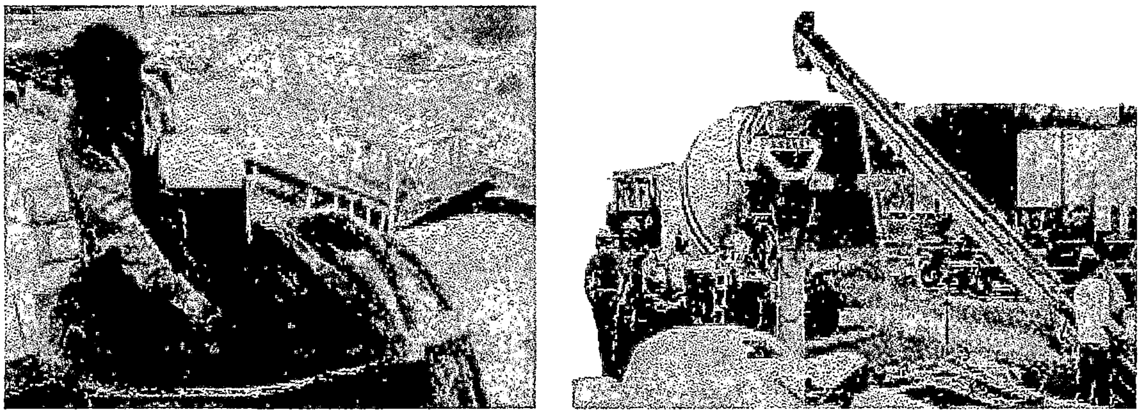
En general no se presentan problemas de segregación ni formación de erizos cuando los diámetros están comprendidos entre 0.4 mm y 0.8 mm y las longitudes entre 25 mm y 70 mm, y se emplean. Y se emplean en cantidades que no exeden del 1.5% en volumen. Con cantidades superiores empiezan a surgir en cuanto a su docilidad, y la formación de bolas agrava la situación dando lugar a masa heterogéneas con zonas muy pobres o muy ricas en fibras. Las fibras de diámetros inferiores a 0.5 mm, en proporciones mayores del 1.0% son muy propensa a la formación de bolas, mientras que los diámetros mayores permiten trabajar con porcentajes mayores.

Cuando una dosificación esta bien realizada no existe problemas en el amasado y en la puesta en obra. El amasado puede realizarse en la central concretera ó en la misma obra. En la central basta con adicionar las fibras a la masa y amasar el conjunto durante un minuto y medio, hasta conseguir la dispersión total de las fibras. En obra se añaden al camión – hormigonera y se mantiene girando la cuba a toda velocidad durante un minuto y medio. Los dos sistemas son buenos, pero de preferencia el primero debido a que de la central sale el hormigón con las características requeridas, mientras que en la obra, a veces, hay que hacer correcciones en el agua de amasado, lo que suele ser mas impreciso.

Una vez conseguida la docilidad adecuada a los medios de puesta en obra disponibles, el hormigón con fibras se coloca por los sistemas tradicionales, incluido el bombeado sin ningún problema.

MEZCLA Y COLOCACIÓN

FIGURAS N° 2.4



2.3.3.4 MECANISMO DE REFUERZO

Para entender como se realiza el refuerzo del hormigón por las fibras hay que examinar la curva tensión-deformación frente a flexión del hormigón tradicional y del reforzado con fibras de acero. Si observamos la curva del hormigón reforzado con fibras vemos que esta es mas o menos lineal, hasta llegar al punto que corresponde a la tensión de la primera fisura, luego la curva se mueve buscando un máximo en otro punto mas elevado llamado "ultima tensión de rotura". En un hormigón tradicional, una vez alcanzada la tensión de la primera fisura, se llega a la máxima tensión y ocurre la rotura. En el reforzado con fibras, la primera fisura tiene lugar para tensiones iguales o ligeramente superiores a la tensión máxima del convencional, empezando a ejercerse el efecto de armado de las fibras por encima de este punto y gracias al efecto compuesto que se produce, y al que colabora que el acero tenga un modulo de elasticidad diez veces superior al del hormigón. Por otra parte la linealidad, hasta alcanzar la primera fisura o limite elástico, puede ser perfecta o sufrir desplazamientos si el volumen de fibras es elevado.

En el momento en que se inicia la fisuración en la zona traccionada de una viga de ensayo comienzan a trabajar las fibras y continúan haciéndolo hasta que se rompen por tracción ó deslizan por perdida de adherencia . auque las fibras están orientadas en todas direcciones. Dentro de la masa del hormigón, siempre hay algunas que actúan de puentes entre las dos partes del hormigón que dividen las fisuras, pudiendo transmitir los esfuerzos con ángulos muy variables de acuerdo con la orientación que posean con respecto al plano de la fisura.

2.3.4 USOS Y APLICACIONES DE LA FIBRAS METALICAS EN EL CONCRETO

A continuación citaremos las aplicaciones de las fibras de acero y mas adelante detallaremos las aplicaciones.

- Concreto lanzado para revestimiento de túneles, estabilizaciones, restauraciones, rehabilitación de drenajes.
- Pisos industriales, pisos comerciales, losas sobre terrenos.

- Sobrepisos
- Pistas de aeropuerto.
- Pavimento de carretera .
- Productos prefabricados.
- Diseños de concreto sin juntas .
- Estructuras hidrodinámicas.
- Cimentaciones especiales para equipos y maquinarias.

2.3.4.1 APLICACIÓN DEL SHOCRETE.

2.3.4.1.1 HISTORIA DEL CONCRETO LANZADO

El principio del "Gunite" fue descubierto en 1907 por Carl E. Akeley (1864-1926), escultor y naturalista del Museo Americano de Historia Natural de Chicago. La necesidad de hacer modelos de animales prehistóricos, aplicando a mano mezclas de arcillas sobre matrices de esqueletos para formar las figuras de dichos animales, llevó al Dr. Akeley a inventar un método para que por medio de aire comprimido pudiera colocar la mezcla seca de cemento y arena en un depósito que, por la presión ejercitada, transportara la mezcla por una manguera aplicándole a la salida de la boquilla la cantidad necesaria de agua y así colocar la mezcla en una armazón de alambre sin escurrirse por su bajo revenimiento, dándole finalmente el acabado deseado. Este método satisfactorio para lograr estas figuras de animales, dio como resultado la fabricación de una maquina denominada "Cement Gun", la cual fue patentada en 1911 y el nombre de "GUNITE" se registro como marca, siendo hasta 1971 cuando el nombre pasa a ser del dominio popular.

La historia del SHOTCRETE es más reciente y se remonta al termino de la segunda guerra mundial y desde entonces se a tornado como un sistema muy utilizado.

El advenimiento de nuevos agregados, fibras y mejores aditivos en las décadas de los 70's y 80's le dio el impulso final al desarrollo del concreto lanzado.

En la actualidad se estima que el GUNITE se utiliza en el 45% de los casos y el SHOTCRETE en el 55%, teniendo entre ambos una producción estimada de 8 millones de m3 por año en todo el mundo, la cual está en constante crecimiento.

2.3.4.1.2 CONCRETO LANZADO

La más reconocida definición de CONCRETO LANZADO (SHOTCRETE, GUNITE) es la señalada por el AMERICAN CONCRETE INSTITUTE (ACI). Ellos han tomado el liderazgo al establecer comités técnicos así como especificaciones y publicaciones sobre esta materia. (ACI 506 de 1983 con actualizaciones en 1990 y 1994).

"CONCRETO LANZADO es un mortero o concreto transportado a través de una manguera y proyectado neumáticamente a alta velocidad sobre una superficie".

Se considera que si la mezcla a lanzar cuenta sólo con agregados finos se llama MORTERO Lanzado y si los agregados son gruesos se denomina CONCRETO.

Por otra parte el concreto con agregado fino es conocido como GUNITE y cuando incluye agregado grueso se designa como SHOTCRETE.

Hay dos clasificaciones de concreto lanzado: seco (al que se le añade el agua en la boquilla) y húmedo (al que el agua se le añade antes de entrar por la manguera).

El concreto conducido a través de tubería de acero y que no es proyectado ni transportado a altas velocidades se conoce como concreto bombeado.

El método de sostenimiento de concreto lanzado o shotcrete, es la aplicación neumática de concreto sobre una superficie. La mezcla que conforma un shotcrete poseen las mismas condiciones de calidad que un concreto, tales como el contenido de cemento, la selección de agregados, la granulometría y la relación agua/cemento. Sin embargo, este método es mucho menos poroso y tiene muy buena adhesión a las paredes de roca debido a su aplicación a alta presión, además de secarse en menor tiempo .

El diseño de sostenimiento con shotcrete obedece a la necesidad de extraer y recuperar mineral con seguridad y alta tecnología, además de permitir mejorar el planeamiento de minado, de modo que se minimicen los movimientos del terreno, evitando su colapso

2.3.5 OTRAS APLICACIONES.

En elementos Prefabricados se están empleando en la Fabricación de Tuberías debido a que, con las fibras, se pueden reducir espesores a la vez que se mejora la impermeabilidad; esta aplicación esta fundada, por otra parte, es la exigencia de los reglamentos de diferentes países en los cuales las tuberías, a partir de determinados diámetros tengan que llevar una armadura de seguridad.

En construcción industrializada permiten reducir espesor de paredes, evitando la colocación de cualquier tipo de armaduras y haciendo innecesaria la presencia de armaduras tradicionales incluso en dinteles de puertas y ventanas. Con el empleo de estos hormigones no se presentan problemas de fisuración.

En pavimentos donde la resistencia a la flexotracción y a veces impacto es fundamental, que se empleen las fibras ya que cuentan de las propiedades mencionadas. Son muchos los pavimentos industriales en lo que se han utilizado, sin necesidad en gran numero de casos de realizar juntas. En España se han hecho miles de metros cuadrados de pavimentos en pisos industriales , pistas de aeropuertos, pistas de estacionamientos, pistas en talleres de automóviles, etc. La ventaja es que se puede eliminar las juntas, se tiene un espesor mas reducido y una vida útil que puede ser de 5 a 8 veces la de un pavimento tradicional.

El aumento de resistencia de flexotracción, el control de fisuración, la resistencia a la fatiga dinámica y la posibilidad de hacer juntas cada 15 mt ó mas (e incluso de no hacerlas) trae consigo el que los hormigones reforzados con fibras se utilicen mucho en pavimentos de autopistas y carreteras, bien en la totalidad de su espesor, bien en forma de recrecidos sobre pavimentos rígidos o flexibles deteriorados, con la ventaja adicional de requerir un espesor reducido de 7 a 10 cm y de poder colocarse con cualquier extendedora tradicional o simplemente con reglas vibrantes. Actualmente, la técnica de los recrecidos con este tipo de hormigones se esta utilizando cada vez mas, debido a las grandes ventajas técnicas y económicas que se presentan.

Otra de las ventajas que presenta el hormigón de fibras es poder colocarse en obra mediante gunitado. Empleando áridos de hasta 10 mm , con fibras de 30, a 50 mm de longitud, se han gunitado con éxito túneles, taludes canales y piscinas. La principal ventaja que presentan estos hormigones, es el revestimiento de túneles, radica en la rapidez de ejecución al eliminar la colocación de la malla electrosoldada, labor siempre lenta y engorrosa en las superficies tan irregulares de un túnel. Por otra parte la capa de gunita puede adaptarse perfectamente a las superficies, con lo cual se tiene una mayor economía en hormigón. Al estar toda la capa proyectada atada por las fibras, no se producen desprendimientos y la capacidad de absorción de esfuerzos queda incrementada.

El gunitado, utilizando fibras de acero inoxidable, es una técnica frecuente actualmente en los revestimientos refractarios de industrias metalúrgicas, de cementos y petroquímicas. Los revestimientos refractarios armados con fibras poseen, gracias al trabazón que estas proporcionan, una gran resistencia frente a los choques térmicos, a la vez que una fuerte resistencia a la abrasión.

El utilizar fibras inoxidables tiene como finalidad evitar las fuertes corrosiones que se producirían en fibras normales, al estar sometidas a atmósferas como suelen existir en los hornos.

Tal vez una aplicación de las interesantes de los hormigones de fibras de acero esté en el campo de los pavimento de aeropuertos.

Los primeros ensayos se realizaron por la U.S. " Army Construction Engineering Research Laboratory" (CERL) y consistieron: uno, en un pavimento de hormigón con fibras y otro, en un recrecido sobre un pavimento deteriorado de hormigón. Ambos tramos de ensayos realizados a escala natural se sometieron a las pruebas de un trafico simulado con características de C-5A con carga de 350 ton. El avión C-5A se emplea en aeropuertos militares de carga media y poseen tres trenes de aterrizaje, con doce ruedas en cada uno de los dos principales y cuatro en el del morro, sobre cada rueda del tren gravitan 13.6 ton. Para simular el aterrizaje se aplicaba el tren sobre cinco líneas paralelas separadas entre si cinco metros.

Bajo la dirección de estos laboratorios se realizo la primera prueba a escala natural en el aeropuerto de Tampa. En forma de recrecidos sobre pavimentos deteriorados, siendo los recrecidos de 150 mm de espesor en pistas de "Runway" y de 100 mm en las de "Taxiway". Los resultados obtenidos fueron totalmente satisfactorios. Con posterioridad a estos ensayos se hicieron los pavimentos de la base de Nolfor. Ampliaciones y reparaciones en los aeropuertos de las Vegas. Actualmente se ha finalizado el aeropuerto de Denver Colorado.

En la actualidad podemos decir que con el empleo de las fibras de acero se ha resuelto muchos de los inconvenientes que tiene el hormigón. Además tales inconvenientes se han resuelto con la ventaja adicional de economía en mano de obra, al evitar en muchas ocasiones parte o toda la armadura tradicional. Espacialmente cuando esta tiene la misión de controlar la fisuración.

2.3.6 FIBRAS DE ACERO INSONEX.

Las fibras de acero Insonex es un producto nacional patentada por la empresa INSOMIN, dedicada a la producción de insumos para la ingeniería minería y civil.

Las fibras de acero insonex, son pequeños segmentos ondulados cuyas propiedades de adherencia constituyen uno de sus mejores beneficios, se utiliza en un amplio rango de aplicaciones para el concreto, aumentando su resistencia al fisuramiento, ductilidad y tenacidad.

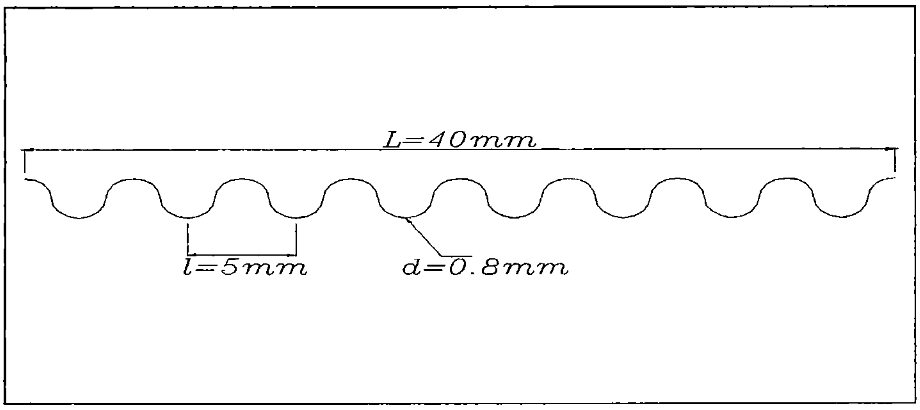
2.3.6.1 CARACTERÍSTICAS DE LA FIBRA DE ACERO INSONEX

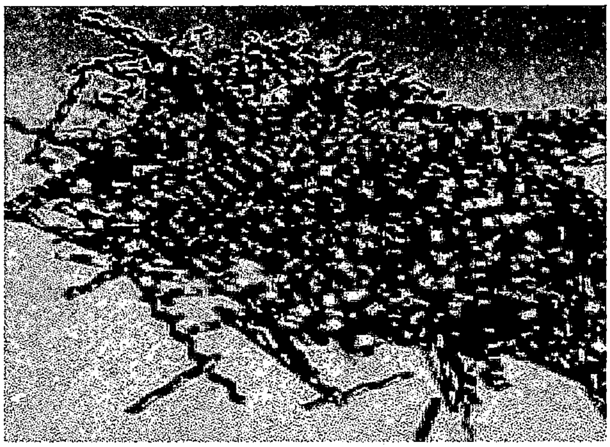
Las fibras de acero insonex, se caracterizan por que su relación longitud/diámetro varia de 50 a 84, esta característica fundamentalmente permite obtener fibras para cada caso de concreto reforzado (cuanto mas alto es la relación l/d el rendimiento es mejor), es decir para distintas aplicaciones. A continuación mencionamos las relaciones l/d.

- L/d de 50 es el valor mínimo requerido para obtener un hormigón dúctil con fibra de acero con dosificaciones razonables de fibra. Estas fibras se utilizan en aplicaciones con requerimientos generales.
- L/d de 65 son fáciles de mezclar y utilizar, al mismo tiempo que proporcionan un hormigón con fibras de acero notablemente mejorado .
- L/d de 80 para aplicaciones que requieran un hormigón muy resistente, con especificaciones muy estrictas

GEOMETRÍA DE LA FIBRA INSONEX

FIGURAS N° 2.5





Su geometría favorece al fraguado eliminando bolsas y vacíos

CUADRO N° 2.1
CARACTERÍSTICAS GENERALES DE LA FIBRA INSONEX

FORMA GEOMÉTRICA	**ONDULADA**
LONGITUD	**40mm**
DIÁMETRO	**0.8mm**
LONGITUD DE ONDA	**5mm**
ALTURA DE ONDA	**0.65mm**
RESIS. MINIMA A LA TRACCION	**76.5Kg/mm2**
PESO PARA SU VENTA	**40.0Kg**

2.3.6.2 BENEFICIOS DE LA FIBRA INSONEX

- El concreto mezclado con fibras Insonex mejora notablemente sus propiedades físicas, elevando su resistencia a la tensión, a la flexión, al corte, a la fatiga, al impacto y lo que es mas importante aumentando su ductilidad.
- Aplicando fibras de acero Insonex es posible minimizar roturas en ambientes corrosivos, debido a que el medio alcalino que ofrece el concreto sirve de protección para cada fibra.
- La fibra Insonex es compatible con toda la variedad de cementos.

2.3.6.3 PRINCIPALES APLICACIONES DE LA FIBRA INSONEX

Las fibras de acero están siendo empleadas en obras de gran envergadura como se menciona a continuación.

2.3.6.3.1 EN SOSTENIMIENTO DE CONSTRUCCIONES SUBTERRÁNEAS

Tanto en obras civiles como mineras las fibras Insonex son usadas en sostenimiento de galerías, piques, chimeneas y túneles, mediante el concreto lanzado (shotcrete). Las ventajas principales del concreto lanzado con Insonex en construcciones subterráneas son las siguientes:

- ☐ Buena ductilidad del concreto lanzado con Insonex comparado con otras mezclas de concreto lanzado simple.
- ☐ Elimina el trabajo de enmallado en estructuras de concreto hiperestatico.
- ☐ Reduce el costo de producción.
- ☐ Ahorra tiempos de construcción por manipuleo de enmallado.
- ☐ En túneles: efecto preventivo de fugas, durabilidad de longitudes, periodos cortos de construcción y reducción de alineamiento.

2.3.6.3.2 EN REFORZAMIENTO DE LOSAS Y PISTAS

La principal diferencia en el comportamiento entre el concreto simple y el concreto reforzado con fibra, es la dureza y la tenacidad del material, como por ejemplo, la capacidad para soportar cargas parejas después de la formación de fisuras. Tal comportamiento es importante especialmente en construcciones hiperestaticas (como en pistas de aeropuertos, en puentes, en losas deportivas. etc) por que ello ase posible la redistribución de esfuerzos durante la fisuración.

Las ventajas principales del concreto reforzado con Insonex son las siguientes: Incremento de la Resistencia a la rotura, Incremento de Resistencia al Impacto, Incremento de Resistencia a la Fatiga, Reducción de Espesor de la Losa, Reducción en el Espesor del Pavimento, Bajo Costo de Reparación, Alarga la Vida Útil.

2.3.6.3.3 EN ESTABILIZACION DE TALUDES.

Las fibras Insonex son las mas adecuadas para el sostenimiento de taludes y para las paredes de retención. Esto debido a que el concreto simple, no es lo suficiente efectivo, ya que el viento y la exposición a un sol intenso tiende a resecarlo prematuramente. Con las fibras Insonex se puede solucionar estos problemas ya que cuenta con buenas propiedades a la flexión, tensión, adherencia con lo cual evitaría el desmoronamiento.

2.3.6.3.4 EN CONTRUCCION CIVIL Y PREFABRICADOS

CONSTRUCCION.

- En construcción de basamentos, paredes y paneles exteriores.
- En construcción de escaleras y paredes acústicas.

PREFABRICADOS.

Reforzar concreto con fibra metálica ahorra tiempo, mano de obra, y dinero en productos precolados. No hay necesidad de cortar y colocar malla electrosoldadas alrededor de moldes, solamente hay que mezclar y vaciar el concreto reforzado con fibra metálica para obtener mejor comportamiento.

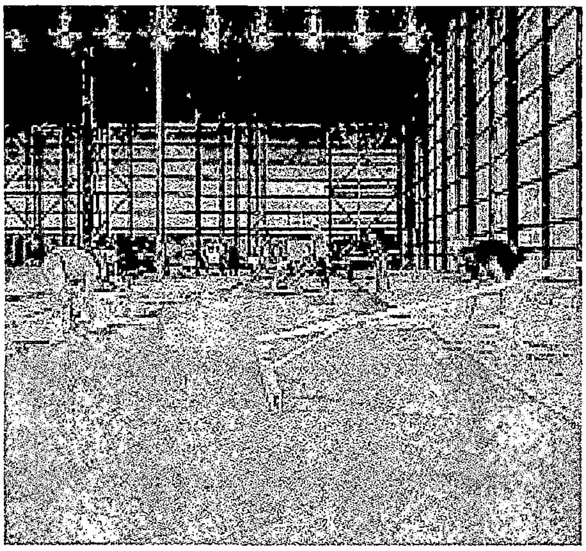
ESTRUCTURA FLUVIALES.

En este tipo de construcciones no se necesitan bastidores de acero de refuerzo ya que tiene buena resistencia al desmoronamiento, como consecuencia de ello se viene aplicando en: DIQUES, PRESAS, CANALES, BOCATOMAS.

APLICACIONES

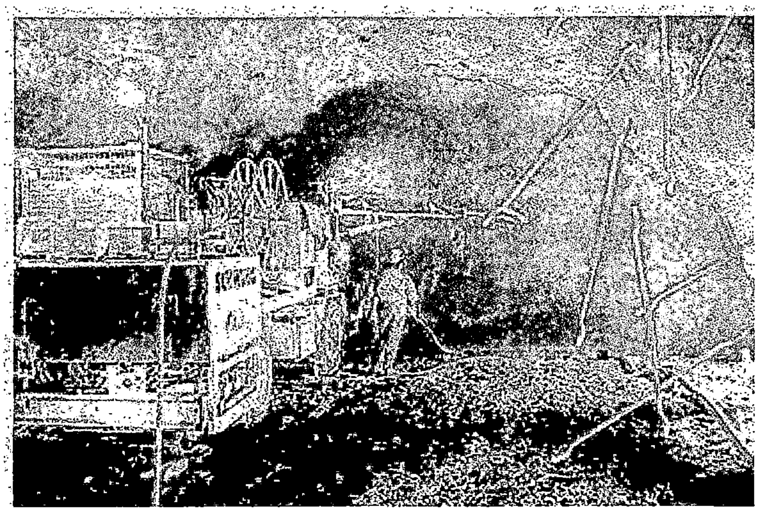
FIGURAS N° 2.6

LOSA (a)

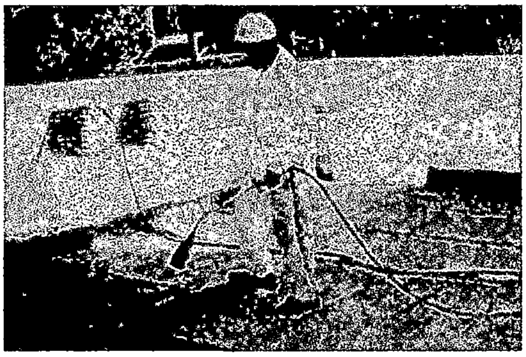


LOSA (b)

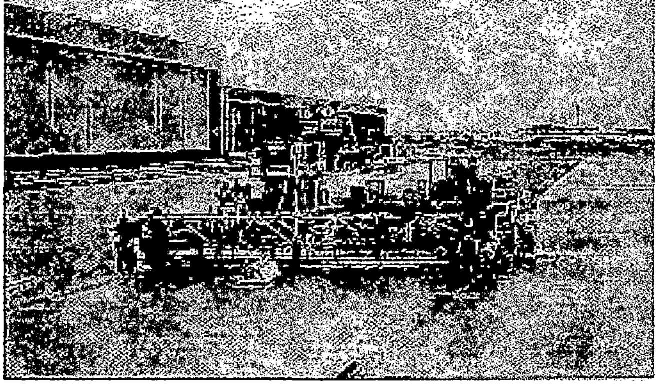
TÚNELES



PISOS INDUSTRIALES

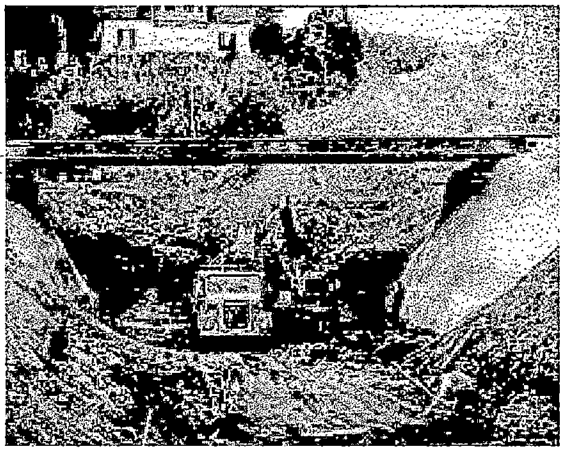


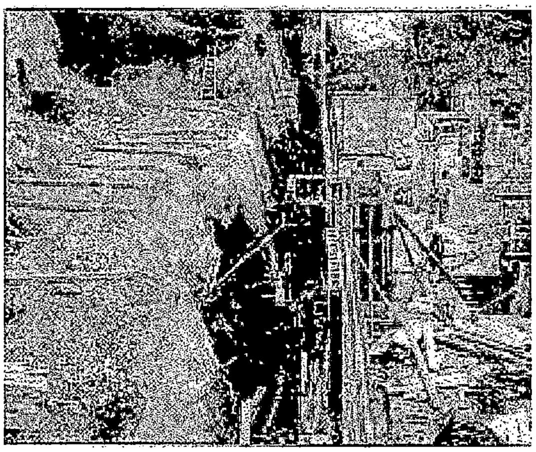
PAVIMENTACIÓN EN AEROPUERTOS



REVESTIMIENTOS DE TUBERIAS

ESTABILIZACIÓN DE TALUDES





CAPITULO 03

CARACTERISTICAS DE LOS MATERIALES

3.1 GENERALIDADES.

Las propiedades de los materiales para la elaboración del concreto influyen notablemente en la calidad de la misma, ya que estos representan las tres cuartas partes de volumen del concreto, en consecuencia tanto el agua, agregado fino, agregado grueso deben cumplir con las especificaciones técnicas.

3.2 EL AGUA

3.2.1 GENERALIDADES.

Se sabe que el agua es el elemento indispensable para la hidratación del cemento y el desarrollo de sus propiedades, por lo tanto este elemento debe cumplir con ciertos requisitos para llevar a cabo su función en la combinación química.

El agua de mezcla tiene tres funciones principales:

1. Reaccionar con el cemento para hidratarlo.
2. Actuar como lubricante para contribuir a la trabajabilidad del conjunto y
3. Procurar la estructura de vacíos necesaria en la pasta para que los productos de hidratación tengan espacio para desarrollarse.

Por lo tanto la cantidad de agua que interviene en la mezcla de concreto es normalmente por razones de trabajabilidad, mayor de lo necesario para la hidratación del cemento.

El problema principal del agua reside en las impurezas y la cantidad de estas, que ocasionan reacciones químicas que alteran el comportamiento normal de la pasta de cemento.

Una regla empírica que sirve para estimar si determinada agua sirve para emplearse en la producción de concreto, consiste en establecer su habilidad para el consumo humano ya que si no daña al hombre no daña al concreto.

En este sentido es interesante distinguir el agua potable en términos de los requerimientos nominales establecidos por los organismos que regulan su producción y uso ya que los requerimientos aludidos son más exigentes de lo necesario.

3.2.2 PRINCIPALES REQUISITOS A CUMPLIR

La Norma NTP 339.088 establece como requisitos para agua de mezcla y curado:

CUADRO N° 3.1

Descripción	**Límite Permisible**
Sólidos en suspensión	5000 ppm máximo
Materia orgánica	3 ppm máximo
Carbonatos y bicarbonatos alcalinos	1000 ppm máximo
Sulfatos (Ion SO4)	600 ppm máximo
Cloruros (Ion CL)	1000 ppm máximo
PH	Entre 5.5 y 8.0

Existe evidencia experimental que el empleo de agua con contenidos individuales de cloruros, sulfatos y carbonatos sobre las 5000 ppm, ocasionan reducción de resistencias hasta del orden del 30% con relación a concretos con agua pura.

La materia orgánica por encima de las 1000 ppm reduce resistencia e incorpora aire.

El criterio que establece la Norma NTP 339.088 y el Comité ACI-318 para determinar la habilidad de determinada agua para emplearse en concreto, consiste en preparar cubos de mortero de acuerdo con la norma ASTM C-109, usando el agua dudosa y compararlos con cubos similares elaborados con agua potable. Si la resistencia en compresión a 7 y 28 días de los cubos con el agua en prueba no es menor del 90% de la de los cubos de control, se acepta el agua como apta para su uso en concreto.

Como dato interesante es una evidencia que en el Perú muy pocas "aguas potables" cumplen con las limitaciones nominales indicadas, sobre todo en lo que se refiere al contenido de sulfatos y carbonatos, sin embargo sirve para el consumo humano y consecuentemente para el concreto, por lo que no debe cometerse el error de establecer especificaciones para agua que luego no se puede satisfacer en la practica.

No existe un patrón definitivo en cuanto a las limitaciones en composición química que debe tener el agua de mezcla, ya que incluso aguas no aptas para el consumo humano sirven para preparar concreto y por otro lado depende mucho del tipo de cemento y las impurezas de los demás ingredientes.

Los efectos perniciosos que pueden esperarse del agua de mezcla con impurezas son: retardo en el endurecimiento, reducción de la resistencia, manchas en el concreto endurecido, eflorescencias, contribución a la corrosión del acero, cambios volumétricos, etc.

3.2.3 AGUA A UTILIZAR

El agua empleada en la presente Tesis para todas las mezclas realizadas es el agua potable, por lo tanto cumple con los requisitos establecidos en la Norma NTP 339.088.

3.3 AGREGADOS

3.3.1 GENERALIDADES

Los agregados son elementos inertes del concreto que son aglomerantes por la pasta de cemento para formar la estructura resistente. Estos, como parte constituyente del concreto ocupan del 60% al 80% del volumen del concreto, y tienen que estar graduados de tal forma que la masa total del concreto actué como una combinación relativamente sólida, homogénea y densa, con los tamaños mas pequeños actuando como un relleno inerte de los vacíos que existen entre las partículas mas grandes. Por eso cumplen una función importante para el logro de ciertas propiedades particulares de calidad, resistencia, economía, etc.

Se clasifican de acuerdo a sus dimensiones y se denominan agregado fino y agregado grueso; de acuerdo a su forma, pueden ser redondeados y angulares. La gran influencia que tienen sobre las propiedades del concreto, dependen de su estructura física y química así como de su granulometría.

La distribución volumétrica de las partículas tienen gran trascendencia en el concreto para tener una estructura densa y eficiente así como una trabajabilidad adecuada. En general, existen pruebas de ensayo necesarias que se realizan a los agregados; unos para establecer su calidad como son: Densidad, Estabilidad Química, Resistencia a la abrasión, etc. Y otros para determinar características para la dosificación de mezclas como el Peso Unitario, Absorción, humedad Superficial, etc.

Debido a que el agregado constituye la parte mayor de la mezcla, entre mas agregado se tenga en la mezcla, esto resultara en un concreto mas económico condición de que la mezcla sea de una razonable manejabilidad para el trabajo especifico.

3.3.2 AGREGADO FINO (NORMA NTP N° 400.037)

Se define como agregado fino a aquel que proviene de la desintegración natural (arena) o artificial de rocas, que pasan el tamiz 9.5 mm (malla 3/8") y queda retenido en el tamiz 74 umm (Malla N° 200).

El agregado fino puede consistir de arena natural o manufacturada, o combinación de ambas, sus partículas serán limpias, de perfil perfectamente angular, duras compactas y resistentes.

El agregado fino utilizado en la presente investigación es proveniente de la cantera "GLORIA", localizado a la altura del Km. 14.5 de la Carretera Central – Ate.

3.3.2.1 GRANULOMETRÍA Y MODULO DE FINURA

3.3.2.1.1 GRANULOMETRÍA (NORMA NTP 400.012)

La distribución de partículas del agregado tienen una gran importancia en los requerimientos del agua de la mezcla y en consecuencia de la trabajabilidad y acabado del concreto fresco.

El análisis granulométrico divide la muestra en fracciones de elementos del mismo tamaño, según las aberturas de los tamices utilizados

Para determinar la gradación de los agregados finos se utilizan los tamices Nº 3/8", 4, 8, 16, 30, 50 y 100; que están basadas de acuerdo a sus mallas cuadradas normalizadas y que sus requerimientos se dan en la tabla Nº 3.2

En general, es recomendable que las granulometría se encuentre dentro de los siguientes limites:

CUADRO 3.2

HUSO GRANULOMÉTRICO

MALLA	PORCENTAJE QUE PASA
9,5 – mm (3/8")	100
4,75 – mm (Nº 4)	95 a 100
2,36 – mm (Nº 8)	80 a 100
1,18 – mm (Nº 8)	50 a 85
600 micrones (Nº 30)	25 a 60
300 micrones (Nº 50)	10 a 30
150 micrones (Nº 100)	2 a 10

- El R.N.C. especifica la granulometría de la arena en concordancia con las normas A.S.T.M.

- Norma ASTM C 33 – 86

CUADRO 3.3

GRANULOMETRÍA

MUESTRA = 500 gr

Malla	M1	M2	M3	M4	M5	Promedio
#4	2	4	2.5	1.5	3	2.6
#8	85	110.5	109	89.5	108.5	100.5
#16	120.5	126.5	123	117.5	118	121.1
#30	95.5	91	89	94	88.5	91.6
#50	88	79	81	90.5	83	84.3
#100	59.5	51	53.5	59	56	55.8
Fondo	49.5	38	42	48	43	44.1
Total	500	500	500	500	500	500

Malla	Peso Retenido (gr)	%Retenido	%Ret. Acumulado	%Acum. Pasa
#4	2.6	0.52	0.52	99.48
#8	100.5	20.1	20.62	79.38
#16	121.1	24.22	44.84	55.16
#30	91.6	18.32	63.16	36.84
#50	84.3	16.86	80.02	19.98
#100	55.8	11.16	91.18	8.82
Fondo	44.1	8.82	100	0
Total	500			

3.3.2.1.2 MÓDULO DE FINURA (NORMA NTP 400.012)

Es un índice aproximado y representa el tamaño promedio de las partículas de la muestra de arena, se usa para controlar la uniformidad de los agregados. La norma establece que la arena debe tener un modulo de finura no menor de 2.3 ni mayor de 3.1.

Es un factor empírico que se obtiene de la suma de los porcentajes acumulados retenidos en las mallas N° 4, 8, 16, 30, 50 y 100 y dividido la sumatoria entre 100.

Se estima que las arenas comprendidas entre los módulos 2.2 a 2.8 producen concretos de buena trajabilidad y reducida segregación; Y las que se encuentran entre 2.8 y 3.1 son las mas favorables para concretos de alta resistencia.

Resultado:

$$Mf.arena = \frac{0.52+20.62+44.84+63.16+80.02+91.18}{100} = \mathbf{3.00}$$

Debe tenerse muy claro que es un criterio que se aplica tanto a la piedra como a la arena, pues es general y sirve para caracterizar cada agregado independiente o la mezcla de agregados en conjunto.

3.3.2.2 SUPERFICIE ESPECÍFICA

Es la suma de las áreas superficiales de las partículas del agregado por unidad de peso, para su determinación se considera la siguiente hipótesis que: todas las partículas son esféricas y el tamaño medio de las partículas que pasan por un tamiz y quedan retenido en el otro es igual al promedio de las aberturas.

CUADRO N° 3.4

Malla	%Retenido(1)	Diam. Promedio(2)	(1)/(2)
#4	0.52	0.714	0.728
#8	20.1	0.357	56.303
#16	24.22	0.179	135.307
#30	18.32	0.089	205.843
#50	16.86	0.044	383.182
#100	11.16	0.022	507.273
Fondo	8.82	0.011	801.818
			2090.453

$$Se = \frac{6(\sum t)}{100*Pe} = \frac{6*2090.45}{100*2.64} = \mathbf{47.51\ cm^2/gr}$$

3.3.2.3 PESO ESPECIFICO Y PORCENTAJE DE ABSORCIÓN (NORMA NTP N° 400.022)

3.3.2.3.1 PESO ESPECÍFICO

Es la relación entre el peso del material y su volumen; su diferencia con el peso unitario estriba en que este no toma en cuenta el volumen que ocupa los vacíos del material. Es necesario para realizar la dosificación de la mezcla y también para verificar que le agregado corresponde al material de peso normal.

A continuación se darán las siguientes definiciones.

A) Peso Especifico de Masa.-Relación entre el peso de la masa del agregado y el volumen total (incluyendo los poros permeables e impermeables, naturales del material).

B) Peso Especifico de Masa Saturada Superficialmente Seco.- Es la relación entre el peso del agregado saturado superficialmente seco y el volumen del mismo.

C) Peso Especifico Aparente.-Relación entre el peso de la masa del agregado y el volumen impermeable de masa del mismo.

3.3.2.3.2 PORCENTAJE DE ABSORCIÓN

Es la cantidad de agua que absorbe el material debido a sus características como porosidad, permeabilidad, etc.

La absorción de un agregado esta representada por el porcentaje de agua que le es necesario para llegar a la condición de saturado superficialmente seco (condición de equilibrio).

Para efectos de calculo se han promediado 3 ensayos que se detallan a continuación:

CUADRO N° 3.5

DATOS	UND	M1	M2	M3	PROM
Psss	gr	500	500	500	500.00
Pprob	gr	202	202	202	202.00
Pprob+Pagua	gr	702	702	702	702.00
Volumen inicial de agua	cc	507	506	505	506.00
Psss+Pprob+Pagua	gr	1201.5	1201	1200.5	1201.00
Volumen final de agua	cc	696	695	694	695.00
Pagua+Pprob	gr	887.5	886	886.5	886.67
Volumen de la muestra (G-C)	cc	185.5	184	184.5	184.67
Pseco horno	gr	488	490	486	488.00
Pesp.sss (A/H)	gr/cc	2.70	2.72	2.71	**2.71**
Pesp.masa (I/H)	gr/cc	2.63	2.66	2.63	**2.64**
Pesp.aparente (I/(H-(A-I)))	gr/cc	2.81	2.82	2.85	**2.83**
Absorcion (A-J)/J*100	%	2.46	2.04	2.88	**2.46**

PESO ESPEC. DE MASA:	***2.64***
PORCENTAJE DE ABSORC.:	***2.46***

3.3.2.4 PESO UNITARIO SUELTO Y COMPACTADO (NORMA NTP N° 400.017)

Es el peso del agregado por unidad de volumen. Este peso es variable dependiendo del grado de compacidad o de humedad, además varia con el tamaño, forma y granulometría del agregado.

Se determina dos pesos unitarios:

- **Peso Unitario Suelto (P.U.S.).-** Es cuando se llena el recipiente dado suavemente sin ninguna presión.

- **Peso Unitario Compactado (P.U.C).-** Es cuando se ejerce presión (compactación) al llenar el recipiente en tres (3), capas según norma.

A continuación se dan los resultados obtenidos para dos (2) ensayos, suelto y compactado.

A) PESO UNITARIO SUELTO

CUADRO N° 3.6

	DATOS	UND	M1	M2	M3	PROM
A	Pmuestra+Pbalde (1/10 p3)	gr	7277	7258	7302	7279
B	Pbalde 1/10 p3	gr	2779.5	2779.5	2779.5	2779.5
C	Pmuestra (A-B)	gr	4497.5	4478.5	4522.5	4499.5
D	Volumen balde 1/10 p3	cc	2831.7	2831.7	2831.7	2831.7
	Peso unitario suelto C/D	gr/cc	1.588	1.582	1.597	1.589

PESO UNITARIO SUELTO: ***1.589 gr/cc***

B) PESO UNITARIO COMPACTADO

CUADRO N° 3.7

	DATOS	UND	M1	M2	M3	PROM
A	Pmuestra+Pbalde (1/10 p3)	gr	7989	8071	8073	8044.33333
B	Pbalde 1/10 p3	gr	2779.5	2779.5	2779.5	2779.5
C	Pmuestra (A-B)	gr	5209.5	5291.5	5293.5	5264.83333
D	Volumen balde 1/10 p3	cc	2831.7	2831.7	2831.7	2831.7
	Peso unitario compactado C/D	gr/cc	1.840	1.869	1.869	1.859

PESO UNITARIO COMPACTADO: ***1.859 gr/cc***

3.3.2.4 CONTENIDO DE HUMEDAD

Se define como el porcentaje de agua que posee el agregado en el estado natural. El ensayo para su determinación se realiza de acuerdo a normas establecidas, lo que indica, que la muestra debe ser representativa y estar de acuerdo al tamaño máximo.

La humedad se expresa de la siguiente manera:

$$\%Humedad = \frac{Peso(muestra) - Peso\sec o}{Peso\sec o} \times 100$$

A continuación se dan los resultados de tres (3) ensayos obtenidos en el laboratorio:

CUADRO N° 3.8

	DATOS	UND	M1	M2	M3	PROM
A	Pmuestra humeda	gr	500	500	500	500
B	Pmuestra seca horno	gr	490	494	494	492.667
C	Contenido de humedad (A-B)/B*100	%	2.041	1.215	1.215	1.48999

CONTENIDO DE HUMEDAD 1.49 %

3.3.2.6 CANTIDAD QUE PASA LA MALLA N° 200

CUADRO N° 3.9

	DATOS	UND	M1	M2	M3	PROM
A	Pmuestra seca horno	gr	500	500	500	500
B	Pmuestra seca (via humeda)	gr	476	478	475	476.33
C	Material que pasa malla 200 (A-B)/B*100	%	4.800	4.400	5.000	4.73

MATERIAL QUE PASA MALLA #200 4.73 %

3.3.3 AGREGADO GRUESO

Se define como agregado grueso aquel retenido en el tamiz 476 mm (No. 4), proviene de la desintegración natural o mecánica de la roca y que cumple con los limites establecidos en la NORMA NTP 400.037.

Para el presente trabajo el agregado grueso es una piedra triturada cuyo Tamaño Nominal Máximo es 1", procedente de la Cantera *"La Gloria"*.

3.3.3.1 GRANULOMETRÍA Y TAMAÑO NOMINAL MÁXIMO (NORMA NTP N° 400.012)

3.3.3.1.1 GRANULOMETRÍA

En el estudio de la granulometría de los agregados a ocupado un importante lugar dentro de las primeras investigaciones realizadas sobre el concreto. El proporcionamiento de los agregados finos y gruesos para producir mezclas de la mas alta compacidad, y por ende, mas resistentes y económicas, dio origen a la propuesta de numerosas curvas prototipo o "ideales".

Se ha estimado en el análisis de la compacidad, que los agregados de similar dimensión producen el mayor numero de vacíos, mientras que de existir una determinada diferencia entre los tamaños, su acomodación se produce con la máxima compacidad.

Actualmente consenso que las granulometrías ideales no pueden generalizarse, por no asegurar ventajas ciertas en lo que respecta a la trabajabilidad y resistencia del concreto.

Según la norma NTP 400.011, Las mallas utilizadas para determinar la granulometría de los agregados, se designan por el tamaño de la abertura cuadrada en pulgadas.

Para el ensayo granulométrico se utilizo las mallas siguientes: 1", ¾", ½", 3/8", y No. 4.

A continuación se presenta el análisis granulométrico promedio de tres (3) ensayos.

CUADRO N° 3.10
GRANULOMETRÍA

MUESTRA = 6000 grs

Malla	**M1**	**M2**	**M3**	**M4**	**M5**	**Promedio**
1"	0	0	0	0	0	0
3/4"	1158	1360	1578	1493	1247	1367.2
1/2"	2512	2639	2683	2540	2415	2557.8
3/8"	1677	1523	1351	1495	1703	1549.8
1/4"	628	449	373.5	454	593	499.5
Fondo	25	29	14.5	18	42	25.7
Total	6000	6000	6000	6000	6000	6000

Malla	**Peso Retenido (gr)**	**%Retenido**	**%Ret. Acumulado**	**%Acum. Pasa**
1"	0	0	0	100
3/4"	1367.2	22.79	22.79	77.21
1/2"	2557.8	42.63	65.42	34.58
3/8"	1549.8	25.83	91.25	8.75
1/4"	499.5	8.33	99.57	0.43
Fondo	25.7	0.43	100:00	0.00
Total	6000			

- 1/5 de la menor separación entre los lados del encofrado;
- 1/3 del peralte de la losa;
- ¾ del espaciamiento mínimo libre entre las varillas o alambres individuales de refuerzo, paquetes de varillas, cables o ductos de preesfuerzo.

3.3.3.1.2 TAMAÑO NOMINAL MÁXIMO

Se indica generalmente como referencia de la granulometría y corresponde a la malla mas pequeña que produce el primer retenido.

T.N.M. = 1”

3.3.3.2 SUPERFICIE ESPECIFICA

Siguiendo el mismo proceso y/o definición del acápite 2.1.2. tenemos:

CUADRO N° 3.11

Malla	%Retenido(1)	Diam. Prom(2)	(1)/(2)
3/4"	22.78	3.16	7.21
1/2"	42.63	2.22	19.20
3/8"	25.83	2.58	10.01
1/4"	8.33	1.11	7.50
Fondo	0.43	0.79	0.54
			44.47

$$Se = \frac{6(\sum t)}{100{*}Pe} = \frac{6{*}44.47}{100{*}2.75} = 0.97\ cm^2/gr$$

3.3.3.3 PESO ESPECÍFICO (NORMA NTP N°400.021)

El ensayo se realizo pesando 2 Kg. De la muestra, primero en el aire y luego en una balanza hidrostática, la diferencia de pesos representa un volumen de agua desplazado es decir, el volumen de la piedra.

A continuación se dará los cálculos de tres ensayos realizados, obteniéndose su promedio.

CUADRO N° 3.12

	DATOS	UND	M1	M2	M3	PROM
A	Psss	gr	500	500	500	500.00
B	Pprob	gr	202	202	202	202.00
C	Pprob+Pagua	gr	702	702	702	702.00
D	Volumen inicial de agua	cc	506	505	505	505.33
E	Psss+Pprob+Pagua	gr	1202	1201.5	1202	1201.83
F	Volumen final de agua	cc	690	690	692	690.67
G	Pagua+Pprob	gr	882	880.5	886.5	883.00
H	Volumen de la muestra (G-C)	cc	180	178.5	184.5	181.00
I	Pseco horno	gr	498.5	497.5	497	497.67
J	**Pesp.sss (A/H)**	gr/cc	2.78	2.80	2.71	**2.76**
K	**Pesp.masa (I/H)**	gr/cc	2.77	2.79	2.69	**2.75**
L	**Pesp.aparente (I/(H-(A-I)))**	gr/cc	2.79	2.83	2.74	**2.79**
M	**Absorcion (A-J)/J*100**	%	0.30	0.50	0.60	**0.47**

PESO ESPECIFICO DE MASA: ***2.75***
PORCENTAJE DE ABSORCION: ***0.47***

3.3.3.4 PESO UNITARIO SUELTO Y COMPACTADO (NORMA NTP N° 400.017)

El ensayo se procederá de igual forma a la prueba de agregado fino.Se tiene a continuación los resultados obtenidos de dos (2) ensayos, suelto y compactado.

A) PESO UNITARIO SUELTO

CUADRO N° 3.13

	DATOS	UND	M1	M2	M3	PROM
A	Pmuestra+Pbalde (1/2p3)	gr	31500	31750	31750	31666.667
B	Pbalde 1/2 p3	gr	11800.0	11800.0	11800.0	11800
C	Pmuestra (A-B)	gr	19700.0	19950.0	19950.0	19866.667
D	Volumen balde 1/2 p3	cc	14158.42	14158.42	14158.42	14158.42
	Peso unitario suelto C/D	gr/cc	1.391	1.409	1.409	1.403

PESO UNITARIO SUELTO: ***1.403*** ***gr/cc***

B) PESO UNITARIO COMPACTADO

CUADRO N° 3.14

	DATOS	UND	M1	M2	M3	PROM
A	Pmuestra+Pbalde (1/2 p3)	gr	33650	34000	33900	33850
B	Pbalde 1/2 p3	gr	11800	11800	11800	11800
C	Pmuestra (A-B)	gr	21850	22200	22100	22050
D	Volumen balde 1/2 p3	cc	14158.42	14158.42	14158.4	14158.42
	Peso unitario compac. C/D	gr/cc	1.543	1.568	1.561	1.557

PESO UNITARIO COMPACTADO: ***1.557 gr/cc***

3.3.3.5 CONTENIDO DE HUMEDAD

Se efectúa colocando el material en el horno hasta que tenga peso constante.

Se dan los resultados y el promedio de tres (3) ensayos efectuados:

CUADRO N° 3.15

	DATOS	UND	M1	M2	M3	PROM
A	Pmuestra humeda	gr	500	500	500	500
B	Pmuestra seca horno	gr	499	498.8	498.2	498.6667
C	Contenido de humed.(A-B)/B*100	%	0.200	0.241	0.361	0.267426

CONTENIDO DE HUMEDAD ***0.267 %***

3.3.3.6 RESUMEN DE LAS PRINCIPALES PROPIEDADES FÍSICAS DE LOS AGREGADOS

CUADRO N° 3.16

ITEM	PROPIEDAD	AGREGADO FINO	AGREGADO GRUESO
1	**Peso Especifico de masa**	**2,64 gr/cc**	**2,75 gr/cc**
2	Peso Especifico de masa y superf. seca	2,71 gr/cc	2,76 gr/cc
3	Peso Especifico Aparente	2,83 gr/cc	2,79 gr/cc
4	**Contenido de Humedad**	**1,48%**	**0,27%**
5	**Porcentaje de Absorción**	**2,46%**	**0,47%**
6	**Peso aparente o unitario suelto**	**1,5876 gr/cc**	**1,4031 gr/cc**
7	**Peso Unitario Compactado**	**1,8341 gr/cc**	**1,5573 gr/cc**
9	Superficie Especifica	47.51 cm2/gr	0.97 cm2/gr.
10	**Modulo de Finura**	**3,00**	**7,14**
11	**Tamaño máximo**	**-----**	**1"**
12	**Tamaño nominal Máximo**	**-----**	**1"**

3.3.4 AGREGADO GLOBAL

3.3.4.1 GENERALIDADES

Es de suma importancia el estudio de los agregados por lo que estos ocupan aproximadamente las 3/4 partes del volumen total del concreto, que influirán en las propiedades del concreto. En lo que respecta la granulometría, lo mas importante es la gradación total. Los agregados fino y gruesos, por separado no necesariamente cumplirán con los husos granulométricos establecidos por las normas ASTM C – 33 e NTP 400 – 012; que sin embargo mezclándolos adecuadamente nos suministran una distribución de partículas eficiente, que para nuestro caso, de aquí en adelante lo denominaremos como agregado global. La misma norma ASTM C – 33, admite esto, ya que nos indica que se podrán emplear agregados que no cumplan con los requisitos, si se demuestra que con ellos se obtiene concretos que satisfacen las especificaciones técnicas del proyecto.

Para la evaluación granulométrica nos remitiremos a los husos DIN 1045 para el agregado global.

Para concreto mas trabajable

- Concreto de mejor trabajabilidad del huso “A” al “B”
- Concretos de trabajabilidad aceptable del huso “B” al “C”

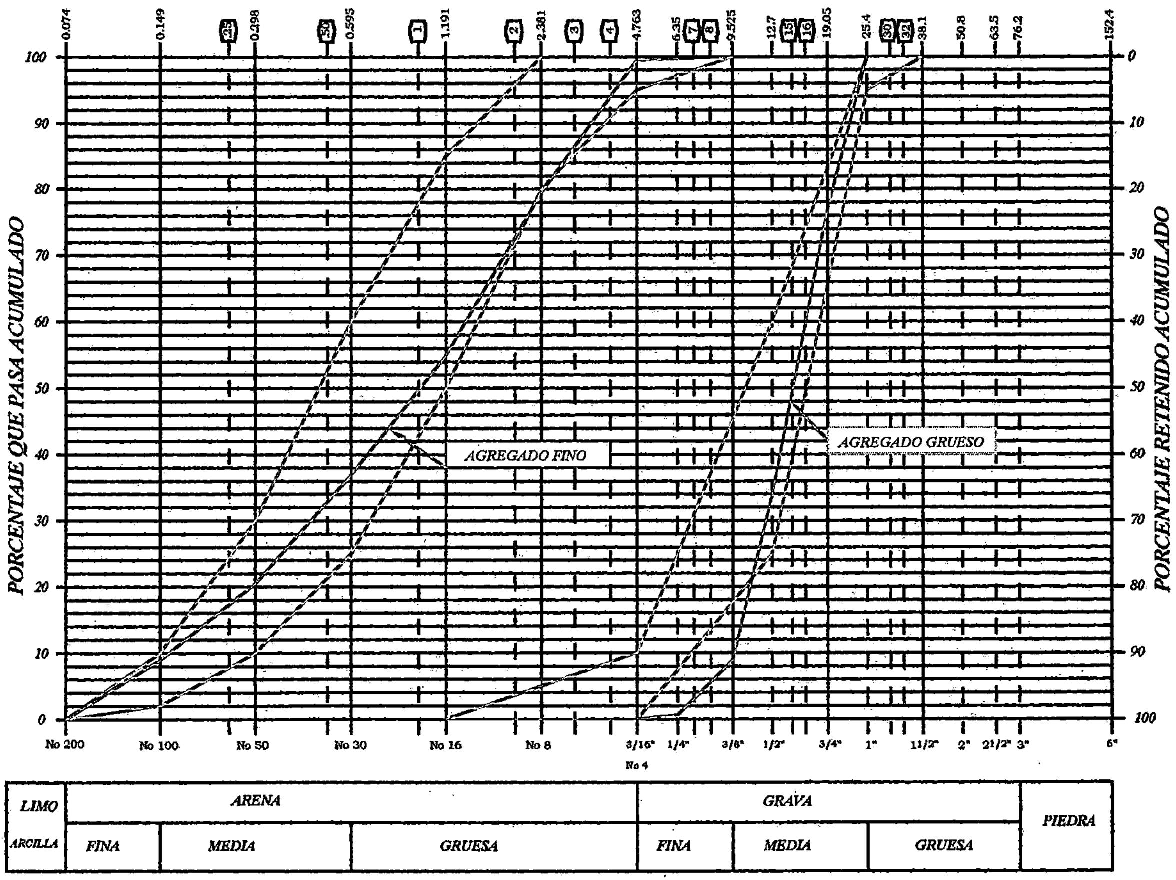
GRÁFICO N° 3.1

UNIVERSIDAD NACIONAL DE INGENIERIA
FACULTAD DE INGENIERIA CIVIL

PROYECTO : TESIS
MUESTREO : ARENA 0.5 Kg Y PIEDRA 6 Kg
PROCEDENCIA : CANTERA GLORIA
FECHA DE ENSAYO : 06/10/2000
BACH : TARAZONA TINOCO JHON LUIS

TAMICES STANDARD ASTM
(ABERTURA EN MILIMETROS)

ANALISIS GRANULOMETRICO



CARACTERIST. FISICAS DE LOS AGREGADOS	FINO	GRUESO
DIAMETRO NOMINAL MAX.	-	1"
MODULO DE FINURA	3.00	7.14
PESO ESPECIFICO (SECO)	2.64	2.75
ABSORCION (%)	2.46	0.47
HUMEDAD (%)	1.49	0.27
PESO UNITARIO (SUELTO)	1.587	1.403
PESO UNITARIO (COMP.)	1.834	1.500

GRANULOMETRIA (% RETENIDO ACUMULADO)

TAMIZ ASTM	PIEDRA	ARENA	HUSO A. GRUESO	HUSO A. FINO
21/2"				
2"				
11/2"			100	
1"	0.00	0.00	95 - 100	
3/4"	22.76	0.00		
1/2"	66.28	0.00	25 - 60	
3/8"	91.56	0.00		100
1/4"	99.62	0.00		
No 4	100	0.50	0 - 10	95 - 100
No 8	100	20.67	0 - 5	80 - 100
No 16	100	44.77		50 - 85
No 30	100	62.97		25 - 60
No 50	100	79.77		10 - 30
No 100	100	91.03		2 - 10
No 200	100	100		

CUADRO N° 3.17

TAMIZ	ABERTURA	AGREGADO GLOBAL (% ACUM. QUE PASA)		
		A	B	C
1 1/2"	(32 mm.)	100	100	100
3/4"	(16 mm.)	62	80	89
1/2"	(08 mm.)	38	62	77
No. 4	(04 mm.)	23	47	65
No. 8	(02 mm.)	14	37	53
No. 16	(01 mm.)	8	28	42
No. 50	(0,25 mm.)	2	8	5

A mayor calidad de los agregados (dureza, resistencia al desgaste, etc, etc), nos proporcionara un concreto de mayor calidad. Son útiles agregados de origen ígneo, para un concreto de alta resistencia a la compresión.

3.3.4.2 PESO UNITARIO COMPACTADO

Para lograr una optima granulometría del agregado global, para el diseño de un concreto de calidad, trabajable y económico, es necesario determinar proporciones de agregado fino y grueso, de manera que nos resulte un agregado global de mayor peso unitario compactado.Esta combinación de máxima densidad creara un volumen mínimo de vacíos, necesitando menos cantidad de pasta de cemento (factor importante), cuando forme parte del concreto. Para ello, se hizo mezclas de diversas proporciones en peso, del agregado fino y grueso determinándose sus respectivos pesos unitarios compactados del agregado global y por ende el máximo.

Para calcular el peso unitario compactado del agregado global, se realizo mezclas en peso del agregado fino y el agregado, con las siguientes proporciones:

CUADRO N° 3.18

%ARENA	40	45	50	55	60
% PIEDRA	60	55	50	45	40

CUADRO N° 3.19
PESO UNITARIO COMPACTADO DE LA COMBINACION

Pbalde = 11.8 kg

Vbalde = 1/2 pie^3

P.m. = 50 kg		**MUESTRA**	**P_{m+b} (kg)**	**$P_m=P_{m+b}-P_b$ (kg)**	**$PUC=P_m/V_b$ (kg/m^3)**
40%Pm = **60%Pm =**	**20.0 kg** **30.0 kg**	M-1	39.60	27.80	1963.50
		M-2	38.80	27.00	1906.99
		M-3	39.80	28.00	1977.62
			PUC =	**1949.37**	**kg/m^3**
45%Pm = **55%Pm =**	**22.5 kg** **27.5 kg**	M-1	40.85	29.05	2051.78
		M-2	41.25	29.45	2080.03
		M-3	40.65	28.85	2037.66
			PUC =	**2056.49**	**kg/m^3**
50%Pm = **50%Pm =**	**25.0 kg** **25.0 kg**	M-1	41.20	29.40	2076.50
		M-2	40.75	28.95	2044.72
		M-3	41.30	29.50	2083.57
			PUC =	**2068.26**	**kg/m^3**
55%Pm = **45%Pm =**	**27.5 kg** **22.5 kg**	M-1	40.90	29.10	2055.31
		M-2	40.80	29.00	2048.25
		M-3	41.10	29.30	2069.44
			PUC =	**2057.67**	**kg/m^3**
60%Pm = **40%Pm =**	**30.0 kg** **20.0 kg**	M-1	40.35	28.55	2016.47
		M-2	40.40	28.60	2020.00
		M-3	39.95	28.15	1988.22
			PUC =	**2008.23**	**kg/m^3**

Como podemos apreciar en el cuadro anterior se realizan tres muestras para cada uno de los porcentajes de arena, piedra de los cuales se les sacara un promedio con lo que se procederá para su grafica.

Esta grafica nos permitirá obtener el máximo peso unitario compactado y su correspondiente porcentaje de arena a continuación mostramos la grafica.

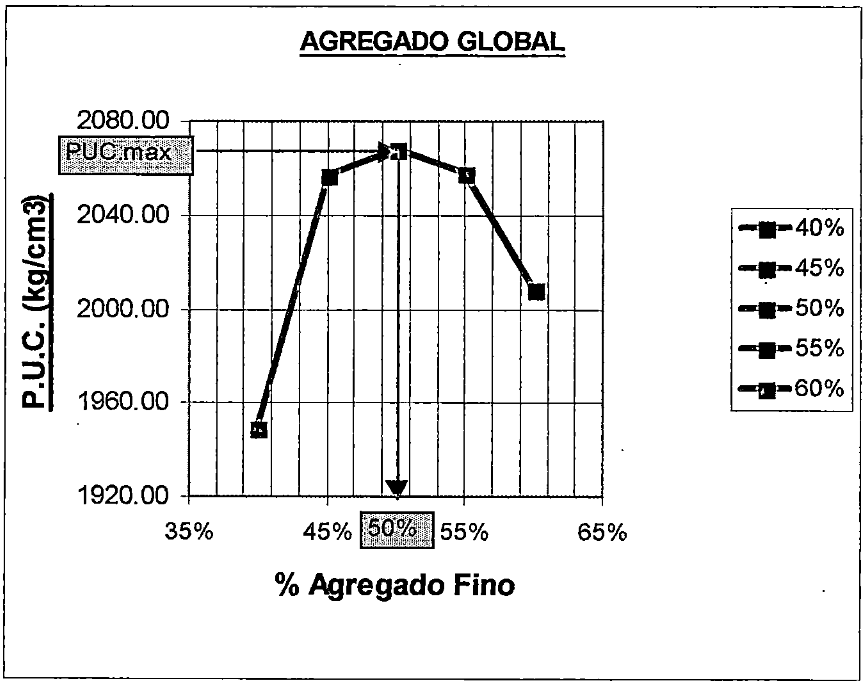
CUADRO N° 3.20

RESUMEN

%A.F.	PUC(kg/m^3)
40%	1949.37
45%	2056.49
50%	2068.26
55%	2057.67
60%	2008.23

GRAFICO N° 3.2

ENSAYO DE MAXIMA COMPACTACION DEL AGREGADO GOBAL



PUC.Max = 2.68.2kg/m^3
AGREGADO FINO = 50%

Podemos apreciar del grafico que su máximo peso unitario se produce para un porcentaje de arena equivalente al 50%, siendo este el primer indicador, en consecuencia este valor nos permitirá aproximarnos al porcentaje optimo.

3.3.4.3 MÉTODO DE LA RESISTENCIA MÁXIMA.

Para la determinación optima de la relación de agregados se procederá a ensayar probetas para concretos diseñados con porcentajes de arena +3% y –3% al porcentaje inicial probable, ósea los porcentajes de agregado fino para el ensayo serán de: 47%, 50% , 53% y la relación de agua cemento para dicho diseño es de 0.45.

Cabe resaltar que para la elaboración de las probetas se realizo en el diseño con asentamiento de 3" a 4", todas las probetas se sometieron a curado y el ensayo a compresión se realizo a la edad de 7 días, a continuación presentamos los resultados obtenidos.

CUADRO N° 3.21

ENSAYOS DE RESISTENCIA A COMPRESION A 7 DIAS DE EDAD (a/c=0.45)

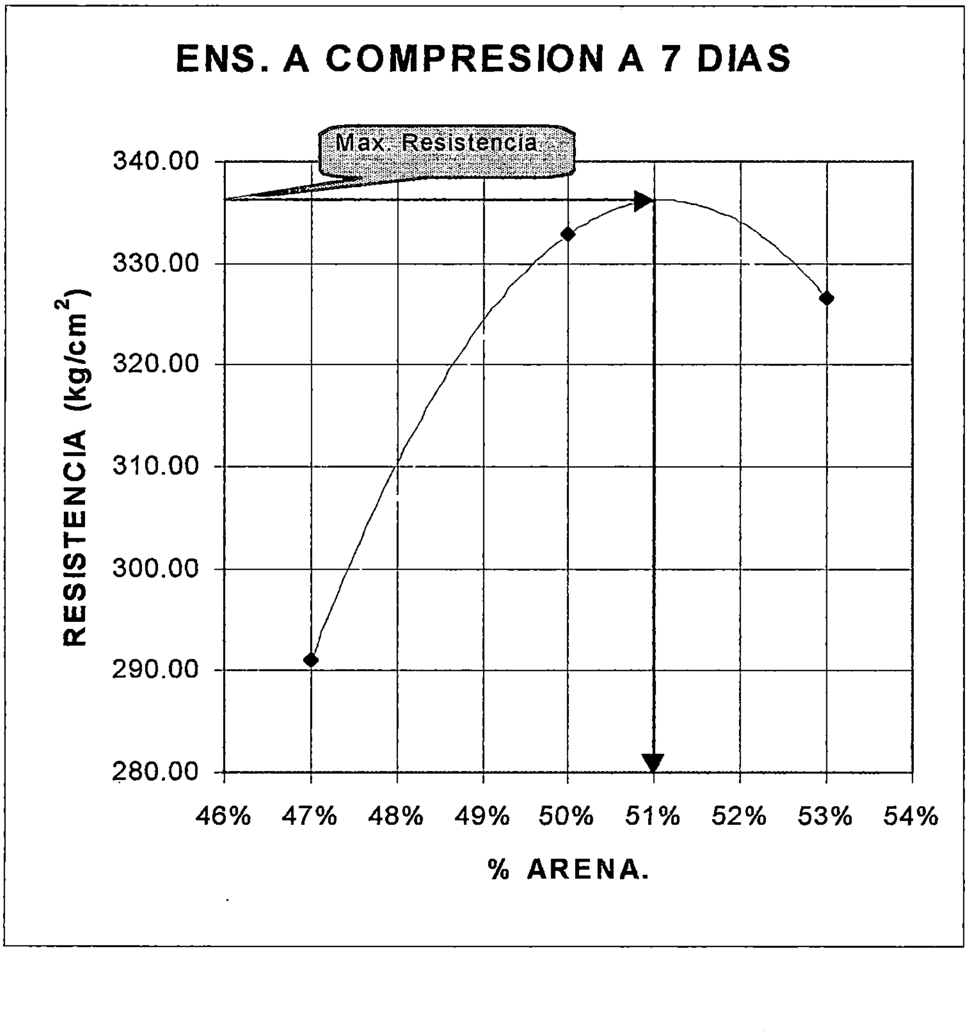
%A.F.	MUESTRA	Diámetro	Area (cm²)	Carga (kg)	fc (kg/cm²)
47%	M-1	14.80	172.00	47600.00	276.74
	M-2	14.90	174.00	50600.00	290.80
	M-3	14.80	172.00	52600.00	305.81
		fc =	**291.12**		
50%	M-1	14.80	172.00	59600.00	346.51
	M-2	14.80	172.00	56800.00	330.23
	M-3	14.80	172.00	55400.00	322.09
		fc =	**332.95**		
53%	M-1	15.00	177.00	53800.00	303.95
	M-2	14.80	172.00	56000.00	325.58
	M-3	14.80	172.00	60200.00	350.00
		fc =	**326.51**		

Con los resultados del promedio (cada 3 probetas) de resistencia a la compresión (f'c) y sus respectivos porcentajes de arena procederemos a graficar para obtener el porcentaje definitivo de arena.

GRAFICO N° 3.3

CURVA PARA OBTENER EL AGREGADO FINO OPTIMO

(Agua/Cemento = 0.45)



MAXIMA RESISTENCIA = 336.2kg/cm^2
% DE AGREGADO FINO = 51

Del grafico podemos apreciar que la máxima resistencia a la edad de 7 días, tiene su correspondiente en porcentaje de ARENA equivalente al 51% en consecuencia los porcentajes finales de Arena, Piedra es 51%, 49% respectivamente, cabe indicar que estos porcentajes de agregados serán definitivos para la elaboración del concreto, tanto el concreto patrón, como en el concreto con la adición de fibras de Acero Insonex, los diseños de estos concretos serán realizados para las relaciones de agua/cemento equivalente a 0.40, 0.45, 0.50. También con estos porcentajes finales de agregados procederemos a realizar los cálculos para la granulometría del AGREGADO GOBAL. A continuación mostramos el cuadro del análisis granulométrico.

CUADRO N° 3.22

GRANULOMETRIA DEL AGREGADO GLOBAL

Norma:	Huso Din 1045
Cantera:	Gloria
Muestra:	50 kg

Tamiz	**% Retenido Acumulado**		
	Arena	**Piedra**	**51%Ar+49%Pd**
1"		0.00	0.00
3/4"		22.76	11.15
1/2"		66.28	32.48
3/8"		91.56	44.86
1/4"		99.62	48.81
N° 4	0.50	100.00	49.26
N° 8	20.67		59.54
N° 16	44.77		71.83
N° 30	62.97		81.11
N° 50	79.77		89.68
N° 100	91.03		95.43
FONDO	100.00		100.00
TOTAL			

Módulo de Finura : Suma%AR(1 1/2",3/4",3/8",N°4,N°8,N°16,N°30,N°50,N°100) / 100

M.F. = 5.03

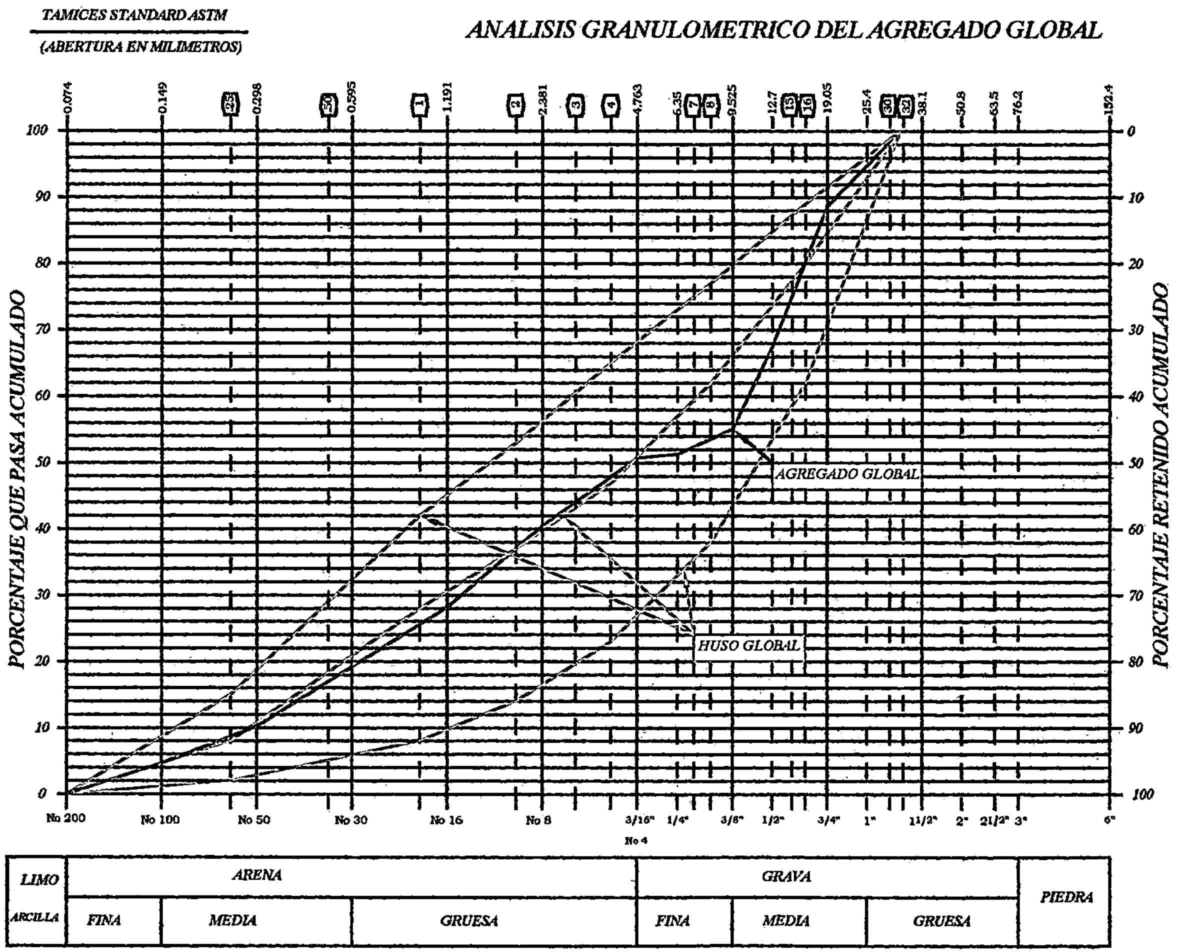
Con los valores que se muestran en el cuadro anterior procederemos a plotear la curva granulométrica de acuerdo al HUSO DIN 1045, a continuación mostramos el grafico mencionado.

GRÁFICO N° 3.4

UNIVERSIDAD NACIONAL DE INGENIERIA
FACULTAD DE INGENIERIA CIVIL

PROYECTO : TESIS
MUESTREO : ARENA 0.5 Kg Y PIEDRA 6 Kg
PROCEDENCIA : CANTERA GLORIA
FECHA DE ENSAYO : 06/10/2000
BACH : TARAZONA TINOCO JHON LUIS

ANALISIS GRANULOMETRICO DEL AGREGADO GLOBAL



CARACTERIST. FISICAS DE LOS AGREGADOS	ARENA	PIEDRA
DIAMETRO NOMINAL MAX.	-	*1"*
MODULO DE FINURA	*3.00*	*7.14*
PESO ESPECIFICO (SECO)	*2.64*	*2.75*
ABSORCION (%)	*2.46*	*0.47*
HUMEDAD (%)	*1.49*	*0.27*
PESO UNITARIO (SUELTO)	*1.587*	*1.403*
PESO UNITARIO (COMP.)	*1.834*	*1.500*

GRANULOMETRIA (% RETENIDO ACUMULADO)

TAMIZ ASTM	Ag. Gr.	Ag. Fi.	51% Ag. Fi 49% Ag. Gr
1"	*0.00*	*0.00*	*0.00*
3/4"	*22.76*	*0.00*	*11.15*
1/2"	*66.28*	*0.00*	*32.48*
3/8"	*91.56*	*0.00*	*44.86*
1/4"	*99.62*	*0.00*	*48.81*
No 4	*100*	*0.50*	*49.26*
No 8	*100*	*20.67*	*59.54*
No 16	*100*	*44.77*	*71.83*
No 30	*100*	*62.97*	*81.11*
No 50	*100*	*79.77*	*89.68*
No 100	*100*	*91.03*	*95.43*
No 200	*100*	*100*	*100*

TAMAÑO MAXIMO = 32 mm			
HUSO DIN 1045			
MALLA (mm)	% QUE PASA ACUMULADO		
	A	*B*	*C*
31.50	*100*	*100*	*100*
16.00	*62*	*80*	*89*
8.00	*38*	*62*	*77*
4.00	*23*	*47*	*65*
2.00	*14*	*37*	*53*
1.00	*8*	*28*	*42*
0.50			
0.25	*2*	*8*	*15*

ESTUDIO DEL COMPORTAMIENTO DEL CONCRETO DE MEDIANA A ALTA RESISTENCIA CON LA INCORPORACION DE FIBRAS DE ACERO Y CPT I

CAPITULO 04

DISEÑO DE MEZCLA

4.1 GENERALIDADES

El diseño de mezclas de concreto, es conceptualmente, la aplicación técnica y práctica de los conocimientos científicos sobre sus componentes y la interacción entre ellos, para lograr un material resultante que satisfaga de la manera más eficiente los requerimientos particulares del proyecto constructivo.

Es usual el suponer que esta técnica consiste en la aplicación sistemática de ciertas tablas y proporciones ya establecidas que satisfacen prácticamente todas las situaciones normales en las obras, lo cual está muy alejado de la realidad, ya que es en esta etapa del proceso constructivo cuando resulta primordial la labor creativa del responsable de dicho trabajo y en consecuencia el criterio personal.

La tecnología del concreto moderna es una premisa básica el que no se puede separar el diseño de la mezcla, del proceso constructivo en su integridad, ya que entre ambos existe una correspondencia biunívoca, pues para cada obra existen condicionantes ambientales, de diseño estructural, de materiales, mano de obra, equipo, etc., que necesariamente requieren una solución original en lo que al diseño de mezcla se refiere.

En realidad, hay que tener presente que no existe ningún método perfecto, ni que nos proporcione una receta infalible para solucionar todos los casos prácticos, por lo que las bondades de un método sobre otro residen finalmente en el criterio personal de quien los aplique y los resultados que cada profesional con su conocimiento técnico y experiencia obtenga en obra; siempre en concordancia con los requerimientos del proyecto por ende la calidad del concreto.

4.2 CONSIDERACIONES Y/O CRITERIOS PARA EL DISEÑO DE LAS MEZCLAS.

Debemos enfocar el concepto de diseño de mezcla para producir un concreto, tan económicamente sea posible, que cumplan con los requisitos requeridos para los estados fresco como el mezclado, transporte, colocación, compactado y acabado; y en el estado endurecido, la resistencia a la compresión y durabilidad.

En general, prácticamente todas las propiedades del concreto endurecido están endurecidas a la resistencia y, en muchos casos, es e4n función del valor de ella que se les cuantifica. Sin embargo, debe siempre recordarse al diseñar una mezcla de concreto que muchos factores ajenos a la resistencia puedan afectar a las propiedades.

Es usual el suponer que esta técnica consiste en la aplicación sistemática de ciertas tablas y proporciones ya establecidas que satisfacen prácticamente todas las situaciones normales en las obras, lo cual esta alejado de la realidad, ya que es en esta etapa del proceso constructivo cuando resulta primordial la labor creativa del responsable de este trabajo y en consecuencia el criterio personal. Debemos advertir finalmente que la etapa de diseño de mezclas de concreto antes que el fin de un proceso, representa solo el inicio de la búsqueda de la mezcla mas adecuada. Conseguir una mezcla con un mínimo de pasta y volumen de vacíos o espacios entre partículas y consecuentemente cumplir con las propiedades requeridas es lo que la tecnología del concreto busca en un diseño de mezcla.

Antes de dosificar una mezcla se debe tener conocimiento del siguiente conjunto de información:

- Los materiales
- Del elemento a vaciar, tamaño y forma de las estructuras
- Resistencia a la compresión requerida
- Condiciones ambientales durante el vaciado
- Condiciones a la que estará expuesta la estructura

4.3 PARAMETROS BASICOS EN EL COMPORTAMIENTO DEL CONCRETO

a) LA TRABAJABILIDAD.

Es una propiedad del concreto fresco que se refiere a la facilidad con que este puede ser mezclado, manejado, transportado, colocado y terminado sin que pierda su homogeneidad (exude ó se segregue). El grado de trabajabilidad apropiado para cada estructura, depende del tamaño y forma del elemento que se vaya a construir, de la disposición y tamaño del refuerzo y de los métodos de colocación y compactación.

Los factores más importantes que influyen en la trabajabilidad de una mezcla son los siguientes: La gradación, la forma y textura de las partículas y las proporciones del agregado, la cantidad del cemento, el aire incluido, insumos como la fibra y la consistencia de la mezcla.

Un método indirecto para determinar la trabajabilidad de la mezcla consiste en medir su consistencia o fluidez por medio del ensayo del asentamiento con el cono.

El requisito de agua es mayor cuando los agregados son más angulares y de textura áspera (pero esta desventaja puede compensarse con las mejoras que se producen en otras características, como la adherencia con la pasta de cemento).

b) LA RESISTENCIA.

La resistencia a la compresión simple es la característica mecánica mas importante de un concreto, pero otras como la durabilidad, la permeabilidad y la resistencia al desgaste son a menudo de similar importancia.

c) LA DURABILIDAD.

El concreto debe poder soportar aquellas exposiciones que pueden privarlo de su capacidad de servicio tales como congelación y deshielo, ciclos repetitivos de mojado y secado calentamiento y enfriamiento, sustancias químicas, ambiente marino y otras semejantes. La resistencia a algunas de ellas puede fomentarse mediante el uso de ingredientes especiales como: cemento de bajo contenido de álcalis, puzolanas o agregados seleccionados para prevenir expansiones dañinas debido a la reacción álcalis, agregados que ocurre en algunas zonas cuando el concreto esta expuesto a un ambiente húmedo, cementos o puzolanas resistentes a los sulfatos para concretos expuestos a agua de mar o en contacto con suelos que contengan sulfatos; o agregados libres de excesivas partículas suaves, cuando se requiere resistencia a la abrasión superficial. La utilización de bajas relaciones de ague/cemento prolonga la vida útil del concreto reduciendo la penetración de líquidos agresivos.

4.4 CRITERIO DE DISEÑO.

En la presente tesis de investigación se seguirá el procedimiento del ACI 211.1, pero teniendo en cuenta la relación optima porcentual de combinación entre la arena y piedra, la cual fue determinada por el método de la máxima compactación del agregado global, con el propósito de economizar el uso del cemento y reducir los vacíos del concreto, para el diseño usaremos como dato de partida las relaciones de agua/cemento de 0.40, 0.45, 0.50. asimismo la cantidad requerida de agua será la obtenida mediante el diseño de mezclas de prueba a fin de obtener el slump requerido.

4.5 COMBINACION DE AGREGADOS CON EL MAYOR PESO UNITARIO.

Para el diseño de mezcla es de suma importancia la proporción de agregados, en consecuencia esto se logra evaluando el **Máximo Peso Unitario Compactado** que se obtiene al combinar diferentes proporciones, entre el agregado fino (ARENA) y el agregado grueso (PIEDRA). Estos resultados ya se han obtenido como se detalla en el capitulo 03 en el tema de **Agregado Global** (en el que se muestran cuadros y grafico). Podemos decir de acuerdo a ello que los porcentajes son de: **Ar/Pdra: 50%/50%.**

4.6 RESUMEN DE LAS PROPIEDADES FÍSICAS DE LOS AGREGADOS.

Para el diseño de mezcla es necesario los valores de las propiedades de los elementos que participan en el concreto que a continuación señalamos.

CEMENTO PORTLAND TIPO I ANDINO

PESO ESPECIFICO = **3.12gr/cm^3**

CUADRO N° 4.1

RESUMEN DE LAS CARACTERISTICAS FISICAS

Descripcion	Und	Agregado	
		Fino	Grueso
Peso Específico de Masa	gr/cc	2.640	2.750
Porcentaje de Absorción	%	2.460	0.470
Contenido de Humedad	%	1.480	0.270
Tamaño máximo Nominal	Plg	----	1"
Combinacion	%	51	49

4.7 SECUENCIA RESUMEN DEL DISEÑO DE MEZCLA

A continuación se presenta la secuencia seguida en el diseño de mezcla:

a) Determinación de la propiedades físicas de los materiales a emplear.

b) Elección de la relación agua/cemento en peso. Si estuviéramos en obra se elegiría la relación agua/cemento sobre la base de la resistencia a la compresión requerida o condiciones de durabilidad.

c) Elección del revenimiento o asentamiento según la consistencia requerida a las condiciones de trabajabilidad.

d) Se considera el tamaño nominal máximo del agregado grueso

e) Se determina si la mezcla tendrá o no aire incorporado. Se estima el porcentaje de aire por metro cúbico y el volumen absoluto que atrapara el concreto en función del Tamaño Nominal Máximo del agregado grueso.

f) Se establece la cantidad de agua por metro cúbico en función del Tamaño Nominal Máximo del agregado, del asentamiento y considerando si la mezcla tiene aire atrapado o incorporado. Esto se establece de las tablas del ACI.

g) Se calcula cantidad de cemento en peso, basándose en la relación agua/cemento y la cantidad de agua a emplear por metro cúbico de concreto.

$$\text{Cemento(Kg)} = \frac{\text{Peso del agua (Kg)}}{\text{Relacion agua/cemento}}$$

h) Calculo de los volúmenes absolutos del agua y cemento:

$$\text{Volumen Absoluto del Agua (m}^3\text{)} \quad \frac{\text{Peso del Agua (Kg)}}{\text{Peso Especifico Agua (Kg/m}^3\text{)}}$$

$$\text{Volumen Absoluto del Cemento (m}^3\text{)} \quad \frac{\text{Peso del Agua (Kg)}}{\text{Peso Especifico Agua (Kg/m}^3\text{)}}$$

i) Después de conocer los volúmenes que ocupan el agua, cemento y aire atrapado; se procede a calcular el volumen, que ocuparan los agregados para un metro cubico de concreto.

$$\text{Vol. Abs.Agreg}(m^3) = 1 - (\text{Vol.Cemento}+\text{Vol. Agua}+\text{Vol. Aire Atrapado})$$

j) Ahora se calcula el volumen de los agregados fino (vf) y grueso (vg) sabiendo que:

$$Vf + Vg = \text{Vol. Abs. Agregados} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{I}$$

$$\%\,\text{Ag.Fino} = \frac{\text{P.E. (Fino)} \times Vf}{\text{P.E. (Fino)} \times Vf + \text{P.E. (Grueso)} \times Vg} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{II}$$

Resolviendo I y II se hallan los volúmenes de los agregados fino (Vf) y (Vg).

k) Luego se calcula los pesos secos de los agregados:

Peso seco Arena (Kg) = Vol. Ag. Fino(m^3) x P.E. de la arena (Kg/ m^3)

Peso seco Piedra (Kg) = Vol. Ag. Grueso(m^3) x P.E. de la Piedra (Kg/ m^3)

l) Se continua calculando el aporte de agua de los agregados:

Agua de la Arena = Peso seco Arena x (% Cont. Humed. - %Absor.)/100

Agua de la Piedra = Peso seco Piedra x (% Cont. Humed. - %Absor.)/100

m) Corrección de la cantidad de agua

Agua de mezcla = Agua Inicial – (Agua de la Arena + Agua de la Piedra)

n) Calculo del Peso Húmedo de los Agregados:

Peso húmedo de la Arena = Peso seco Arena x (1+ %Cont. Humedad)

Peso húmedo de la Piedra = Peso seco Piedra x (1+ %Cont. Humedad)

o) Finalmente tendremos el diseño de mezcla para un metro cúbico de concreto:

Cemento (Kg); Agua(Lts); Peso Húmedo de la Piedra (Kg); Peso Húmedo de la Arena (Kg).

Con este diseño se obtuvo la dosificación para un metro cúbico de concreto; pero en la presente investigación se uso una mezcladora de 0.021 m^3

Siguiendo el método del ACI se realizo una mezcla de prueba en la que se obtuvo un concreto que no era trabajable (Asentamiento 1").

4.8 RELACIÓN OPTIMA DE AGREGADOS.

Los valores anteriores de porcentajes de arena y piedra constituyen una primera aproximación, en consecuencia para obtener el porcentaje definitivo procederemos a diseñar concretos con +3% y -3% del agregado fino (arena) obtenido y tomaremos de las relaciones a estudiar (0..40, 0.45, 0.50), el de 0.45 y un rango de asentamiento de 4 ½ a 5 ½ ,pues luego se someterán las probetas a curado, a la edad de 7 días se realizaran los ensayos a compresión, con los resultados de resistencia a la compresión y los porcentajes de arena procederemos a graficar, determinando según la grafica un porcentaje de arena de 51% y consecuentemente piedra de 49%.

A continuación desarrollaremos los diseños para cada uno de los porcentajes de arena (47, 50, 53) %. Realizaremos 3 diseños para diferentes cantidades de agua por m^3 de concreto con el propósito de encontrar el que genere un asentamiento de 5 pulgadas de asentamiento.

También presentamos los diseños los diseños que generan 5" de asentamiento para determinar el porcentaje optimo del agregado fino (ARENA).

DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 1:

%Arena	0.47
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	210
% Aire	1.50%

DATOS :

Descripción		Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)		2640	2750	3120
Cont. de Humedad (%)		1.480	0.270	
Porc. de Absorción (%)		2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P.U.Sec	P.U.Hum	50 kg
Cemento	466.67	0.150	466.67	1.00	1.00	9.77
Agua	210.00	0.210	219.56	0.45	0.47	4.60
Arena	792.84	0.297	804.57	1.70	1.72	16.85
Piedra	894.05	0.324	896.47	1.92	1.92	18.78
Sum. Total	2363.56	0.980	2387.26	5.06	5.12	50.0
%Aire de Diseño =		1.50%		Asentamiento :		2 1/2"
S. Parcial (Cem+Agua+Aire) =		0.375				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.625

Peso seco = Peso Especifico x Volumen

Peso seco Agreg. Fino = 2640 xVa

Peso seco Agreg. Grueso = 2750 xVp

rf = 0.47

Entonces:

V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.300

V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.325

Suma = 0.625

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 792.84

Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 894.05

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 804.57

Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 896.47

Correccion de Agua :

Agregado Fino = Asx(%w-%Abs)/100 = -7.770

Agregado Grueso = Psx(%w-%Abs)/100 = -1.788

Corrección = -9.558

Agua Corregida = Agua - Corrección = 219.56

DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 2:

%Arena	0.47
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	230
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P. U. Hum	Tanda de 50 kg
Cemento	511.11	0.164	511.11	1.00	1.00	10.84
Agua	230.00	0.230	239.03	0.45	0.47	5.07
Arena	749.43	0.281	760.52	1.47	1.49	16.13
Piedra	845.10	0.306	847.38	1.65	1.66	17.97
Sum. Total	2335.64	0.981	2358.04	4.57	4.61	50.0
%Aire de Diseño =		1.50%		Asentamiento :		3 1/2"
S. Parcial (Cem+Agua+Aire) =		0.409				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.591

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.47

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.284
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.307
Suma = 0.591

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 749.43
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 845.10

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 760.52
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 847.38

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -7.344
Agregado Grueso = Psx(%w-%Abs)/100 = -1.690
Corrección = -9.035

Agua Corregida = Agua - Corrección = 239.03

DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 3:

%Arena	0.47
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	260
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	577.78	0.185	577.78	1.00	1.00	12.48
Agua	260.00	0.260	268.25	0.45	0.46	5.80
Arena	684.31	0.256	694.44	1.18	1.20	15.00
Piedra	771.67	0.280	773.75	1.34	1.34	16.72
Sum. Total	2293.76	0.981	2314.22	3.97	4.01	50.0
%Aire de Diseño =		1.50%		Asentamiento :		7 1/2"
S. Parcial (Cem+Agua+Aire) =		0.460				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.540

Peso seco = Peso Especifico x Volumen

Peso seco Agreg. Fino = 2640 xVa

Peso seco Agreg. Grueso = 2750 xVp

rf = 0.47

Entonces:

V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.259

V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.281

Suma = 0.540

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 684.31

Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 771.67

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 694.44

Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 773.75

Correccion de Agua :

Agregado Fino = Asx(%w-%Abs)/100 = -6.706

Agregado Grueso = Psx(%w-%Abs)/100 = -1.543

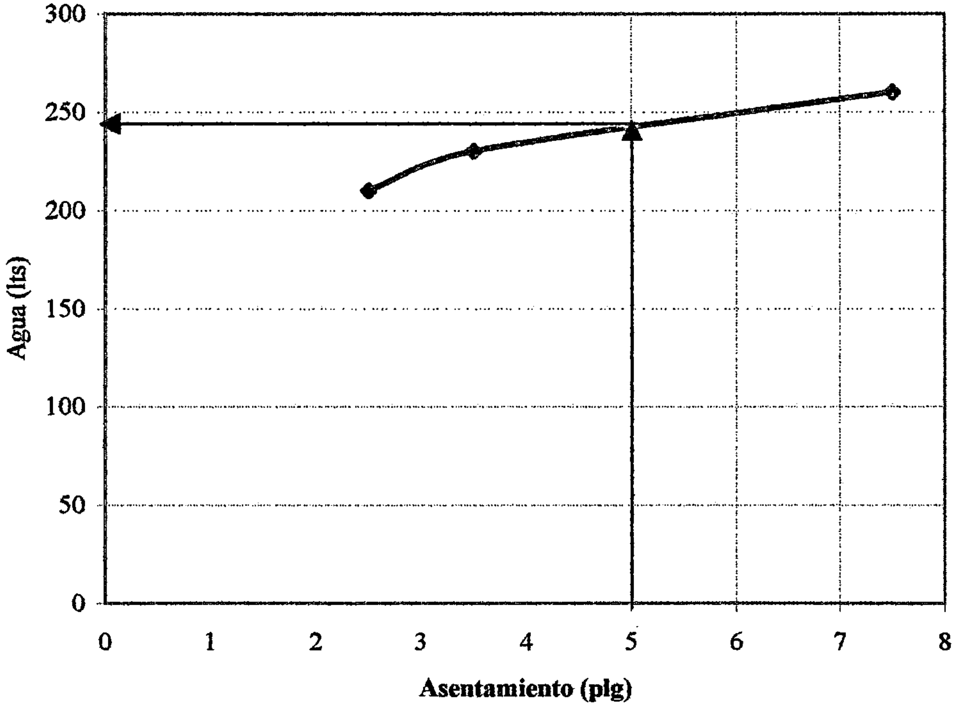
Corrección = -8.250

Agua Corregida = Agua - Corrección = 268.25

GRAFICA 1 ASENTAMIENTO VS AGUA
% Arena = 47 a/c = 0.45

Asent. (plg)	Agua (lts)
2 1/2	210
3 1/2	230
7 1/2	260

Asent. (plg)	Agua (lts)
5	247



DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 4:

%Arena	0.50
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	215
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P.U.Seco	P.U.Hum	50 kg
Cemento	477.78	0.153	477.78	1.00	1.00	10.04
Agua	215.00	0.215	224.80	0.45	0.47	4.72
Arena	830.88	0.311	843.18	1.74	1.76	17.72
Piedra	830.88	0.301	833.12	1.74	1.74	17.51
Sum. Total	2354.54	0.980	2378.88	4.93	4.98	50.0
%Aire de Diseño =		1.50%		Asentamiento :		2"
S. Parcial (Cem+Agua+Aire) =		0.383				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.617

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.5
Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.315
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.302
Suma = 0.617

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 830.88
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 830.88

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 843.18
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 833.12

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -8.143
Agregado Grueso = Psx(%w-%Abs)/100 = -1.662
Corrección = -9.804

Agua Corregida = Agua - Corrección = 224.80

DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 5:

%Arena	0.50
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	230
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P.U.Seco	P.U.Hum	50 kg
Cemento	511.11	0.164	511.11	1.00	1.00	10.84
Agua	230.00	0.230	239.40	0.45	0.47	5.08
Arena	796.29	0.298	808.07	1.56	1.58	17.14
Piedra	796.29	0.289	798.44	1.56	1.56	16.94
Sum. Total	2333.68	0.981	2357.02	4.57	4.61	50.0
%Aire de Diseño =		1.50%		Asentamiento :		4 1/4"
S. Parcial (Cem+Agua+Aire) =		0.409				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.591

Peso seco = Peso Especifico x Volumen

Peso seco Agreg. Fino = 2640 xVa

Peso seco Agreg. Grueso = 2750 xVp

rf = 0.5

Entonces:

V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.302

V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.290

Suma = 0.591

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 796.29

Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 796.29

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 808.07

Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 798.44

Correccion de Agua :

Agregado Fino = Asx(%w-%Abs)/100 = -7.804

Agregado Grueso = Psx(%w-%Abs)/100 = -1.593

Corrección = -9.396

Agua Corregida = Agua - Corrección = 239.40

DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 6:

%Arena	0.50
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	250
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P.U.Seco	P.U.Hum	50 kg
Cemento	555.56	0.178	555.56	1.00	1.00	11.93
Agua	250.00	0.250	258.85	0.45	0.47	5.56
Arena	750.16	0.281	761.26	1.35	1.37	16.35
Piedra	750.16	0.272	752.19	1.35	1.35	16.16
Sum. Total	2305.88	0.981	2327.86	4.15	4.19	50.0
%Aire de Diseño =		1.50%		Asentamiento :		6 1/4"
S. Parcial (Cem+Agua+Aire) =		0.443				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.557

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.5

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.284
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.273
Suma = 0.557

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 750.16
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 750.16

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 761.26
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 752.19

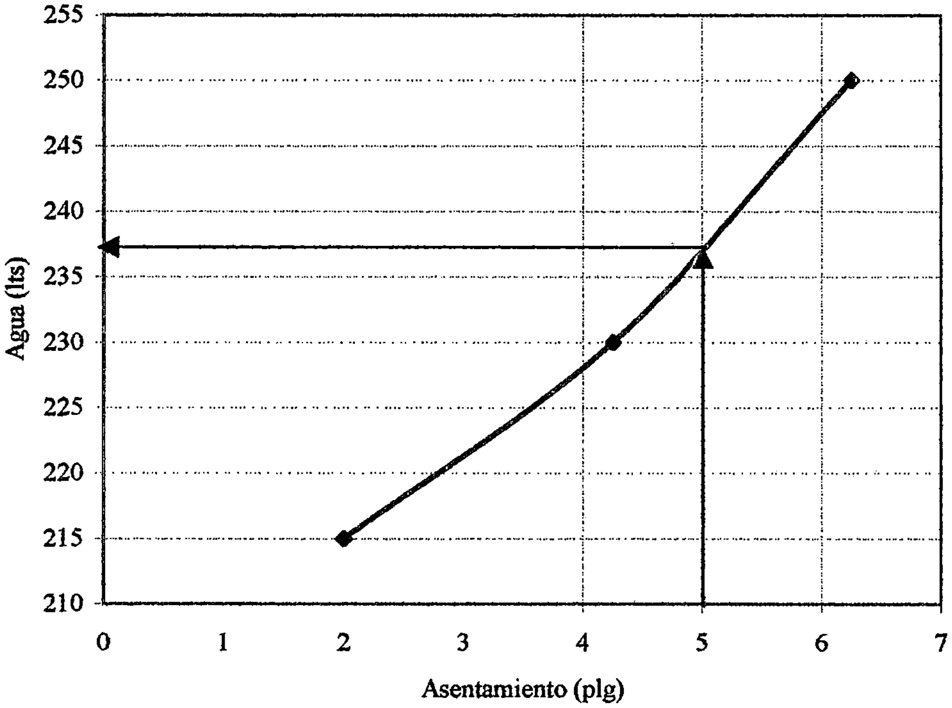
Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -7.352
Agregado Grueso = Psx(%w-%Abs)/100 = -1.500
Corrección = -8.852

Agua Corregida = Agua - Corrección = 258.85

GRAFICA 2 ASENTAMIENTO VS AGUA
% Arena = 50 a/c = 0.45

Asent. (plg)	Agua (lts)
2	215
4 1/4	230
6 1/4	250

Asent. (plg)	Agua (lts)
5	236



DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 7:

%Arena	0.53
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	215
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	477.78	0.153	477.78	1.00	1.00	10.05
Agua	215.00	0.215	225.18	0.45	0.47	4.74
Arena	879.66	0.329	892.68	1.84	1.87	18.77
Piedra	780.07	0.283	782.18	1.63	1.64	16.45
Sum. Total	2352.51	0.980	2377.81	4.92	4.98	50.0
%Aire de Diseño =		1.50%		Asentamiento :		1 3/4"
S. Parcial (Cem+Agua+Aire) =		0.383				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.617

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.53

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.333
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.284
Suma = 0.617

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 879.66
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 780.07

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 892.68
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 782.18

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -8.621
Agregado Grueso = Psx(%w-%Abs)/100 = -1.560
Corrección = -10.181

Agua Corregida = Agua - Corrección = 225.18

DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 8:

%Arena	0.53
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	230
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P.U.Seco	P.U.Hum	50 kg
Cemento	511.11	0.164	511.11	1.00	1.00	10.85
Agua	230.00	0.230	239.76	0.45	0.47	5.09
Arena	843.03	0.316	855.51	1.65	1.67	18.16
Piedra	747.59	0.271	749.61	1.46	1.47	15.91
Sum. Total	2331.74	0.980	2355.99	4.56	4.61	50.0
%Aire de Diseño =		1.50%		Asentamiento :		3 3/8"
S. Parcial (Cem+Agua+Aire) =		0.409				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.591

Peso seco = Peso Especifico x Volumen

Peso seco Agreg. Fino = 2640 xVa

Peso seco Agreg. Grueso = 2750 xVp

rf = 0.53

Entonces:

V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.319

V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.272

Suma = 0.591

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 843.03

Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 747.59

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 855.51

Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 749.61

Correccion de Agua :

Agregado Fino = Asx(%w-%Abs)/100 = -8.262

Agregado Grueso = Psx(%w-%Abs)/100 = -1.495

Corrección = -9.757

Agua Corregida = Agua - Corrección = 239.76

DISEÑO DE MEZCLA PRELIMINAR

DISEÑO 9:

%Arena	0.53
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	250
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	555.56	0.178	555.56	1.00	1.00	11.94
Agua	250.00	0.250	259.19	0.45	0.47	5.57
Arena	794.20	0.297	805.95	1.43	1.45	17.32
Piedra	704.29	0.255	706.19	1.27	1.27	15.17
Sum. Total	2304.04	0.981	2326.89	4.15	4.19	50.0
%Aire de Diseño =		1.50%		Asentamiento :		7"
S. Parcial (Cem+Agua+Aire) =		0.443				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.557

Peso seco = Peso Especifico x Volumen

Peso seco Agreg. Fino = 2640 xVa

Peso seco Agreg. Grueso = 2750 xVp

rf = 0.53

Entonces:

V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.301

V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.256

Suma = 0.557

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 794.20

Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 704.29

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 805.95

Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 706.19

Correccion de Agua :

Agregado Fino = Asx(%w-%Abs)/100 = -7.783

Agregado Grueso = Psx(%w-%Abs)/100 = -1.409

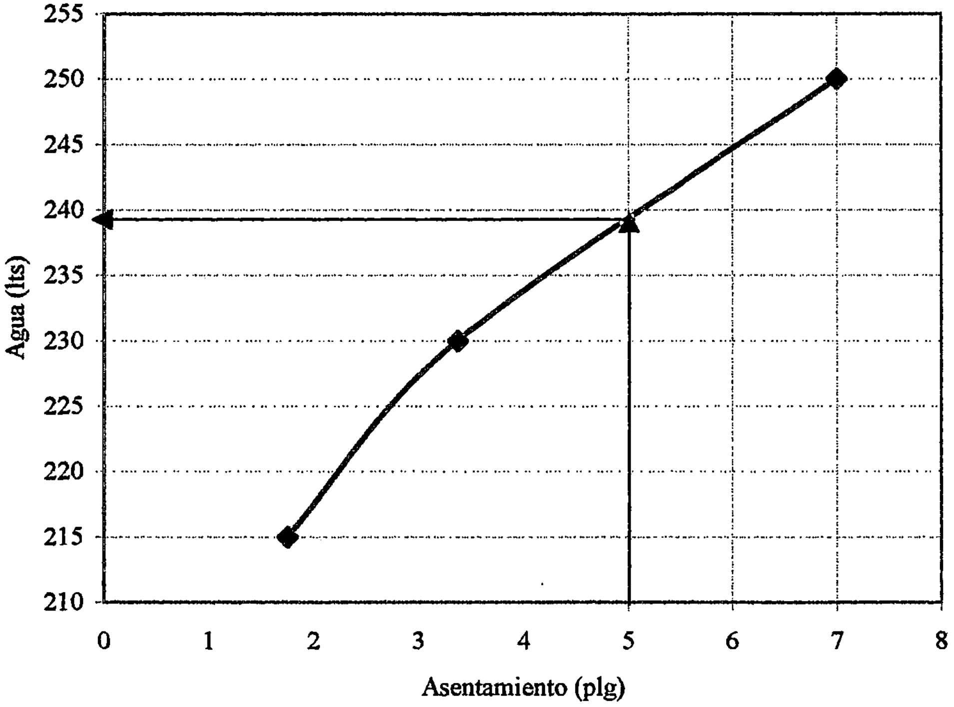
Corrección = -9.192

Agua Corregida = Agua - Corrección = 259.19

GRAFICA 3 ASENTAMIENTO VS AGUA
% Arena = 53 a/c = 0.45

Asent. (plg)	Agua (lts)
1 3/4	215
3 3/8	230
7	250

Asent. (plg)	Agua (lts)
5	239



DISEÑO DE MEZCLA PARA F´c MAX

DISEÑO 1:

%Arena	0.47
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	247
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	548.89	0.176	548.89	1.00	1.00	11.76
Agua	247.00	0.247	255.59	0.45	0.47	5.48
Arena	712.53	0.267	723.07	1.30	1.32	15.50
Piedra	803.49	0.291	805.66	1.46	1.47	17.27
Sum. Total	2311.90	0.981	2333.21	4.21	4.25	50.0
%Aire de Diseño =		1.50%		Asentamiento :		5 1/2"
S. Parcial (Cem+Agua+Aire) =		0.438				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.562

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.47

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.270
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.292
Suma = 0.562

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 712.53
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 803.49

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 723.07
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 805.66

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -6.983
Agregado Grueso = Psx(%w-%Abs)/100 = -1.607
Corrección = -8.590

Agua Corregida = Agua - Corrección = 255.59

DISEÑO DE MEZCLA PARA F'c MAX

DISEÑO 2:

%Arena	0.50
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	237
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P.U.Seco	P.U.Hum	50 kg
Cemento	526.67	0.169	526.67	1.00	1.00	11.22
Agua	237.00	0.237	246.21	0.45	0.47	5.25
Arena	780.14	0.292	791.69	1.48	1.50	16.87
Piedra	780.14	0.283	782.25	1.48	1.49	16.67
Sum. Total	2323.95	0.981	2346.81	4.41	4.46	50.0
%Aire de Diseño =		1.50%		Asentamiento :		5"
S. Parcial (Cem+Agua+Aire) =		0.421				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.579

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.5

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.296
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.284
Suma = 0.579

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 780.14
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 780.14

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 791.69
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 782.25

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -7.645
Agregado Grueso = Psx(%w-%Abs)/100 = -1.560
Corrección = -9.206

Agua Corregida = Agua - Corrección = 246.21

DISEÑO DE MEZCLA PARA F'c MAX

DISEÑO 3:

%Arena	0.53
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	239
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones		Tanda de 50 kg
				P.U.Seco	P.U.Hum	
Cemento	531.11	0.170	531.11	1.00	1.00	11.33
Agua	239.00	0.239	248.50	0.45	0.47	5.30
Arena	821.06	0.308	833.21	1.55	1.57	17.78
Piedra	728.11	0.264	730.07	1.37	1.37	15.58
Sum. Total	2319.27	0.981	2342.89	4.37	4.41	50.0
%Aire de Diseño =		1.50%		Asentamiento :		5 1/4"
S. Parcial (Cem+Agua+Aire) =		0.424				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.576

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.53

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.311
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.265
Suma = 0.576

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 821.06
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 728.11

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 833.21
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 730.07

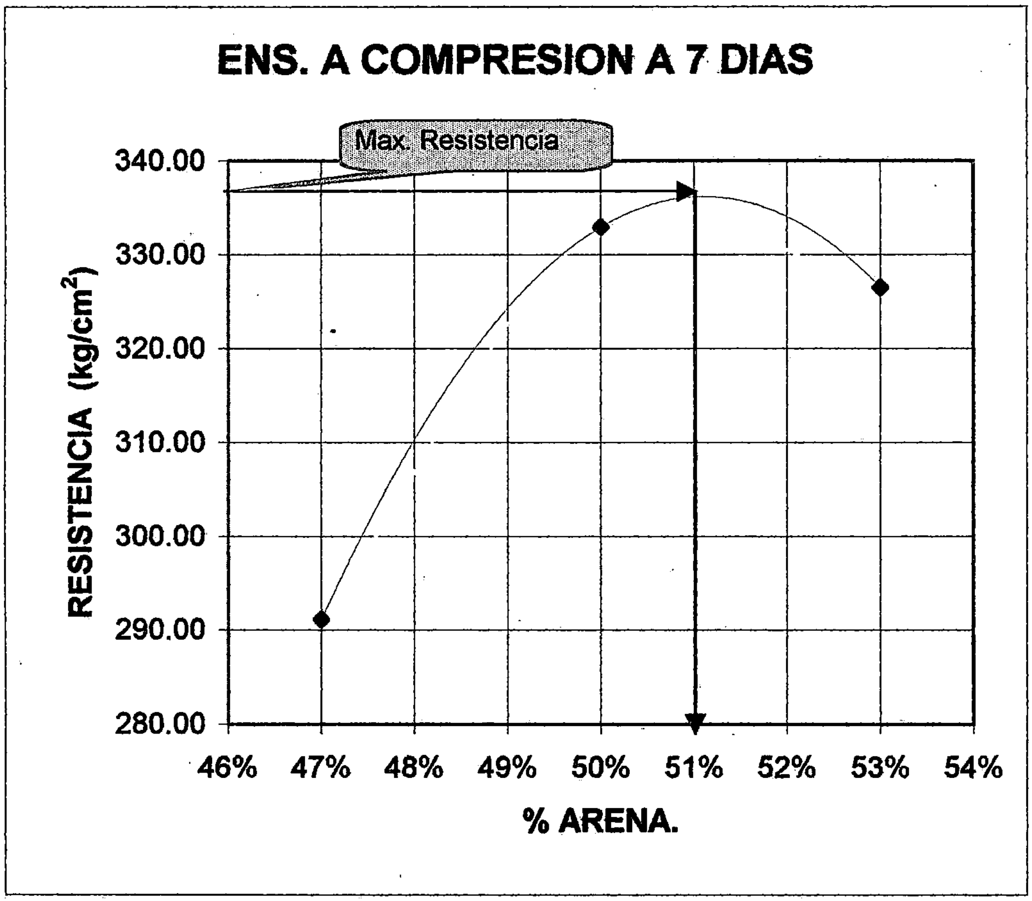
Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -8.046
Agregado Grueso = Psx(%w-%Abs)/100 = -1.456
Corrección = -9.503

Agua Corregida = Agua - Corrección = 248.50

En el siguiente cuadro presentamos los resultados obtenidos, respecto al ensayo a compresión, para los diferentes porcentajes de arena (47%, 50%, 53%) y para una relación agua/cemento de 0.45, todos ensayados a la edad de 7 días.

%A.F.	fc (kg/m^2)
47%	291.12
50%	332.95
53%	326.51

GRAFICO 4.1



f'c =	336.2 Kg/cm^2
% Ag. Fino=	51

Como podemos ver del grafico 4.1 la mayor resistencia se genera para un porcentaje de agregado fino de 51% y consecuentemente para el agregado grueso de 49%, finalmente estos serán los porcentajes definitivos para el concreto patrón.

4.9 DISEÑO DE MEZCLA PARA EL AGUA OPTIMA.

Como ya se tiene los porcentajes definitivos de los agregados de arena, piedra , ahora procederemos a calcular para cada una de las relaciones de agua/cemento , la cantidad de agua por metro cúbico de concreto, que genere un asentamiento de 5", con el propósito de encontrar las dosificaciones para la elaboración del concreto patrón, para las relaciones de agua/cemento. Para cada relación de a/c se calcularan mínimo 3 puntos, con el propósito de poder plotear la curva producida de las diferentes cantidades de agua y sus respectivos valores de asentamiento del cual se obtendrá la cantidad de agua que genera un asentamiento de 5". A continuación mostramos los cálculos y grafica para cada relación de a/c en estudio.

DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.40

DISEÑO 1:

%Arena	0.51
A/C	0.40
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	250
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	625.00	0.200	625.00	1.00	1.00	13.38
Agua	250.00	0.250	258.61	0.40	0.41	5.53
Arena	734.28	0.275	745.15	1.17	1.19	15.95
Piedra	705.49	0.256	707.39	1.13	1.13	15.14
Sum. Total	2314.77	0.981	2336.15	3.70	3.74	50.0
%Aire de Diseño =		1.50%		Asentamiento :		4"
S. Parcial (Cem+Agua+Aire) =		0.465				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.535

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.278
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.257
Suma = 0.535

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 734.28
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 705.49

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 745.15
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 707.39

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -7.196
Agregado Grueso = Psx(%w-%Abs)/100 = -1.411
Corrección = -8.607

Agua Corregida = Agua - Corrección = 258.61

DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.40

DISEÑO 2:

%Arena	0.51
A/C	0.40
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	260
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones		Tanda de 50 kg
				P.U.Seco	P.U.Hum	
Cemento	650.00	0.208	650.00	1.00	1.00	14.00
Agua	260.00	0.260	268.32	0.40	0.41	5.78
Arena	709.55	0.266	720.05	1.09	1.11	15.51
Piedra	681.72	0.247	683.56	1.05	1.05	14.72
Sum. Total	2301.27	0.981	2321.93	3.54	3.57	50.0
%Aire de Diseño =		1.50%		Asentamiento :		5"
S. Parcial (Cem+Agua+Aire) =		0.483				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.517

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51
Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.269
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.248
Suma = 0.517

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 709.55
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 681.72

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 720.05
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 683.56

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -6.954
Agregado Grueso = Psx(%w-%Abs)/100 = -1.363
Corrección = -8.317

Agua Corregida = Agua - Corrección = 268.32

DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.40

DISEÑO 3:

%Arena	0.51
A/C	0.40
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	265
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	662.50	0.212	662.50	1.00	1.00	14.31
Agua	265.00	0.265	273.17	0.40	0.41	5.90
Arena	697.18	0.261	707.50	1.05	1.07	15.28
Piedra	669.84	0.243	671.65	1.01	1.01	14.51
Sum. Total	2294.52	0.981	2314.82	3.46	3.49	50.0
%Aire de Diseño =		1.50%		Asentamiento :		6"
S. Parcial (Cem+Agua+Aire) =		0.492				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.508

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.264
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.244
Suma = 0.508

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 697.18
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 669.84

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 707.50
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 671.65

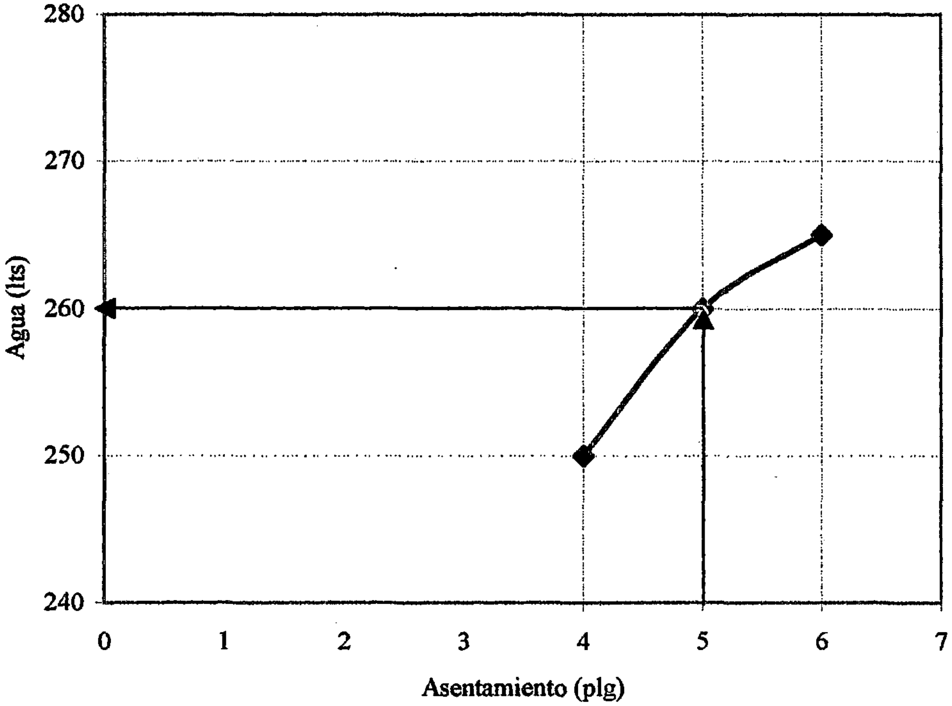
Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -6.832
Agregado Grueso = Psx(%w-%Abs)/100 = -1.340
Corrección = -8.172

Agua Corregida = Agua - Corrección = 273.17

GRAFICA 4 ASENTAMIENTO VS AGUA
% Arena = 51 a/c = 0.40

Asent. (plg)	Agua (lts)
4	250
5	260
6	265

Asent. (plg)	Agua (lts)
5	260



DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.45

DISEÑO 1:

%Arena	0.51
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	225
% Aire	1.50%

DATOS :

Descripción		**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)		2640	2750	3120
Cont. de Humedad (%)		1.480	0.270	
Porc. de Absorción (%)		2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	500.00	0.160	500.00	1.00	1.00	10.58
Agua	225.00	0.225	234.65	0.45	0.47	4.96
Arena	823.64	0.308	835.83	1.65	1.67	17.68
Piedra	791.34	0.287	793.48	1.58	1.59	16.78
Sum. Total	2339.98	0.980	2363.96	4.68	4.73	50.0
%Aire de Diseño =		1.50%		Asentamiento :		3 3/4"
S. Parcial (Cem+Agua+Aire) =		0.400				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.600

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.312
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.288
Suma = 0.600

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 823.64
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 791.34

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 835.83
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 793.48

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -8.072
Agregado Grueso = Psx(%w-%Abs)/100 = -1.583
Corrección = -9.654

Agua Corregida = Agua - Corrección = 234.65

DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.45

DISEÑO 2:

%Arena	0.51
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	235
% Aire	1.50%

DATOS :

Descripción		Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)		2640	2750	3120
Cont. de Humedad (%)		1.480	0.270	
Porc. de Absorción (%)		2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P.U.Seco	P.U.Hum	Tanda de 50 kg
Cemento	522.22	0.167	522.22	1.00	1.00	11.11
Agua	235.00	0.235	244.38	0.45	0.47	5.20
Arena	800.12	0.300	811.97	1.53	1.55	17.28
Piedra	768.75	0.279	770.82	1.47	1.48	16.40
Sum. Total	2326.09	0.981	2349.39	4.45	4.50	50.0
%Aire de Diseño =		1.50%		Asentamiento :		4 7/8"
S. Parcial (Cem+Agua+Aire) =		0.417				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.583

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51
Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.303
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.280
Suma = 0.583

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 800.12
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 768.75

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 811.97
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 770.82

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -7.841
Agregado Grueso = Psx(%w-%Abs)/100 = -1.537
Corrección = -9.379

Agua Corregida = Agua - Corrección = 244.38

DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.45

DISEÑO 3:

%Arena	0.51
A/C	0.45
Asent.	41/2"-51/2"
T.N.Max	1"
Agua	240
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco (kg/m3)	Vol. Abs (m3)	Peso Humedo (kg/m3)	Proporciones P. U. Seco	P. U. Humed	Tanda de 50 kg
Cemento	533.33	0.171	533.33	1.00	1.00	11.39
Agua	240.00	0.240	249.24	0.45	0.47	5.32
Arena	788.37	0.295	800.03	1.48	1.50	17.08
Piedra	757.45	0.274	759.49	1.42	1.42	16.21
Sum. Total	2319.15	0.981	2342.10	4.35	4.39	50.0
%Aire de Diseño =		1.50%		Asentamiento :		5 3/4"
S. Parcial (Cem+Agua+Aire) =		0.426				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.574

Peso seco = Peso Especifico x Volumen

Peso seco Agreg. Fino = 2640 xVa

Peso seco Agreg. Grueso = 2750 xVp

rf = 0.51

Entonces:

V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.299

V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.275

Suma = 0.574

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 788.37

Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 757.45

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 800.03

Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 759.49

Correccion de Agua :

Agregado Fino = Asx(%w-%Abs)/100 = -7.726

Agregado Grueso = Psx(%w-%Abs)/100 = -1.515

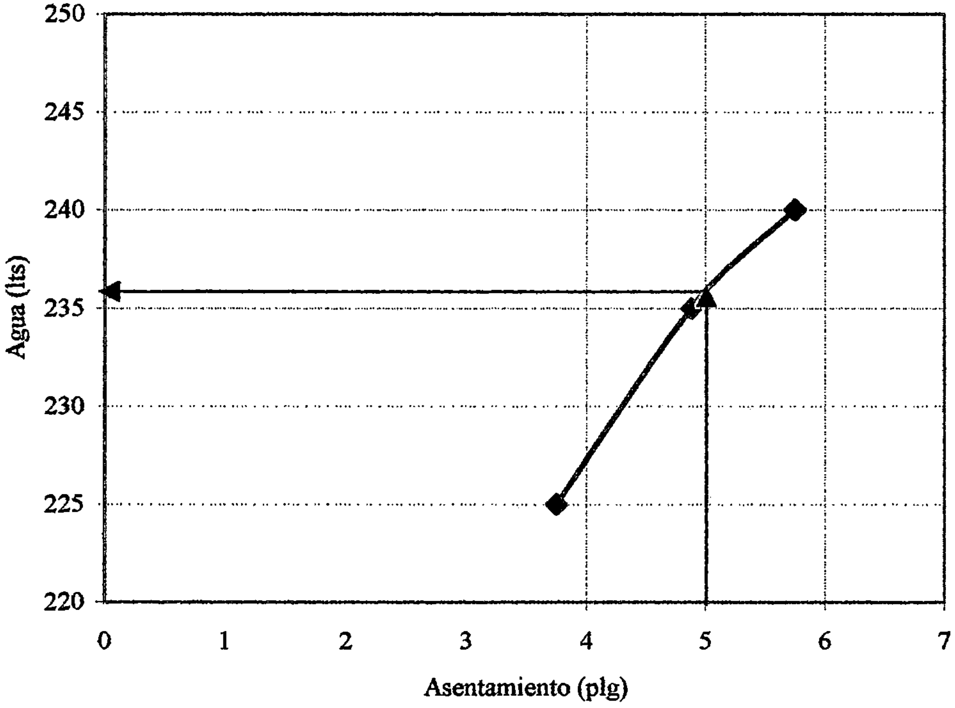
Corrección = -9.241

Agua Corregida = Agua - Corrección = 249.24

Asent. (plg)	Agua (lts)
3 3/4	225
4 7/8	235
5 3/4	240

Asent. (plg)	Agua (lts)
5	236

GRAFICA 5 ASENTAMIENTO VS AGUA
% Arena = 51 a/c = 0.45



DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.50

DISEÑO 1:

%Arena	0.51
A/C	0.50
Asent.	4 1/2"-5 D13091/2"
T.N.Max	1"
Agua	215
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P. U. Seco	?. U. Humed	50 kg
Cemento	430.00	0.138	430.00	1.00	1.00	9.06
Agua	215.00	0.215	225.18	0.50	0.52	4.75
Arena	868.18	0.325	881.03	2.02	2.05	18.57
Piedra	834.14	0.302	836.39	1.94	1.95	17.63
Sum. Total	2347.32	0.980	2372.60	5.46	5.52	50.0
%Aire de Diseño =		1.50%		Asentamiento :		4"
S. Parcial (Cem+Agua+Aire) =		0.368				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.632

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.329
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.303
Suma = 0.632

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 868.18
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 834.14

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 881.03
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 836.39

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -8.508
Agregado Grueso = Psx(%w-%Abs)/100 = -1.668
Corrección = -10.176

Agua Corregida = Agua - Corrección = 225.18

DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.50

DISEÑO 2:

%Arena	0.51
A/C	0.50
Asent.	4 1/2"-5 1/2"
T.N.Max	1"
Agua	220
% Aire	1.50%

DATOS :

Descripción	**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P. U. Seco	. U. Humed	50 kg
Cemento	440.00	0.141	440.00	1.00	1.00	9.30
Agua	220.00	0.220	230.04	0.50	0.52	4.86
Arena	856.91	0.321	869.60	1.95	1.98	18.38
Piedra	823.31	0.298	825.53	1.87	1.88	17.45
Sum. Total	2340.22	0.980	2365.17	5.32	5.38	50.0
%Aire de Diseño =		1.50%		Asentamiento :		5"
S. Parcial (Cem+Agua+Aire) =		0.376				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.624

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.325
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.299
Suma = 0.624

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 856.91
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 823.31

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 869.60
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 825.53

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -8.398
Agregado Grueso = Psx(%w-%Abs)/100 = -1.647
Corrección = -10.044

Agua Corregida = Agua - Corrección = 230.04

DISEÑO DE MEZCLA PARA EL AGUA OPTIMA A/C=0.50

DISEÑO 3:

%Arena	0.51
A/C	0.50
Asent.	4 1/2"-5 1/2"
T.N.Max	1"
Agua	225
% Aire	1.50%

DATOS :

Descripción		**Ag. Fino**	**Ag. Grueso**	**Cemento**
Peso Especifico (kg/m^3)		2640	2750	3120
Cont. de Humedad (%)		1.480	0.270	
Porc. de Absorción (%)		2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P. U. Seco	. U. Humed	50 kg
Cemento	450.00	0.144	450.00	1.00	1.00	9.54
Agua	225.00	0.225	234.91	0.50	0.52	4.98
Arena	845.65	0.317	858.16	1.88	1.91	18.20
Piedra	812.48	0.294	814.68	1.81	1.81	17.28
Sum. Total	2333.13	0.980	2357.75	5.18	5.24	50.0
%Aire de Diseño =		1.50%		Asentamiento :		7"
S. Parcial (Cem+Agua+Aire) =		0.384				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.616

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.320
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.295
Suma = 0.616

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 845.65
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 812.48

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 858.16
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 814.68

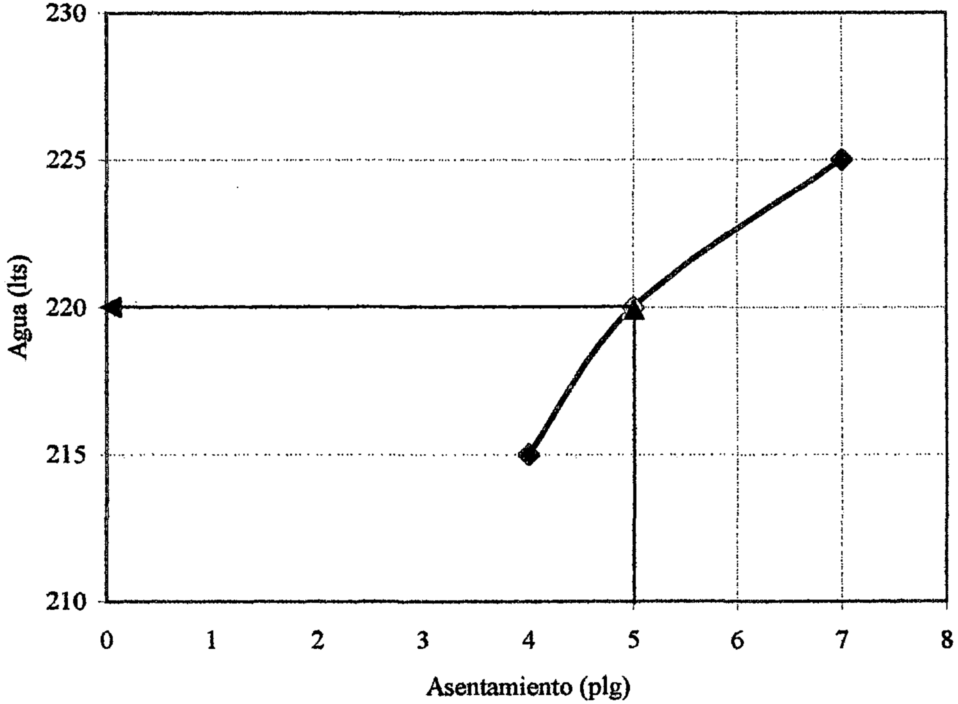
Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -8.287
Agregado Grueso = Psx(%w-%Abs)/100 = -1.625
Corrección = -9.912

Agua Corregida = Agua - Corrección = 234.91

GRAFICA 6 ASENTAMIENTO VS AGUA
% Arena = 51 a/c = 0.50

Asent. (plg)	Agua (lts)
4	215
5	220
7	225

Asent. (plg)	Agua (lts)
5	220



4.10 DISEÑO DE MEZCLA DEL CONCRETO PATRON (SIN FIBRAS)

Las dosificaciones del diseño de mezcla para cada una de las relaciones de agua/cemento (0.40, 0.45, 0.50).producen un asentamiento de 5" de acuerdo a la curva que se mostró anteriormente, estas dosificaciones permanecerán invariables para los ensayos del concreto tanto en su estado fresco, como en su estado endurecido, cuyos resultados serán comparados con el concreto cuando se le añade fibra de acero Insonex, cabe resaltar que las dosificaciones finales son para una tanda de 50 Kg, ya que la mezcladora del laboratorio de ensayo de materiales tiene la capacidad suficiente para realizar dicho trabajo, esta tanda produce 3 probetas. A continuación mostramos las dosificaciones para cada una de las relaciones estudiadas.

DISEÑO DE MEZCLA FINALPARA A/C=0.40

DISEÑO 1:

%Arena	0.51
A/C	0.40
Asent.	4 1/2"-5 1/2"
T.N.Max	1"
Agua	260
% Aire	1.50%

DATOS :

Descripción	Ag. Fino	Ag. Grueso	Cemento
Peso Especifico (kg/m^3)	2640	2750	3120
Cont. de Humedad (%)	1.480	0.270	
Porc. de Absorción (%)	2.460	0.470	

cación por m^3 de Concreto			Tanda de Prueba			
Material	Peso Seco	Vol. Abs	Peso Humedo	Proporciones		Tanda de
	(kg/m3)	(m3)	(kg/m3)	P. U. Seco	. U. Humed	50 kg
Cemento	650.00	0.208	650.00	1.00	1.00	14.00
Agua	260.00	0.260	268.32	0.40	0.41	5.78
Arena	709.55	0.266	720.05	1.09	1.11	15.51
Piedra	681.72	0.247	683.56	1.05	1.05	14.72
Sum. Total	2301.27	0.981	2321.93	3.54	3.57	50.0
%Aire de Diseño =		1.50%		Asentamiento :		5"
S. Parcial (Cem+Agua+Aire) =		0.483				
Sum. Total =		1.00				

1) DISEÑO SECO:

Vol.Tot = Vol.Fino + Grueso = 0.517

Peso seco = Peso Especifico x Volumen
Peso seco Agreg. Fino = 2640 xVa
Peso seco Agreg. Grueso = 2750 xVp
rf = 0.51

Entonces:
V Ag. Fino = rfxVTxPepd/(Pear + rf(Pepd-Pear)) = 0.269
V Ag. Grueso = Vol. Total - Vol. Agregado. Fino = 0.248
Suma = 0.517

Peso seco Agreg. Fino = 2640 xV. Ag.Fino = 709.55
Peso seco Agreg. Grueso = 2750 xV. Ag.Grueso = 681.72

2) DISEÑO HUMEDO:

Peso Humedo Agreg. Fino = Asx(1+%w/100) = 720.05
Peso Humedo Agreg. Grueso = Psx(1+%w/100) = 683.56

Correccion de Agua :
Agregado Fino = Asx(%w-%Abs)/100 = -6.954
Agregado Grueso = Psx(%w-%Abs)/100 = -1.363
Corrección = -8.317

Agua Corregida = Agua - Corrección = 268.32

Para el diseño de las relaciones de agua/cemento 0.45, 0.50 se procedera de la misma manera que el diseño anterior, a continuacion presentamos el cuadro resumen final para el concreto patrón (sin fibras) para cada una de las tres relaciones a estudiar.

CUADRO N° 4.2

RESUMEN DE DISEÑO DE MEZCLAS FINALES

RELACION (A/C)	MATERIAL	PESO (KG/M3)	VOL ABS. (M3)	TANDA 50 kg
0.40	Cemento	650.00	0.21	14.00
	Agua	268.32	0.26	5.78
	Ag. Fino	720.05	0.27	15.50
	Ag. Grueso	683.56	0.25	14.72
	S Total	2321.93	1.0	50
	%Aire de Diseño		1.50%	
	Asentamiento	5"		
0.45	Cemento	524.44	0.17	11.17
	Agua	245.35	0.24	5.22
	Ag. Fino	809.58	0.30	17.24
	Ag. Grueso	768.56	0.28	16.37
	S Total	2347.93	1.0	50
	%Aire de Diseño		1.50%	
	Asentamiento	5"		
0.50	Cemento	440.00	0.14	9.30
	Agua	230.04	0.22	4.86
	Ag. Fino	869.60	0.32	18.38
	Ag. Grueso	825.53	0.30	17.45
	S Total	2365.17	1.0	50
	%Aire de Diseño		1.50%	
	Asentamiento	5"		

4.11 DISEÑO DE MEZCLA DEL CONCRETO CON FIBRAS DE ACERO INSONEX.

Para la presente tesis de investigación cuyas relaciones de agua/cemento a estudiar son de 0.40, 0.45, 0.50. Se agregara fibra de acero Insonex en dosificaciones de 30, 40 y 50 Kg/m^3 de concreto para cada una de las relaciones de agua/cemento, cabe resaltar que cuando se le añade fibra de acero Insonex a cada uno de los diseños patrones el asentamiento se reducirá a un rango de: (3" a 4"), ubicándose dentro de un rango trabajable.

Para la dosificación de la fibra en cada uno de los diseños se tomo el siguiente criterio para su calculo.

C(cantidad de fibra para la mezcla) = D*T/S

DONDE:

C = CANTIDAD DE FIBRA PARA LA MEZCLA (Kg).
D = DOSIFICACION DE LA FIBRA DE ACERO (Kg/m^3).
T = TANDA DE LA MEZCLA (Kg).
S = SUMA DE LOS PESOS HUMEDOS DEL CEMENTO + AGUA + PIEDRA + ARENA (Kg/m^3).

A continuación presentamos cuadros con las dosificaciones de fibra de acero Insonex para cada una de las relaciones de agua/cemento.

CUADRO N° 4.3

RESUMEN DE DISEÑO DE MEZCLAS FINALES
DOSIFICACIÓN DE FIBRA: 30 Kg/m3 DE CONCRETO

RELACION (A/C)	MATERIAL	PESO (KG/M3)	VOL ABS. (M3)	TANDA 50 kg
0.40	Cemento	650.00	0.21	14.00
	Agua	268.32	0.26	5.78
	Ag. Fino	720.05	0.27	15.50
	Ag. Grueso	683.56	0.25	14.72
	S Total	2321.93	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	30		0.646
	Asentamiento	5"		
0.45	Cemento	524.44	0.17	11.17
	Agua	245.35	0.24	5.22
	Ag. Fino	809.58	0.30	17.24
	Ag. Grueso	768.56	0.28	16.37
	S Total	2347.93	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	30		0.639
	Asentamiento	5"		
0.50	Cemento	440.00	0.14	9.30
	Agua	230.04	0.22	4.86
	Ag. Fino	869.60	0.32	18.38
	Ag. Grueso	825.53	0.30	17.45
	S Total	2365.17	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	30		0.634
	Asentamiento	5"		

CUADRO N° 4.4

RESUMEN DE DISEÑO DE MEZCLAS FINALES
DOSIFICACIÓN DE FIBRA: 40 Kg/m3 DE CONCRETO

RELACION (A/C)	MATERIAL	PESO (KG/M3)	VOL ABS. (M3)	TANDA 50 kg
0.40	Cemento	650.00	0.21	14.00
	Agua	268.32	0.26	5.78
	Ag. Fino	720.05	0.27	15.50
	Ag. Grueso	683.56	0.25	14.72
	S Total	2321.93	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	40		0.861
	Asentamiento	5"		
0.45	Cemento	524.44	0.17	11.17
	Agua	245.35	0.24	5.22
	Ag. Fino	809.58	0.30	17.24
	Ag. Grueso	768.56	0.28	16.37
	S Total	2347.93	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	40		0.852
	Asentamiento	5"		
0.50	Cemento	440.00	0.14	9.30
	Agua	230.04	0.22	4.86
	Ag. Fino	869.60	0.32	18.38
	Ag. Grueso	825.53	0.30	17.45
	S Total	2365.17	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	40		0.845
	Asentamiento	5"		

CUADRO N° 4.5

RESUMEN DE DISEÑO DE MEZCLAS FINALES DOSIFICACIÓN DE FIBRA: 50 Kg/m3 DE CONCRETO

RELACION (A/C)	MATERIAL	PESO (KG/M3)	VOL ABS. (M3)	TANDA 50 kg
0.40	Cemento	650.00	0.21	14.00
	Agua	268.32	0.26	5.78
	Ag. Fino	720.05	0.27	15.50
	Ag. Grueso	683.56	0.25	14.72
	S Total	2321.93	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	50		1.077
	Asentamiento	5"		
0.45	Cemento	524.44	0.17	11.17
	Agua	245.35	0.24	5.22
	Ag. Fino	809.58	0.30	17.24
	Ag. Grueso	768.56	0.28	16.37
	S Total	2347.93	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	50		1.065
	Asentamiento	5"		
0.50	Cemento	440.00	0.14	9.30
	Agua	230.04	0.22	4.86
	Ag. Fino	869.60	0.32	18.38
	Ag. Grueso	825.53	0.30	17.45
	S Total	2365.17	1.0	50
	%Aire de Diseño		1.50%	
	Fibra	50		1.057
	Asentamiento	5"		

CAPITULO 05

PROPIEDADES DEL CONCRETO EN ESTADO FRESCO

5.1 GENERALIDADES.

Las propiedades del concreto fresco tienen variaciones, debido a una serie de factores tales como la fuente de abastecimiento del agregado, modificaciones en el tamaño máximo nominal, en la granulometría, en el tipo de cemento, cambios de volumen, variación de la temperatura, método de mezclado, entre otros.

La selección de las propiedades de la unidad cúbica del concreto es fundamental, por ello es necesario efectuar ensayos de prueba, a fin de establecer interrelaciones cuantitativas con los materiales a ser empleados, para obtener un concreto con las propiedades requeridas.

5.2 ENSAYOS DEL CONCRETO EN SU ESTADO FRESCO.

5.2.1 ENSAYO DE CONSISTENCIA DEL CONCRETO NTP 339.035:1999

Consistencia.-

Es la propiedad que define la humedad de la mezcla por el grado de fluidez de la misma, es decir cuando más húmeda sea la mezcla, mayor será la facilidad con que fluya durante su colocación.

Método del Cono de Abrams.

De acuerdo a la Norma ASTM C 143 – 71 ó NPT 339.035, el molde se coloca sobre una superficie plana y humedecida, manteniéndola fija, por unas aletas en el piso. Se vierte concreto con la espátula hasta un tercio del volumen, se coloca en torno del borde superior del molde, para asegurar su homogeneidad, se apisona con una varilla, aplicando 25 golpes, distribuidos uniformemente en forma concéntrica. Luego se coloca otras dos capas con el mismo procedimiento de llenado a cada tercio del volumen y su consolidación, de manera que la varilla penetre en la capa inmediata superior.

La primera capa tendrá una altura aproximada de 67 mm y la segunda de 155 mm. la tercera capa se llenara en exceso, para luego enrasar con el badilejo, al termino de la consolidación. En el caso de faltar material se añadirá el concreto necesario. Lleno y enrasado el molde se levanta lentamente y cuidadosamente en dirección vertical. Se estima que desde el inicio de la operación hasta el termino no debe transcurrir mas de 2 minutos, el proceso de desmolde no tomará mas de 7 segundos.

El asentamiento se mide con aproximación de 5 mm, determinando la diferencia entre la altura del molde y la altura medida de la cara libre del cono deformado. Se aconseja que al termino del ensayo se golpe suavemente con la varilla de apisonar una de las generatrices del cono, produciendo la caída del pistón, con buena experiencia, la observación de su comportamiento resulta de interés. Las mezclas bien dosificadas asientan lentamente sin perder su homogeneidad, revelando buena consistencia. Por el contrario las mezclas defectuosas se disgregan y caen por separado.

La consistencia de acuerdo a su asentamiento es:

Consistencia Seca, que corresponde a un asentamiento de 0" a 2", mezcla que tienen el grado de humedad necesario como para que al apretarlos con la mano quede adherida a esta la lechada de cemento. Tienen solo el agua necesaria para que su superficie, después de vibrado quede blanda y unida.

Consistencia Plástica, que corresponde a un asentamiento entre 3" a 4". Son los que contienen agua necesaria para dar a la masa una consistencia pastosa.

Consistencia Fluida, que corresponde a un asentamiento de más de 5". Son aquellas que tienen tanta agua que fluyen como una pasta blanda.

5.2.2 ENSAYO DE FLUIDEZ (N.T.P 339.085)

Se llama también ensayo de la mesa de sacudida o de escurrimiento. El ensayo responde principalmente a la variación del contenido de agua de la mezcla y sirve para indicar la consistencia y proclividad a la segregación. Es con respecto a la segregación que este ensayo es de utilidad, pues además nos proporciona un índice de mezclas rígidas, ricas y cohesivas.

En este ensayo, el índice de consistencia se determina con el aumento del diámetro que experimenta la base inferior de un tronco de cono fresco sometido a sacudidas sucesivas.

Para el calculo del índice de fluidez tenemos:

$$\boxed{F = \frac{(D - 25)}{25} \times 100}$$

Donde: F = Porcentaje de fluidez.
D = Diámetro Promedio.

5.2.3 ENSAYO DE PESO UNITARIO (NTP 339.046)

Peso Unitario.

Es un control para verificar la uniformidad del concreto y comprobar el rendimiento de la mezcla al comparar el peso unitario del diseño con el unitario real, el contenido de cemento y el contenido de aire.

El Peso Unitario de los concretos comunes varía entre los 2300 y 2500 kg/m3, dependiendo de las características y tamaño máximo del agregado grueso.

Método de Ensayo del Peso Unitario.

De acuerdo a la Norma ASTM C – 138 y la NPT 339.046, el ensayo consiste en la determinación del peso del concreto por unidad de volumen. El molde a usar será metálico de un volumen de:

½ pie^3 para agregados hasta de 2"
1 pie^3 para agregados de mas de 2"

El procedimiento es muy simple y consiste en llenar el molde respectivo en tres capas con 25 golpes en cada capa, utilizando la varilla de 5/8" de diámetro y longitud 60 cm con una punta semiesférica. En la ultima capa se coloca material en exceso para enrasar a tope.

Después de consolidar cada capa, se procederá a golpear ligeramente las paredes del molde con la varilla, para eliminar los vacíos que pudieran haber quedado. Luego el concreto y el recipiente que lo contiene son pesados, obteniéndose por diferencia el peso del concreto, que al ser dividido entre el volumen del recipiente nos dará el peso unitario del concreto fresco, que generalmente se expresa en kg/m^3.

5.2.4 ENSAYO DEL TIEMPO DE FRAGUADO (NTP 339.082)

Tiempo de Fraguado.

Este control tiene una trascendencia muy importante, por cuanto nos da la pauta del tiempo que se dispone en el proceso constructivo para las operaciones de colocación y acabado.

Arbitrariamente se ha dividido el fraguado en dos periodos:

El fraguado Inicial, se caracteriza por un aumento en la viscosidad y en la temperatura de la mezcla.

El fraguado Final, se caracteriza por el endurecimiento de la mezcla con el aumento de su resistencia.

Los factores que influyen en el tiempo de fraguado del concreto son los siguientes:

- Variaciones en la dosificación del concreto.
- Temperatura de la mezcla.
- Temperatura ambiente.
- Contenido de cemento de la mezcla.
- Dimensiones del elemento de concreto
- Consistencia y relación agua/cemento.
- Características de exudación.
- Aditivos empleados.

Método de Ensayo del Tiempo de Fraguado.

El ensayo del tiempo de fraguado del concreto por resistencia a la penetración se basa en la Norma ASTM C 403 ó la NPT 339.082, que consiste en utilizar la parte más fina del concreto, se tamiza la mezcla por la malla N° 4, con la ayuda de la mesa vibratoria. La mezcla que pasa por dicha malla es llenada en dos moldes cilíndricos de 6" de diámetro y de 6" de alto, se llena cada molde en dos capas, cada capa se compacta con 25 golpes, se llena hasta una altura mínima de 14 cm, se golpe a los costados del molde para eliminar las burbujas de aire y luego se enrasa.

Se anota la hora de inicio de ensayo. Se dispone de 6 agujas, cuyos diámetros son de 1", 13/16", 9/16", 5/16", 4/16", y 3/16" respectivamente.

Según el estado de endurecimiento del mortero, se debe colocar el aparato con una aguja de tamaño apropiado y se pone esta en contacto con el mortero. Se aplica una fuerza vertical gradual y uniforme hacia abajo, hasta lograr una penetración de 25 mm en un tiempo de 10 segundos.

Se registra la fuerza aplicada, el área de la aguja de penetración y la hora del ensayo. En cargas posteriores se debe tener cuidado en eludir sitios en los cuales el mortero ha sido alterado por penetraciones previas.

La distancia libre entre la aguja y el lugar de cualquier penetración anterior, debe ser al menos dos veces el diámetro de la aguja que se use, pero en ningún caso inferior a 15 mm, además se debe dejar una distancia libre entre la aguja y la pared del recipiente de por lo menos 25 mm.

Para muestras normales y temperaturas normales el primer ensayo se recomienda realizarlo cuando haya transcurrido 3 a 4 horas y los demás ensayos cada hora. Para mezclas aceleradas o a altas temperaturas se recomienda hacer el primer ensayo cuando haya transcurrido de 1 a 2 horas y los demás ensayos a intervalos de 30 minutos.

Para condiciones de baja temperatura o mezclas retardantes, el primer ensayo se recomienda realizarlo cuando hayan transcurrido 4 horas o mas, las posteriores cargas deben realizarse a intervalos de 1 hora a menos que el incremento de resistencia a la penetración indique que es aconsejable un intervalo mas corto.

Para cada ensayo de fraguado, se deben hacer por lo menos 6 penetraciones y los intervalos de tiempo entre ellos, serán tales que suministren puntos adecuados y lo suficientes espaciados para dibujar una curva satisfactoria de velocidad de endurecimiento.

El fraguado del concreto depende básicamente del contenido de Aluminato Tricalcico del cemento, finura del cemento, relación agua/cemento, temperatura y humedad del ensayo. La Norma establece el tiempo de fraguado del concreto con asentamiento superior a cero por medio de agujas de penetración sobre una muestra tamizada. El principio del método consiste en determinar la velocidad de endurecimiento de una muestra de concreto.

La fragua inicial se produce cuando la resistencia a la penetración alcanza un valor de 500 lb/pulg^2. La fragua final se da cuando se llega a un valor de 4000 lb/pulg^2.

5.2.5 ENSAYO DEL CONTENIDO DE AIRE (NTP 339.080)

Sirve para medir el volumen de aire atrapado en porcentaje, de los espacios entre las partículas de agregados. El contenido del aire depende del acomodo entre partículas, aporte de los materiales, las condiciones de operación, la granulometría y tamaño máximo del agregado, por lo que su valor es relativo. Este contenido de aire atrapado, dependerá generalmente del tamaño máximo nominal del agregado, es decir a medida que aumente ese tamaño, se incrementara el contenido de aire.

La presencia de aire en las mezclas tienden a reducir la resistencia del concreto por incremento de la porosidad del mismo.

PROCEDIMIENTO DEL ENSAYO

El procedimiento para encontrar el contenido de aire es mediante el método de presión "Aparato Washington". El aparato consta de dos partes, en una se encuentra la cámara donde se almacena el aire a presión y el manómetro que indica la cantidad de agua penetrada en el concreto o presión de aire, lo cual se puede deducir que será el mismo porcentaje de vacíos que tendrá el concreto, la otra parte del aparato es un molde cilíndrico donde se coloca el concreto, similar al peso unitario.

por cada capa, se enrasa la superficie.

a) Se coloca el concreto el concreto en el recipiente en tres capas con 25 golpes de modo que no quede burbujas de aire en la superficie.

b) Se coloca la tapa y se procede a llenar de aire la cámara de presión

c) Luego por unas aberturas se introduce agua al concreto y se procede luego a cerrar las aberturas.

d) Se abre la llave que une la cámara de aire con el concreto y la presión del aire hace introducir el agua en los vacíos de concreto lo que el manómetro indica

Los resultados de los ensayos del concreto al estado fresco, se muestran en el capítulo 7.

5.2.6 ENSAYO DE EXUDACIÓN (NTP 339.077)

Exudación.

Propiedad por la cual una parte del agua de mezcla se separa de la masa y sube hacia la superficie del concreto. Es un caso típico de sedimentación en que los sólidos se asientan dentro de la masa plástica. El fenómeno esta gobernado por las leyes físicas del flujo de un liquido en un sistema capilar, antes que el efecto de la viscosidad y la diferencia de densidades.

Esta influenciada por la cantidad de finos en los agregados y la finura del cemento, por lo que cuanto más fino es la molienda de este y mayor es el porcentaje de material menor que la malla N° 100, la exudación será menor pues se reduce el agua de mezcla.

La exudación se produce inevitablemente en el concreto, pues es una propiedad inherente a su estructura, luego lo importante es evaluar y controlar en cuanto a los efectos negativos que pudiera tener.

Método de Ensayo de Exudación.

Esta basada en la Norma ASTM 232 – 71, el procedimiento consiste en que una vez obtenida la mezcla, se le vierte en un molde (balde de ½ pie^3), en tres capas compactado con 25 golpes cada capa, luego se enrasa y se retirará aproximadamente 1" de espesor de mezcla, hecho esto se procederá a pesar la mezcla con el recipiente obteniéndose por diferencia el peso de la mezcla (tamaño de muestra).

Para facilitar la extracción del agua de exudación se colocará un taco de 5 cm. de altura debajo de uno de los bordes del molde con la mezcla, de modo que este aparezca inclinado hacia donde se juntará el agua, que el concreto exudará conforme transcurre el tiempo.

Con una pipeta se irá retirando y midiendo el agua que la mezcla exude ejecutándose este cada 10 minutos 4 veces, luego se ejecutará cada 30 minutos, hasta que ya el concreto no exude cantidad alguna de agua. Despúes que el agua haya sido extraída, se devuelve el recipiente a su posición original sin golpearlo.

Cuando se requiere solamente el volumen total de agua exudada el procedimiento de extracción periódica puede ser omitido y la extracción se hará en una operación.

Cálculos:

Con los datos de:

Peso de la mezcla en Kg. (W muestra)
La cantidad total de agua exudada (W agua-exud.)

Mas los datos de diseño:

Cantidad de agua por m^3 en Kg. (W ag-m^3)
Peso total de materiales para 1 m^3 de concreto (Wm^3)

Se calcula:

$$\text{Wagua-muestra} = (\text{W muestra} * \text{W ag-m}^3) / \text{Wm}^3$$

Luego:

$$\% \text{ de exudación} = (\text{W agua-exud.} * 100) / \text{Wagua-muestra}$$

CAPITULO 06

PROPIEDADES DEL CONCRETO EN ESTADO ENDURECIDO

6.0 PROPIEDADES DEL CONCRETO AL ESTADO ENDURECIDO

6.1 GENERALIDADES

La estructura interna del concreto endurecido consistente en el aglomerante, estructura básica o matriz, constituida por la pasta de cemento y agua, que aglutina a los agregados gruesos, finos, aire y vacíos, estableciendo un comportamiento resistente debido en gran parte a la capacidad de la pasta para adherirse a los agregados y soportar esfuerzos de tracción y compresión, así como a un efecto puramente mecánico propiciado por el acomodo de las partículas inertes y sus características propias.

Por lo tanto la estructura del concreto no es homogénea, y en consecuencia no es isotrópica, es decir no mantiene las mismas propiedades en diferentes direcciones.

Un aspecto sumamente importante en la estructura del concreto endurecido reside en la porosidad o sistema de vacíos. Gran parte del agua interviene en la mezcla, solo cumple la función de lubricante en el estado plástico, ubicándose en líneas de flujo y zonas de sedimentación de los sólidos, de manera que al producirse el endurecimiento y evaporarse, quedan los vacíos o poros, que condicionan el comportamiento posterior del concreto para absorber líquidos y su permeabilidad o capacidad de flujo a través de él.

Los ensayos que permiten determinar las propiedades del concreto al estado endurecido, y por ende controlar la calidad del concreto, deben efectuarse de acuerdo a las normas, debido a que resultados erróneos pueden llevar al cuestionamiento de la calidad del concreto.

6.2 ENSAYOS DEL CONCRETO EN ESTADO ENDURECIDO

6.2.1 RESISTENCIA A LA COMPRESION (NTP 339.0.34)

Es la capacidad de soportar cargas y esfuerzos, siendo su mejor comportamiento en compresión en comparación con la tracción, debido a las propiedades adherentes de la pasta de cemento.

Un factor indirecto pero no por eso menos importante en la resistencia, lo constituye el curado ya que es el complemento del proceso de hidratación sin el cual no se llegan a desarrollar completamente las características resistentes del concreto.

PROCEDIMIENTO DE ENSAYO

- Una vez elaborada la mezcla de concreto, se procede a llenar las probetas de 15x30 cm en tres capas, compactando cada capa con 25 golpes verticales mediante una varilla lisa de 5/8" con punta semiesférica, uniformemente repartidos de afuera hacia adentro en forma de espiral.
- Después de llenar el molde, se procede a golpear suavemente las paredes del molde, utilizando la varilla, para eliminar los vacíos que pudieran haber quedado.
- Se enrasa la superficie del molde, a fin de obtener una superficie plana.
- Las probetas deberán retirarse del molde al cabo de 20 h ± 4 h, después de elaborados. En estas horas iniciales, se deben almacenar sobre una superficie horizontal, evitando golpes o vibraciones.
- Después de retiradas del molde las probetas deben almacenarse a temperatura permanente entre 23°C ± 2°C y bajo condiciones de humedad tales que siempre se mantenga agua libre en toda su superficie (por ejemplo sumergidos totalmente en agua saturada de cal).
- Para conseguir la aplicación uniforme de la carga por parte de la prensa hidráulica, se procede a refrendar los extremos de las probetas empleando una mezcla de azufre y de material granuloso (capping).

La norma del ACI especifica para una prueba de resistencia el promedio de dos cilindros de la misma muestra probada a la misma edad, el cual normalmente es de 28 días.

6.2.2 RESISTENCIA A LA TRACCION POR COMPRESION DIAMETRAL ASTM C-496-66, NTP 339.084

La resistencia a la tracción del concreto es relativamente baja. Una buena aproximación para la resistencia a la tracción f_{ct} es $0.10f'c < f_{ct} < 0.20f'c$. Es más difícil medir la resistencia a la tracción que la resistencia a compresión debido a los problemas de agarre con las maquinas de prueba. Debido a la existencia de diversos métodos que requieren una operación compleja, se optó por el método de tracción por hendimiento o prueba brasileña consistente en romper un cilindro de concreto, del tipo normalizado para el ensayo de compresión, entre los cabezales de una prensa, según generatrices opuestas.

La resistencia a la tracción debe darse según la relación:

$$T = (2*P) / (3.14*D*L)$$

Donde:

P = Fuerza de compresión
D = Diámetro
L = Longitud del cilindro.

PROCEDIMIENTO DE ENSAYO

- Antes de la prueba debe procederse a determinar la longitud.
- Si las dimensiones de las placas de apoyo de la maquina de compresión, son menores que la longitud del cilindro, debe interponerse una platina suplementaria de acero maquinado, de por lo menos 50 mm de ancho y espesor no menor que la distancia entre el borde de las placas de 1 apoyo y el extremo del cilindro.

- Debe colocarse entre el cilindro y la superficie de los cabezales de la maquina de ensayo, o eventualmente la platina suplementaria de ser utilizada, tablillas de madera contraplacadas, de 3 mm de espesor y 25mm de ancho. A lo largo de toda la longitud del cilindro, con el fin de que la probeta al momento de realizar la prueba se mantenga quieta.

- Se aplica la carga a la probeta con una velocidad en forma continua, evitando el impacto.

- La velocidad de aplicación de la carga indicada para probetas normales esta comprendida entre 5000 y 1000 da N/min hasta la rotura.

6.2.3 ENSAYO DE MODULO DE ELASTICIDAD ESTATICO (ASTM 496-63)

En general es la capacidad del concreto de deformarse bajo carga, sin tener deformación permanente.

El concreto no es un material elástico estrictamente hablando, ya que no tiene comportamiento lineal en ningún tramo de su diagrama carga vs deformación en compresión, sin embargo, convencionalmente se acostumbra definir un "Módulo de Elasticidad Estático" del concreto mediante una recta tangente a la parte inicial del diagrama, o a una recta secante que une el origen del diagrama con un punto establecido que normalmente es un % de la tensión ultima.

Los módulos de elasticidad normales oscilan entre 250,000 a 350,000 kg/cm^2 y están en relación directa con la resistencia a la compresión del concreto y por ende con la relación agua/cemento. Conceptualmente, las mezclas más ricas tienen módulo de elasticidad mayores y mayor capacidad de deformación de las mezclas pobres.

Al someterse una probeta de concreto a una carga que se incrementa constantemente, ocurre una deformación plástica o escurrimiento.

La curva esfuerzo - deformación muestra una zona de trabajo donde los esfuerzos y las deformaciones son proporcionales para fines prácticos.

Este limite de proporcionalidad para el caso del módulo de elasticidad es el 40% de la resistencia a la compresión y la deformación para este punto.

Es importante decir que la deformación del módulo elástico es una aproximación por cualquiera de los métodos que existen; sencillamente por que el concreto no es perfectamente elástico.

Como el concreto no es un material linealmente elástico, en ningún momento sigue la ley de Hooke, es decir que el diagrama esfuerzo deformación no presenta ningún tramo recto. De manera que el "seudo Módulo de Elasticidad", es la pendiente de la secante a la curva carga vs deformación desde el origen a un punto de tensión determinada (generalmente la tensión de trabajo).

Para esfuerzos de trabajo pequeños y alternantes el módulo en el origen puede tomarse como el módulo de elasticidad dinámico.

El módulo de elasticidad del concreto Ec es una función compleja de muchas variables como la tensión de trabajo, forma de solicitación, duración de las cargas, estado higroscópico, etc.

El ACI sugiere la siguiente expresión para su calculo:

$$\mathbf{Ec = W^{1.5} * 4270 * (f'c)^{0.5}}$$

Donde:

W = Peso especifico del concreto t/m^3.

f'c = Resistencia en kg/cm^2.

Existen varios métodos como el mencionado anteriormente; para la presente tesis de investigación se ha utilizado un Compresómetro– Extensómetro CT – 167, cuyo procedimiento seguido se describe a continuación, el cual se ajusta el establecido en la norma ASTM C-469.

Asimismo se hizo uso de una prensa hidráulica.

PROCEDIMIENTO DE ENSAYO

Compresómetro – Extensómetro CT – 167 NORMA ASTM C - 496

1 Generalidades

El Compresómetro – Extensómetro CT - 167, para probetas de concreto, determina el módulo de elasticidad (módulo de Young) y la relación de Poisson del concreto en compresión.

El uso de la CT-167, medida de la deformación axial y la extensión diametral, puede realizarse en probetas cilíndricas de 6" de diámetro o corazones diamantinos, cuando se aplica esfuerzo de compresión sobre los especímenes.

El equipo es construido con una aleación ligera de magnesio y aluminio. Los puntos montantes y de contacto son de acero maquinado. Los controles (barras espaciadoras) son de acero inoxidable.

La deformación axial y diametral puede leerse en un dial LC-2 con una exactitud de 25 micropulgadas (media división del indicador del LC-2 0.5x100µpulgx0.5).

Esta calidad es mejor que las 5 micropulgadas por pulgada de esfuerzo requerido por la norma ASTM C-469. El dial LC-2, tiene un rango de 0.2 pulgadas graduadas en divisiones de 0.0001. La relación de palanca del instrumento multiplica por 2 la deformación. Luego una mitad de la división del dial indicador representa micropulgadas de deformación de la longitud inicial (o diámetro) de la probeta de 6".

Unidades métricas se suministran con el VLC-2M con un rango de 5 mm y graduado en divisiones de 0.0002 mm.

Tres "anillos" de metal suministrados con el equipo permite montar convenientemente a la altura media del cilindro de concreto.

Para la preparación del espécimen y detalles del procedimiento del ensayo, referirse a la norma ASTM C-469.

2. Ensamble

2.1 Ensamble el Equipo CT-167. El dial vertical mide la deformación axial, mientras que el otro mide la deformación diametral.

2.2 Desenrosque los 7 tornillos de fijación (2 en anillo superior, 3 en el inferior y 2 en el anillo medio), hasta que las puntas de los tornillos queden niveladas con la superficie interna de los anillos.

2.3 Coloque la probeta de concreto al interior del Compresómetro, ubicándola al centro de los anillos.

2.4 Al ubicar la probeta de concreto al interior del Compresómetro, los anillos que se ubican en la parte superior e inferior de cilindro, la distancia vertical de estas con los extremos del cilindro deben ser en lo posible iguales.

2.5 Ajuste manualmente los dos tornillos del anillo medio, a fin de que el vástago vertical del dial axial se ubique al centro de las dos porciones del anillo medio.

2.6 Retire las dos barras espaciadoras.

2.7 Coloque en cero tanto el dial axial como el dial diametral.

3 Ejecución de la prueba

Es recomendable determinar la resistencia a la compresión de una probeta de igual calidad a la probeta a someterse al ensayo del módulo de elasticidad.

3.1 Colocar la probeta con el equipo CT-167 en la maquina de ensayo (prensa hidráulica), teniendo cuidado de centrarla axialmente.

3.2 Anote la lectura de los diales.

3.3 Calibrar el equipo, lectura de los diales, para ello someter a carga la probeta; se corregirá los diales a la lectura cero si estos sufrieron algún desplazamiento de sus respectivas agujas.

3.4 Aplique la carga continuamente a una velocidad de aproximadamente de 0.05 pulg/min. (1.25 mm/min.). En las maquinas operadas hidráulicamente aplique la carga a una velocidad constante en un rango de 35±5 psi/s (241± 34Kpa/s).

Registre sin interrupción las lecturas, en carga aplicadas y la deformación longitudinal en el punto (1), esfuerzo S1, cuando la deformación longitudinal es de 50 millonésima y (2) cuando la carga aplicada es igual al 40% de la rotura, esfuerzo S2. La deformación longitudinal se define como la total deformación dividida entre la longitud efectiva del calibre.

3.5 Registre la deformación transversal en los mismos puntos (en caso de requerirse de determinar la relación de Poisson).

4 Cálculos

4.1 Calcule el Módulo de Elasticidad con una aproximación de 50,000 psi (344.74 Mpa) como sigue:

$$\mathbf{E} = \frac{\mathbf{(S2 - S1)}}{\mathbf{(e2\text{-}0.5x10^{-4})}}$$

Donde:

E = Módulo de elasticidad (psi)
S2 = Esfuerzo correspondiente al 40% de la carga ultima
S1 = Esfuerzo correspondiente a una deformación longitudinal e1, de 50μpulg/pulg

e2 = Deformación longitudinal producida por el esfuerzo S2.

3.1 El calculo de la relación de Poisson, con una aproximación de 0.01 es como sigue:

$$\mathbf{m} = \frac{(\mathbf{Et2 - Et1})}{(\mathbf{e2 - 0.5x10^{-4}})}$$

Donde:

m = Relación de Poisson
Et2 = Deformación transversal al centro del espécimen producido por el esfuerzo S2
Et1 = Deformación transversal al centro del espécimen producido por el esfuerzo S1.
e2 = Deformación longitudinal producida por el esfuerzo S2.

5 Mantenimiento

5.2 Asegúrese de contar con el equipo completo antes y después de realizada la prueba, llámese anillos de metal (03 und), tornillos de fijación (07 und), barras espaciadoras, tuercas, diales, entre otros.

5.3 Tener cuidado en el manipuleo de las partes que conforman el equipo CT-167, tanto al realizar el ensayo como en su almacenaje.

6 Herramientas

6.4 Ver catálogos de concreto para el moldeo de probetas.

6.5 Prensa hidráulica para la compresión, ver catalogo Soiltest de concreto.

7.2.4 ENSAYO DE RESISTENCIA A LA FLEXIÓN EN VIGAS NTP 339.078:2001

Como es difícil aplicar tensión uniaxial al espécimen de concreto, la resistencia a la tracción del concreto se determina por métodos indirectos: la prueba de flexión y la prueba de cuarteadura, para este tema de investigación se utilizara el primero, estos métodos producen valores de resistencia que son mayores que la resistencia a la tracción real bajo carga uniaxial.

En la prueba de flexión, el esfuerzo a la tensión máxima teórica alcanzada en la fibra del fondo de una viga de prueba se conoce como modulo de ruptura. El valor del modulo de ruptura depende las de la viga y sobre todo de la disposición de la carga. Hoy en día la carga simétrica en dos puntos (a los tercios de la luz) se usa en Estados unidos de América. Esto produce un momento de flexión constante entre los puntos de carga, de modo que un tercio de la luz esta sujeto al esfuerzo máximo y por tanto, es ahí donde probablemente se produzca el agrietamiento.

PROCEDIMIENTO DE ENSAYO

a) Las dimensiones de los especimenes rectangulares, utilizados para el ensayo de flexión son de 15 x 15 x 75 cms.

b) Se coloca con respecto a la posición de vaciado y se centra con respecto a las placas de apoyo. Las placas de aplicación de carga se ponen en contacto con la muestra y sobre los punto extremos del tercio central de la luz libre.

c) Las dimensiones serán tomadas con una aproximación de 1mm con la finalidad de determinar el promedio en la sección de falla.

d) Si la fractura ocurre dentro del tercio medio central de la viga, se calcula el modulo de ruptura, con base en teoría elástica ordinaria como sigue:

$$\mathbf{Mr} = \frac{\mathbf{PL}}{\mathbf{bh^2}}$$

Donde:

Mr = Modulo de ruptura en kg/cm^2
P = Carga máxima en kg
L = Luz en cms
b = Ancho promedio del espécimen rectangular en cms
h = Altura promedio del espécimen rectangular en cms.

e) Si la fractura se produce fuera del tercio medio central entonces el resultado de la prueba de be descartarse. Por otro lado, ASTM C78-84 permite la falla fuera de los puntos de carga a una distancia promedio a del apoyo mas cercano, por medio de la ecuación:

$$\mathbf{Mr} = \frac{\mathbf{3Pa}}{\mathbf{bh^2}}$$

Donde:

a = Distancia entre la línea de falla y el apoyo mas cercano.

f) Sin embargo si la falla ocurre en una sección, tal que ($L/3 - a$) > $0.05L$, entonces se debe descartar el ensayo.

6.2.5 ENSAYO DE RESISTENCIA AL IMPACTO ACI-542

La resistencia al impacto del concreto reforzado con fibra de acero, es medido por una prueba el cual se usa un martillo de 4.5 kg que cae sobre una bola de acero centrado sobre una muestra de 1.5 a 2.5 plg de grosor por 6 plg de diámetro. El numero de golpes requerido para romper y separar una muestra de fibra a una edad de 28 días es de 200 a 500 o mas golpes dependiendo de la configuración extensión y cantidad de la fibra. La muestra de shotcrete simple normalmente sede de 20 a 40 golpes.

PROCEDIMIENTO DE ENSAYO

a). Se construyeron moldes cilíndricos (discos) de 6 plg. de diámetro interior y con una altura de 2 ½ plg.. El procedimiento fue vaciar una sola capa y compactarla mediante 25 golpes con una varilla de 5/8 plg. de diámetro, uniformemente distribuidas en la sección del recipiente y enrasarlos.

b). Al día siguiente de vaciado los moldes se procedió a desmoldar y pasar los discos cilíndricos la poza de curado hasta el día de ensayo.

c). Una vez que los discos cilíndricos estén fuera de la poza de curado se dejo secar a temperatura ambiente para luego proceder a ensayarlos mediante una carga de Impacto, La carga fue entregada por un peso de 10 libras (455 grs) desde una altura de 18 plg. (45.72 cm).

d). Los impactos de la carga sobre las muestras deberían de realizarse sobre un mismo punto.

e). Se procedió a contar el numero de golpes hasta producirse la primera fisuracion en la muestra (disco).

CAPITULO 07

RESUTADOS DE LOS ENSAYOS EN EL CONCRETO

7.1 ENSAYOS EN EL CONCRETO PATRÓN (SIN FIBRA)

7.1.1 ENSAYOS EN EL CONCRETO FRESCO PARA LAS RELACIONES DE a/c = 0.40, 0.45, 0.50

7.1.1.1 ENSAYO DE ASENTAMIENTO (plg)

RELACION a/c	ASENTAMIENTO
0.40	5"
0.45	5"
0.50	5"

7.1.1.2 ENSAYO DE FLUIDEZ (%)

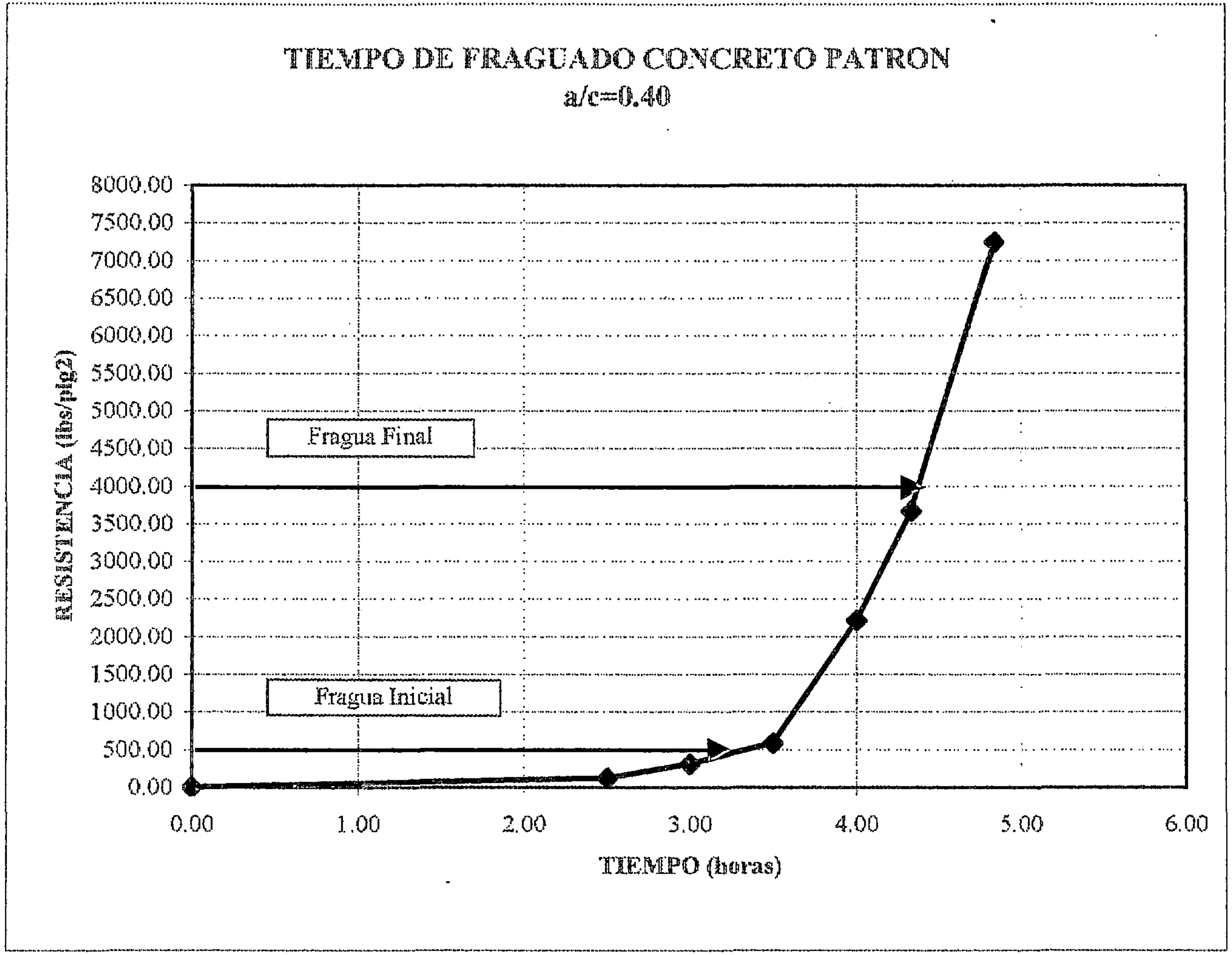
RELACION a/c	FLUIDEZ (%)
0.40	112.60
0.45	109.97
0.50	101.77

7.1.1.3 ENSAYO DE PESO UNITARIO COMPACTADO (kg/m^3)

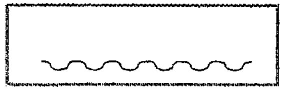
RELACION a/c	P.U.C. (Kg/m^3)
0.40	2400.00
0.45	2407.14
0.50	2414.29

7.1.1.4 ENSAYO DE TIEMPO DE FRAGUADO (hr:min)

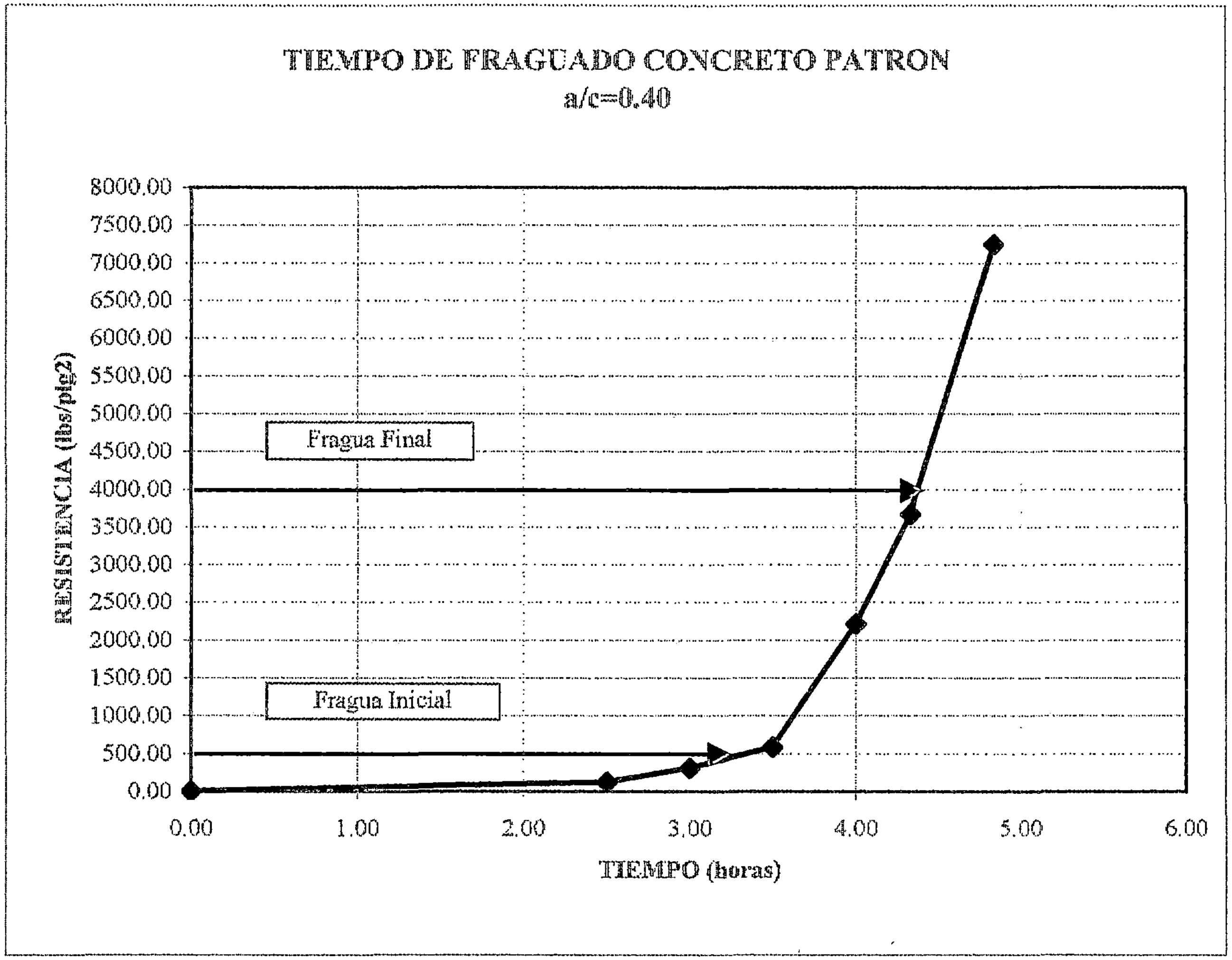
RELACION a/c	SECCION Plg^2	TIEMPO Hr	FUERZA Lbs	RESIST. (Lbs/plg^2)	FRAGUA INICIAL	FRAGUA FINAL
0.40		00:00		0.00	3:24	4:24
	0.99402	02:50	120	120.72		
	0.51848	03:00	160	308.59		
	0.24850	03:30	145	583.50		
	0.07669	04:00	170	2216.72		
	0.04908	04:20	180	3667.48		
	0.02761	04:50	200	7243.75		
0.45		00:00		0.00	3:15	4:18
	0.99402	02:30	120	120.72		
	0.51848	03:00	125	241.09		
	0.24850	03:30	170	684.10		
	0.07669	04:00	180	2347.11		
	0.04908	04:30	190	3871.23		
	0.02761	05:00	200	7243.75		
0.50		00:00		0.00	3:10	4:15
	0.99402	02:30	150	150.90		
	0.51848	03:00	170	327.88		
	0.24850	03:30	190	764.59		
	0.07669	04:00	180	2347.11		
	0.04908	04:10	150	3056.23		
	0.02761	04:40	190	6881.56		


TIEMPO DE FRAGUADO CONCRETO PATRON
a/c=0.40

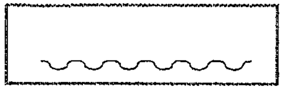
FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA



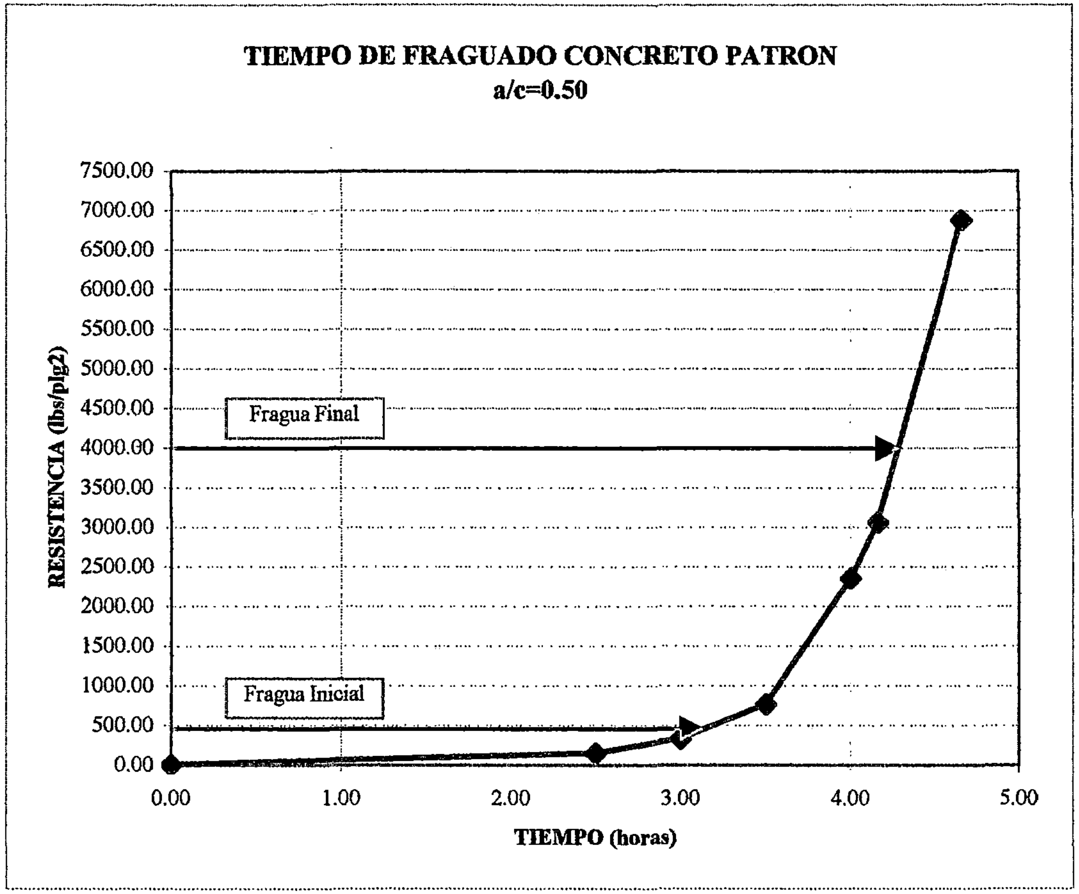
Fragua Inicial	=	03:24
Fragua final	=	04:24



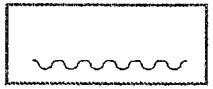
FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA



Fragua Inicial	=	03:24
Fragua final	=	04:24



FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**



Fragua Inicial	=	03:10
Fragua final	=	04:15

7.1.1.5 ENSAYO DE CONTENIDO DE AIRE (%)

RELACION a/c	CONTENIDO AIRE (%)
0.40	1.35
0.45	1.38
0.50	1.45

7.1.1.6 ENSAYO DE EXUDACIÓN (%)

RELACION a/c	EXUDACION (%)
0.40	1.82
0.45	2.02
0.50	2.53

7.1.1.7 ENSAYO EN EL CONCRETO ENDURECIDO PARA LAS RELACIONES

DE a/c = 0.40, 0.45, 0.50

7.1.1.8 ENSAYO DE RESISTENCIA A LA COMPRESIÓN (kg/cm^2)

- **RELACIÓN AGUA / CEMENTO 0.40**

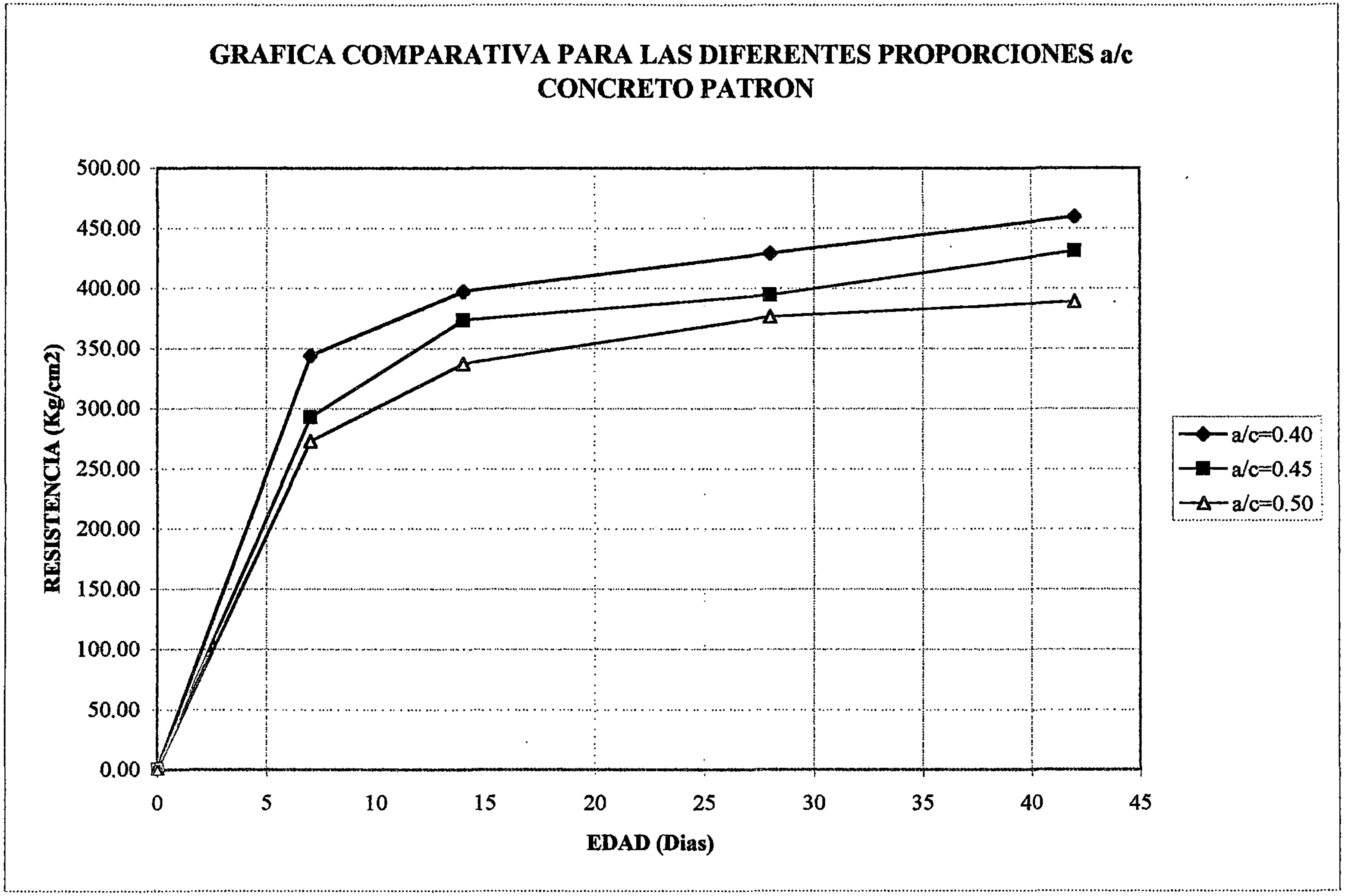
N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	60600	15.01	342.47	344.25
7	62200	14.93	355.29	
7	59200	15.00	335.00	
14	69000	15.00	390.46	397.25
14	71000	15.00	401.78	
14	70600	15.00	399.51	
28	75100	14.90	430.70	428.93
28	72000	15.00	407.44	
28	75000	14.95	427.26	
28	72000	14.93	411.27	
28	75800	15.00	428.94	
28	81600	14.90	467.98	
42	77800	14.90	446.19	459.67
42	80000	14.94	456.35	
42	84200	15.00	476.47	

- **RELACIÓN AGUA / CEMENTO 0.45**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	49800	14.90	285.61	292.85
7	52000	14.92	297.42	
7	51600	14.91	295.53	
14	63200	15.00	357.64	373.11
14	66000	15.00	373.48	
14	68600	15.00	388.20	
28	70600	14.96	401.65	394.07
28	69800	14.97	396.57	
28	64400	14.90	369.34	
28	72000	14.99	407.98	
28	68000	14.99	385.31	
28	69900	14.85	403.58	
42	75100	15.00	424.98	430.92
42	79400	15.10	443.38	
42	75000	15.00	424.41	

- **RELACIÓN AGUA / CEMENTO 0.50**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	47300	14.85	273.10	272.84
7	45400	14.91	260.02	
7	49500	14.86	285.41	
14	58700	14.90	336.65	337.16
14	61600	14.85	355.66	
14	56400	15.00	319.16	
28	63400	14.80	368.53	376.06
28	66300	14.84	383.31	
28	64000	14.97	363.62	
28	68100	14.81	395.32	
28	66400	14.96	377.76	
28	65000	15.00	367.82	
42	66600	15.00	376.88	388.79
42	69000	14.90	395.72	
42	69400	14.98	393.77	


GRAFICA COMPARATIVA PARA LAS DIFERENTES PROPORCIONES a/c
CONCRETO PATRON

FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

7.1.1.9 ENSAYO DE RESISTENCIA A LA TRACCIÓN POR COMPRESIÓN DIAMETRAL (kg/cm^2)

- **RELACIÓN AGUA / CEMENTO 0.40**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	30400	15.00	30.45	42.39	41.27
28	29200	15.03	30.81	40.14	

- **RELACIÓN AGUA / CEMENTO 0.45**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	26200	14.94	30.5	36.60	37.83
28	28200	15.00	30.64	39.06	

- **RELACIÓN AGUA / CEMENTO 0.50**

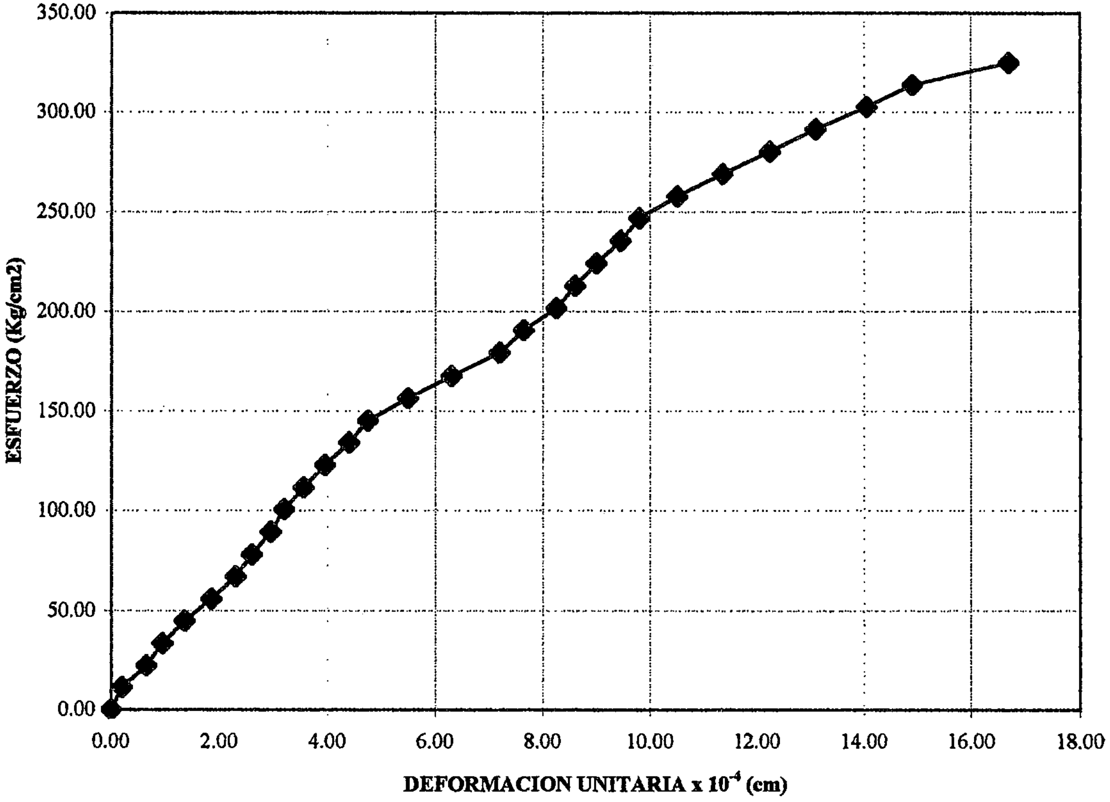
N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	24000	14.92	30.5	33.58	32.45
28	22200	14.87	30.35	31.32	

7.1.1.10 ENSAYO DE MÓDULO ELÁSTICO ESTÁTICO

RELACIÓN a/c	MOD. ELAST. EST. (x10^5 kg/cm^2)
0.40	2.6833
0.45	2.4024
0.50	2.1972

Esfuerzo	Def.Unit
0.00	0.00
11.17	0.20
22.34	0.65
33.50	0.95
44.67	1.35
55.84	1.85
67.01	2.30
78.18	2.60
89.35	2.95
100.51	3.20
111.68	3.55
122.85	3.95
134.02	4.40
145.19	4.75
156.36	5.50
167.52	6.30
179.37	7.20
190.58	7.65
201.79	8.25
213.00	8.60
224.22	9.00
235.43	9.45
246.64	9.80
257.85	10.50
269.06	11.35
280.27	12.25
291.48	13.10
302.69	14.05
313.90	14.90
325.11	16.70

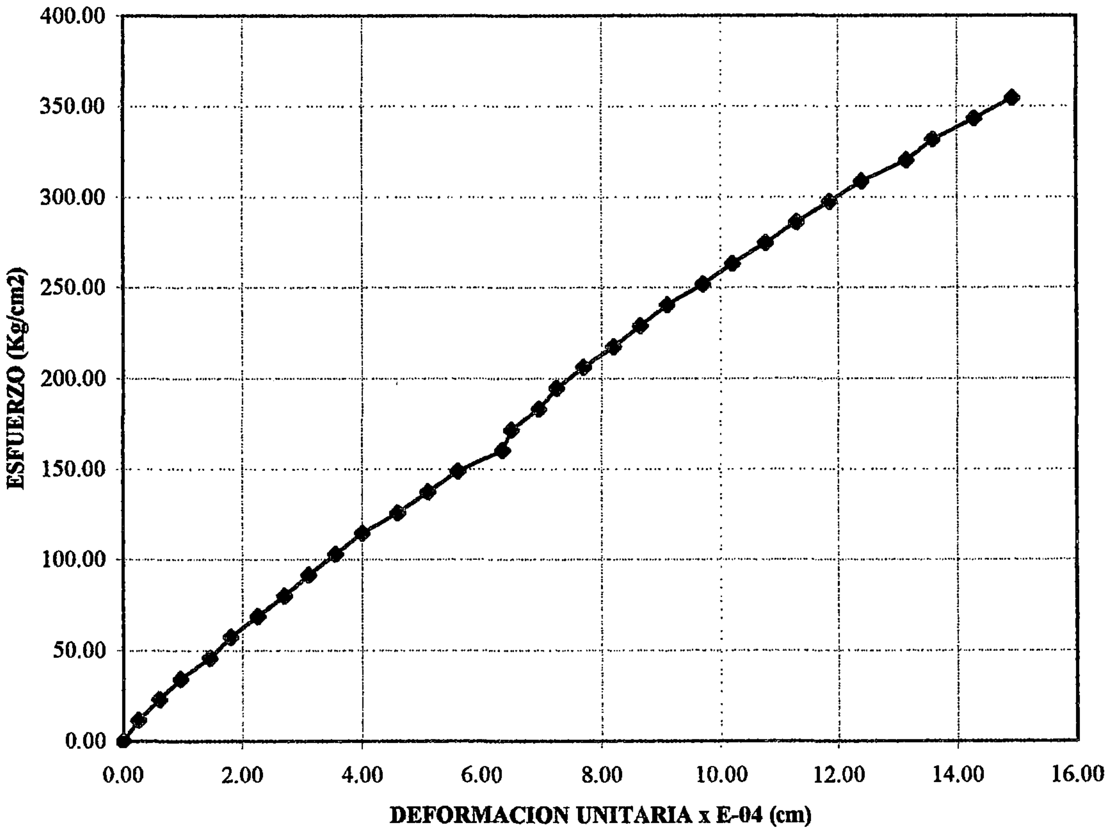
MODULO ELASTICO ESTATICO CONCRETO PATRON
RELACION AGUA CEMENTO 0.40



FIBRA : INSONEX
LONGITU 40 mm

Esfuerzo	Def.Unit
0.00	0.00
11.44	0.25
22.88	0.60
34.32	0.95
45.76	1.45
57.20	1.80
68.64	2.25
80.08	2.70
91.51	3.10
102.95	3.55
114.39	4.00
125.83	4.60
137.27	5.10
148.71	5.60
160.15	6.35
171.59	6.50
183.03	6.95
194.47	7.25
205.91	7.70
217.35	8.20
228.79	8.65
240.23	9.10
251.67	9.70
263.11	10.20
274.54	10.75
285.98	11.30
297.42	11.85
308.86	12.40
320.30	13.15
331.74	13.60
343.18	14.30
354.62	14.95

MODULO ELASTICO ESTATICO CONCRETO PATRON
RELACION AGUA CEMENTO 0.45

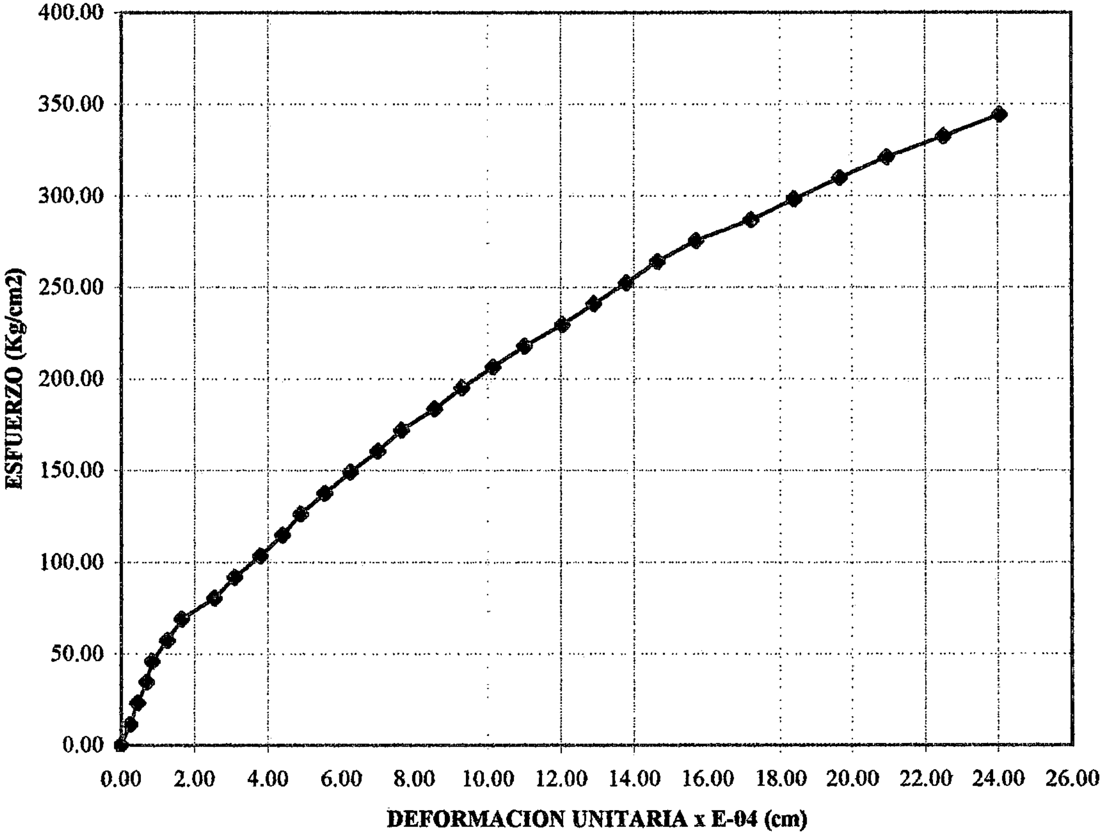


FIBRA : **INSONEX**
LONGITU **40 mm**

Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia, con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

Esfuerzo	Def.Unit
0.00	0.00
11.47	0.25
22.94	0.45
34.41	0.70
45.88	0.85
57.35	1.25
68.82	1.65
80.29	2.55
91.76	3.10
103.23	3.80
114.70	4.40
126.17	4.90
137.64	5.55
149.11	6.25
160.58	7.00
172.05	7.65
183.52	8.55
194.99	9.30
206.46	10.15
217.93	11.00
229.40	12.05
240.87	12.90
252.34	13.80
263.81	14.65
275.28	15.70
286.75	17.20
298.22	18.40
309.69	19.65
321.16	20.95
332.63	22.50
344.10	24.05

MODULO ELASTICO ESTATICO CONCRETO PATRON
RELACION AGUA CEMENTO 0.50



FIBRA : INSONEX
LONGITU 40 mm

7.1.1.11 ENSAYO DE RESISTENCIA A LA FLEXIÓN (kg/cm^2)

- **RELACIÓN AGUA / CEMENTO 0.40**

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2350	15.40	15.50	60.00	38.11	41.94
28	2640	15.00	15.00	60.00	46.93	
28	2340	15.10	15.10	60.00	40.78	

- **RELACIÓN AGUA / CEMENTO 0.45**

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2230	15.00	15.00	60.00	39.64	40.76
28	2430	15.00	15.10	60.00	42.63	
28	2250	15.00	15.00	60.00	40.00	

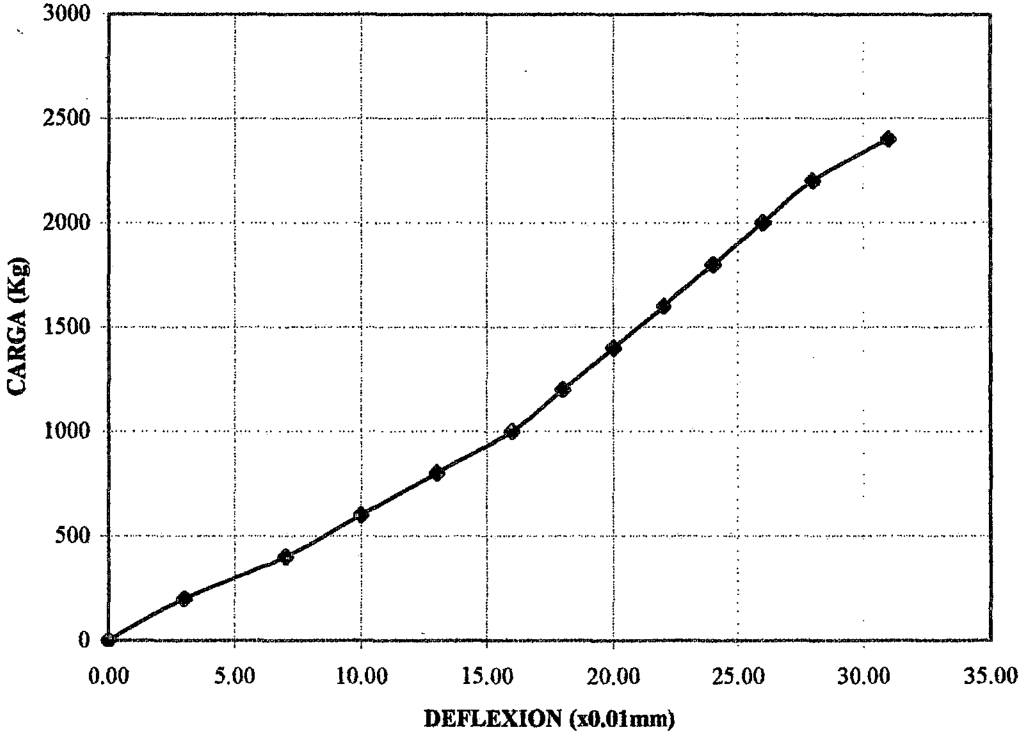
- **RELACIÓN AGUA / CEMENTO 0.50**

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2210	15.10	15.10	60.00	38.51	38.71
28	2160	15.00	15.10	60.00	37.89	
28	2250	15.10	15.00	60.00	39.74	

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	3.00
400	7.00
600	10.00
800	13.00
1000	16.00
1200	18.00
1400	20.00
1600	22.00
1800	24.00
2000	26.00
2200	28.00
2400	31.00

FLUENCIA	**2640**

RESISTENCIA A LA FLEXION CONCRETO PATRON
a/c=0.40

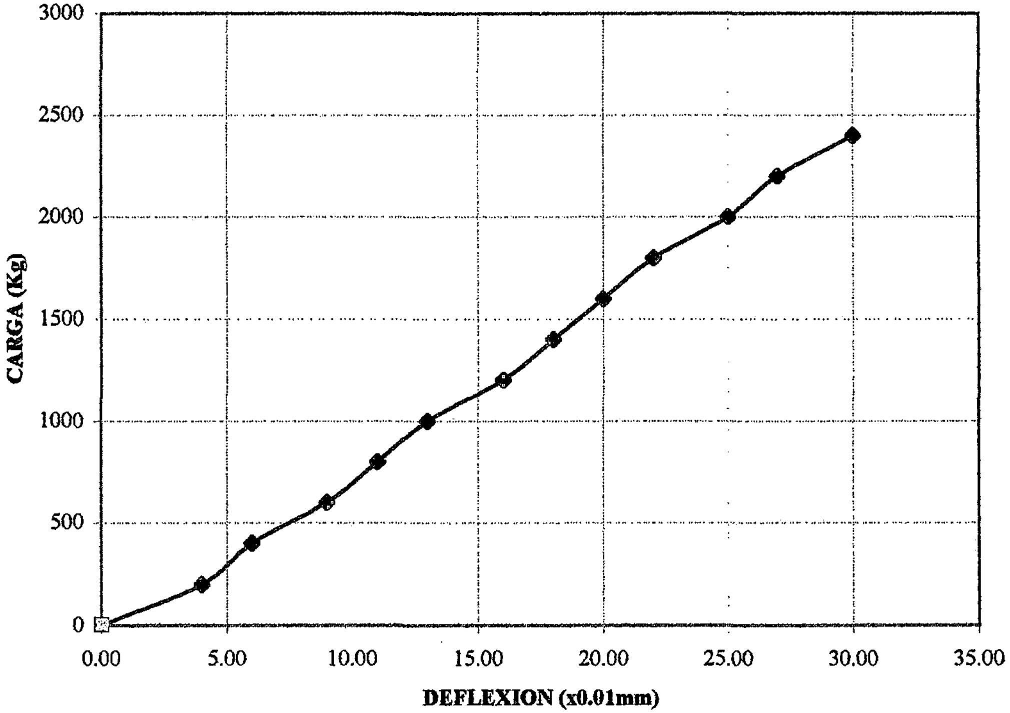


FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	4.00
400	6.00
600	9.00
800	11.00
1000	13.00
1200	16.00
1400	18.00
1600	20.00
1800	22.00
2000	25.00
2200	27.00
2400	30.00

FLUENCIA	**2430**

RESISTENCIA A LA FLEXION CONCRETO PATRON
a/c=0.45

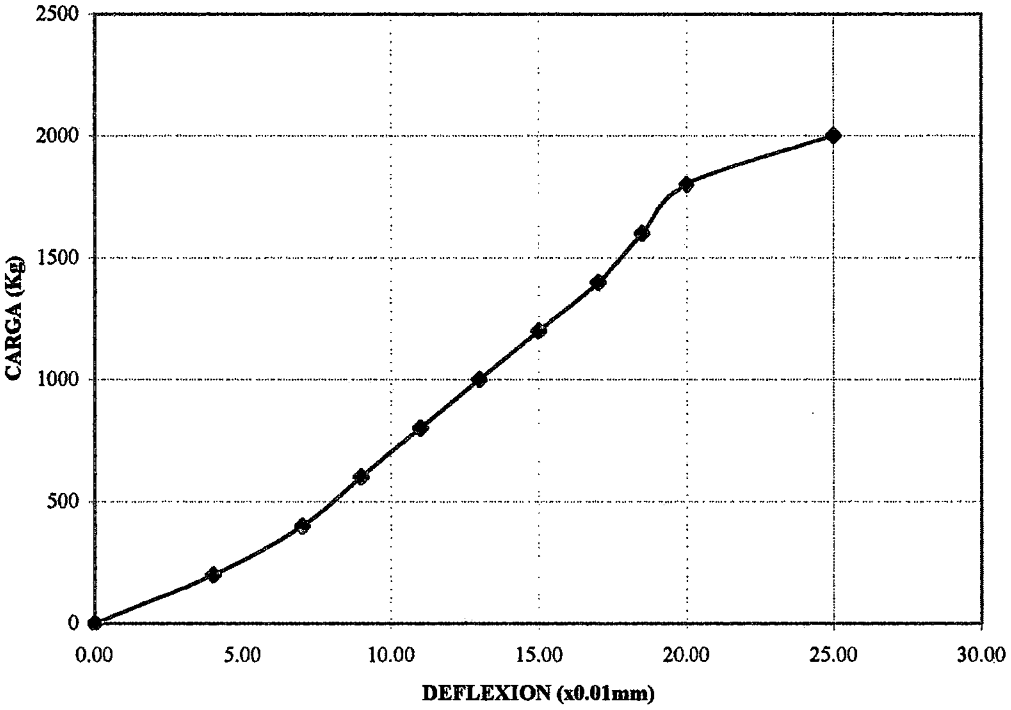


FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	4.00
400	7.00
600	9.00
800	11.00
1000	13.00
1200	15.00
1400	17.00
1600	18.50
1800	20.00
2000	25.00

FLUENCIA	**2250**

RESISTENCIA A LA FLEXION CONCRETO PATRON
a/c=0.50



FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

7.1.1.12 ENSAYO DE RESISTENCIA AL IMPACTO (N° golpes)

- **RELACIÓN AGUA / CEMENTO 0.40**

N° DIAS	ALTURA		DIAMETRO		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.65	6.63	15.00	15.04	115	108
28	6.64		15.03		108	
28	6.61		15.08		100	
42	6.50	6.50	15.00	15.02	107	112
42	6.60		15.05		118	
42	6.40		15.00		110	

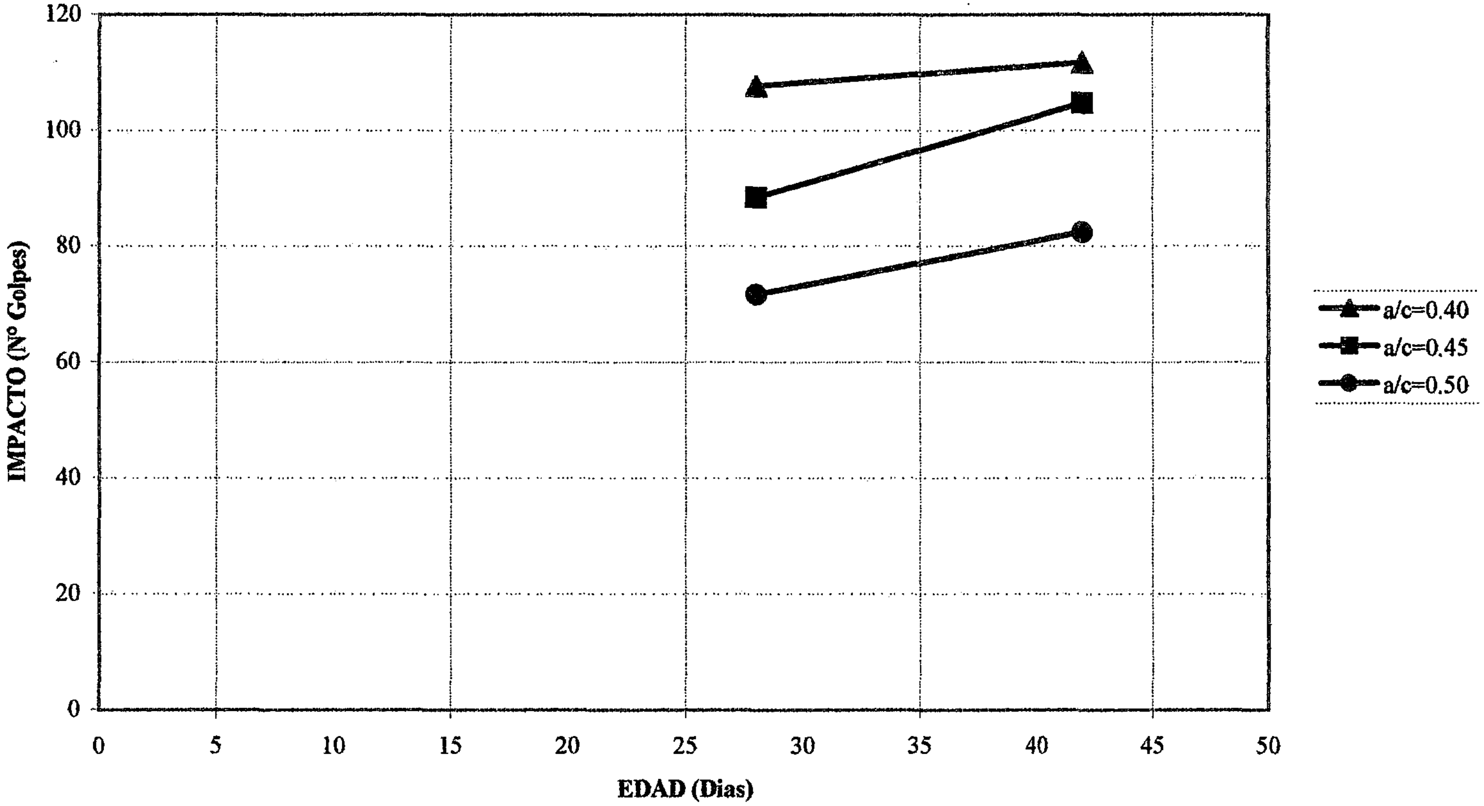
- **RELACIÓN AGUA / CEMENTO 0.45**

N° DIAS	ALTURA		DIAMETRO		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.60	6.62	14.94	14.99	90	88
28	6.65		14.94		95	
28	6.62		15.08		80	
42	6.75	6.62	15.00	14.97	87	105
42	6.40		14.90		100	
42	6.70		15.00		127	

- **RELACIÓN AGUA / CEMENTO 0.50**

N° DIAS	ALTURA		DIAMETRO		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.60	6.64	15.00	14.95	70	72
28	6.66		15.00		80	
28	6.66		14.86		65	
42	6.40	6.43	15.00	15.03	84	82
42	6.50		15.20		90	
42	6.40		14.90		73	

GRAFICA COMPARATIVA PARA DIFERENTES RELACIONES DE A/C



FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

7.2 ENSAYOS EN EL CONCRETO CON FIBRAS DE ACERO INSONEX

7.2.1 ENSAYOS EN EL CONCRETO FRESCO PARA LAS RELACIONES DE a/c = 0.40, 0.45, 0.50 Y DOSIFICACIONES DE FIBRA DE 30, 40, 50 kg/m3 DE CONCRETO

7.2.1.1 ENSAYO DE ASENTAMIENTO (plg)

- **RELACIÓN AGUA / CEMENTO 0.40**

DOSIFIC (Kg/m^3)	ASENTAMIENTO
30	4"
40	3 3/4"
50	3 1/2"

- **RELACIÓN AGUA/CEMENTO 0.45**

DOSIFIC (Kg/m^3)	ASENTAMIENTO
30	3 3/4"
40	3 1/2"
50	3 1/4"

- **RELACIÓN AGUA/CEMENTO 0.50**

DOSIFIC (Kg/m^3)	ASENTAMIENTO
30	3 3/4"
40	3 1/2"
50	3 1/4"

7.2.1.2 ENSAYO DE FLUIDEZ (%)

- **RELACIÓN AGUA / CEMENTO 0.40**

DOSIFIC (Kg/m^3)	FLUIDEZ (%)
30	107.68
40	104.40
50	90.94

- **RELACIÓN AGUA / CEMENTO 0.45**

DOSIFIC (Kg/m^3)	FLUIDEZ (%)
30	105.71
40	103.74
50	100.46

- **RELACIÓN AGUA / CEMENTO 0.50**

DOSIFIC (Kg/m^3)	FLUIDEZ (%)
30	100.13
40	96.85
50	94.23

7.2.1.3 ENSAYO DE PESO UNITARIO COMPACTADO (kg/m^3)

- **RELACIÓN AGUA / CEMENTO 0.40**

DOSIFIC (Kg/m^3)	P.U.C. (Kg/m^3)
30	2407.14
40	2414.29
50	2421.43

- **RELACIÓN AGUA / CEMENTO 0.45**

DOSIFIC (Kg/m^3)	P.U.C. (Kg/m^3)
30	2421.43
40	2428.57
50	2435.71

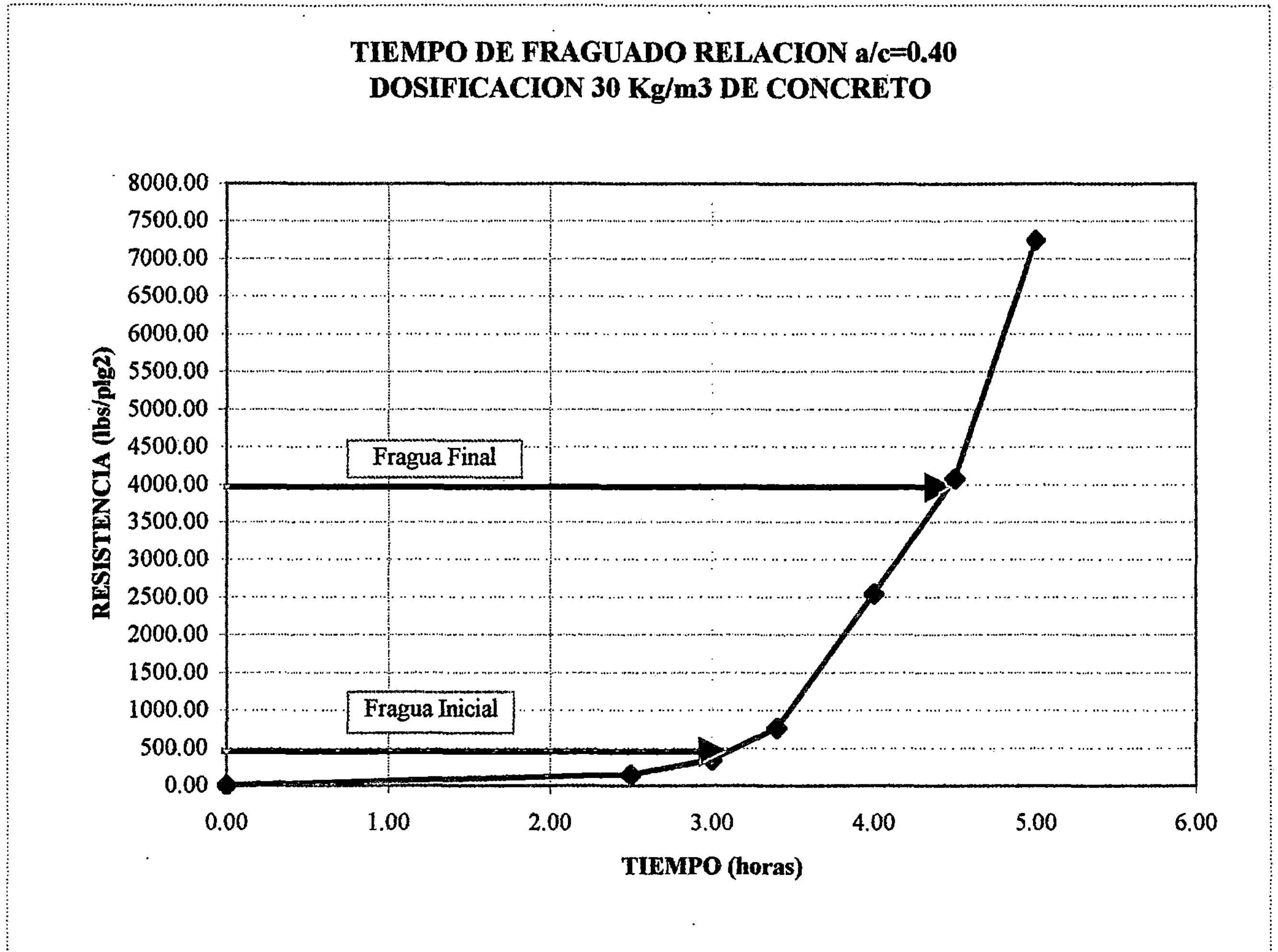
- **RELACIÓN AGUA / CEMENTO 0.50**

DOSIFIC (Kg/m^3)	P.U.C. (Kg/m^3)
30	2442.86
40	2450.00
50	2457.14

7.2.1.4 ENSAYO DE TIEMPO DE FRAGUADO (Hr:min)

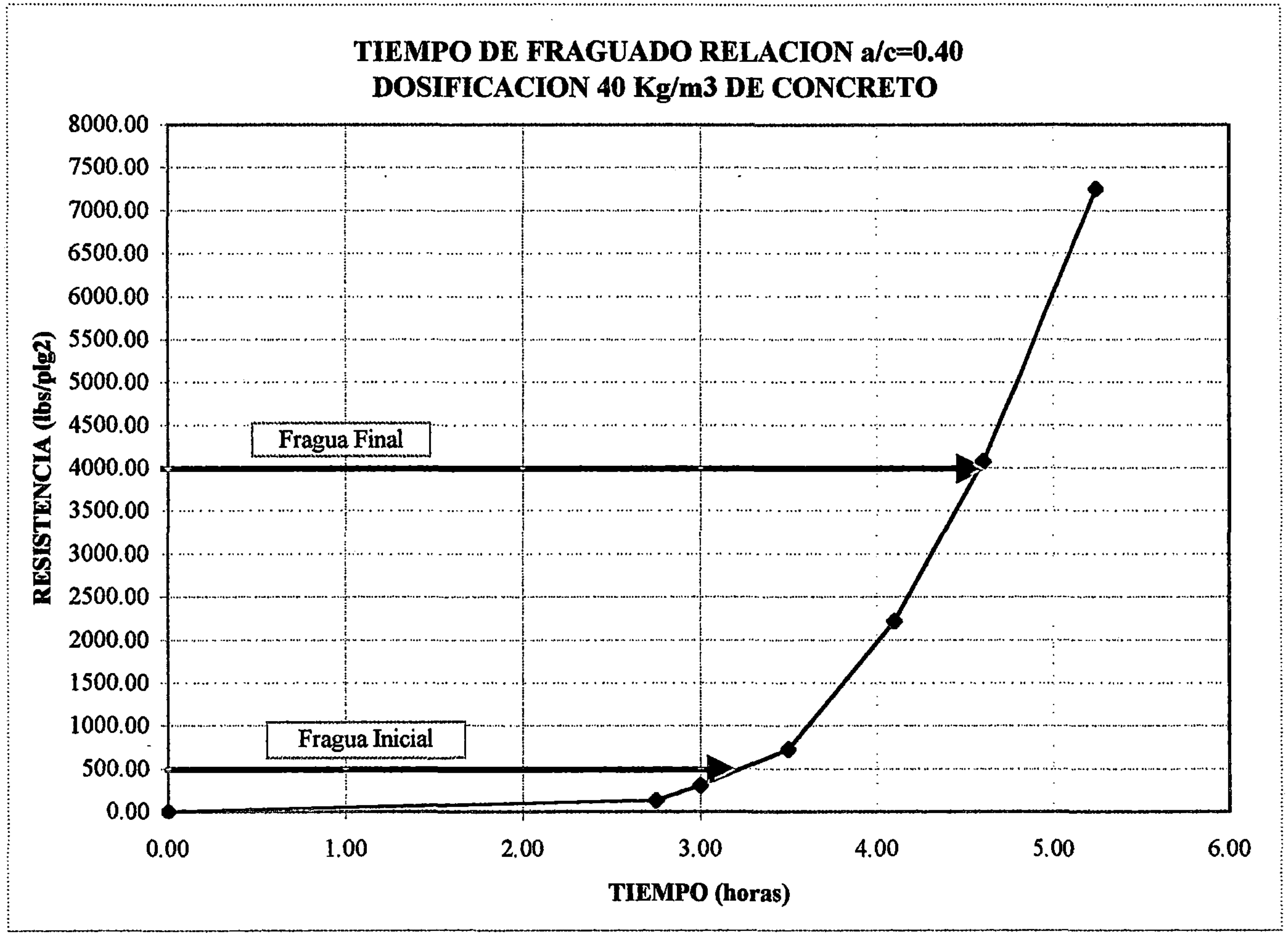
- **RELACIÓN AGUA / CEMENTO 0.40**

DOSIFIC (Kg/m^3)	SECCION Plg^2	TIEMPO Hr:min	FUERZA Lbs	RESIST. (Lbs/plg^2)	FRAGUA INICIAL	FRAGUA FINAL
30		00:00		0.00	3:19	4:20
	0.99402	02:30	140	140.84		
	0.51848	03:00	175	337.53		
	0.24850	03:24	190	764.59		
	0.07669	04:00	195	2542.70		
	0.04908	04:30	200	4074.98		
	0.02761	05:00	200	7243.75		
40		00:00		0.00	3:14	4:16
	0.99402	02:45	130	130.78		
	0.51848	03:00	160	308.59		
	0.24850	03:30	180	724.35		
	0.07669	04:06	170	2216.72		
	0.04908	04:20	200	4074.98		
	0.02761	05:00	200	7243.75		
50		00:00		0.00	3:09	4:14
	0.99402	02:30	140	140.84		
	0.51848	02:50	160	308.59		
	0.24850	03:30	180	724.35		
	0.07669	04:00	200	2607.90		
	0.04908	04:20	200	4074.98		
	0.02761	05:00	200	7243.75		


TIEMPO DE FRAGUADO RELACION a/c=0.40
DOSIFICACION 30 Kg/m3 DE CONCRETO

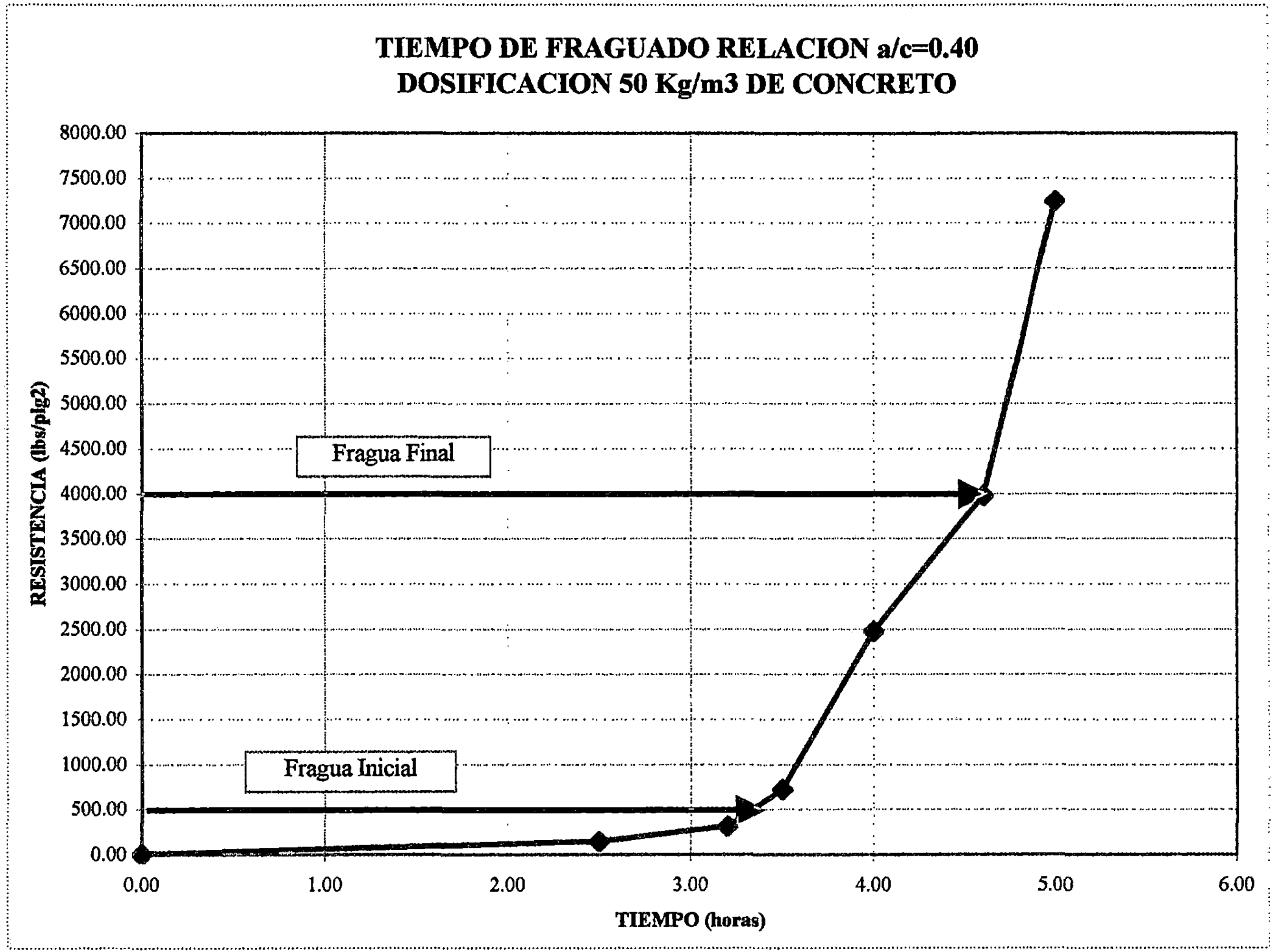
FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

Fragua Inicial	=	03:19
Fragua final	=	04:20


TIEMPO DE FRAGUADO RELACION a/c=0.40
DOSIFICACION 40 Kg/m3 DE CONCRETO

FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

Fragua Inicial	=	03:14
Fragua final	=	04:16



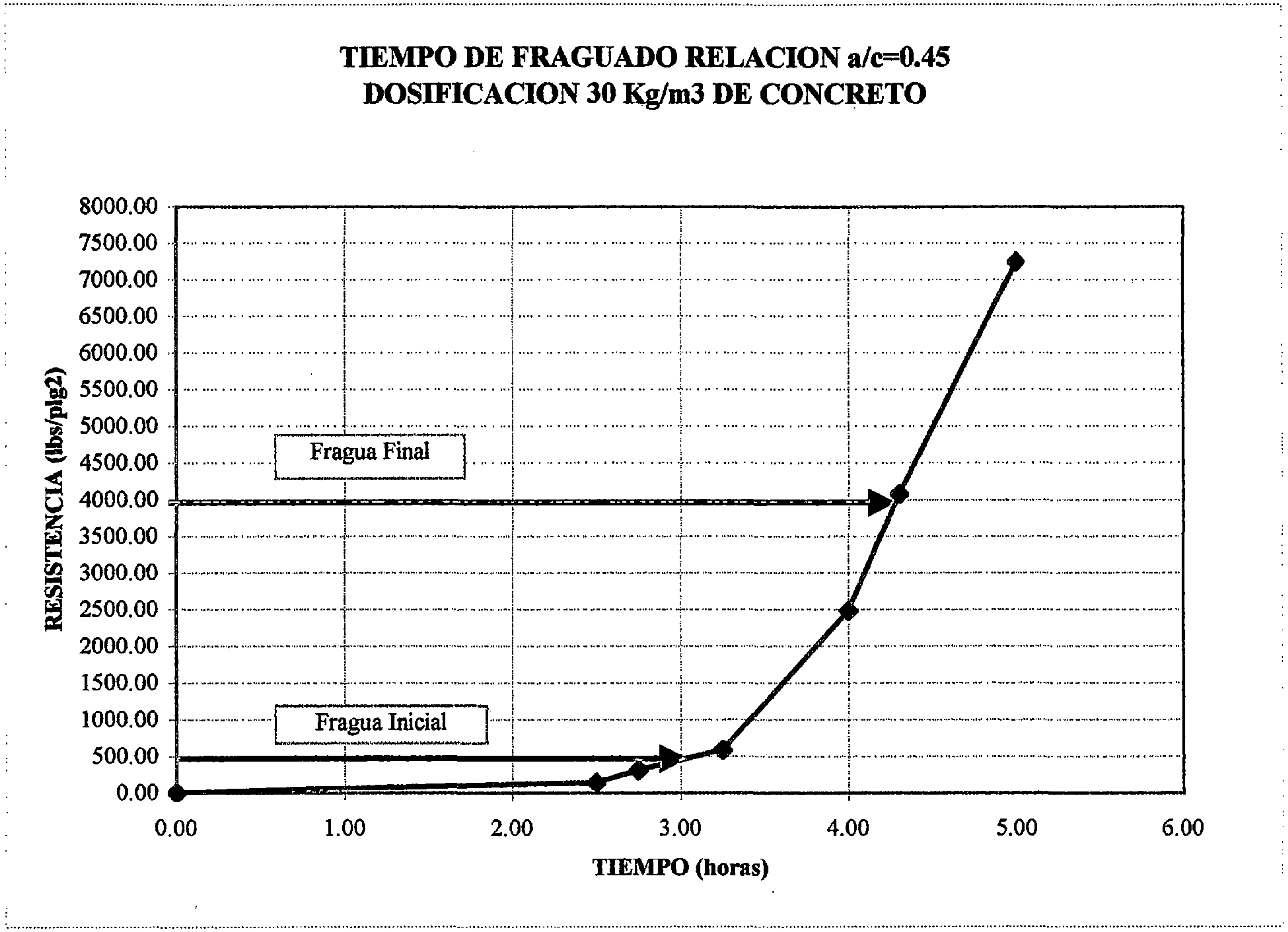
TIEMPO DE FRAGUADO RELACION a/c=0.40
DOSIFICACION 50 Kg/m3 DE CONCRETO

FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

Fragua Inicial	=	03:09
Fragua final	=	04:14

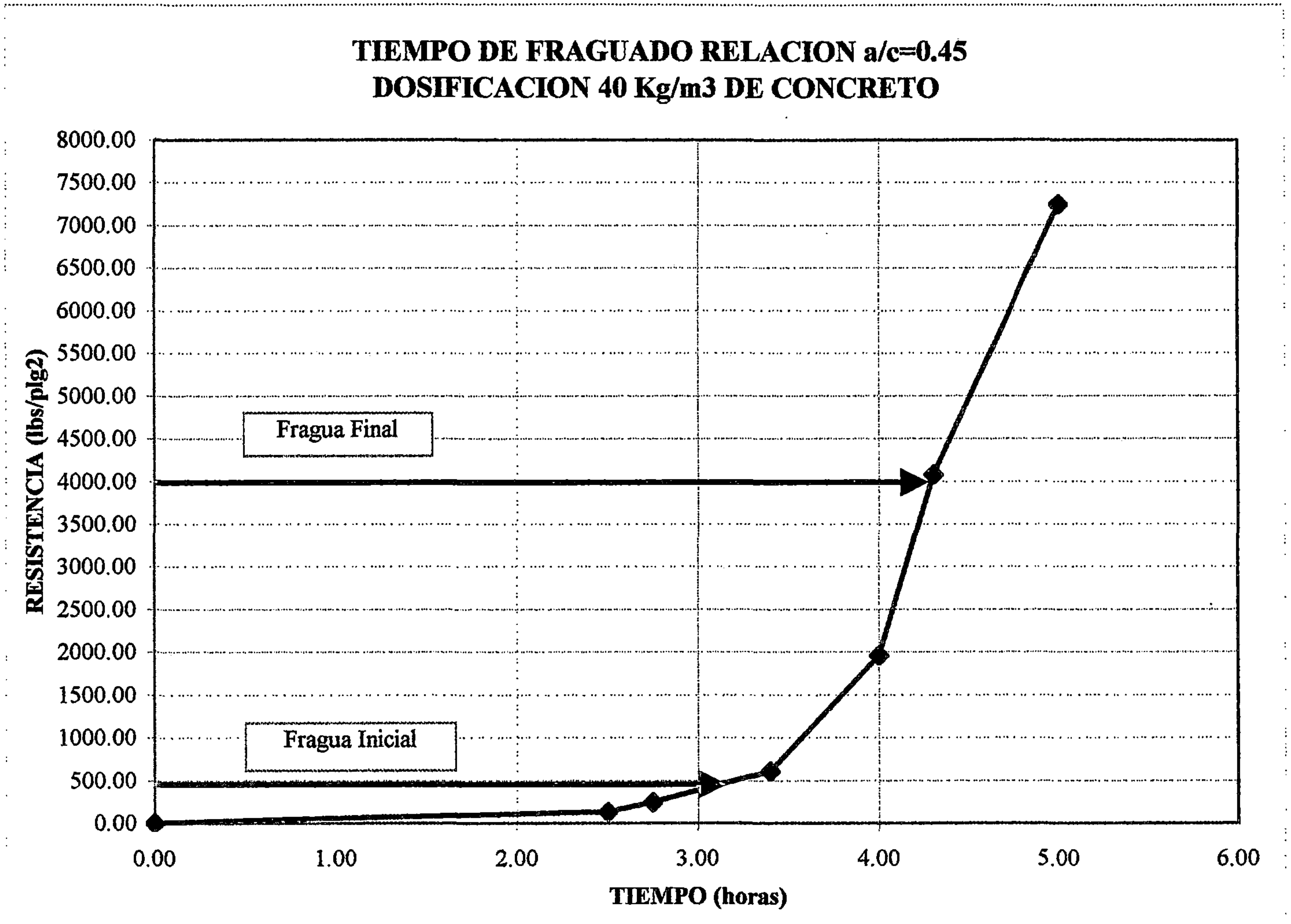
- **RELACIÓN AGUA / CEMENTO 0.45**

DOSIFIC (Kg/m^3)	SECCION Plg^2	TIEMPO Hr:min	FUERZA Lbs	RESIST. (Lbs/plg^2)	FRAGUA INICIAL	FRAGUA FINAL
30		00:00		0.00	3:13	4:16
	0.99402	02:30	135	135.81		
	0.51848	02:45	160	308.59		
	0.24850	03:20	150	603.62		
	0.07669	04:00	190	2477.51		
	0.04908	04:18	200	4074.98		
	0.02761	05:00	200	7243.75		
40		00:00		0.00	3:10	4:12
	0.99402	02:30	130	130.78		
	0.51848	02:45	125	241.09		
	0.24850	03:24	150	603.62		
	0.07669	04:00	150	1955.93		
	0.04908	04:15	200	4074.98		
	0.02761	05:00	200	7243.75		
50		00:00		0.00	3:05	4:08
	0.99402	02:30	130	130.78		
	0.51848	02:45	160	308.59		
	0.24850	03:10	140	563.38		
	0.07669	04:00	185	2412.31		
	0.04908	04:12	200	4074.98		
	0.02761	05:00	200	7243.75		

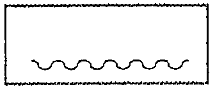


FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

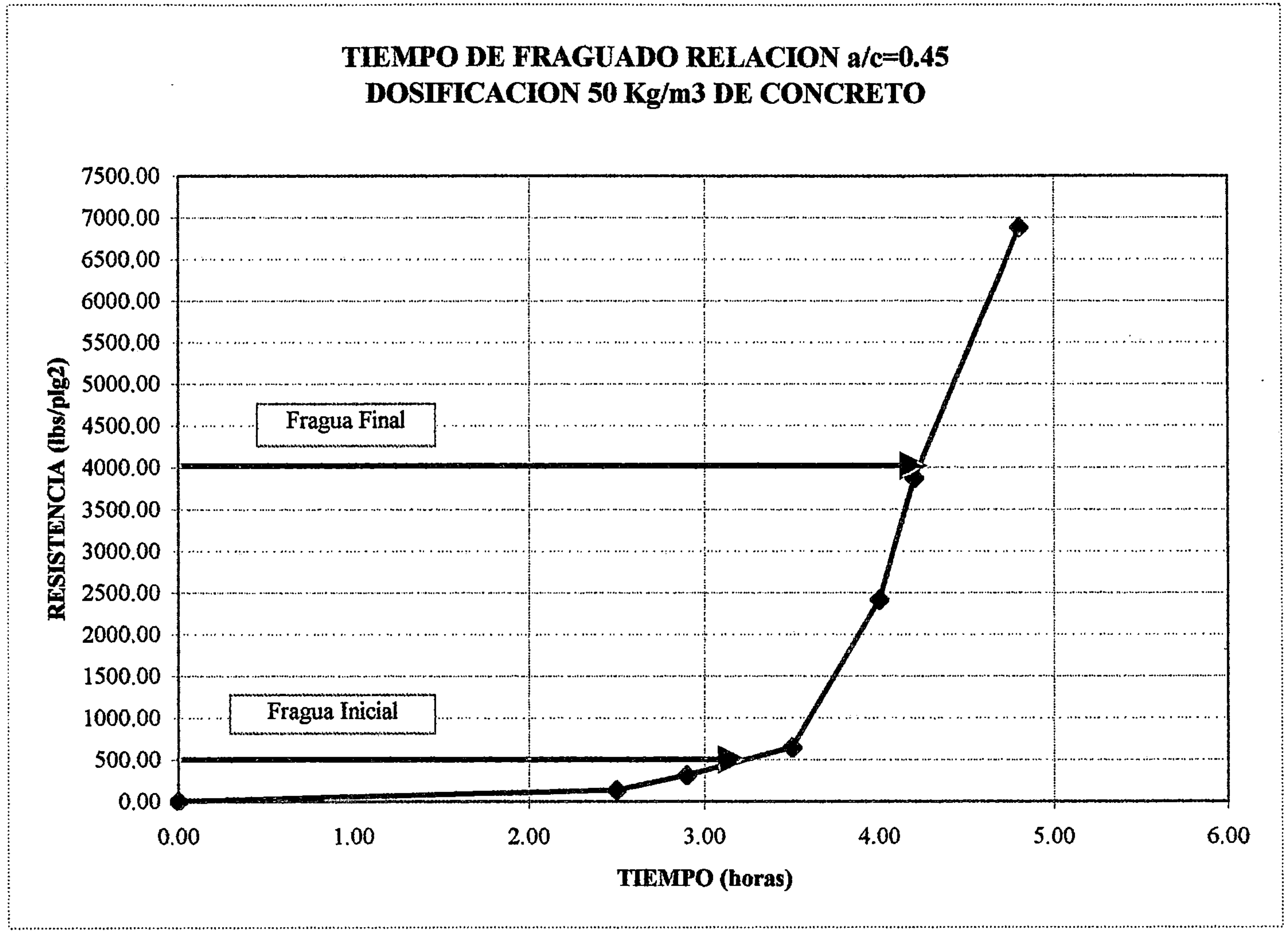
Fragua Inicial	=	03:13
Fragua final	=	04:16



FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**



Fragua Inicial	=	03:10
Fragua final	=	04:12



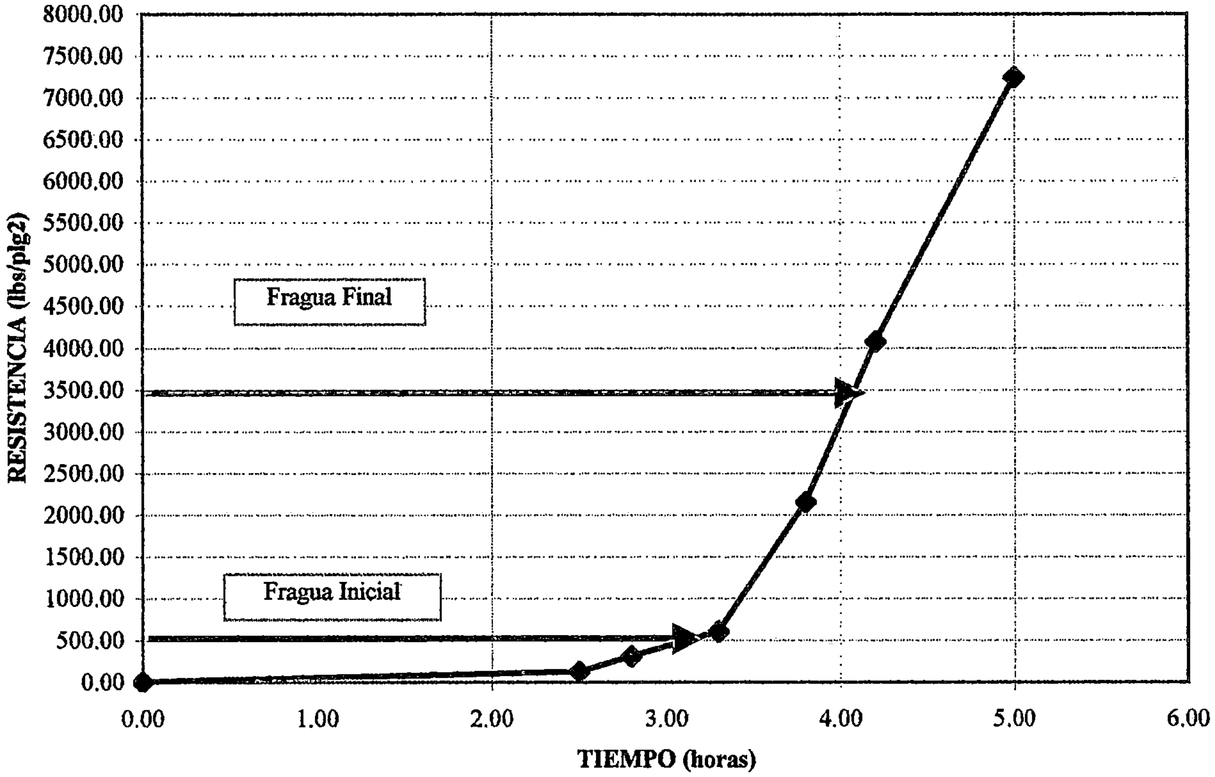
FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

Fragua Inicial	=	03:05
Fragua final	=	04:08

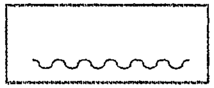
- **RELACIÓN AGUA / CEMENTO 0.50**

DOSIFIC (Kg/m^3)	SECCION Plg^2	TIEMPO Hr:min	FUERZA Lbs	RESIST. (Lbs/plg^2)	FRAGUA INICIAL	FRAGUA FINAL
30		00:00		0.00	03:08	04:13
	0.99402	02:30	120	120.72		
	0.51848	02:48	160	308.59		
	0.24850	03:18	180	724.35		
	0.07669	04:00	165	2151.52		
	0.04908	04:15	200	4074.98		
	0.02761	05:00	200	7243.75		
40		00:00		0.00	03:06	04:11
	0.99402	02:30	125	125.75		
	0.51848	02:54	160	308.59		
	0.24850	03:30	180	724.35		
	0.07669	04:00	140	1825.53		
	0.04908	04:13	200	4074.98		
	0.02761	05:00	200	7243.75		
50		00:00		0.00	03:02	04:08
	0.99402	02:30	150	150.90		
	0.51848	03:00	145	279.66		
	0.24850	03:30	180	724.35		
	0.07669	04:00	140	1825.53		
	0.04908	04:10	200	4074.98		
	0.02761	05:00	190	6881.56		

TIEMPO DE FRAGUADO RELACION a/c=0.50
DOSIFICACION 30 Kg/m3 DE CONCRETO

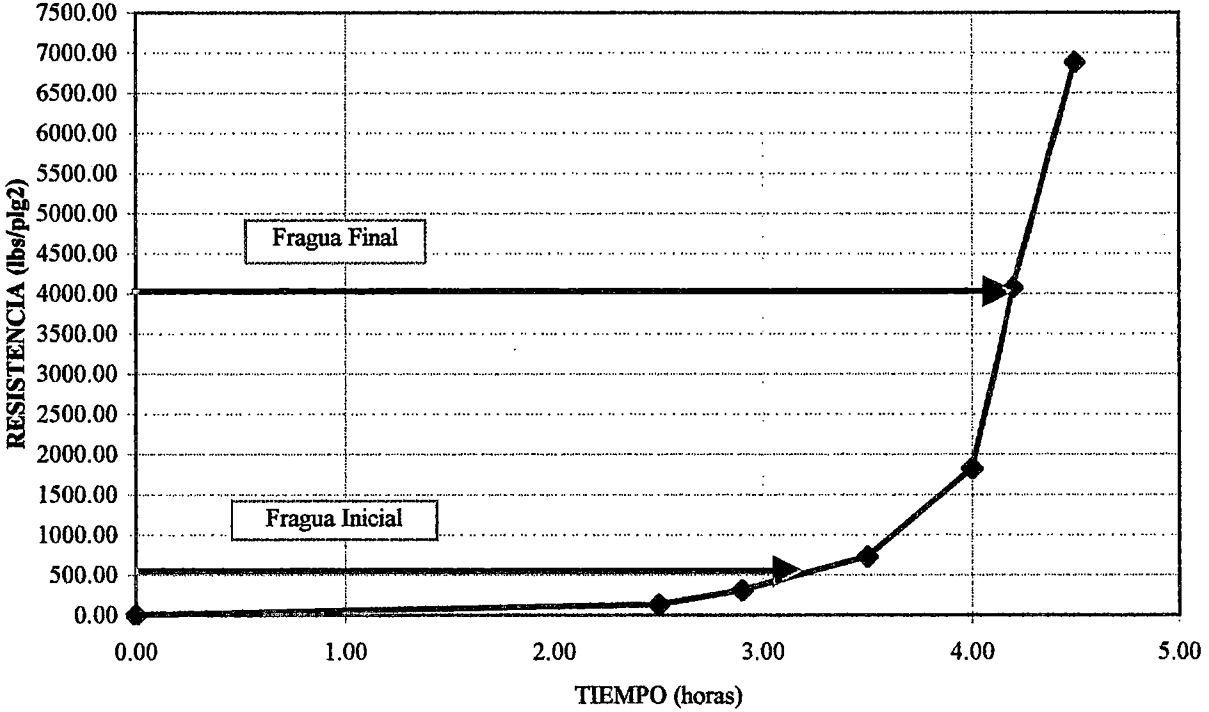


FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**



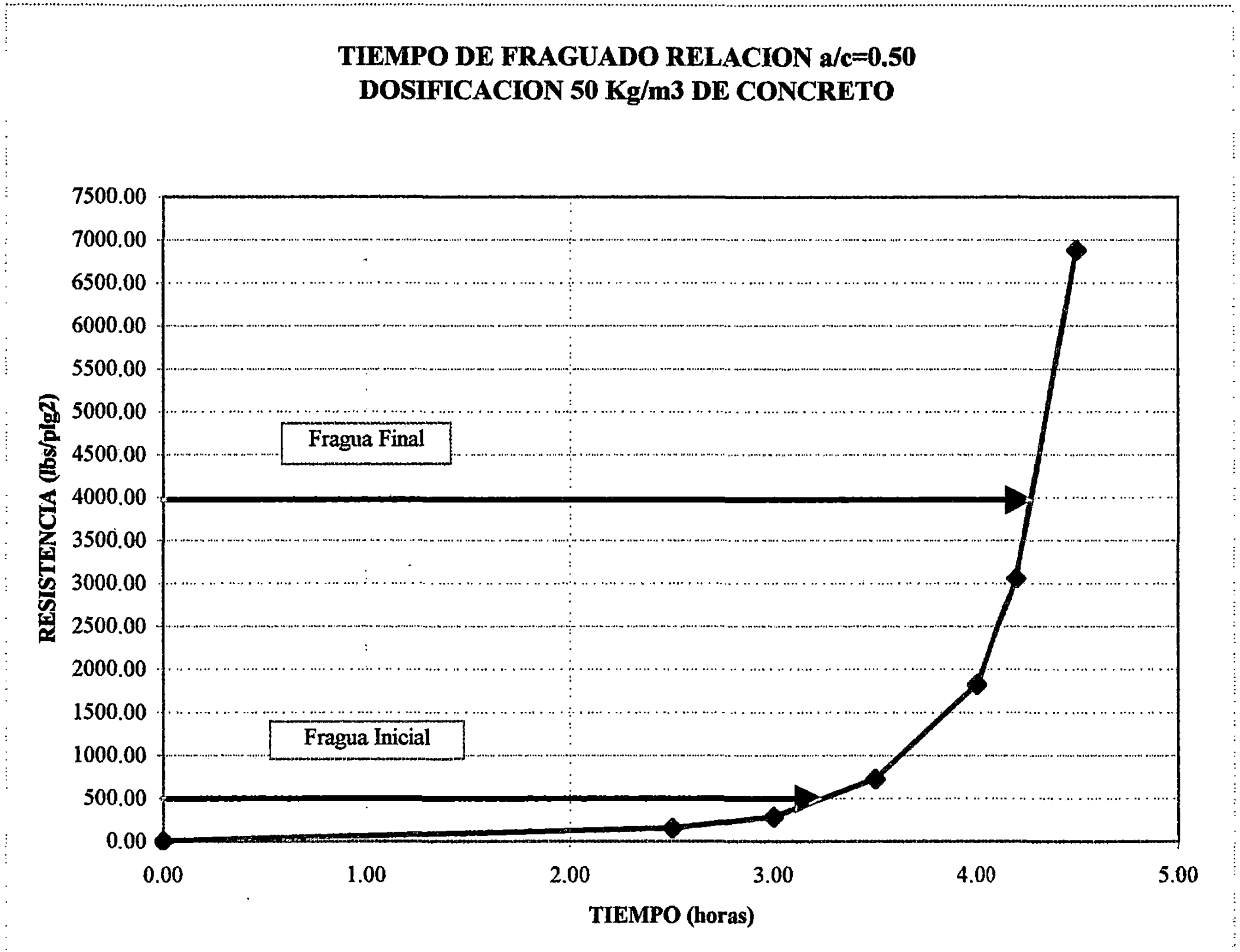
Fragua Inicial	=	03:08
Fragua final	=	04:13

TIEMPO DE FRAGUADO RELACION a/c=0.50
DOSIFICACION 40 Kg/m3 DE CONCRETO



FIBRA : INSONEX
LONGITUD : 40 mm
FORMA :

Fragua Inicial	=	03:06
Fragua final	=	04:11



TIEMPO DE FRAGUADO RELACION a/c=0.50
DOSIFICACION 50 Kg/m3 DE CONCRETO

FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

Fragua Inicial	=	03:02
Fragua final	=	04:08

7.2.1.5 ENSAYO DE CONTENIDO DE AIRE(%)

- **RELACIÓN AGUA/CEMENTO 0.40**

DOSIFIC (Kg/m^3)	CONTENIDO DE AIRE (%)
30	1.37
40	1.39
50	1.42

- **RELACIÓN AGUA/CEMENTO 0.45**

DOSIFIC (Kg/m^3)	CONTENIDO DE AIRE (%)
30	1.43
40	1.46
50	1.49

- **RELACIÓN AGUA/CEMENTO 0.50**

DOSIFIC (Kg/m^3)	CONTENIDO DE AIRE (%)
30	1.49
40	1.53
50	1.58

7.2.1.6 ENSAYO DE EXUDACIÓN (%)

- **RELACIÓN AGUA / CEMENTO 0.40**

DOSIFIC (Kg/m^3)	EXUDACIÓN (%)
30	1.73
40	1.57
50	1.48

- **RELACIÓN AGUA / CEMENTO 0.45**

DOSIFIC (Kg/m^3)	EXUDACIÓN (%)
30	1.90
40	1.69
50	1.62

- **RELACIÓN AGUA / CEMENTO 0.50**

DOSIFIC (Kg/m^3)	EXUDACIÓN (%)
30	2.47
40	2.04
50	1.86

7.2.2 ENSAYOS EN EL CONCRETO ENDURECIDO PARA LAS RELACIONES DE a/c = 0.40, 0.45, 0.50 Y DOSIFICACIONES DE FIBRA DE 30, 40, 50 Kg/m^3 DE CONCRETO

7.2.2.1 ENSAYO DE RESISTENCIA A LA COMPRESIÓN (kg/cm^2)

- **RELACIÓN AGUA / CEMENTO 0.40**
  - **DOSIFICACIÓN 30 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	63800	15.06	358.16	348.75
7	58000	15.06	325.60	
7	63800	14.97	362.48	
14	70000	15.10	390.89	398.20
14	72300	15.00	409.13	
14	68800	14.90	394.57	
28	73200	14.96	416.44	431.48
28	74300	14.90	426.11	
28	77000	14.97	437.48	
28	72800	14.90	417.51	
28	77900	15.10	435.00	
28	80000	14.94	456.35	
42	81100	14.80	471.42	466.61
42	84000	14.95	478.53	
42	79500	15.00	449.88	

➢ DOSIFICACIÓN 40 kg/m^3 DE CONCRETO

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	63200	14.96	359.55	354.98
7	62400	14.97	354.53	
7	62500	15.06	350.86	
14	70500	15.07	395.25	402.91
14	72800	14.95	414.72	
14	70000	14.95	398.77	
28	76300	15.00	431.77	444.82
28	75000	15.04	422.16	
28	81400	15.10	454.55	
28	78600	15.03	443.01	
28	77900	14.94	444.37	
28	83600	15.00	473.08	
42	78400	14.84	453.27	466.86
42	80000	14.97	454.52	
42	87900	15.07	492.80	

➢ DOSIFICACIÓN 50 kg/m^3 DE CONCRETO

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	63800	14.95	363.45	355.22
7	60000	14.96	341.35	
7	62500	14.85	360.86	
14	72000	14.90	412.92	403.82
14	68000	15.02	383.78	
14	73000	14.97	414.75	
28	80400	14.97	456.80	446.68
28	78200	15.00	442.52	
28	79400	15.07	445.15	
28	82400	14.89	473.20	
28	76900	15.00	435.16	
28	75200	14.97	427.25	
42	84000	15.00	475.34	471.46
42	85000	14.90	487.48	
42	79800	15.00	451.57	

- **RELACIÓN AGUA/CEMENTO 0.45**

  - **DOSIFICACIÓN 30 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	55200	14.98	313.20	318.57
7	52000	14.98	295.05	
7	61400	15.00	347.45	
14	63300	15.00	358.20	374.86
14	68000	15.00	384.80	
14	66000	14.84	381.58	
28	69200	15.05	388.99	396.52
28	61400	14.98	348.38	
28	73400	15.00	415.36	
28	76000	14.80	441.77	
28	66000	14.86	380.55	
28	71400	15.00	404.04	
42	78000	14.90	447.33	430.92
42	75000	14.96	426.68	
42	74000	15.00	418.75	

  - **DOSIFICACIÓN 40 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	61200	15.00	346.32	324.71
7	56600	15.00	320.29	
7	54200	14.98	307.53	
14	65400	14.85	377.60	375.14
14	66000	14.80	383.65	
14	64100	14.97	364.19	
28	68000	15.00	384.80	398.27
28	71400	14.80	415.03	
28	69300	14.90	397.44	
28	70900	15.00	401.21	
28	70500	15.10	393.68	
28	70700	15.05	397.43	
42	77200	14.90	442.75	432.83
42	74200	15.10	414.34	
42	78000	15.00	441.39	

- **DOSIFICACIÓN 50 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	56600	14.90	324.60	324.79
7	56200	14.94	320.59	
7	57400	14.90	329.19	
14	63100	15.00	357.07	381.44
14	72800	15.06	408.69	
14	66900	15.00	378.58	
28	70400	14.84	407.02	406.77
28	73400	15.02	414.25	
28	68200	15.00	385.93	
28	69800	14.94	398.17	
28	72400	15.00	409.70	
28	75200	15.00	425.54	
42	75000	15.10	418.81	436.73
42	78000	15.10	435.56	
42	79800	14.93	455.82	

- **RELACIÓN AGUA/CEMENTO 0.50**
  - **DOSIFICACIÓN 30 kg/m^3 DE CONCRETO**

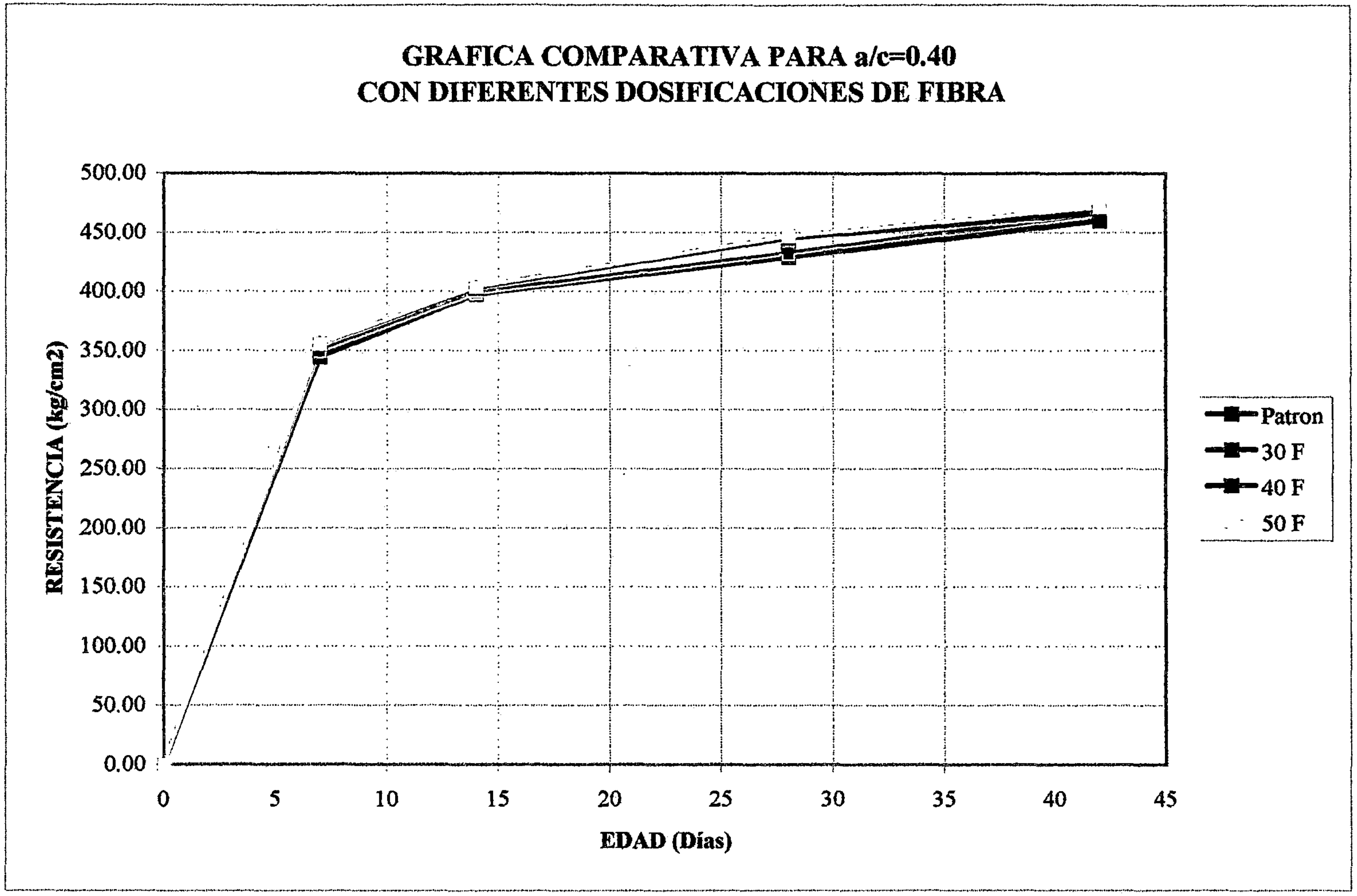
N° DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	54200	15.02	305.89	294.08
7	48600	14.90	278.72	
7	53300	15.10	297.63	
14	57500	14.80	334.24	341.33
14	58000	14.95	330.41	
14	63500	15.00	359.34	
28	63400	15.00	358.77	380.10
28	64900	14.90	372.20	
28	67000	15.00	379.14	
28	67800	15.00	383.67	
28	68400	14.93	390.70	
28	70000	15.00	396.12	
42	68500	15.10	382.51	404.60
42	70000	15.05	393.49	
42	78400	15.10	437.80	

- **DOSIFICACIÓN 40 kg/m^3 DE CONCRETO**

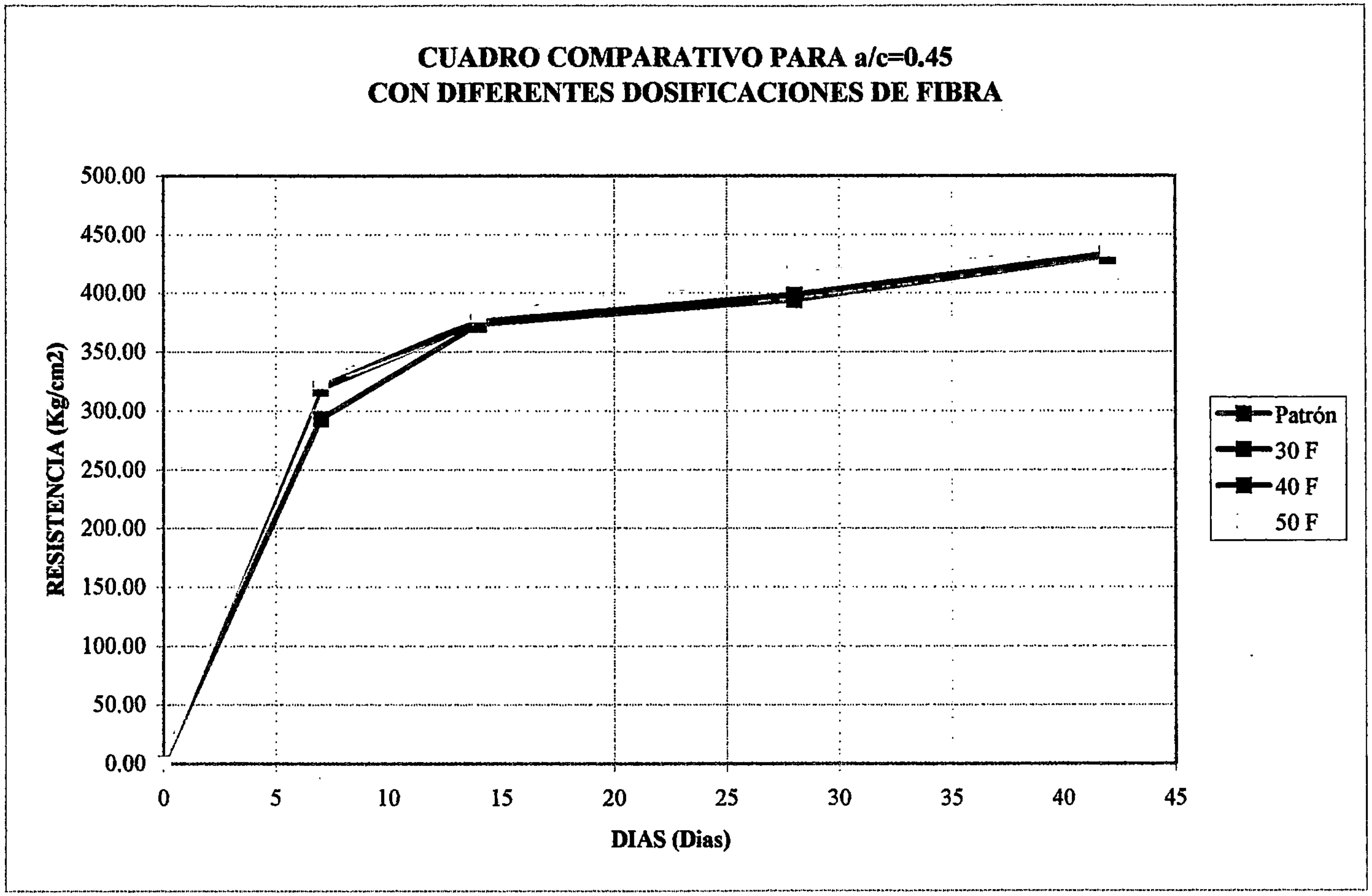
Nº DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	50800	15.00	287.47	296.25
7	48600	14.98	275.75	
7	57600	15.01	325.51	
14	63000	14.96	358.42	344.42
14	57700	14.98	327.39	
14	61400	15.00	347.45	
28	68900	15.00	389.89	384.36
28	62100	15.00	351.41	
28	71600	15.10	399.82	
28	65600	14.80	381.32	
28	66700	14.86	384.59	
28	71000	15.05	399.11	
42	74400	14.94	424.41	404.78
42	75400	14.90	432.42	
42	63600	15.05	357.51	

- **DOSIFICACIÓN 50 kg/m^3 DE CONCRETO**

Nº DIAS	CARGA (Kg)	DIAMETRO (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
7	45800	15.00	259.17	297.13
7	53800	15.00	304.45	
7	58000	15.01	327.77	
14	63000	14.85	363.74	349.91
14	58800	14.90	337.22	
14	60000	14.80	348.77	
28	73500	15.00	415.92	385.55
28	64300	15.04	361.93	
28	73600	15.00	416.49	
28	65200	14.80	378.99	
28	67500	15.00	381.97	
28	62000	14.85	357.97	
42	76900	15.00	435.16	410.13
42	69000	14.90	395.72	
42	70600	15.00	399.51	

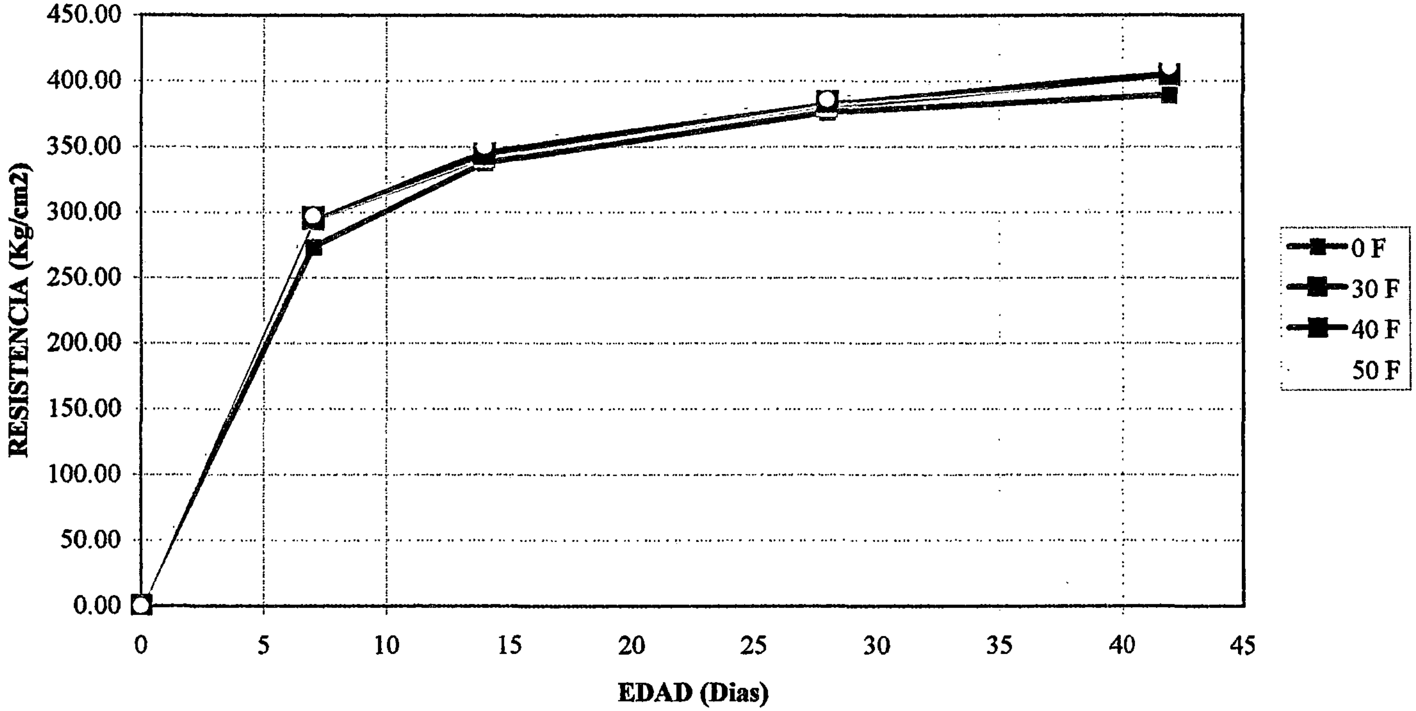


FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**



FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

CUADRO COMPARATIVO PARA a/c=0.50
CON DIFERENTES DOSIFICACIONES DE FIBRA



FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

7.2.2.2 ENSAYO DE RESISTENCIA A LA TRACCIÓN POR COMPRESIÓN DIAMETRAL (kg/cm^2)

- **RELACIÓN AGUA/CEMENTO 0.40**
  - **DOSIFICACIÓN 30 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	28200	14.92	30.20	39.86	43.95
28	34000	14.97	30.10	48.04	

  - **DOSIFICACIÓN 40 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	32000	15.10	30.08	44.85	44.84
28	32000	15.00	30.30	44.82	

  - **DOSIFICACIÓN 50 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	34600	14.94	30.16	48.88	46.12
28	31200	15.02	30.50	43.36	

- **RELACIÓN AGUA/CEMENTO 0.45**
  - **DOSIFICACIÓN 30 kg/m^3 DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	29600	14.95	30.50	41.35	39.59
28	27100	15.00	30.40	37.83	

- **DOSIFICACIÓN 40 kg/m³ DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm²)	PROMEDIO (Kg/cm²)
28	29000	14.94	30.20	40.92	41.64
28	30200	15.00	30.25	42.37	

- **DOSIFICACIÓN 50 kg/m³ DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm²)	PROMEDIO (Kg/cm²)
28	29500	15.04	30.28	41.24	43.16
28	32500	15.00	30.60	45.08	

- **RELACIÓN AGUA/CEMENTO 0.50**
  - **DOSIFICACIÓN 30 kg/m³ DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm²)	PROMEDIO (Kg/cm²)
28	25200	14.94	30.10	35.69	34.63
28	24200	15.07	30.45	33.57	

- **DOSIFICACIÓN 40 kg/m³ DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm²)	PROMEDIO (Kg/cm²)
28	26400	14.90	30.40	37.10	36.79
28	26300	15.10	30.40	36.47	

- **DOSIFICACIÓN 50 kg/m³ DE CONCRETO**

N° DIAS	CARGA (Kg)	DIAMETRO (cm)	LUZ (cm)	RESISTENCIA (Kg/cm²)	PROMEDIO (Kg/cm²)
28	25600	14.99	30.30	35.88	37.90
28	28700	15.06	30.40	39.91	

7.2.2.3 ENSAYO DE MÓDULO ELÁSTICO ESTÁTICO

- **RELACIÓN AGUA/CEMENTO 0.40**

DOSIFIC a/c	MOD. ELAST. EST. ($x10^5$ kg/cm²)
30	2.7301
40	2.8113
50	2.8763

- **RELACIÓN AGUA/CEMENTO 0.45**

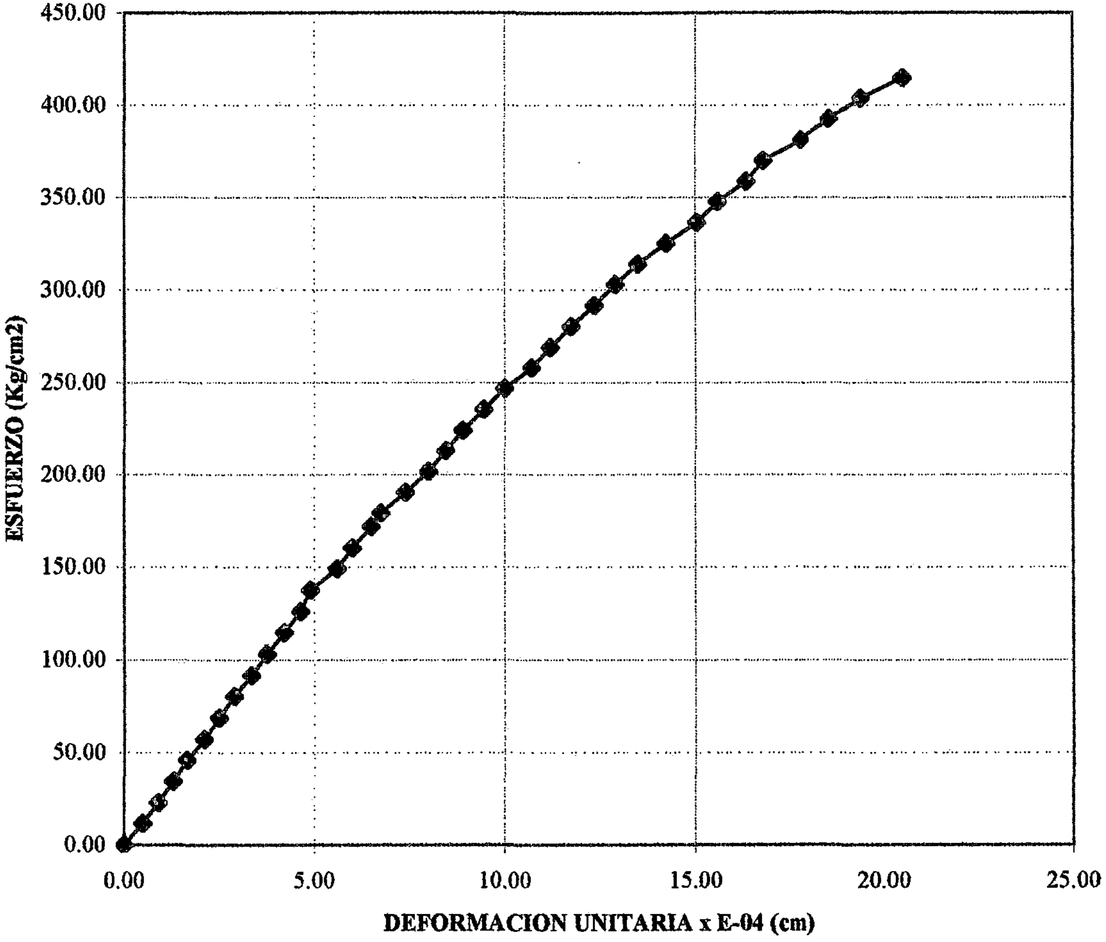
DOSIFIC a/c	MOD. ELAST. EST. ($x10^5$ kg/cm²)
30	2.4299
40	2.4939
50	2.5240

- **RELACIÓN AGUA/CEMENTO 0.50**

DOSIFIC a/c	MOD. ELAST. EST. ($x10^5$ kg/cm²)
30	2.2276
40	2.3178
50	2.3554

Esfuerzo	Def.Unit
0.00	0.00
11.47	0.50
22.94	0.90
34.41	1.30
45.88	1.65
57.35	2.10
68.82	2.50
80.29	2.90
91.76	3.35
103.23	3.75
114.70	4.20
126.17	4.65
137.64	4.90
149.11	5.60
160.58	6.00
172.05	6.50
179.37	6.75
190.58	7.40
201.79	8.00
213.00	8.45
224.22	8.90
235.43	9.45
246.64	10.00
257.85	10.70
269.06	11.20
280.27	11.75
291.48	12.35
302.69	12.90
313.90	13.50
325.11	14.25
336.32	15.05
347.53	15.60
358.74	16.35
369.96	16.80
381.17	17.80
392.38	18.55
403.59	19.40
414.80	20.50

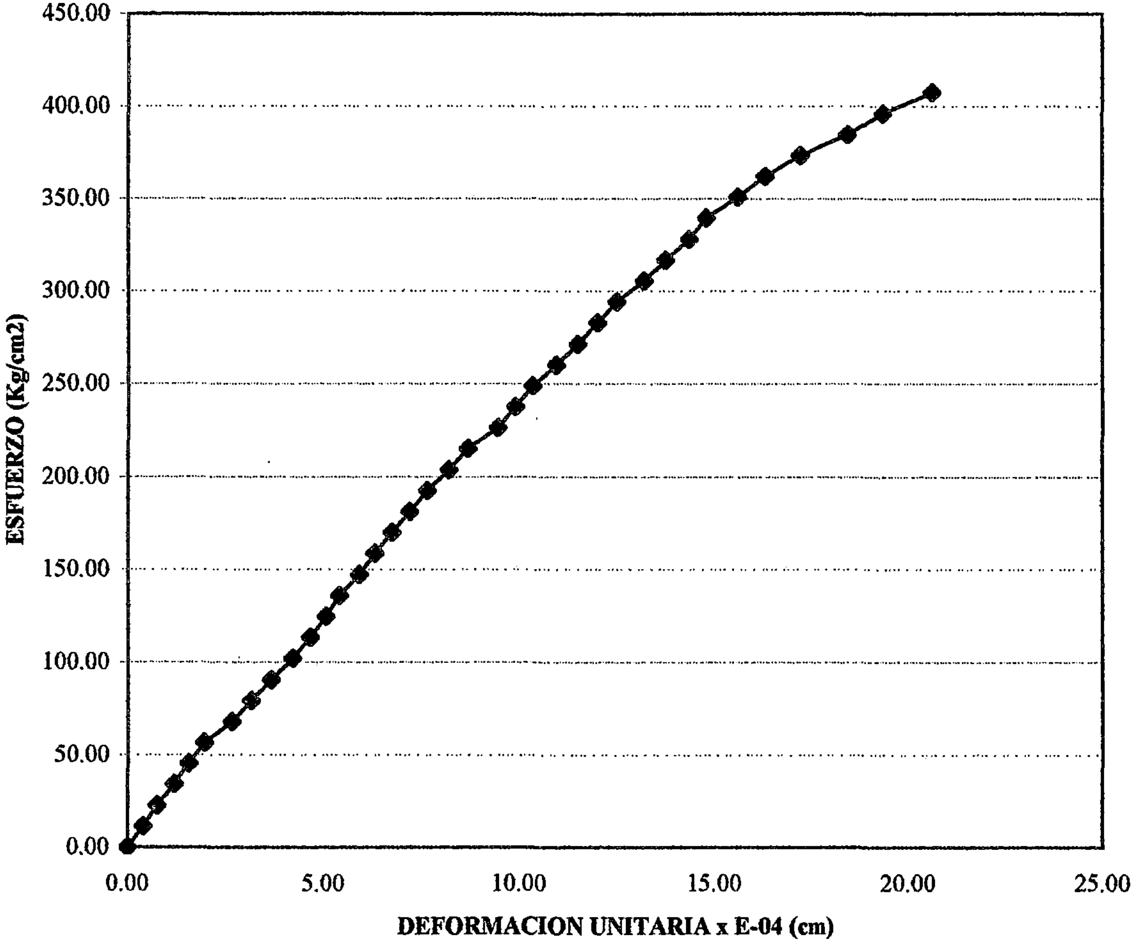
MODULO ELASTICO ESTATICO RELACION a/c= 0.40
DOSIFICACION DE LA FIBRA 30 Kg/m3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD **40 mm**

Esfuerzo	Def.Unit
0.00	0.00
11.32	0.40
22.64	0.75
33.95	1.20
45.27	1.55
56.59	1.95
67.91	2.65
79.22	3.15
90.54	3.65
101.86	4.20
113.18	4.65
124.49	5.05
135.81	5.40
147.13	5.90
158.45	6.30
169.76	6.75
181.08	7.20
192.40	7.65
203.72	8.20
215.04	8.70
226.35	9.45
237.67	9.90
248.99	10.35
260.31	10.95
271.62	11.50
282.94	12.00
294.26	12.50
305.58	13.20
316.89	13.75
328.21	14.35
339.53	14.80
350.85	15.60
362.17	16.30
373.48	17.20
384.80	18.45
396.12	19.35
407.44	20.60

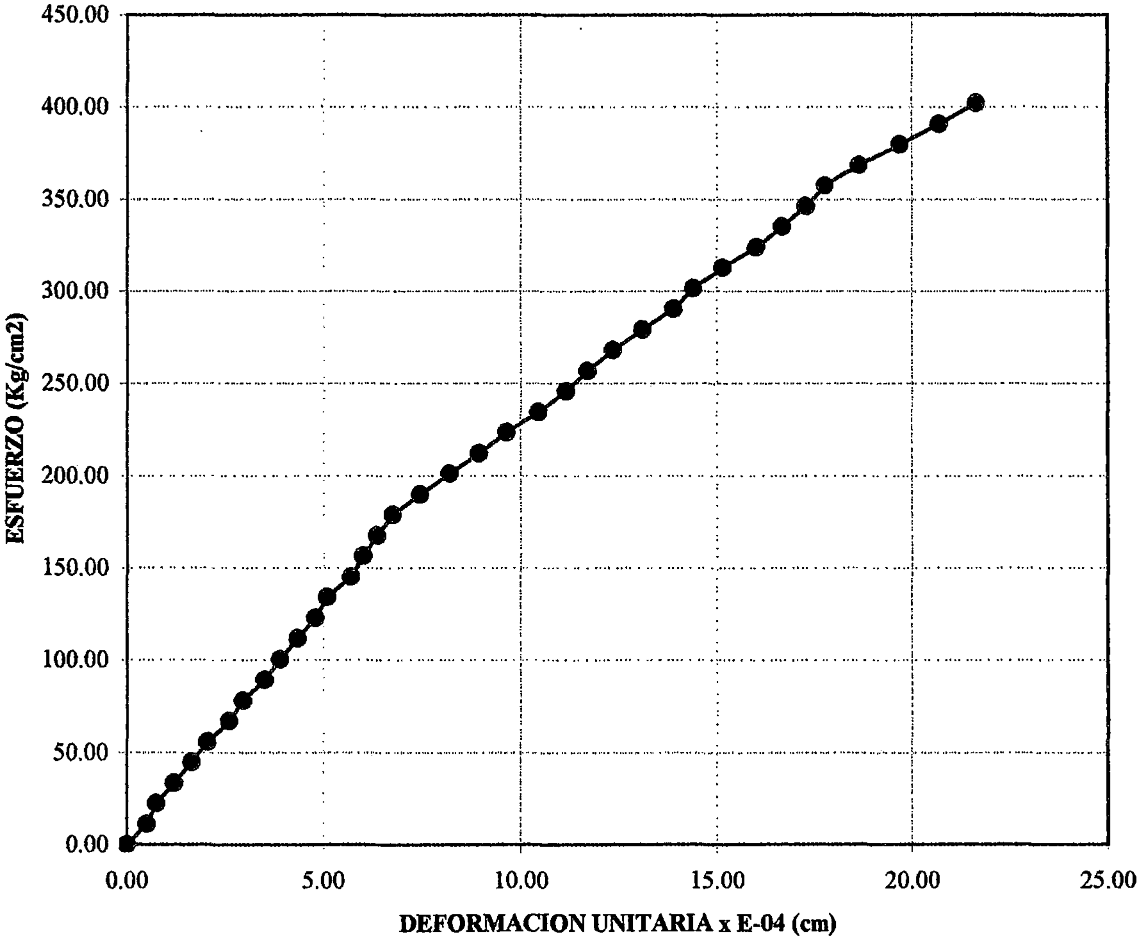
MODULO ELASTICO ESTATICO RELACION a/c=0.40
DOSIFICACION DE LA FIBRA 40 Kg/m3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**

Esfuerzo	Def.Unit
0.00	0.00
11.17	0.50
22.34	0.75
33.50	1.20
44.67	1.65
55.84	2.05
67.01	2.60
78.18	2.95
89.35	3.50
100.51	3.90
111.68	4.35
122.85	4.80
134.02	5.10
145.19	5.70
156.36	6.00
167.52	6.35
178.69	6.75
189.86	7.45
201.03	8.20
212.20	8.95
223.37	9.65
234.53	10.45
245.70	11.15
256.87	11.70
268.04	12.35
279.21	13.10
290.37	13.90
301.54	14.40
312.71	15.15
323.88	16.00
335.05	16.65
346.22	17.25
357.38	17.75
368.55	18.65
379.72	19.70
390.89	20.70
402.06	21.65

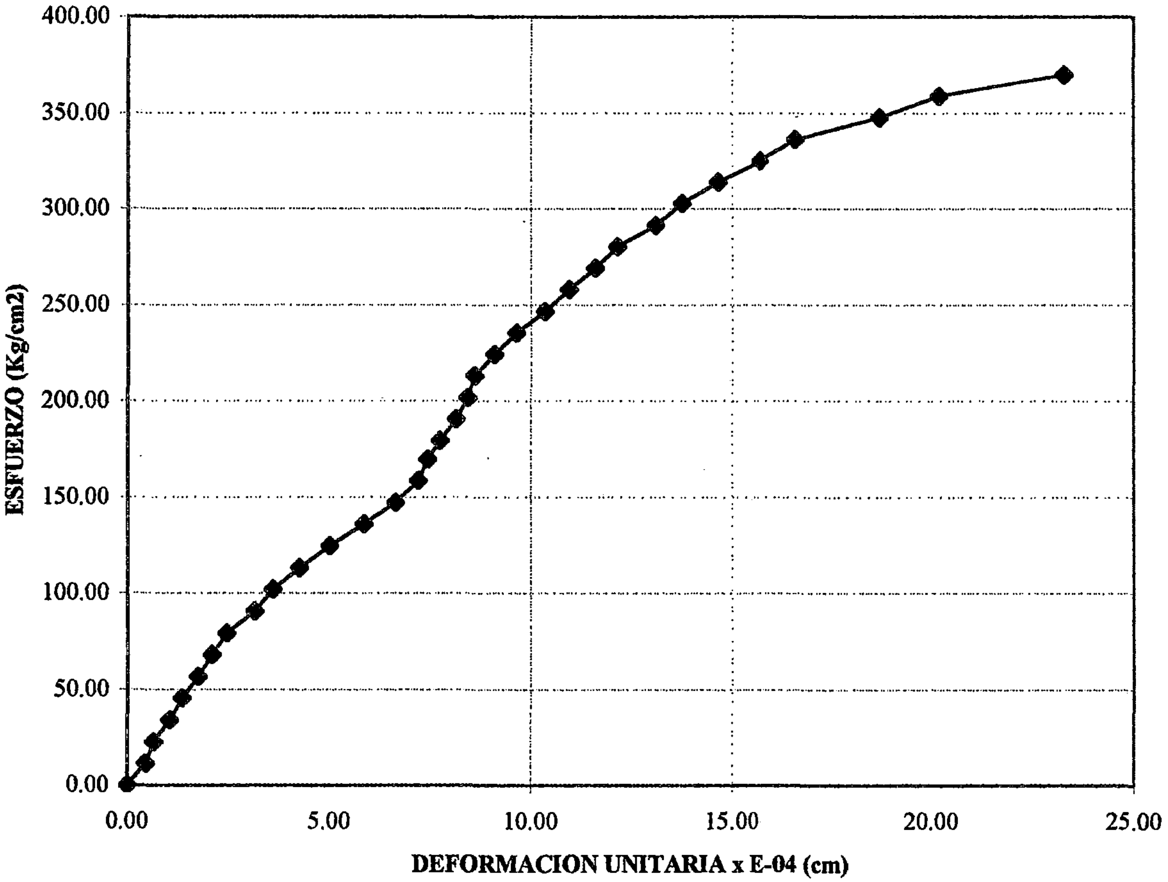
MODULO ELASTICO ESTATICO RELACION a/c=0.40
DOSIFICACION DE LA FIBRA 50 Kg/m3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**

Esfuerzo	Def.Unit
0.00	0.00
11.32	0.45
22.64	0.65
33.95	1.05
45.27	1.35
56.59	1.75
67.91	2.10
79.22	2.45
90.54	3.15
101.86	3.60
113.18	4.25
124.49	5.00
135.81	5.85
147.13	6.65
158.45	7.20
169.76	7.45
179.37	7.75
190.58	8.15
201.79	8.45
213.00	8.60
224.22	9.10
235.43	9.65
246.64	10.35
257.85	10.95
269.06	11.60
280.27	12.15
291.48	13.10
302.69	13.75
313.90	14.65
325.11	15.70
336.32	16.60
347.53	18.70
358.74	20.20
369.96	23.30

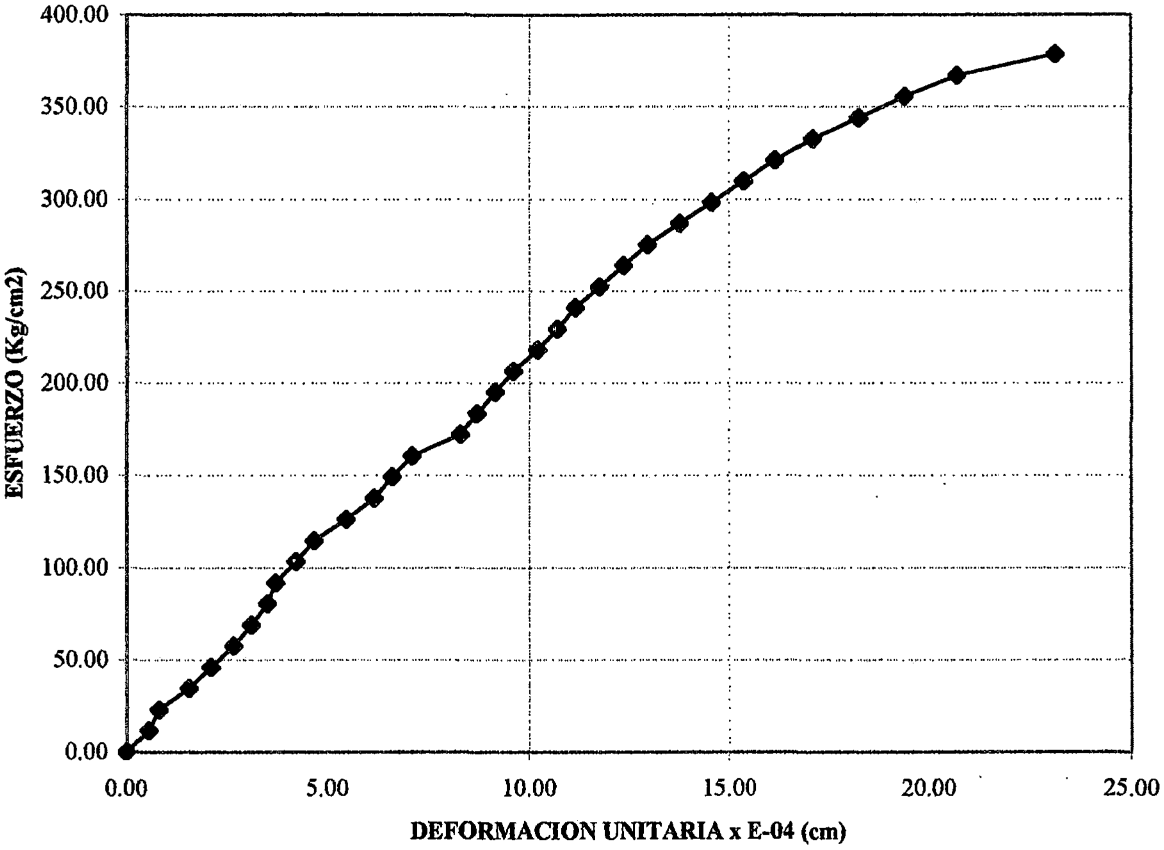
MODULO ELASTICO ESTATICO RELACION a/c= 0.50
DOSIFICACION DE LA FIBRA 30 Kg/m3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**

Esfuerzo	Def.Unit
0.00	0.00
11.47	0.55
22.94	0.80
34.41	1.55
45.88	2.10
57.35	2.65
68.82	3.10
80.29	3.50
91.76	3.70
103.23	4.20
114.70	4.65
126.17	5.45
137.64	6.15
149.11	6.60
160.58	7.10
172.05	8.30
183.52	8.70
194.99	9.15
206.46	9.60
217.93	10.20
229.40	10.70
240.87	11.15
252.34	11.75
263.81	12.35
275.28	12.95
286.75	13.75
298.22	14.55
309.69	15.35
321.16	16.15
332.63	17.10
344.10	18.25
355.57	19.40
367.04	20.70
378.51	23.15

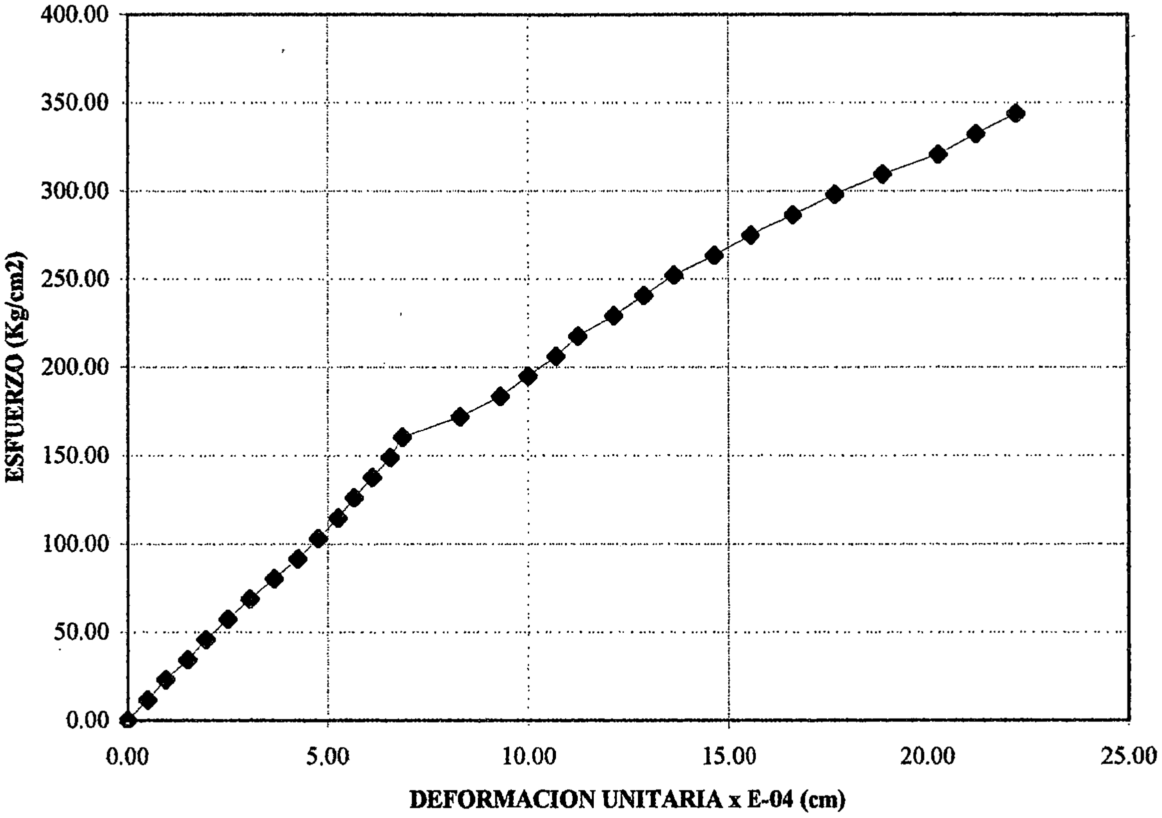
MODULO ELASTICO ESTATICO RELACION a/c=0.50
DOSIFICACION DE LA FIBRA 40 Kg/m3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**

Esfuerzo	Def.Unit
0.00	0.00
11.45	0.50
22.91	0.95
34.36	1.50
45.82	1.95
57.27	2.50
68.73	3.05
80.18	3.65
91.64	4.25
103.09	4.75
114.55	5.25
126.00	5.65
137.46	6.10
148.91	6.55
160.37	6.85
171.82	8.30
183.28	9.30
194.73	10.00
206.18	10.70
217.64	11.25
229.09	12.15
240.55	12.90
252.00	13.65
263.46	14.65
274.91	15.55
286.37	16.65
297.82	17.70
309.28	18.90
320.73	20.30
332.19	21.25
343.64	22.25

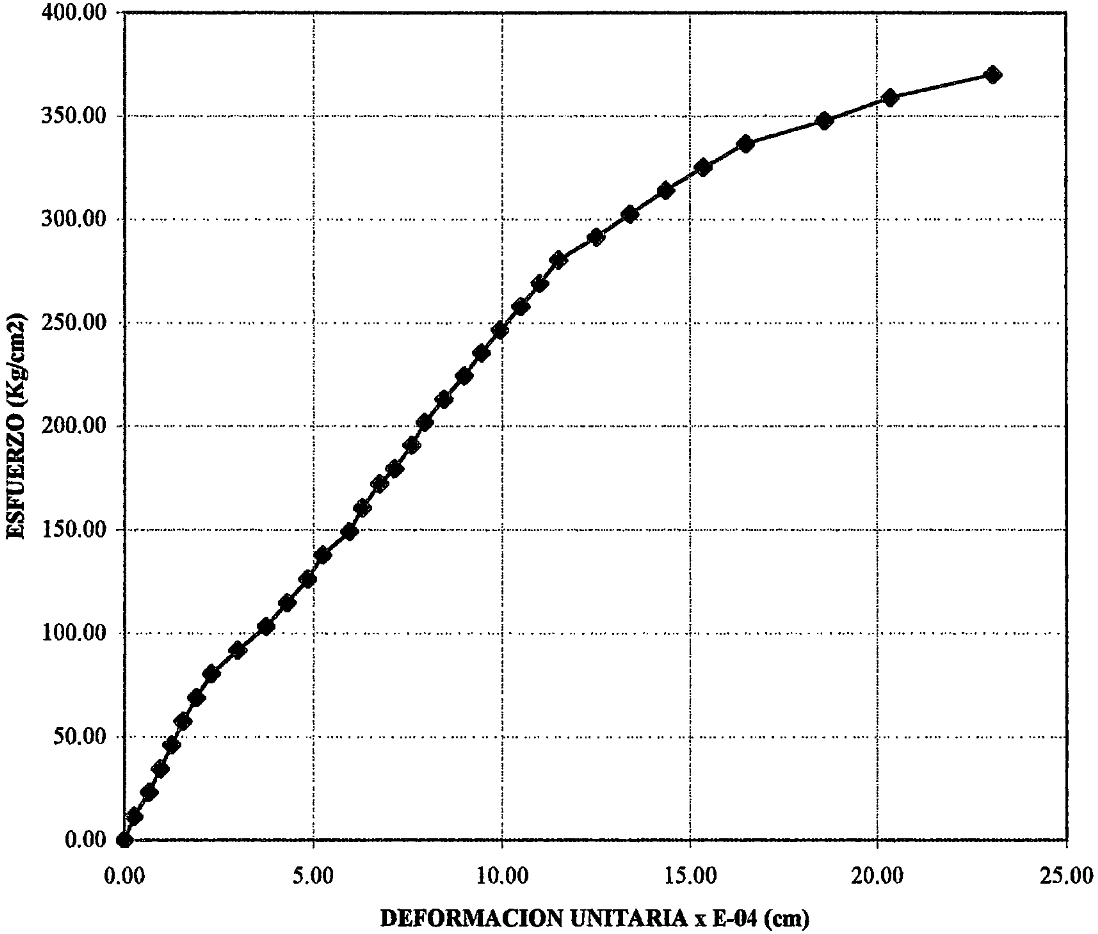
MODULO ELASTICO ESTATICO RELACION a/c=0.50
DOSIFICACION DE LA FIBRA 50 Kg/m3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**

Esfuerzo	Def.Unit
0.00	0.00
11.47	0.25
22.94	0.65
34.41	0.95
45.88	1.25
57.35	1.55
68.82	1.90
80.29	2.30
91.76	3.00
103.23	3.75
114.70	4.30
126.17	4.85
137.64	5.25
149.11	5.95
160.58	6.30
172.05	6.75
179.37	7.15
190.58	7.60
201.79	7.95
213.00	8.45
224.22	9.00
235.43	9.45
246.64	9.95
257.85	10.50
269.06	11.00
280.27	11.50
291.48	12.50
302.69	13.40
313.90	14.35
325.11	15.35
336.32	16.50
347.53	18.60
358.74	20.35
369.96	23.10

MODULO ELASTICO ESTATICO RELACION a/c= 0.45
DOSIFICACION DE LA FIBRA 30 Kg/m3 DE CONCRETO

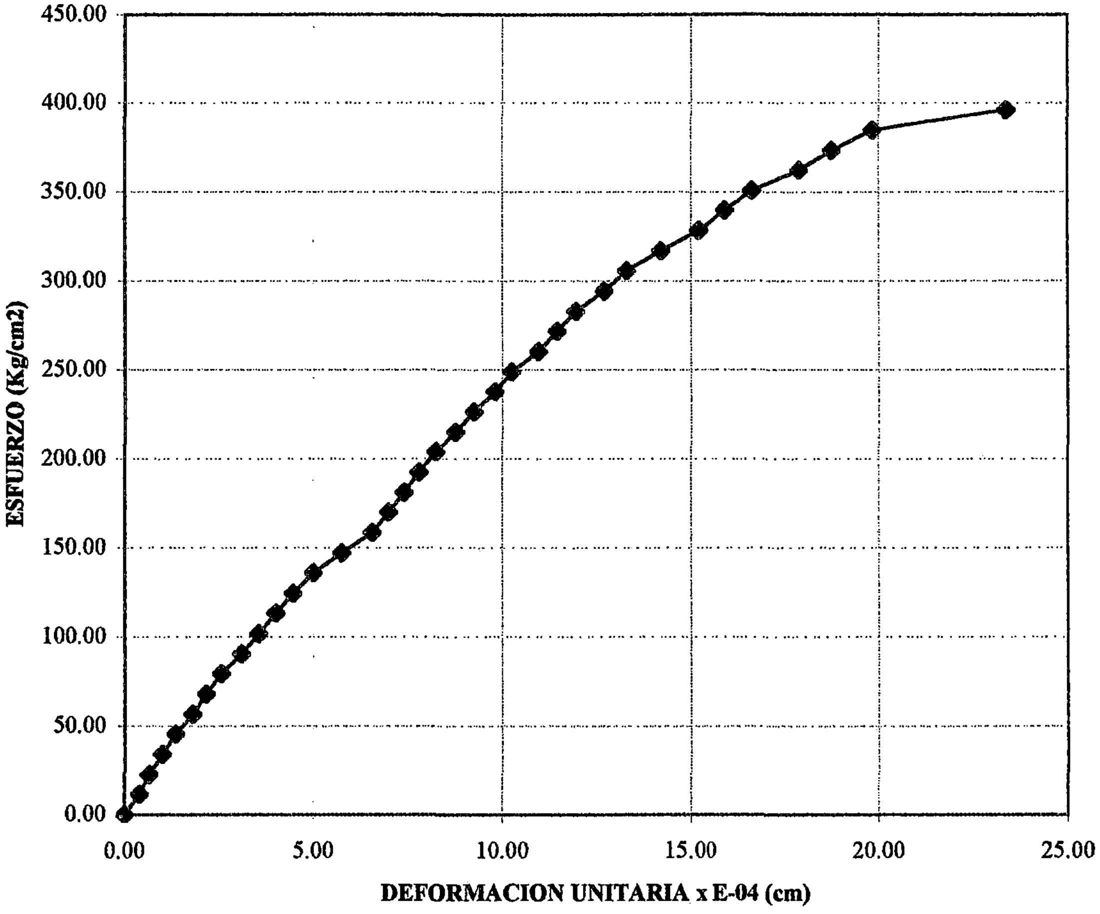


FIBRA : **INSONEX**
LONGITUD **40 mm**

Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia, con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

Esfuerzo	Def.Unit
0.00	0.00
11.32	0.40
22.64	0.65
33.95	1.00
45.27	1.35
56.59	1.80
67.91	2.15
79.22	2.55
90.54	3.10
101.86	3.55
113.18	4.00
124.49	4.45
135.81	5.00
147.13	5.75
158.45	6.55
169.76	7.00
181.08	7.40
192.40	7.80
203.72	8.25
215.04	8.75
226.35	9.25
237.67	9.80
248.99	10.25
260.31	10.95
271.62	11.45
282.94	11.95
294.26	12.70
305.58	13.30
316.89	14.20
328.21	15.20
339.53	15.90
350.85	16.65
362.17	17.90
373.48	18.75
384.80	19.85
396.12	23.40

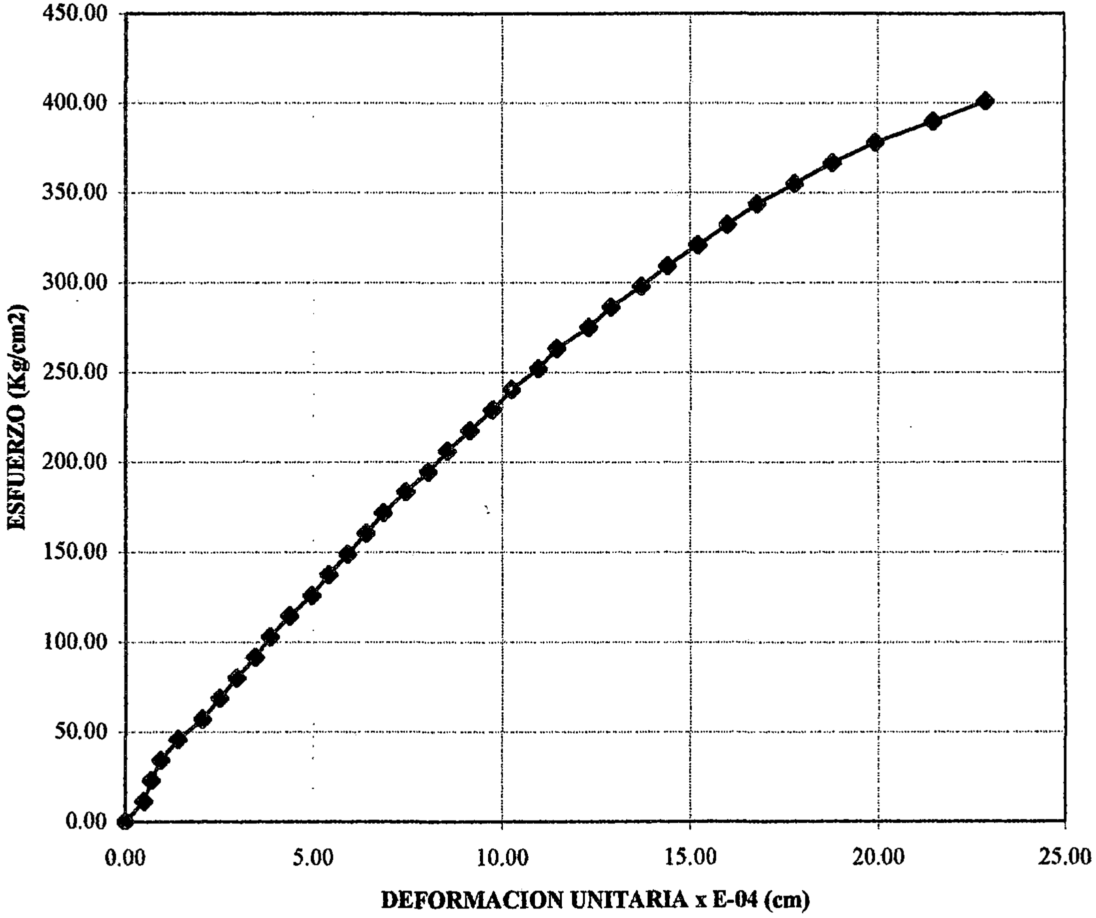
MODULO ELASTICO ESTATICO RELACION a/c=0.45
DOSIFICACION DE LA FIBRA 40 Kg/m3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD **40 mm**

Esfuerzo	Def.Unit
0.00	0.00
11.45	0.50
22.91	0.70
34.36	0.95
45.82	1.40
57.27	2.05
68.73	2.50
80.18	2.95
91.64	3.45
103.09	3.85
114.55	4.35
126.00	4.95
137.46	5.40
148.91	5.90
160.37	6.40
171.82	6.85
183.28	7.45
194.73	8.05
206.18	8.55
217.64	9.15
229.09	9.75
240.55	10.25
252.00	10.95
263.46	11.45
274.91	12.30
286.37	12.90
297.82	13.70
309.28	14.40
320.73	15.20
332.19	16.00
343.64	16.80
355.10	17.80
366.55	18.80
378.01	19.95
389.46	21.50
400.91	22.90

MODULO ELASTICO ESTATICO RELACION a/c=0.45
DOSIFICACION DE LA FIBRA 50 Kg/m3 DE CONCRETO



FIBRA : INSONEX
LONGITUD 40 mm

Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia, con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

7.2.2.4 ENSAYO DE RESISTENCIA A LA FLEXIÓN (kg/cm^2)

- RELACIÓN AGUA/CEMENTO 0.40

  - DOSIFICACIÓN 30 kg/m^3 DE CONCRETO

Nº DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	3160	15.00	15.10	60.00	55.44	47.62
28	2520	15.20	15.40	60.00	41.94	
28	2680	15.10	15.30	60.00	45.49	

  - DOSIFICACIÓN 40 kg/m^3 DE CONCRETO

Nº DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2830	15.10	15.10	60.00	49.32	48.69
28	2800	15.20	15.10	60.00	48.47	
28	2770	15.10	15.10	60.00	48.27	

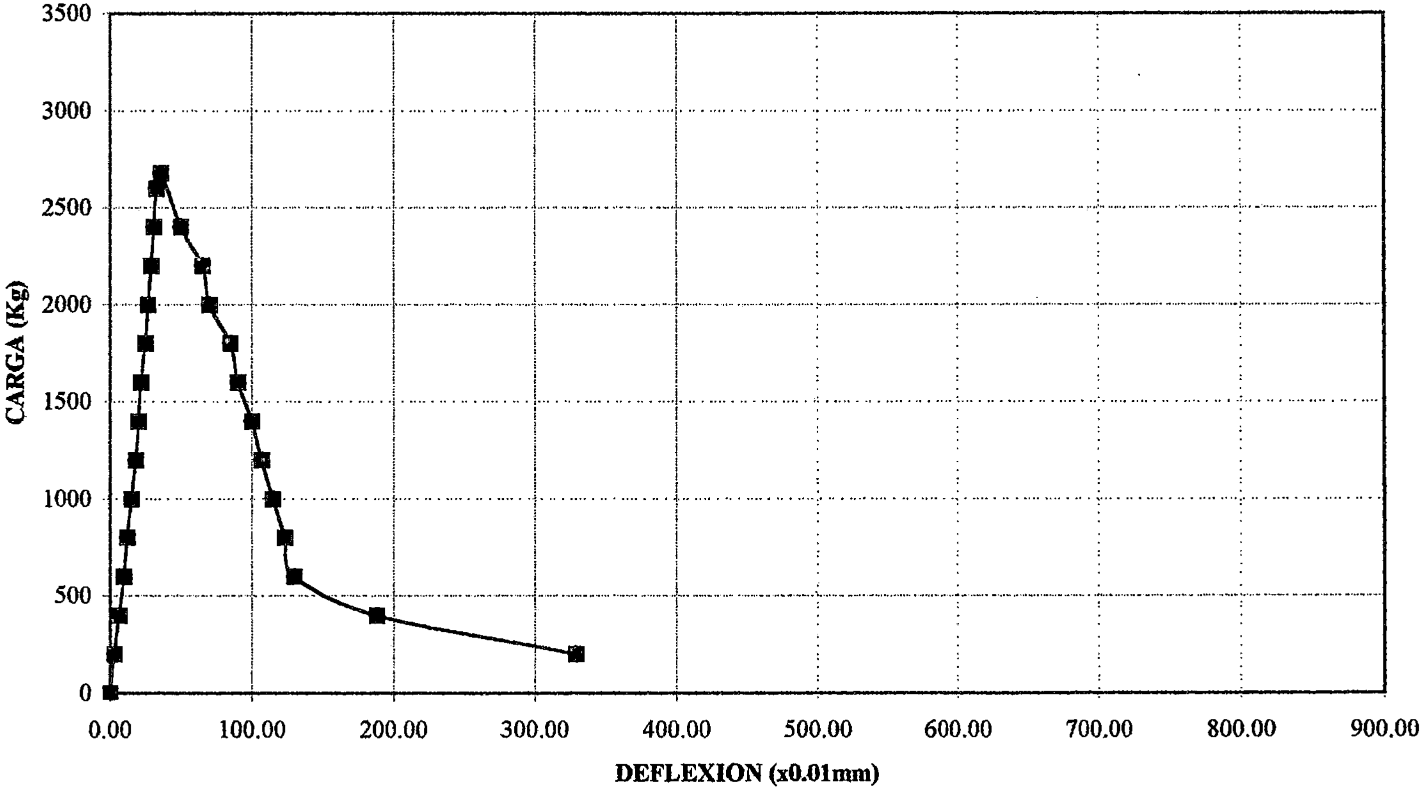
  - DOSIFICACIÓN 50 kg/m^3 DE CONCRETO

Nº DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2900	15.20	15.30	60.00	48.90	50.61
28	2940	15.20	15.00	60.00	51.58	
28	2985	15.10	15.20	60.00	51.34	

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	3.00
400	6.50
600	10.00
800	12.00
1000	15.00
1200	18.00
1400	20.00
1600	22.00
1800	25.00
2000	27.00
2200	29.00
2400	31.00
2600	33.00
2680	36.00
2400	50.00
2200	65.00
2000	70.00
1800	85.00
1600	90.00
1400	100.00
1200	107.00
1000	115.00
800	123.00
600	130.00
400	188.00
200	329.00

FLUENCIA	2680

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.40
DOSIFICACIÓN DE FIBRA = 30 Kg/m^3 DE CONCRETO

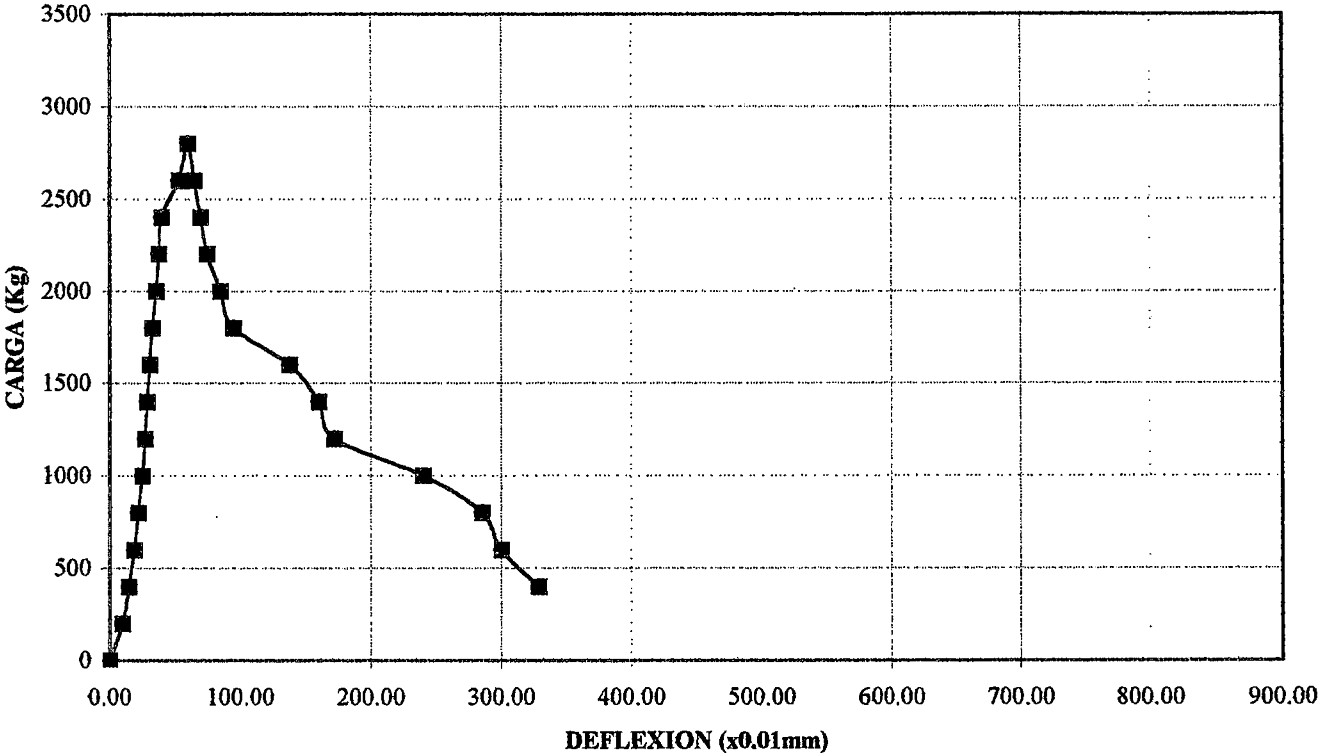


FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	10.00
400	15.00
600	19.00
800	22.00
1000	25.00
1200	27.00
1400	29.00
1600	31.00
1800	33.00
2000	36.00
2200	38.00
2400	40.00
2600	53.00
2800	60.00
2600	65.00
2400	70.00
2200	75.00
2000	85.00
1800	95.00
1600	138.00
1400	160.00
1200	172.00
1000	240.00
800	285.00
600	300.00
400	329.00

FLUENCIA	2800

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.40
DOSIFICACIÓN DE FIBRA = 40 Kg/m^3 DE CONCRETO



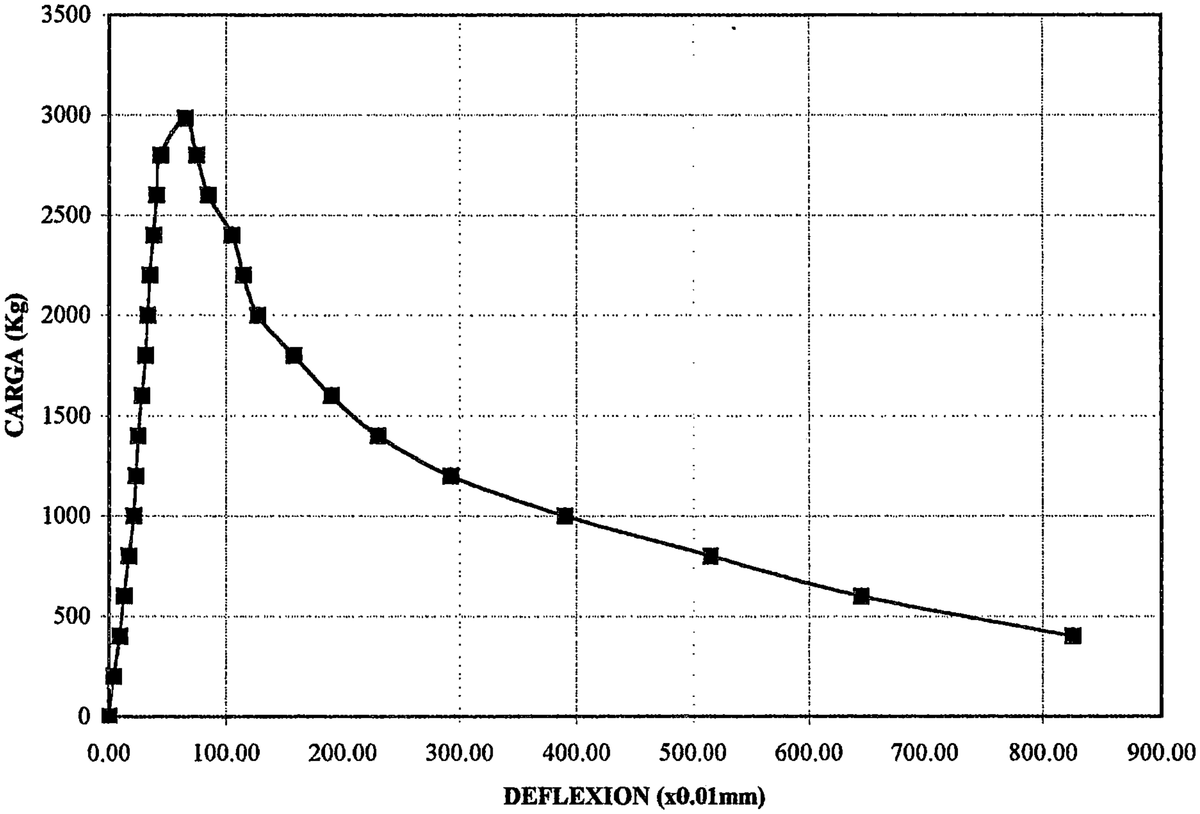
FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia, con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	4.00
400	9.00
600	13.00
800	17.00
1000	21.00
1200	23.00
1400	25.00
1600	28.00
1800	31.00
2000	33.00
2200	35.00
2400	38.00
2600	41.00
2800	44.00
2985	65.00
2800	75.00
2600	85.00
2400	105.00
2200	115.00
2000	127.00
1800	158.00
1600	190.00
1400	230.00
1200	292.00
1000	390.00
800	515.00
600	645.00
400	825.00

FLUENCIA	**2985**

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.40
DOSIFICACIÓN DE FIBRA = 50 Kg/m^3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

- RELACIÓN AGUA/CEMENTO 0.45

➢ DOSIFICACIÓN 30 kg/m^3 DE CONCRETO

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2520	15.10	15.10	60.00	43.92	44.15
28	2490	15.10	15.10	60.00	43.39	
28	2540	15.00	15.00	60.00	45.16	

➢ DOSIFICACIÓN 40 kg/m^3 DE CONCRETO

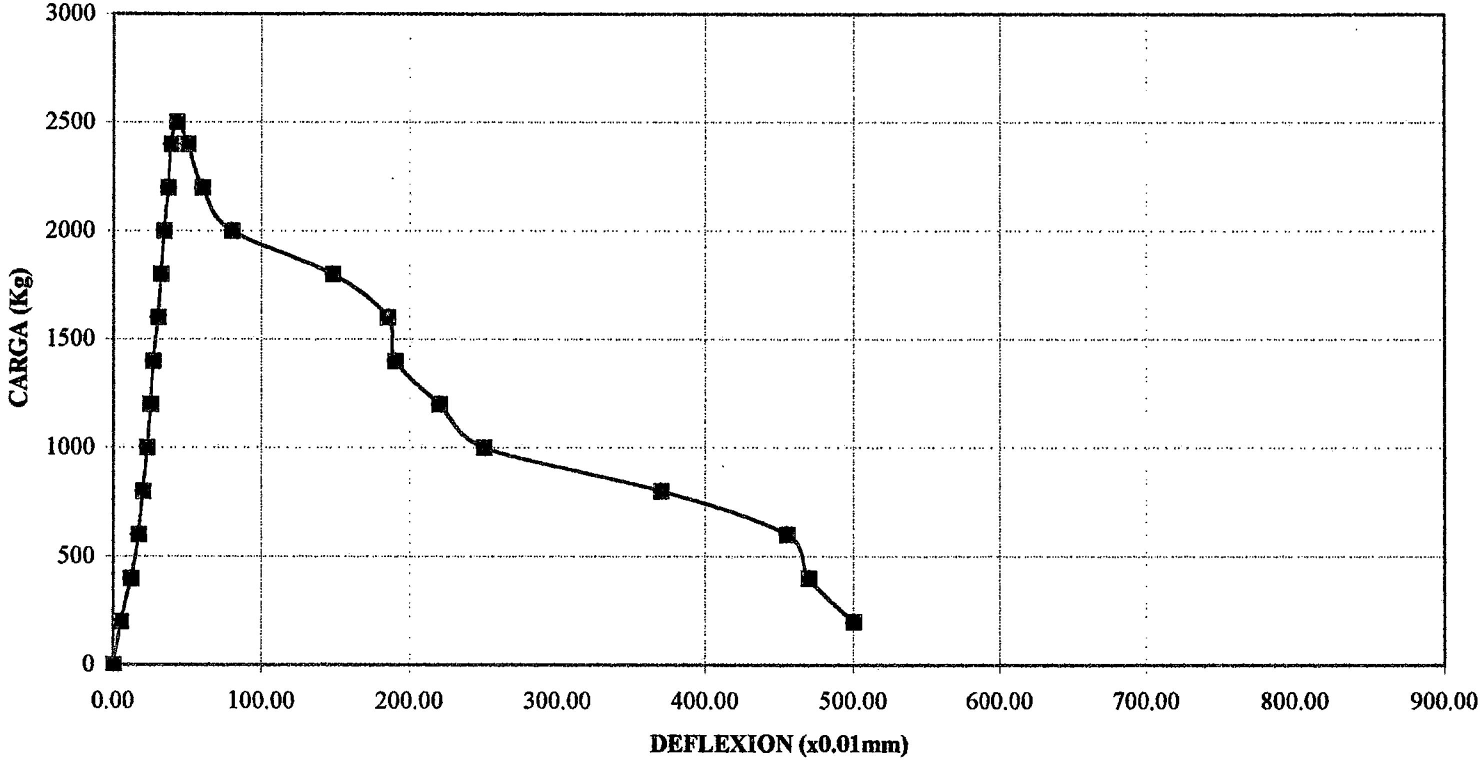
N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2520	15.00	15.20	60.00	43.63	47.13
28	2800	15.20	15.00	60.00	49.12	
28	2810	15.00	15.20	60.00	48.65	

➢ DOSIFICACIÓN 50 kg/m^3 DE CONCRETO

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2760	15.00	15.00	60.00	49.07	48.26
28	2650	15.00	15.00	60.00	47.11	
28	2770	15.00	15.10	60.00	48.59	

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	5.00
400	12.00
600	17.00
800	20.00
1000	23.00
1200	25.00
1400	27.00
1600	30.00
1800	32.00
2000	34.00
2200	37.00
2400	39.00
2500	43.00
2400	50.00
2200	60.00
2000	80.00
1800	148.00
1600	185.00
1400	190.00
1200	220.00
1000	250.00
800	370.00
600	455.00
400	470.00
200	500.00

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.45
DOSIFICACIÓN DE FIBRA = 30 Kg/m^3 DE CONCRETO



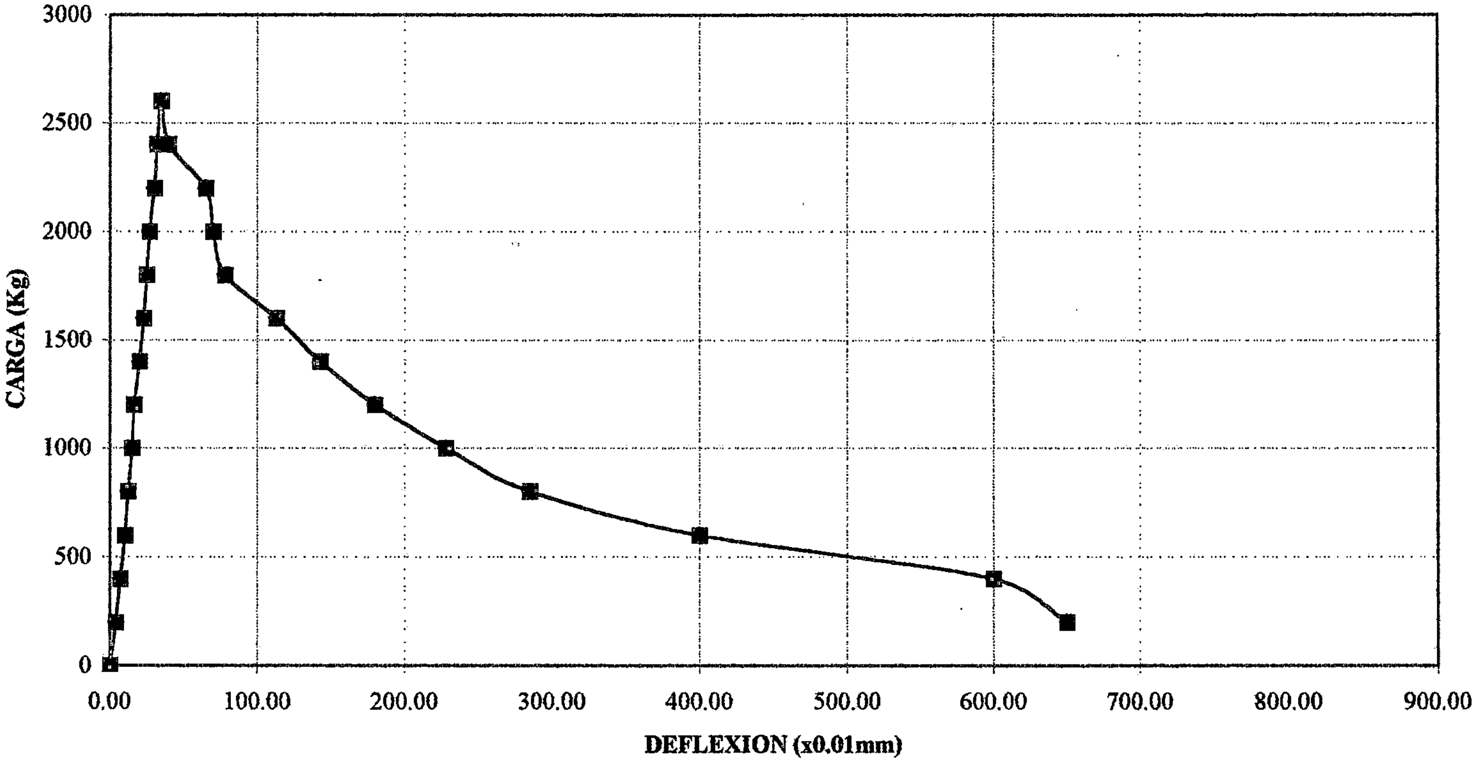
FLUENCIA	2500

FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	4.00
400	7.00
600	10.00
800	12.50
1000	15.00
1200	16.50
1400	20.00
1600	23.00
1800	25.00
2000	27.00
2200	30.00
2400	32.00
2600	35.00
2400	40.00
2200	65.00
2000	70.00
1800	78.00
1600	113.00
1400	143.00
1200	180.00
1000	228.00
800	285.00
600	400.00
400	600.00
200	650.00

FLUENCIA	**2600**

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.45
DOSIFICACIÓN DE FIBRA = 40 Kg/m^3 DE CONCRETO



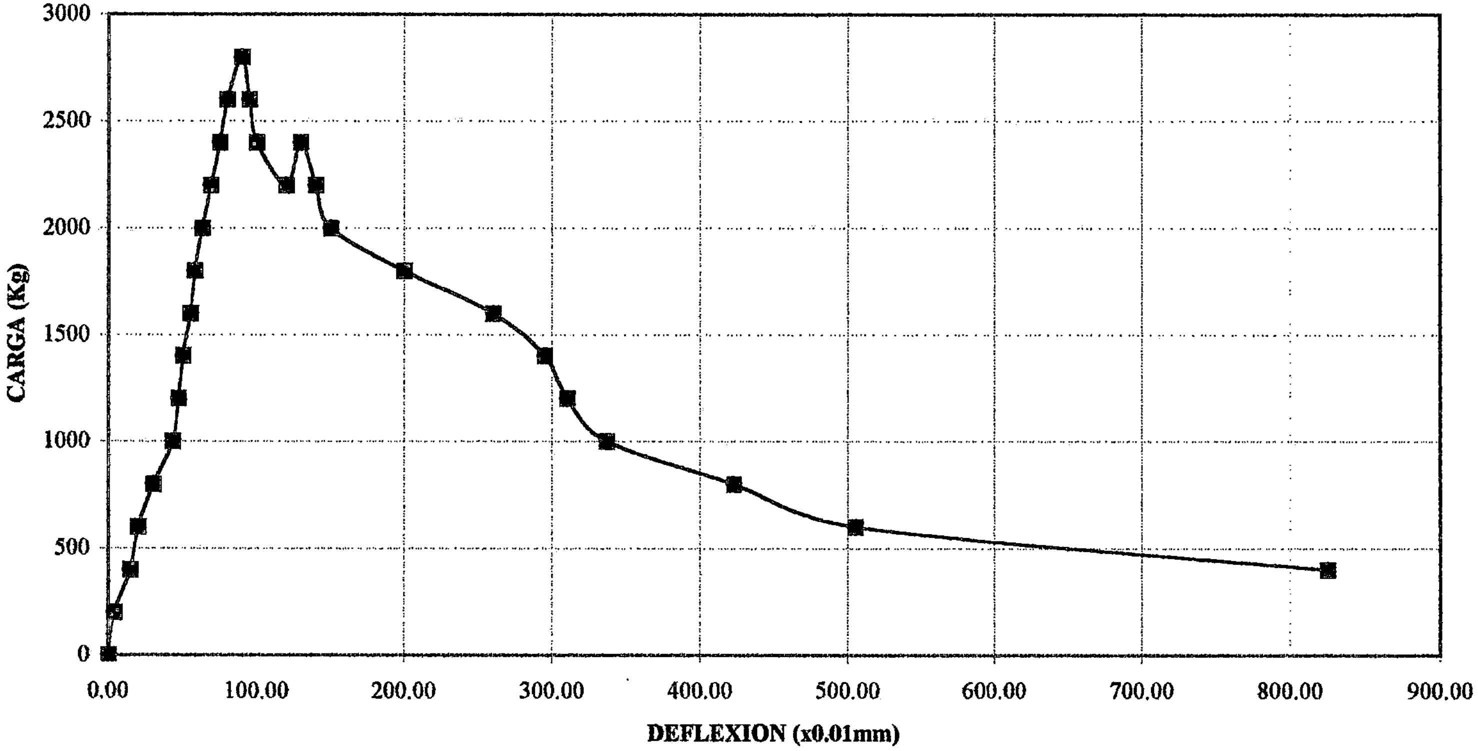
FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	4.00
400	15.00
600	20.00
800	30.00
1000	43.00
1200	47.00
1400	50.00
1600	55.00
1800	58.00
2000	63.00
2200	69.00
2400	75.00
2600	80.00
2800	90.00
2600	95.00
2400	100.00
2200	120.00
2400	130.00
2200	140.00
2000	150.00
1800	200.00
1600	260.00
1400	295.00
1200	310.00
1000	337.00
800	423.00
600	505.00
400	825.00

FLUENCIA	2800

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.45
DOSIFICACIÓN DE FIBRA = 50 Kg/m^3 DE CONCRETO



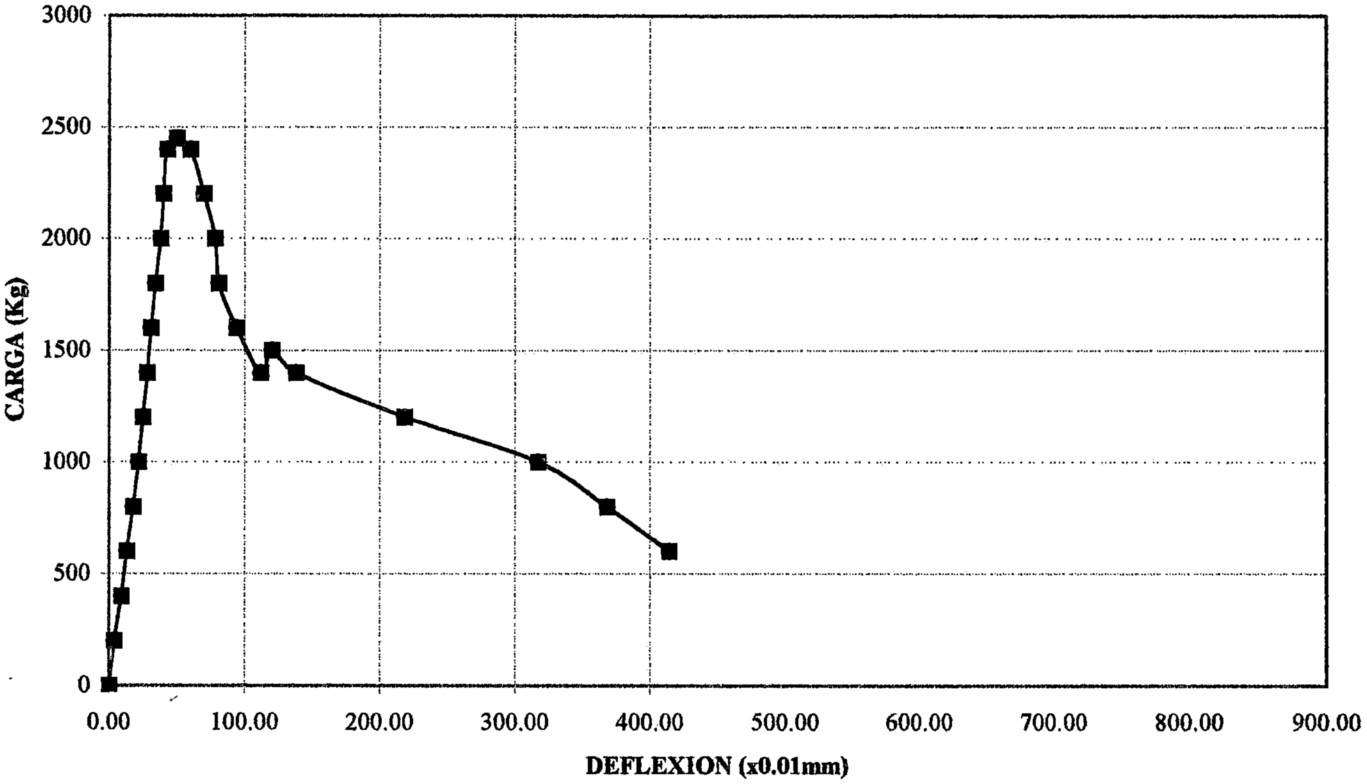
FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	4.00
400	9.00
600	13.00
800	18.00
1000	22.00
1200	25.00
1400	28.00
1600	31.00
1800	34.00
2000	38.00
2200	40.00
2400	43.00
2450	50.00
2400	60.00
2200	70.00
2000	78.00
1800	81.00
1600	94.00
1400	112.00
1500	120.00
1400	138.00
1200	218.00
1000	317.00
800	368.00
600	414.00

FLUENCIA	**2450**

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.50
DOSIFICACIÓN DE FIBRA = 30 Kg/m^3 DE CONCRETO

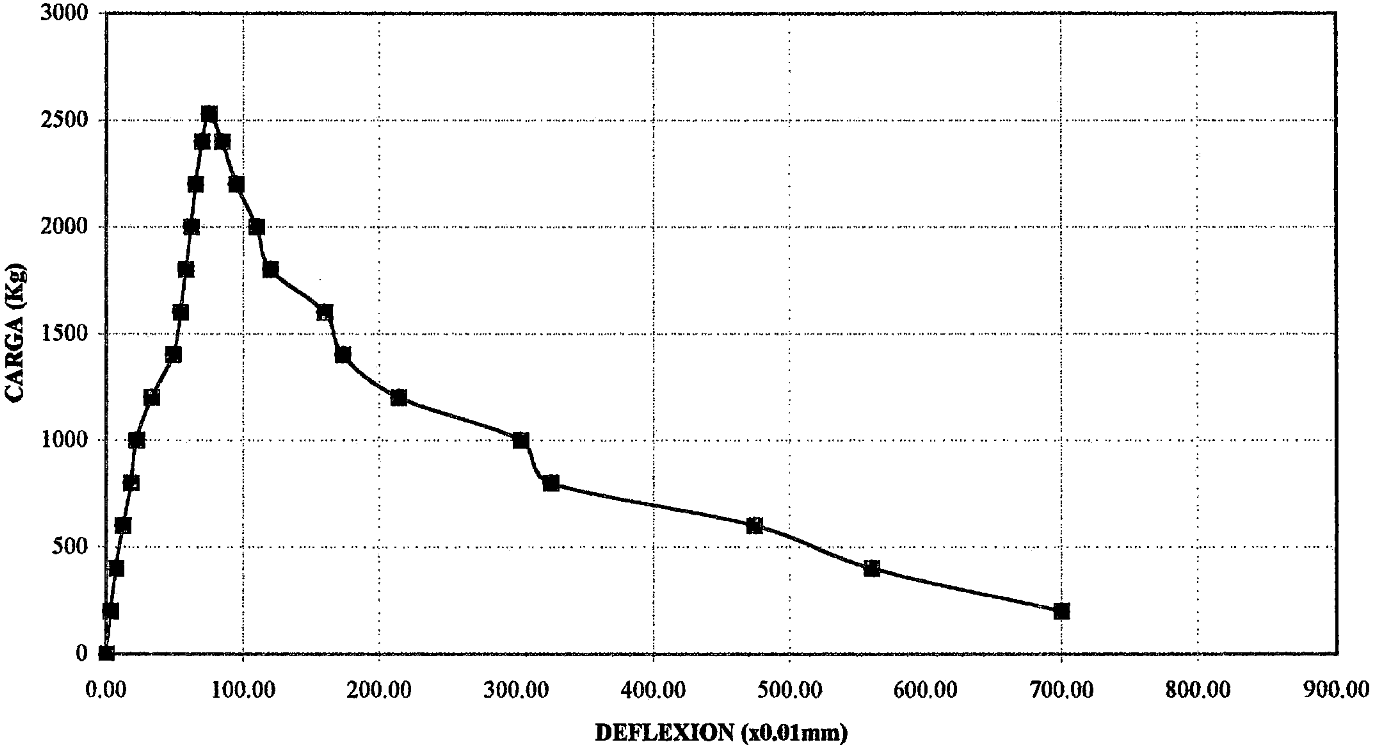


FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	3.00
400	7.00
600	12.00
800	18.00
1000	22.00
1200	33.00
1400	49.00
1600	54.00
1800	58.00
2000	62.00
2200	65.00
2400	70.00
2530	75.00
2400	85.00
2200	95.00
2000	110.00
1800	120.00
1600	160.00
1400	173.00
1200	214.00
1000	303.00
800	325.00
600	474.00
400	560.00
200	700.00

FLUENCIA	2530

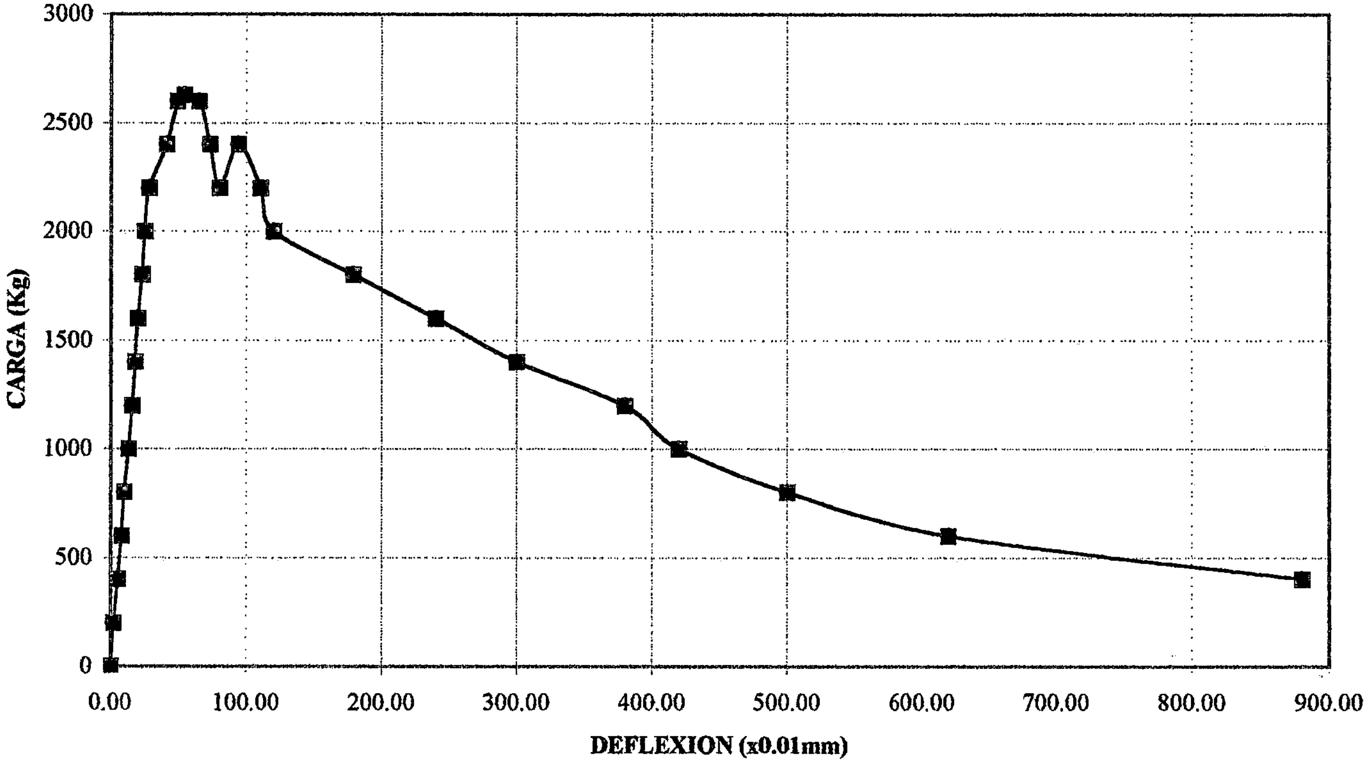
RESISTENCIA A LA FLEXION RELACIÓN a/c=0.50
DOSIFICACIÓN DE FIBRA = 40 Kg/m^3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

CARGA (Kg)	DEFLEXION (x0.01mm)
0	0.00
200	2.00
400	5.00
600	8.00
800	10.00
1000	13.00
1200	16.00
1400	18.00
1600	20.00
1800	23.00
2000	25.00
2200	28.00
2400	41.00
2600	49.00
2630	54.00
2600	65.00
2400	73.00
2200	80.00
2400	94.00
2200	110.00
2000	120.00
1800	179.00
1600	240.00
1400	300.00
1200	380.00
1000	420.00
800	500.00
600	620.00
400	880.00
FLUENCIA	**2630**

RESISTENCIA A LA FLEXION RELACIÓN a/c=0.50
DOSIFICACIÓN DE FIBRA = 50 Kg/m^3 DE CONCRETO



FIBRA : **INSONEX**
LONGITUD : **40 mm**
FORMA : **ONDULADA**

Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia, con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

- RELACIÓN AGUA/CEMENTO 0.50

➢ DOSIFICACIÓN 30 kg/m^3 DE CONCRETO

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2530	15.20	15.20	60.00	43.23	41.59
28	2410	15.30	15.40	60.00	39.85	
28	2440	15.20	15.20	60.00	41.69	

➢ DOSIFICACIÓN 40 kg/m^3 DE CONCRETO

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2530	15.30	15.20	60.00	42.94	44.35
28	2700	15.10	15.20	60.00	46.44	
28	2540	15.30	15.10	60.00	43.69	

➢ DOSIFICACIÓN 50 kg/m^3 DE CONCRETO

N° DIAS	CARGA (Kg)	BASE (cm)	ALTURA (cm)	LUZ (cm)	MODULO (Kg/cm^2)	PROMEDIO (Kg/cm^2)
28	2780	15.10	15.10	60.00	48.45	47.32
28	2630	15.10	15.20	60.00	45.23	
28	2770	15.10	15.10	60.00	48.27	

7.2.2.5 ENSAYO DE RESISTENCIA AL IMPACTO (N° golpes)

- RELACIÓN AGUA/CEMENTO 0.40

➤ DOSIFICACIÓN 30 kg/m^3 DE CONCRETO

N° DIAS	ALTURA(cm)		DIAMETRO (cm)		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.64	6.63	14.95	14.99	127	132
28	6.68		15.01		130	
28	6.58		15.00		138	
42	6.52	6.57	15.20	15.00	133	139
42	6.70		14.95		135	
42	6.50		14.85		150	

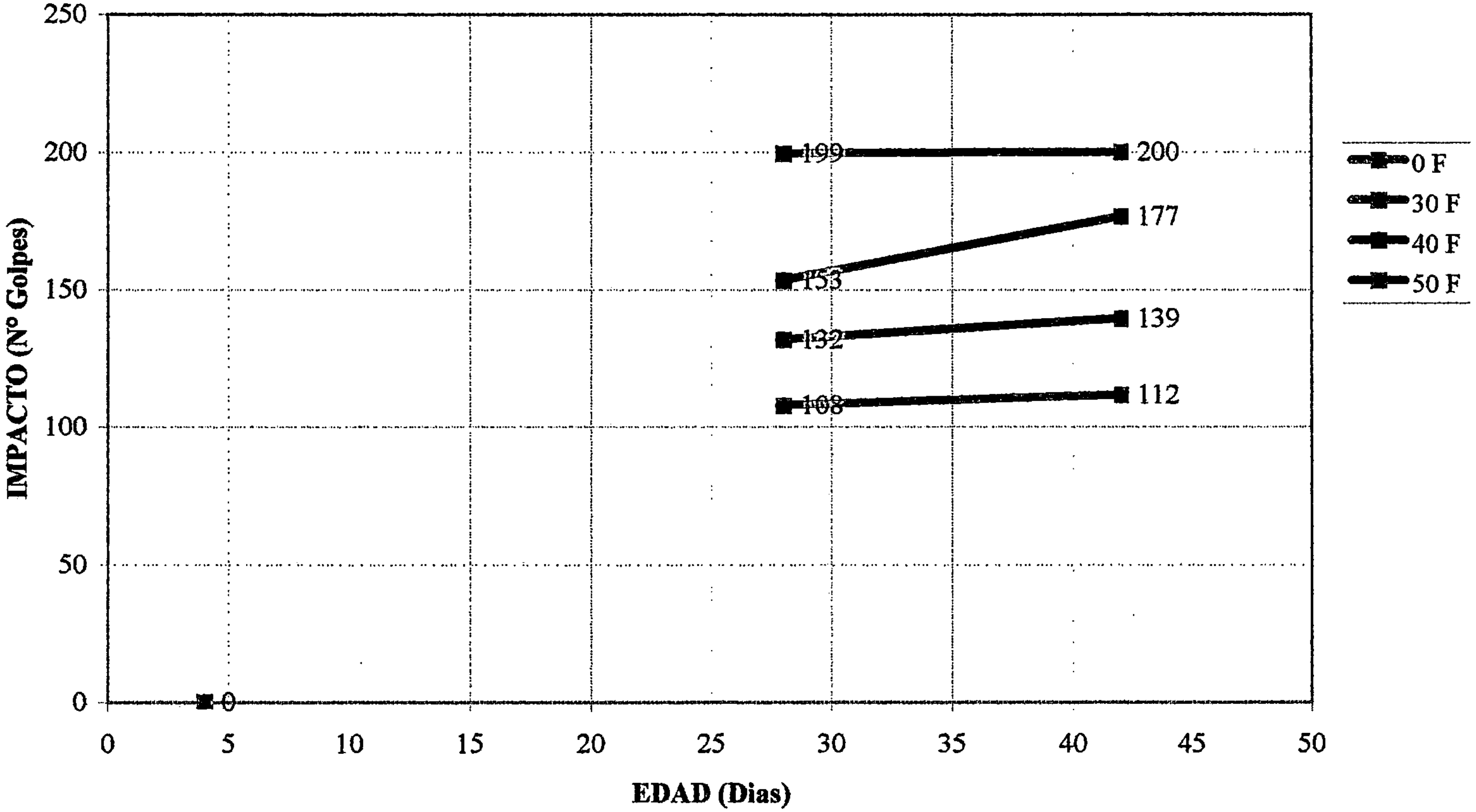
➤ DOSIFICACIÓN 40 kg/m^3 DE CONCRETO

N° DIAS	ALTURA(cm)		DIAMETRO (cm)		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.63	6.66	14.96	14.93	180	153
28	6.65		14.92		130	
28	6.70		14.92		150	
42	7.00	6.90	14.90	14.88	200	177
42	7.00		14.80		150	
42	6.70		14.95		180	

➤ DOSIFICACIÓN 50 kg/m^3 DE CONCRETO

N° DIAS	ALTURA(cm)		DIAMETRO (cm)		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.65	6.65	14.94	14.93	148	199
28	6.70		14.85		200	
28	6.60		15.00		250	
42	6.80	6.87	14.90	14.93	150	200
42	6.80		14.90		250	
42	7.00		15.00		200	

CUADRO COMPARATIVO PARA a/c=0.40
CON DIFERENTES DOSIFICACIONES DE FIBRA



FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

- RELACIÓN AGUA/CEMENTO 0.45

➢ DOSIFICACIÓN 30 kg/m^3 DE CONCRETO

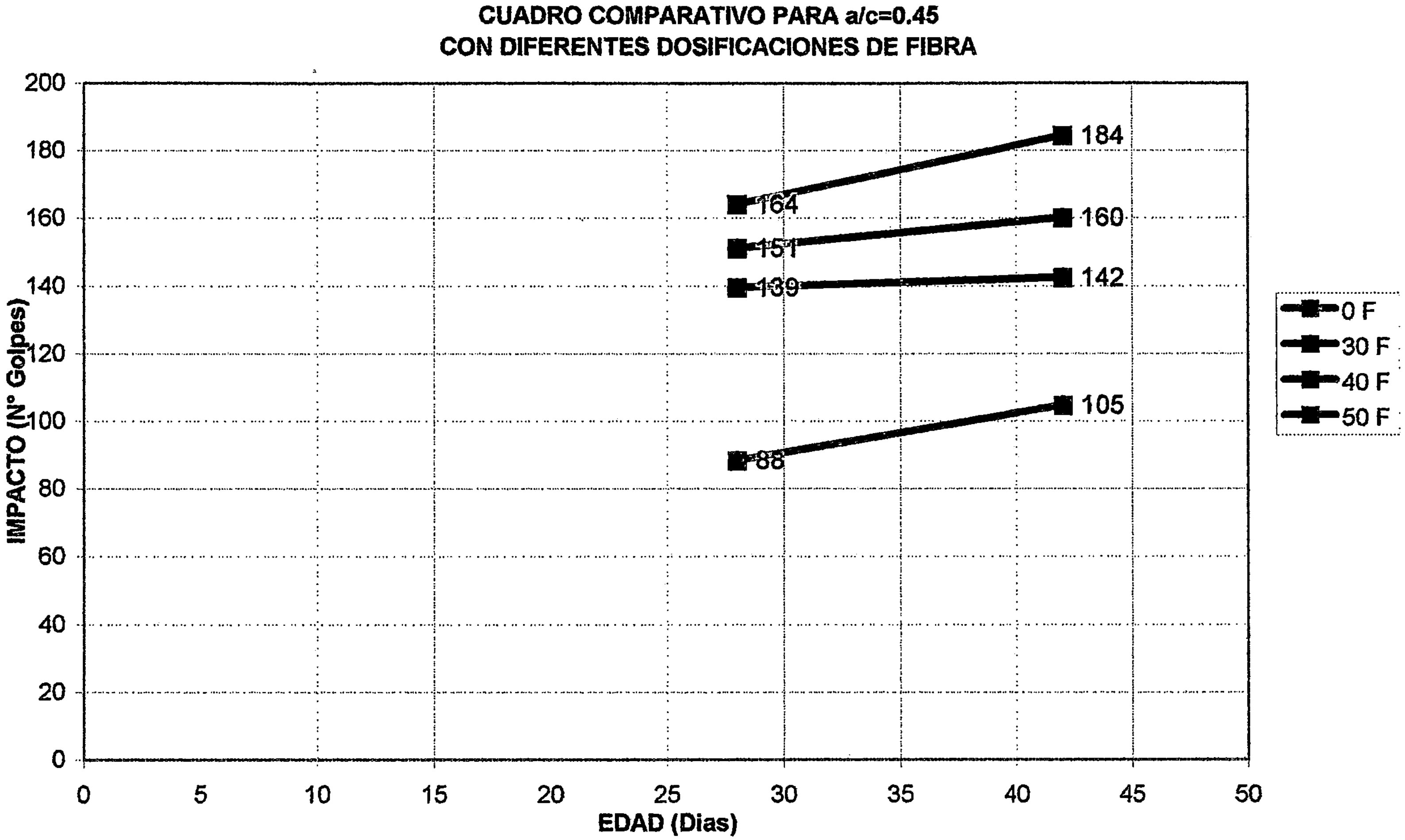
N° DIAS	ALTURA (cm)		DIAMETRO (cm)		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.68	6.80	14.93	14.89	197	139
28	6.88		14.75		113	
28	6.83		15.00		108	
42	6.60	6.63	15.10	14.97	120	142
42	6.70		15.00		160	
42	6.60		14.80		147	

➢ DOSIFICACIÓN 40 kg/m^3 DE CONCRETO

N° DIAS	ALTURA (cm)		DIAMETRO (cm)		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.60	6.73	15.04	15.06	156	151
28	7.10		15.15		200	
28	6.50		14.98		97	
42	6.90	6.67	15.10	15.10	200	160
42	6.80		15.10		150	
42	6.30		15.10		130	

➢ DOSIFICACIÓN 50 kg/m^3 DE CONCRETO

N° DIAS	ALTURA (cm)		DIAMETRO (cm)		N° GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.80	7.05	14.98	14.99	134	164
28	7.42		15.00		200	
28	6.94		15.00		158	
42	6.30	6.57	15.00	15.00	173	184
42	7.10		15.00		250	
42	6.30		15.00		130	



FIBRA : INSONEX
LONGITUD : 40 mm
FORMA : ONDULADA

- **RELACIÓN AGUA/CEMENTO 0.50**

➢ DOSIFICACIÓN 30 kg/m^3 DE CONCRETO

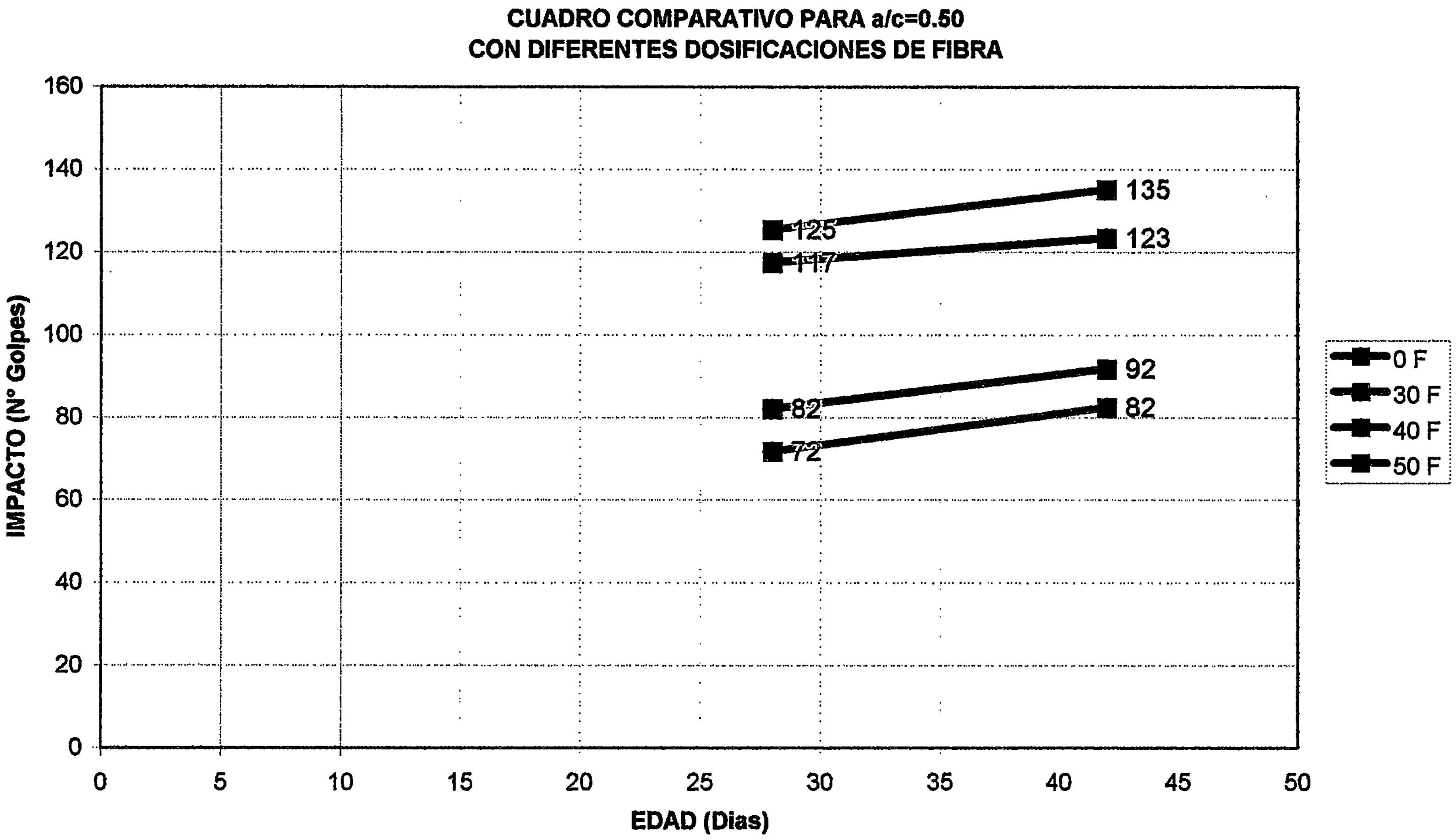
Nº DIAS	ALTURA (cm)		DIAMETRO (cm)		Nº GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.44	6.46	14.94	14.95	67	82
28	6.44		14.86		93	
28	6.50		15.05		86	
42	6.40	6.43	15.00	15.03	100	92
42	6.50		15.10		85	
42	6.40		15.00		90	

➢ DOSIFICACIÓN 40 kg/m^3 DE CONCRETO

Nº DIAS	ALTURA (cm)		DIAMETRO (cm)		Nº GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.33	6.35	14.85	14.93	116	117
28	6.40		15.04		96	
28	6.31		14.90		140	
42	6.50	6.57	15.00	14.97	150	123
42	6.60		15.00		100	
42	6.60		14.90		120	

➢ DOSIFICACIÓN 50 kg/m^3 DE CONCRETO

Nº DIAS	ALTURA (cm)		DIAMETRO (cm)		Nº GOLPES	
	H	PROM	D	PROM	G	PROM
28	6.50	6.55	15.04	15.08	116	125
28	6.73		15.10		160	
28	6.42		15.10		100	
42	6.70	6.53	15.00	14.97	160	135
42	6.50		15.00		155	
42	6.40		14.90		90	



FIBRA	**INSONEX**
LONGITU	**40 mm**
FORMA	**ONDULADA**

CAPITULO 08

ANALISIS DE LOS RESUTADOS OBTENIDOS

8.1 GENERALIDADES

En el presente capitulo analizaremos los resultados obtenidos en el LABORATORIO DE ENSAYO DE MATERIALES DE LA UNI (LEM-UNI), del tema de tesis titulado ¨ ESTUDIO DEL COMPORTAMIENTO DEL CONCRETO DE MEDIANA A ALTA RESISTENCIA, CON LA INCORPORACION DE FIBRAS DE ACERO Y CPTI ANDINO ¨

Para el análisis de los agregados haremos las comparaciones analíticas de todos los elementos participantes para la elaboración del concreto con los cuadros normalizados que nos proporciona la ASTM y la NTP.

Los análisis realizados tanto al agregado FINO como GRUESO son los siguientes :

- PESO UNITARIO SUELTO.
- PESO UNITARIO COMPACTADO.
- PESO ESPECIFICO DE MASA.
- PESPECIFICO DE MASA SATURADO SUPERFICIALMENTE SECO.
- PESO ESPECIFICO APARENTE.
- PORCENTAJE DE ABSORCIÓN.
- CONTENIDO DE HUMEDAD.
- SUPERFICIE ESPECIFICA.
- MODULO DE FINURA.

Con la particularidad que para el agregado GRUESO (PIEDRA), se le realizo también los ensayos de :

- TAMAÑO MÁXIMO.
- TAMAÑO NOMINAL MÁXIMO.

Y para el agregado FINO (ARENA) se realizo también el ensayo de :

- MATERIAL QUE PASA LA MALLA # 200.

Cabe mencionar también que para el concreto se realizaron los ensayos en su dos estados (FRESCO Y ENDURECIDO) :

ESTADO FRESCO : Asentamiento, Fluidez, Peso Unitario Compactado, Tiempo de Fraguado, Contenido de Aire, Exudación.

ESTADO ENDURECIDO: Resistencia a la Compresión, Tracción por Compresión Diametral, Modulo Elástico Estático, Flexión , Impacto.

El análisis comparativo lo realizaremos entre el concreto patrón(sin fibras) para las relaciones de agua/cemento : 0.40, 0.45, 0.50 y un concreto con FIBRAS DE ACERO INSONEX para dosificaciones de: 30, 40, 50 Kg/m^3 de concreto respectivamente. Como podemos verificar, el presente capitulo es de suma importancia ya que los resultados obtenidos con los agregados y el concreto nos permita evaluar su comportamiento para finalmente emitir conclusiones y recomendaciones que lo plasmaremos en los capítulos siguientes.

8.2 EVALUACION DE LOS AGREGADOS.

Si cuantificamos la presencia de los agregados en el concreto, estos constituyen alrededor del 75% en volumen , de una mezcla típica de concreto. En consecuencia es importante que los agregados tengan buena Resistencia, Durabilidad, que su superficie este libre de impurezas como barro, limo y materiales orgánicos que pueden debilitar el enlace con la pasta del cemento.

8.3 EVALUACION DE AGREGADO FINO

El agregado fino utilizado para la presente tesis de investigación proviene de la cantera GLORIA(Km 14.8 CARRETERA CENTRAL). A continuación describimos los resultados, con respecto a la granulometría podemos decir, que la curva granulométrica que se genera con los resultados vemos que se encuentra dentro de los limites determinados por la ASTM C- 33. Además podemos notar que la curva se inclina mas al lado derecho, con tendencia hacia una arena gruesa. En consecuencia tendrá una buena adherencia y trabajabilidad en el concreto. Pero si este agregado fino tuviera una tendencia hacia el lado izquierdo traería como consecuencia segregaciones en el concreto debido a su poca adherencia.

Respecto al valor obtenido en los ensayos el modulo de finura tiene un valor de 3.0, el cual verificando con el rango recomendable (2.3 a 3.1), vemos que se encuentra dentro del rango, además podemos notar que el valor obtenido tiende hacia el máximo valor clasificándose como una arena relativamente gruesa. Este agregado es apropiado para concretos ricos y consolidados dando mayores resistencias mecánicas.

Los valores obtenidos del Contenido de Humedad y Porcentaje de Absorción son: 1.49% , 2.46% respectivamente. Es de suma importancia verificar constantemente estos resultados ya que influyen notablemente en el diseño del concreto, cabe indicar que nuestros ensayos lo llevamos acabo en una temporada de verano, como consecuencia de ello teníamos que controlar constantemente su absorción y su contenido de humedad.

Con respecto al Porcentaje de Finos que Pasan la Malla # 200, se obtuvo un valor igual a 4.73%, confirmando que se encuentra dentro del rango permisible (3% a 5%), valores mayores a 7% indicaría una disminución en su resistencia del concreto, debido a que afecta a la adherencia entre los agregados y la pasta.

8.4 EVALUACION DEL AGREGADO GRUESO

De igual manera que en el agregado fino, el agregado grueso tiene propiedades en que sus valores obtenidos influyen notablemente en su resistencia (calidad del concreto), a continuación analizamos los resultados.

Con respecto a su granulometría , podemos verificar que curva granulométrica que se genera con los resultados se encuentra dentro del huso seleccionado, este huso se ha determinado teniendo en cuenta su tamaño nominal, verificando la tabla podemos seleccionar (1¨ a N4) perteneciente a la ASTM N57. El tamaño máximo (TM) y tamaño nominal máximo es de 1¨, el tamaño máximo nos da una idea para poder clasificar el agregado en una obra determinada y el tamaño nominal máximo (TNM) es un parámetro vinculado al diseño de mezcla.

8.5 EVALUACION DEL AGREGADO GLOBAL.

Después de la combinación para diferentes proporciones, entre el agregado FINO y GRUESO, se busco aquella combinación que se obtenga el máximo peso unitario compactado, llegándose a obtener la proporción de agregado grueso (PIEDRA) 49% y agregado fino (ARENA) 51%. Cabe mencionar que la curva granulométrica del agregado global se encuentra dentro del HUSO DIN (1045), confirmando que su combinación es aceptable. Con respecto a su modulo de finura se obtuvo el valor de 5.03 confirmado su aceptación ya que se encuentra en el rango permisible.

8.6 FIBRA DE ACERO INSONEX

La fibra de ACERO INSONEX, es un producto nacional producida por la empresa INSOMIN dedicada a la investigación y desarrollo de productos para la ingeniería.

La dimensión de la fibra es de 40mm de longitud, su diámetro es de 0.8 mm ,su forma geométrica es ondulada y su longitud de onda es de 5mm. El concreto mezclado con FIBRAS INSONEX mejora notablemente sus propiedades físicas, elevando las resistencias a la tensión ,a la flexión ,al impacto.

Cuando se realiza el mezclado del concreto, el orden recomendable para una mejor distribución homogénea, es añadir la fibra después del agregado grueso y combinarlos ambos, seguidamente por el agregado fino y finalmente por el cemento, agua.

8.7 ANALISIS COMPARATIVO EN EL CONCRETO FRESCO.

8.7.1 ENSAYO DE ASENTAMIENTO (plg).

RELACION	**DOSIFICACION(Fibra Insonex Kg/m3)**			
a/c	0	30	40	50
0.40	5	4	3 3/4	3 1/2
0.45	5	3 3/4	3 1/2	3 1/4
0.50	5	3 3/4	3 1/2	3 1/4

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN.

RELACION	**DOSIFICACION(Fibra Insonex Kg/m3)**			
a/c	0	30	40	50
0.40	100.00	80.00	75.00	70.00
0.45	100.00	75.00	70.00	65.00
0.50	100.00	75.00	70.00	65.00

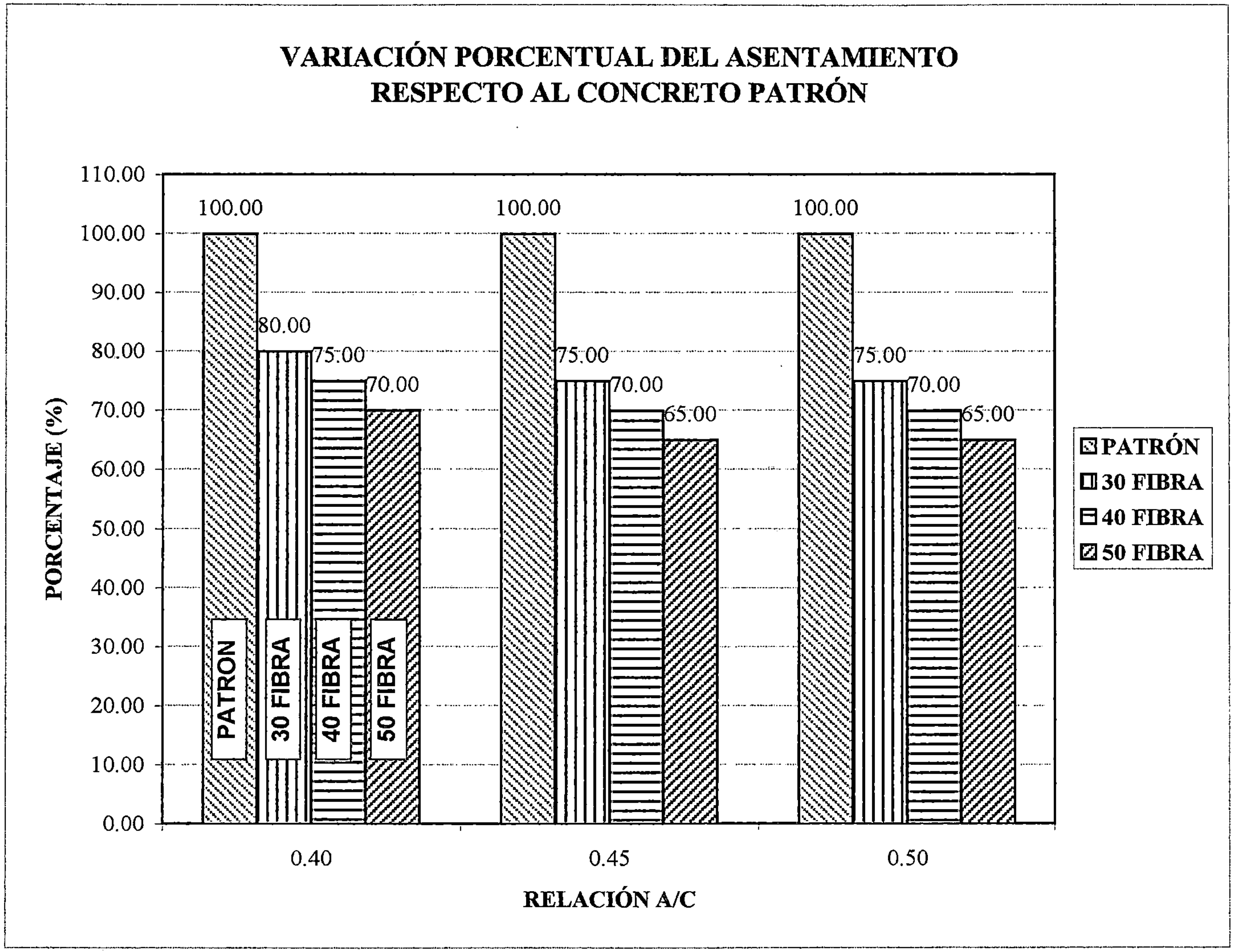
Del primer cuadro podemos observar, que en forma general el ASENTAMIENTO, disminuye cuando se mezcla con las diferentes dosificaciones de Fibra Insonex, alcanzando valores que se encuentran en el rango de 3plg a 4plg de asentamiento. Cabe mencionar que para el diseño patrón se trabajo para un ASENTAMIENTO (Slump) en el rango de 4 ½ a 5 ½

Con respecto a la variación porcentual entre el concreto a patrón y las diferentes dosificaciones de fibra podemos observar que:

En la relación de a/c = 0.40, disminuye en 20%, 25%, 30% cuando se le añade fibra de acero Insonex, para las dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

En la relación de a/c = 0.45, disminuye en 25%, 30%, 35% cuando se le añade fibra de acero Insonex, para dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

En la relación de a/c = 0.50, disminuye en 25%, 30%, 35% cuando se le añade fibra de acero Insonex, para dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.


VARIACIÓN PORCENTUAL DEL ASENTAMIENTO
RESPECTO AL CONCRETO PATRÓN
PORCENTAJE (%)
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
100.00
80.00
75.00
70.00
100.00
75.00
70.00
65.00
100.00
75.00
70.00
65.00
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

8.7.2 ENSAYO DE FLUIDEZ (%).

RELACION	DOSIFICACION(Fibra Insonex Kg/m3)			
a/c	0	30	40	50
0.40	112.60	107.68	104.40	90.94
0.45	109.97	105.71	103.74	100.46
0.50	101.77	100.13	96.85	94.23

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

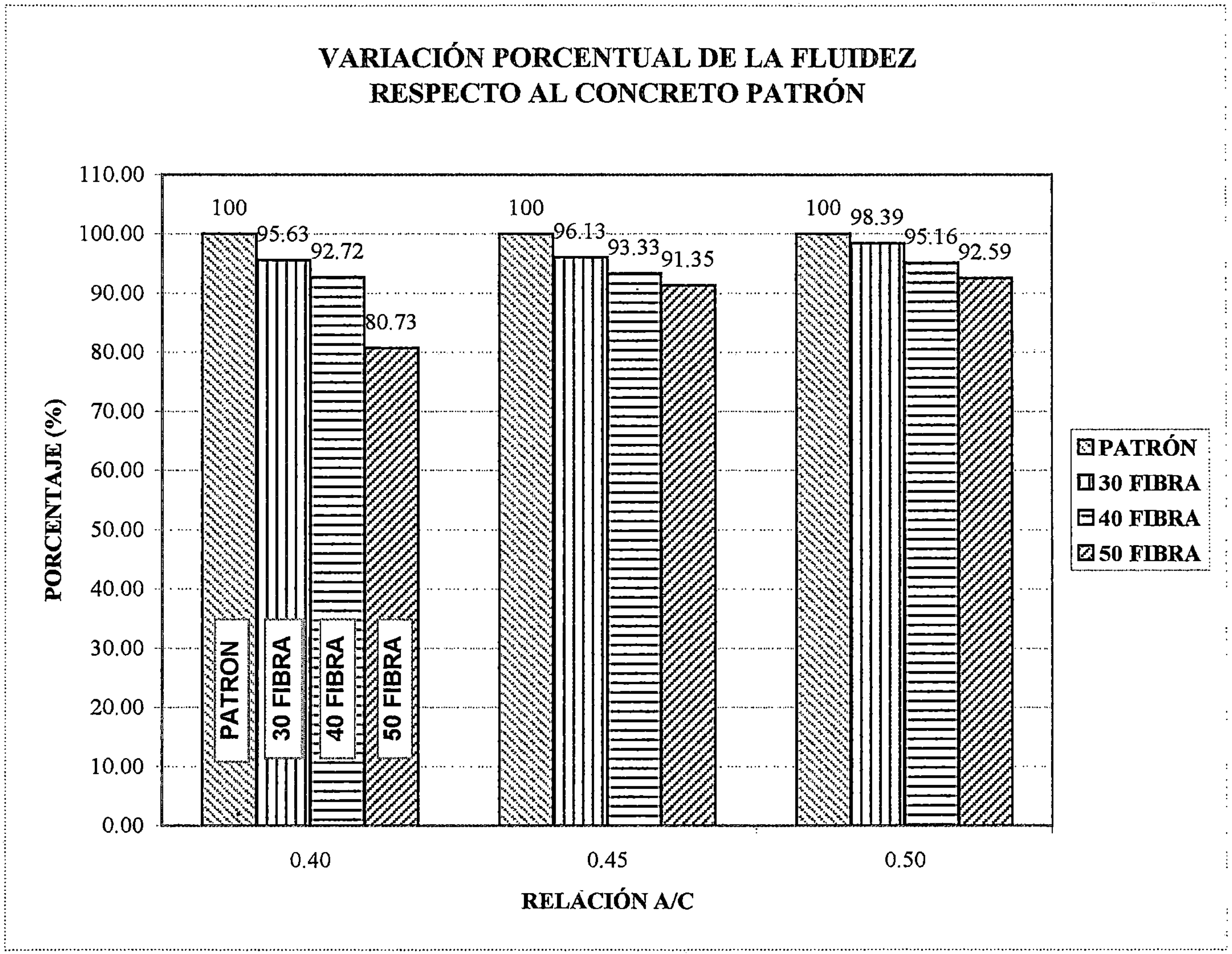
RELACION	DOSIFICACION(Fibra Insonex Kg/m3)			
a/c	0	30	40	50
0.40	100.00	95.63	92.72	80.73
0.45	100.00	96.13	93.33	91.35
0.50	100.00	98.39	95.16	92.59

Del primer cuadro podemos observar que la FLUIDEZ disminuye proporcionalmente respecto a la cantidad de fibra que se le añade al concreto y para el segundo cuadro podemos observar las variaciones respecto al concreto patrón.

Para la relación a/c = 0.40 Disminuye 4.37%, 7.28%, 19.23% cuando se le añade fibra de acero Insonex en dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivame

Para la relación a/c = 0.45 Disminuye 3.88%, 5.67 %, 8.65 % cuando se le añade fibra de acero Insonex en dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivame

Para la relación a/c = 0.50 Disminuye 1.61.%, 4.84%, 7.41% cuando se le añade fibra de acero Insonex en dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente


VARIACIÓN PORCENTUAL DE LA FLUIDEZ RESPECTO AL CONCRETO PATRÓN
PORCENTAJE (%)
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
100
95.63
92.72
80.73
100
96.13
93.33
91.35
100
98.39
95.16
92.59
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

8.7.3 ENSAYO DE PESO UNITARIO COMPACTADO(Kg/m3)

RELACION a/c	**DOSIFICACION(Fibra Insonex Kg/m3)**			
	0	30	40	50
0.40	2400.00	2407.14	2414.29	2421.43
0.45	2407.14	2421.43	2428.57	2435.71
0.50	2414.29	2442.86	2450.00	2457.14

- RELACION PORCENTUAL RESPECTO AL CONCRETO PATRÓN

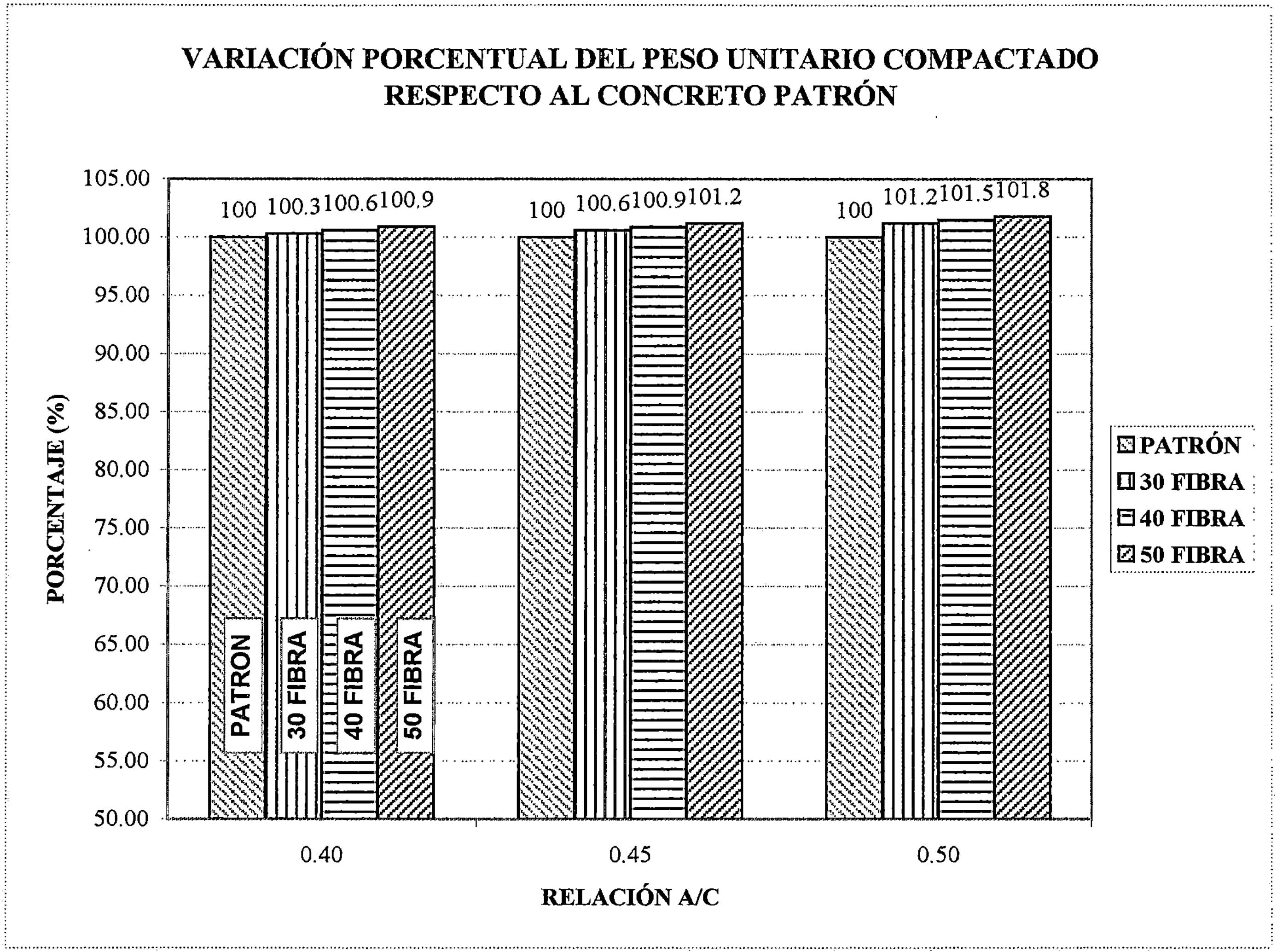
RELACION a/c	**DOSIFICACION(Fibra Insonex Kg/m3)**			
	0	30	40	50
0.40	100.00	100.30	100.60	100.89
0.45	100.00	100.59	100.89	101.19
0.50	100.00	101.18	101.48	101.78

Como podemos observar en forma general, para las diferentes dosificaciones de Fibra de Acero Insonex el peso unitario compactado se incrementa, a continuación describimos las variaciones.

Para la relación de a/c = 0.40, se Incrementa en: 0.3%, 0.6%, 0.89% respecto al concreto patrón, cuando se le añade Fibra de Acero Insonex para las dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación de a/c = 0.45, se Incrementa en: 0.59%, 0.89%, 1.19% respecto al concreto patrón, cuando se le añade Fibra de Acero Insonex para las dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación de a/c = 0.50, se Incrementa en: 1.18%, 1.48%, 1.78% respecto al concreto patrón, cuando se le añade Fibra de Acero Insonex para las dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.



VARIACIÓN PORCENTUAL DEL PESO UNITARIO COMPACTADO RESPECTO AL CONCRETO PATRÓN

8.7.4 ENSAYO DE TIEMPO DE FRAGUADO(hr : min)

☐ FRAGUADO INICIAL

RELACION	DOSIFICACION(Fibra Insonex Kg/m3)			
a/c	0	30	40	50
0.40	3:24	3:19	3:14	3:09
0.45	3:15	3:13	3:10	3:05
0.50	3:10	3:08	3:06	3:02

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

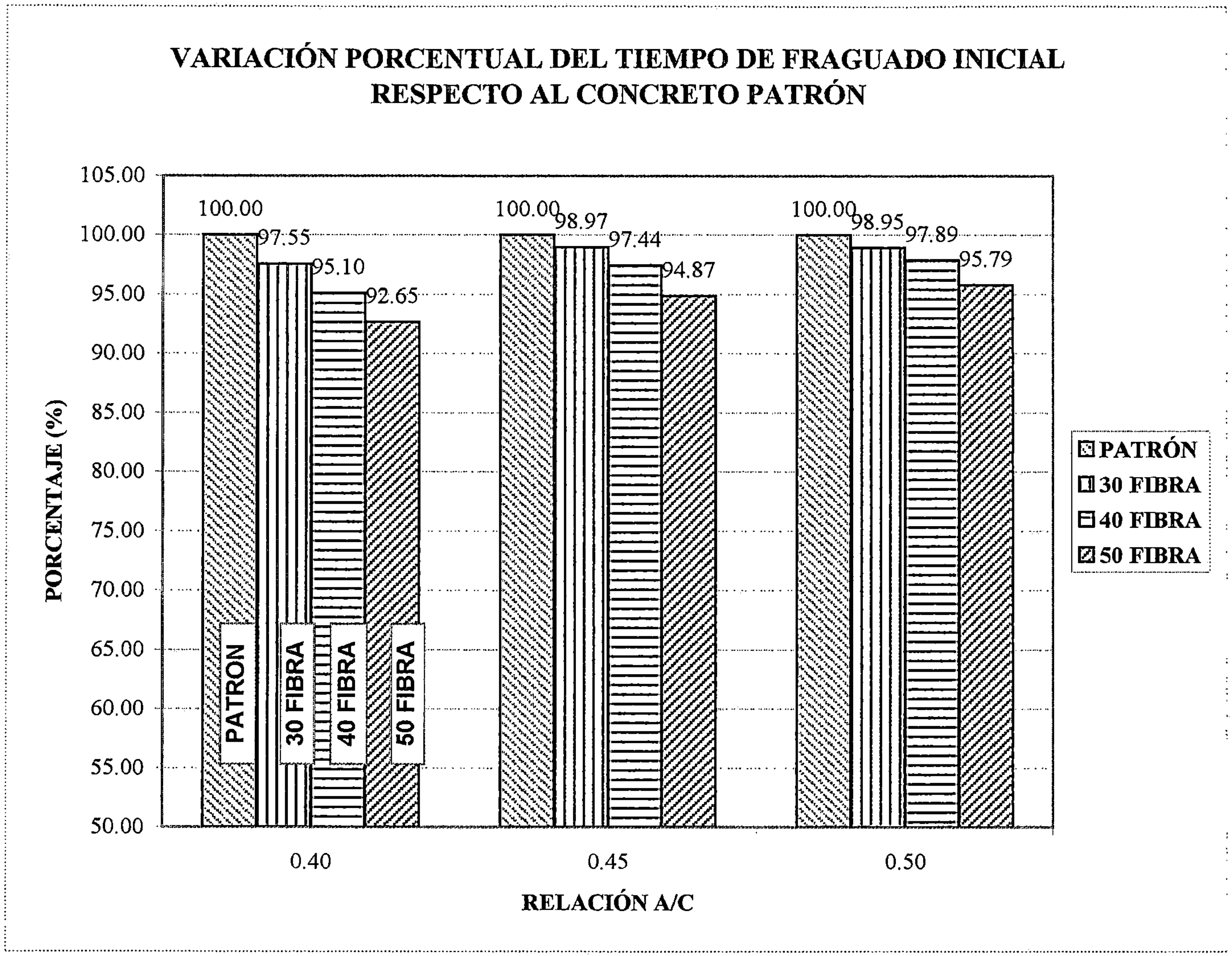
RELACION	DOSIFICACION(Fibra Insonex Kg/m3)			
a/c	0	30	40	50
0.40	100.00	97.55	95.10	92.65
0.45	100.00	98.97	97.44	94.87
0.50	100.00	98.95	97.89	95.79

De los cuadros podemos observar que el Tiempo de Fraguado Inicial, Disminuye para todas las relaciones de a/c estudiadas, a medida que se adiciona la fibra de acero insonex, a continuación detallamos.

Para la relación a/c=0.40 observamos que disminuye en: 2.45%, 4.9%, 7.35% respecto al concreto patrón (sin fibras), para las dosificaciones de fibra de acero insonex de 30, 40, 50 kg/m^3 de concreto respectivamente

Para la relación a/c=0.45 observamos que disminuye en: 1.03%, 2.56%, 5.13% respecto al concreto patrón (sin fibras), para las dosificaciones de fibra de acero insonex de 30, 40, 50 kg/m^3 de concreto respectivamente

Para la relación a/c=0.50 observamos que disminuye en: 1.05%, 2.11%, 4.21% . respecto al concreto patrón (sin fibras), para las dosificaciones de fibra de acero insonex de 30, 40, 50 kg/m^3 de concreto respectivamente


VARIACIÓN PORCENTUAL DEL TIEMPO DE FRAGUADO INICIAL RESPECTO AL CONCRETO PATRÓN
PORCENTAJE (%)
105.00
100.00
95.00
90.00
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
100.00
97.55
95.10
92.65
100.00
98.97
97.44
94.87
100.00
98.95
97.89
95.79
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

- FRAGUADO FINAL

RELACION a/c	**DOSIFICACION(Fibra Insonex Kg/m3)**			
	0	30	40	50
0.40	4:24	4:20	4:16	4:14
0.45	4:18	4:16	4:12	4:08
0.50	4:15	4:13	4:11	4:08

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

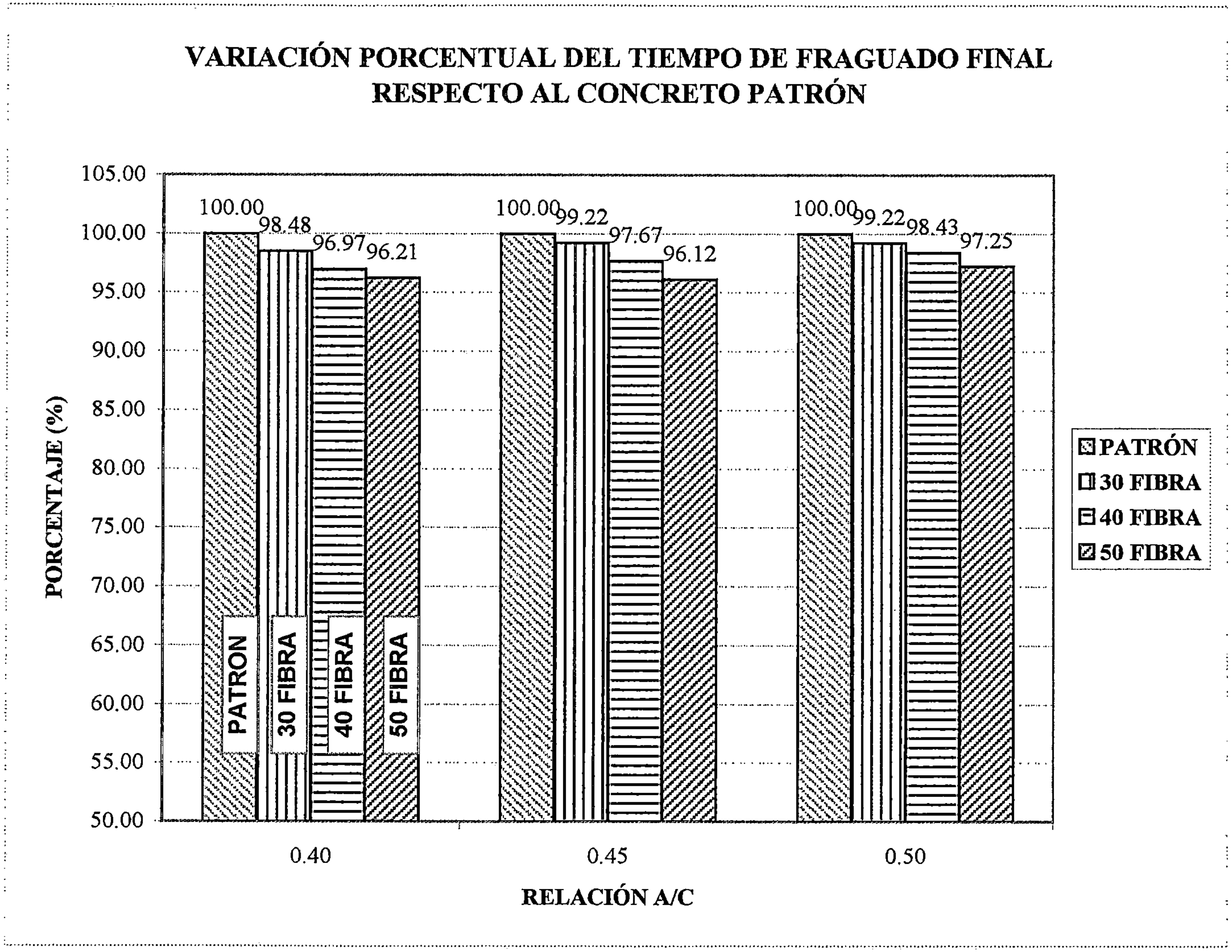
RELACION a/c	**DOSIFICACION(Fibra Insonex Kg/m3)**			
	0	30	40	50
0.40	100.00	98.48	96.97	96.21
0.45	100.00	99.22	97.67	96.12
0.50	100.00	99.22	98.43	97.25

Como podemos observar del cuadro anterior para todas las relaciones de agua/cemento, disminuye el tiempo de fraguado final a medida que se adiciona la fibra de acero insonex.

Para la relación a/c=0.40, disminuye en 1.52%, 3.03%, 3.79% con respecto al concreto patrón cuando se le añade dosificaciones de fibra de 30, 40, 50 kg/m^3 de concreto respectivamente.

Para la relación a/c=0.45, disminuye en 0.78%, 2.33%, 3.88% con respecto al concreto patrón cuando se le añade dosificaciones de fibra de 30, 40, 50 kg/m^3 de concreto respectivamente.

Para la relación a/c=0.50, disminuye en 0.78%, 1.57%, 2.75% con respecto al concreto patrón cuando se le añade dosificaciones de fibra de 30, 40, 50 kg/m^3 de concreto respectivamente.


VARIACIÓN PORCENTUAL DEL TIEMPO DE FRAGUADO FINAL RESPECTO AL CONCRETO PATRÓN
PORCENTAJE (%)
105.00
100.00
95.00
90.00
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
100.00
98.48
96.97
96.21
100.00
99.22
97.67
96.12
100.00
99.22
98.43
97.25
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

8.7.5 ENSAYO DE CONTENIDO DE AIRE (%)

RELACION	**DOSIFICACION(Fibra Insonex Kg/m3)**			
a/c	0	30	40	50
0.40	1.35	1.37	1.39	1.42
0.45	1.38	1.43	1.46	1.49
0.50	1.45	1.49	1.53	1.58

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

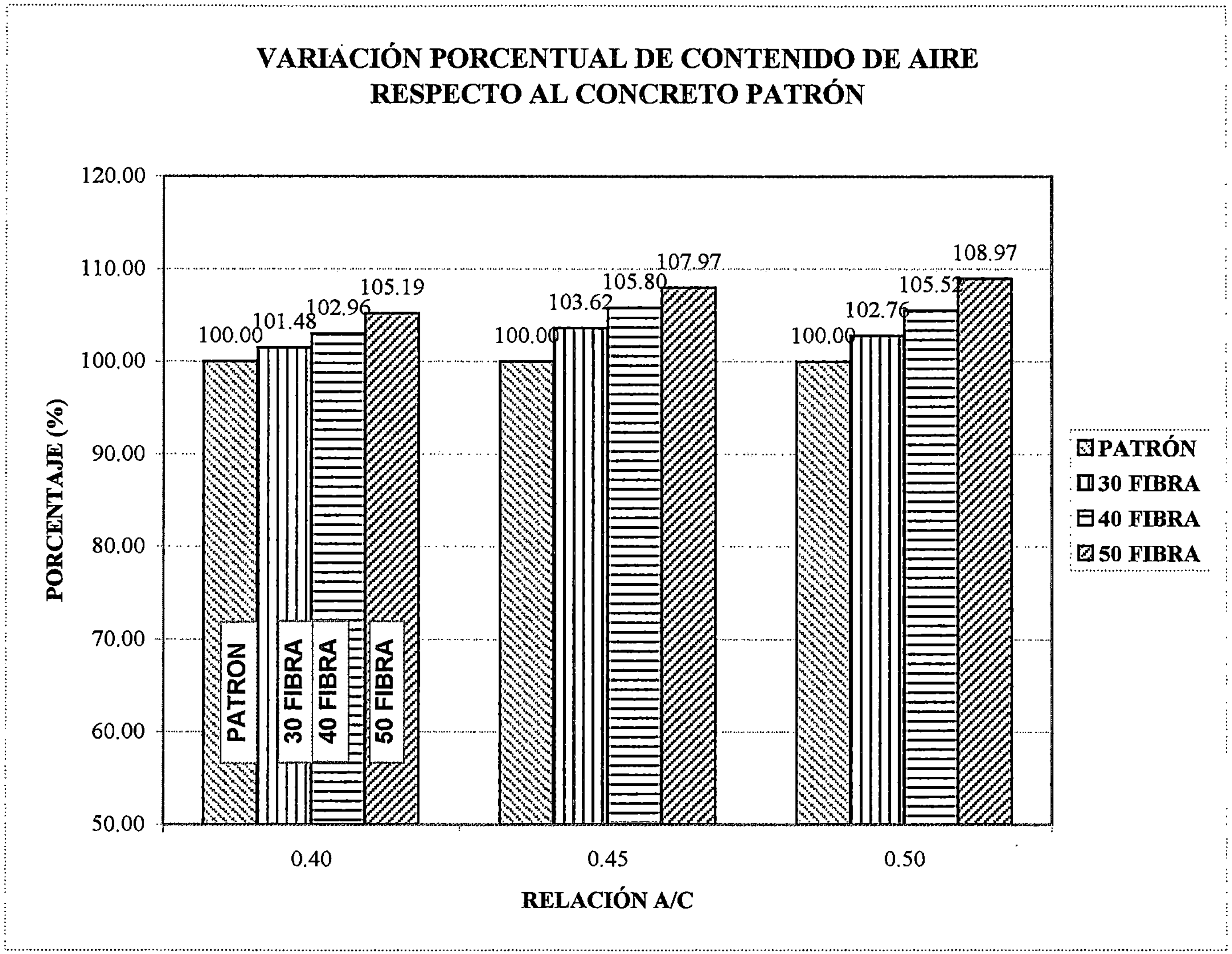
RELACION	**DOSIFICACION(Fibra Insonex Kg/m3)**			
a/c	0	30	40	50
0.40	100.00	101.48	102.96	105.19
0.45	100.00	103.62	105.80	107.97
0.50	100.00	102.76	105.52	108.97

Como podemos verificar de los cuadros, el contenido de aire aumenta cuando se adiciona fibras de acero Insonex respecto al concreto patrón, a continuación detallamos las variaciones:

En la relación a/c = 0.40, se incrementa en 1.48%, 2.96%, 5.19% cuando se le adiciona fibra de acero insonex en dosificaciones de 30, 40, 50 kg/m^3 de concreto respectivamente.

En la relación a/c = 0.45, se incrementa en 3.62%, 5.80%, 7.97% cuando se le adiciona fibra de acero insonex en dosificaciones de 30, 40, 50 kg/m^3 de concreto respectivamente.

En la relación a/c = 0.50, se incrementa en 2.76%, 5.52%, 8.97% cuando se le adiciona fibra de acero insonex en dosificaciones de 30, 40, 50 kg/m^3 de concreto respectivamente.


VARIACIÓN PORCENTUAL DE CONTENIDO DE AIRE RESPECTO AL CONCRETO PATRÓN
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
PORCENTAJE (%)
100.00
101.48
102.96
105.19
100.00
103.62
105.80
107.97
100.00
102.76
105.52
108.97
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

8.7.6 ENSAYO DE EXUDACIÓN (%)

RELACION a/c	**DOSIFICACION(Fibra Insonex Kg/m3)**			
	0	30	40	50
0.40	1.82	1.73	1.57	1.48
0.45	2.02	1.90	1.69	1.62
0.50	2.53	2.47	2.04	1.86

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

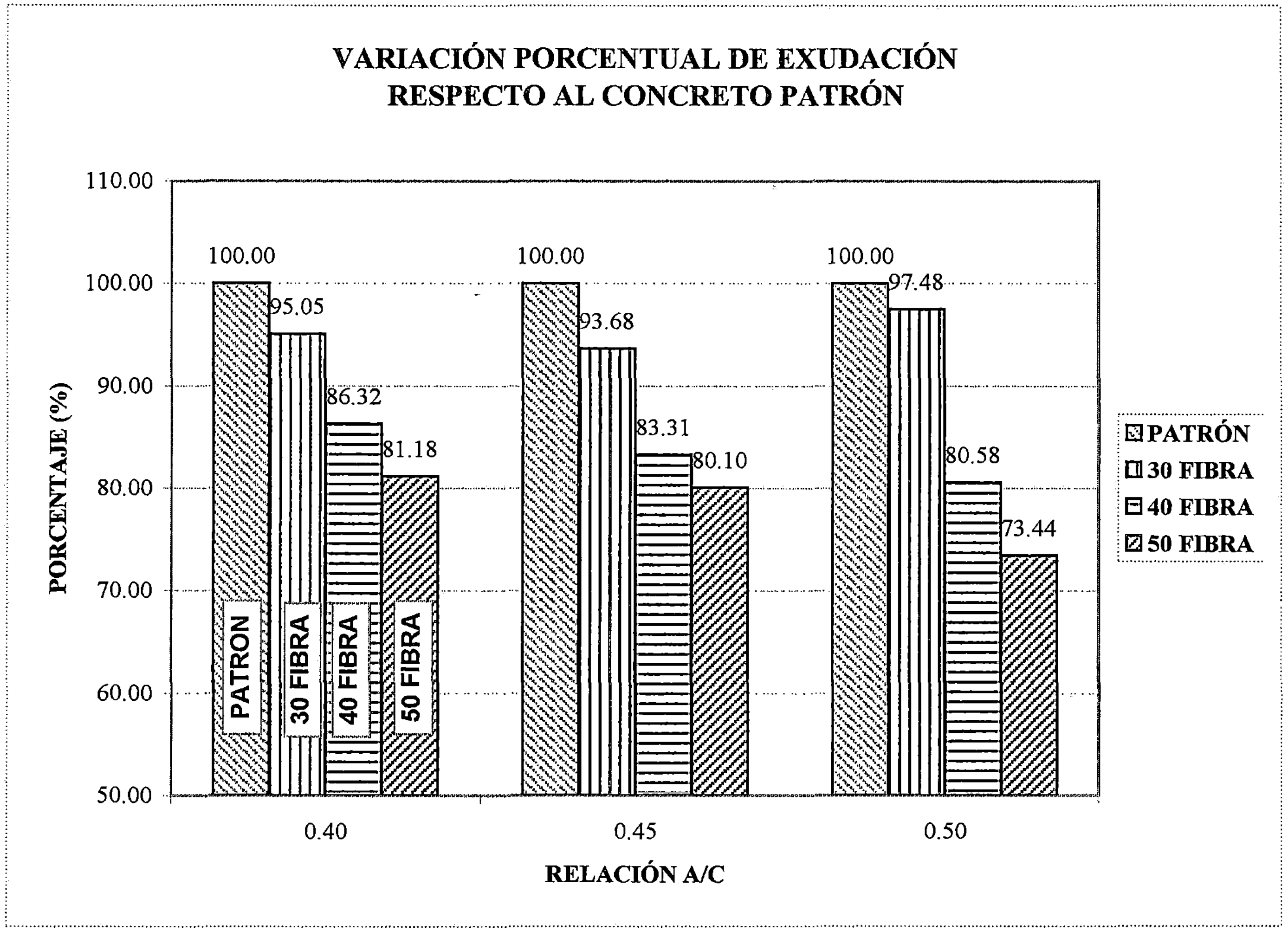
RELACION a/c	**DOSIFICACION(Fibra Insonex Kg/m3)**			
	0	30	40	50
0.40	100.00	95.05	86.32	81.18
0.45	100.00	93.68	83.31	80.10
0.50	100.00	97.48	80.58	73.44

Como podemos observar de los cuadros la exudación disminuye proporcionalmente a las fibras de acero para todas las relaciones de agua/cemento, a continuación detallamos las variaciones respecto al concreto patrón

En la relación a/c = 0.40, disminuye en 4.5%, 13.68%, 18.82% cuando se le adiciona fibra de acero insonex en dosificaciones de 30, 40, 50 kg/m^3 de concreto respectivamente

En la relación a/c = 0.45, disminuye en 6.32%, 16.69%, 19.9% cuando se le adiciona fibra de acero insonex en dosificaciones de 30, 40, 50 kg/m^3 de concreto respectivamente

En la relación a/c = 0.50, disminuye en 2.52%, 19.42%, 26.56% cuando se le adiciona fibra de acero insonex en dosificaciones de 30, 40, 50 kg/m^3 de concreto respectivamente


VARIACIÓN PORCENTUAL DE EXUDACIÓN RESPECTO AL CONCRETO PATRÓN
PORCENTAJE (%)
110.00
100.00
90.00
80.00
70.00
60.00
50.00
100.00
95.05
86.32
81.18
100.00
93.68
83.31
80.10
100.00
97.48
80.58
73.44
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

8.8 ANALISIS COMPARATIVO EN EL CONCRETO ENDURECIDO.

8.8.1 ENSAYO DE RESISTENCIA A LA COMPRESIÓN (kg/cm2)

- RELACIÓN A/C=0.40

Nº DIAS	DOSIFICACION DE LA FIBRA (Kg/m^3)			
	0	30	40	50
7	344.25	348.75	354.98	355.22
14	397.25	398.20	402.91	403.82
28	428.93	431.48	444.82	446.68
42	459.67	466.61	466.86	471.46

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

Nº DIAS	DOSIFICACION DE LA FIBRA (Kg/m^3)			
	0	30	40	50
7	100.00	101.31	103.12	103.19
14	100.00	100.24	101.43	101.65
28	100.00	100.60	103.71	104.14
42	100.00	101.51	101.57	102.57

- VARIACIÓN PORCENTUAL RESPECTO A LOS 28 DÍAS

Nº DIAS	DOSIFICACION DE LA FIBRA (Kg/m^3)			
	0	30	40	50
7	80.26	80.83	79.80	79.52
14	92.61	92.29	90.58	90.40
28	100.00	100.00	100.00	100.00
42	107.17	108.14	104.96	105.55

- RELACIÓN A/C=0.45

N° DIAS	**DOSIFICACION DE LA FIBRA (Kg/m^3)**			
	0	**30**	**40**	**50**
7	292.85	318.57	324.71	324.79
14	373.11	374.86	375.14	381.44
28	394.07	396.52	398.27	406.77
42	430.92	430.92	432.83	436.73

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

N° DIAS	**DOSIFICACION DE LA FIBRA (Kg/m^3)**			
	0	**30**	**40**	**50**
7	100.00	108.78	110.88	110.91
14	100.00	100.47	100.55	102.24
28	100.00	100.62	101.06	103.22
42	100.00	100.00	100.44	101.35

- VARIACIÓN PORCENTUAL RESPECTO A LOS 28 DÍAS

N° DIAS	**DOSIFICACION DE LA FIBRA (Kg/m^3)**			
	0	**30**	**40**	**50**
7	74.31	80.34	81.53	79.85
14	94.54	94.54	94.19	93.77
28	100.00	100.00	100.00	100.00
42	109.35	108.68	108.68	107.37

☐ RELACIÓN A/C=0.50

N° DIAS	DOSIFICACION DE LA FIBRA (Kg/m^3)			
	0	30	40	50
7	272.84	294.08	296.25	297.13
14	337.16	341.33	344.42	349.91
28	376.06	380.10	384.36	385.55
42	388.79	404.60	404.78	410.13

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

N° DIAS	DOSIFICACION DE LA FIBRA (Kg/m^3)			
	0	30	40	50
7	100.00	107.78	108.58	108.90
14	100.00	101.24	102.15	103.78
28	100.00	101.07	102.21	102.52
42	100.00	104.07	104.11	105.49

- VARIACIÓN PORCENTUAL RESPECTO A LOS 28 DÍAS

N° DIAS	DOSIFICACION DE LA FIBRA (Kg/m^3)			
	0	30	40	50
7	72.55	77.37	77.08	77.07
14	89.66	89.80	89.61	90.76
28	100.00	100.00	100.00	100.00
42	103.39	106.45	105.31	106.38

En forma general podemos decir que, de acuerdo a los resultados obtenidos la resistencia a la compresión se incrementa en todas las relaciones agua/cemento, cabe incidir que a la edad de 7 días se incrementa notablemente y para las edades de 14, 28, y 42 días aumenta en menores porcentajes para las diferentes proporciones de fibra de acero insonex, a continuación detallamos las variaciones:

En la relación a/c=0.40 aumenta a la edad de 7 días como mínimo en 1.37%, y máximo 3.19% para las dosificaciones de 30, 50 kg/m^3 de concreto respectivamente. A la edad de 14 días aumenta como mínimo en 0.24% y como máximo en 1.65% para las dosificaciones de 30 y 50 kg/m^3 de concreto respectivamente. A la edad de 28 días aumenta como mínimo en 0.6% y como máximo 4.14% para las dosificaciones de 30 y 50 kg/m^3 de concreto respectivamente y a la edad de 42 días aumenta como mínimo 1.51% y como máximo 2.57% para las dosificaciones de 30 y 50 kg/m^3 de concreto respectivamente.

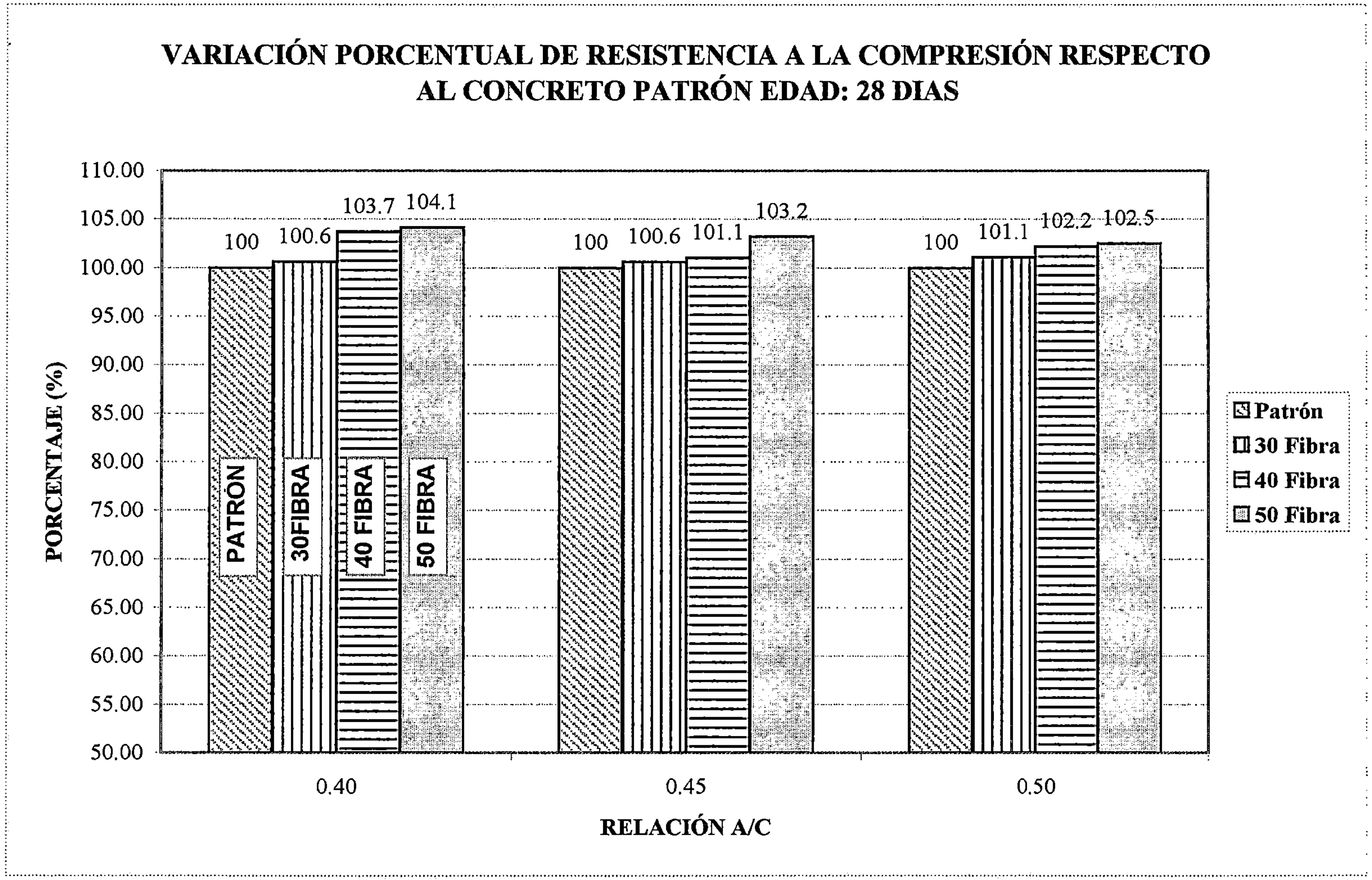
A continuación presentaremos la variación porcentual respecto a un concreto patrón a la edad de 28 días para las diferentes dosificaciones de fibra de acero insonex.

A la edad de 7 días para el concreto patrón, tenemos un 80.26%, a los 14 días 92.61% y a los 42 días 107.17%, cuando se le añade fibra insonex una dosificación de 30 kg/m^3 de concreto se tiene: a los 7 días un 80.83%, a los 14 días 92.29% y los 42 días 108.14%, para una dosificación de fibra equivalente a 40 kg/m^3 de concreto a la edad de 7 días tenemos 79.80%, a la edad de 14 días 90.58% y a la edad de 42 días 104.96%, para una dosificación de 50 kg/m^3 de concreto podemos decir para la edad de 7 días tiene 79.52%,a los 14 días 90.40% y finalmente para la edad de 42 días 105.55%.

Para la relación a/c=0.45 de acuerdo a los resultados vemos que aumenta la compresión a medida que se incrementa la dosificación de fibra insonex, observamos que a la edad de 7 días aumenta como mínimo 8.78% y como máximo 10.91% para las dosificaciones de 30 y 50 kg/m^3 de concreto respectivamente. También se observa que para edad del14 días aumenta como mínimo 0.47% y máximo 2.24% cuando se le añade fibra insonex dosificaciones de 30, 50 kg/m^3 de concreto respectivamente, a la edad de 28 días aumenta como mínimo 0.62% y máximo 3.22% para las dosificaciones de fibra insonex de 30, 50 kg/m^3 de concreto respectivamente, finalmente a la edad de 42 días los incrementos son de 0.0% 0.44% y 1.35% para las dosificaciones de 30, 40, 50 kg/m^3 de concreto respectivamente, a continuación describiremos las variaciones porcentuales respecto a los 28 días para las diferentes dosificaciones de fibra de acero insonex. Para el concreto patrón tenemos a los 7 días de edad el 74.31%, a los 14 días 94.68% y a la edad de 42 días 109.35%. Cuando se le añade fibra de acero insonex una dosificación de 30 kg/m^3 de concreto tenemos: a los 7 días 80.34%, a los 14 días 94.545 y finalmente a los 42 días 108.6%. Para la dosificación de 40 kg/m^3 de concreto tenemos a los 7 días 81.53%, as los 14 días 94.19% y finalmente a los 42 días 105.79%. Para una dosificación de 50 kg/m^3 de concreto tenemos a la edad de 7 días 79.85%, a la edad de 14 días 93.77% y finalmente a la edad de 42 días un valor de 107.37%.

Para la relación a/c= 0.50 podemos afirmar que, de acuerdo a los resultados obtenidos lo siguiente: respecto al concreto patrón a la edad de 7 días se tiene un incremento como mínimo de 7.78% y como máximo 8.9% cuando se le añade fibra de acero insonex las proporciones de 30 y 50 kg/m^3 de concreto respectivamente. Con respecto a la edad de 14 días se verifica que aumenta como mínimo 1.24% y como máximo 3.78% para las dosificaciones de 30 y 50 kg/m^3 de concreto respectivamente, a los 28 días se verifica que aumenta como mínimo 1.07% y como máximo 2.52% cuando se le añade dosificaciones de 30 y 50 kg/m^3 de concreto respectivamente, finalmente a la edad de 42 días verificamos que aumenta como mínimo 4.07% y como máximo 5.49% cuando se le añade dosificaciones de 30 y 50 kg/m^3 de concreto respectivamente.

A continuación analizaremos las variaciones porcentuales respecto a la edad de 28 días para el concreto patrón y cuando se añade todas las dosificaciones de fibra de acero insonex. En el concreto patrón a la edad de 7 días tiene una resistencia de 72.55% a los 14 días 89.65% y finalmente a los 42 días 103.38%.Cuando se le añade fibra de acero insonex una dosificación de 30 kg/m^3 de concreto se tiene: a la edad de 7 días 77.37%, a la edad de 14 días 89.80%, finalmente a los 42 días 106.45%. Para una dosificación de 40 kg/m^3 de concreto se tiene: a la edad de 7 días 77.08%, a la edad de 14 días 89.61%, finalmente a los 42 días105.31%. Para una dosificación de 50 kg/m^3 de concreto se tiene: a la edad de 7 días 77.07%, a la edad de 14 días 90.76%, finalmente a los 42 días 106.38%.


VARIACIÓN PORCENTUAL DE RESISTENCIA A LA COMPRESIÓN RESPECTO AL CONCRETO PATRÓN EDAD: 28 DIAS
PORCENTAJE (%)
110.00
105.00
100.00
95.00
90.00
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
100
100.6
103.7
104.1
100
100.6
101.1
103.2
100
101.1
102.2
102.5
PATRÓN
30FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
▨ Patrón
▥ 30 Fibra
▤ 40 Fibra
▩ 50 Fibra

8.8.2 ENSAYO DE RESISTENCIA A LA TRACCIÓN POR COMPRESIÓN DIAMETRAL (Kg/cm^2)

RELACION a/c	DOSIFICACION DE FIBRA (Kg/m^3)			
	0	30	40	50
0.40	41.27	43.95	44.84	46.12
0.45	37.83	39.59	41.64	43.16
0.50	32.45	34.63	36.79	37.90

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

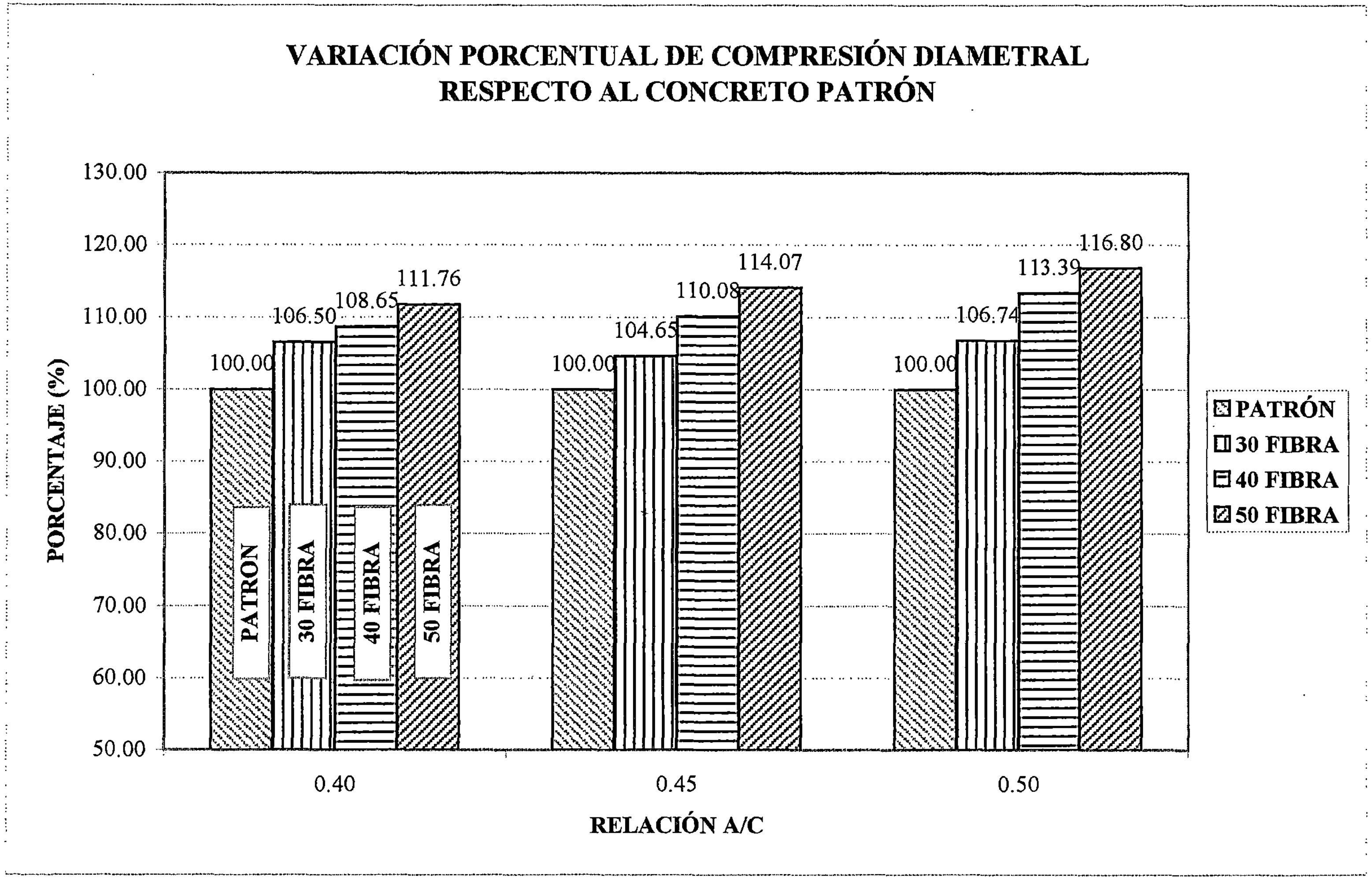
RELACION a/c	DOSIFICACION DE FIBRA (Kg/m^3)			
	0	30	40	50
0.40	100.00	106.50	108.65	111.76
0.45	100.00	104.65	110.08	114.07
0.50	100.00	106.74	113.39	116.80

Como podemos observar la Resistencia a la Tracción por Compresión Diametral respecto al concreto patrón, aumenta directamente proporcional a la dosificación de la fibra Insonex, a continuación detallamos las variaciones.

Para la relación de agua/cemento equivalente a 0.40, se incrementa en los porcentajes de 6.50%, 8.65%, 11.76% cuando se le añade Fibra de Acero Insonex en las proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación de agua/cemento equivalente a 0.45, se incrementa en los porcentajes de 4.5%, 10.08%, 11.76% cuando se le añade Fibra de Acero Insonex en las proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación de agua/cemento equivalente a 0.50, se incrementa en los porcentajes de 6.74%, 13.39%, 16.8% cuando se le añade Fibra de Acero Insonex en las proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.



Tesis: "Estudio del comportamiento del concreto de mediana a alta resistencia, con la incorporación de Fibras de Acero y cemento Pórtland tipo I Andino"

8.8.3 ENSAYO DE MÓDULO ELÁSTICO ESTÁTICO (10^5 *Kg/cm^2)

RELACION a/c	DOSIFICACION (Kg/m^3)			
	0	30	40	50
0.40	2.6833	2.7301	2.8113	2.8763
0.45	2.4024	2.4299	2.4939	2.5240
0.50	2.1972	2.2276	2.3178	2.3554

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

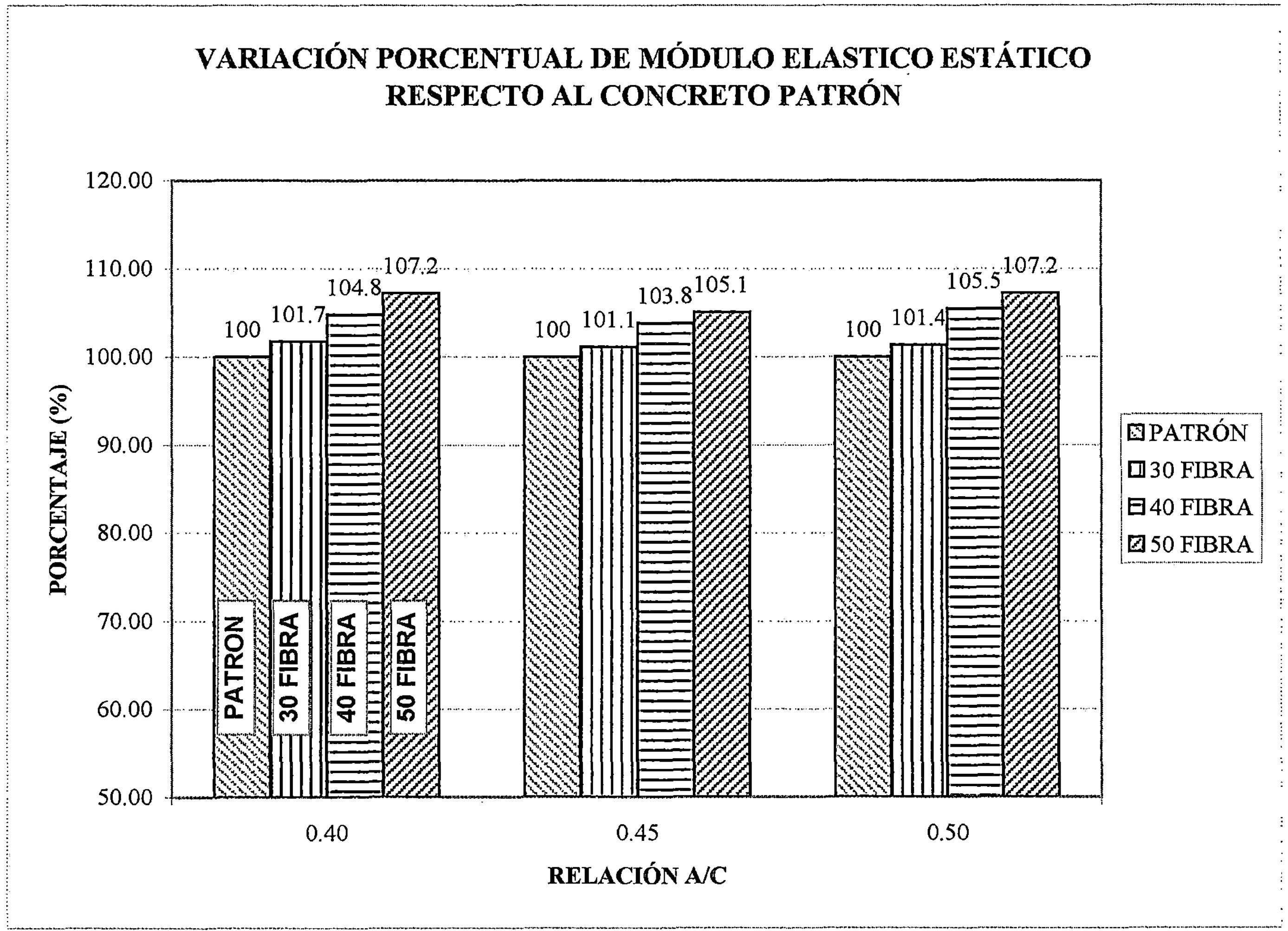
RELACION a/c	DOSIFICACION (Kg/m^3)			
	0	30	40	50
0.40	100.00	101.74	104.77	107.19
0.45	100.00	101.14	103.81	105.06
0.50	100.00	101.38	105.49	107.20

Como podemos observar el Módulo Elástico Estático respecto al concreto patrón, aumenta directamente proporcional a la dosificación de la fibra Insonex, a continuación detallamos las variaciones.

Para la relación de agua/cemento equivalente a 0.40, se incrementa en los porcentajes de 1.74%, 4.77%, 7.19% cuando se le añade Fibra de Acero Insonex en las proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación de agua/cemento equivalente a 0.45, se incrementa en los porcentajes de 1.14%, 3.81%, 5.06% cuando se le añade Fibra de Acero Insonex en las proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación de agua/cemento equivalente a 0.50, se incrementa en los porcentajes de 1.38%, 5.49%, 7.20% cuando se le añade Fibra de Acero Insonex en las proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.


VARIACIÓN PORCENTUAL DE MÓDULO ELASTICO ESTÁTICO RESPECTO AL CONCRETO PATRÓN
PORCENTAJE (%)
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
100
101.7
104.8
107.2
100
101.1
103.8
105.1
100
101.4
105.5
107.2
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

8.8.4 ENSAYO DE RESISTENCIA A LA FLEXIÓN (Kg/cm^2)

RELACION a/c	**DOSIFICACION DE FIBRA (Kg/m^3)**			
	0	**30**	**40**	**50**
0.40	41.94	47.62	48.69	50.61
0.45	40.76	44.15	47.13	48.26
0.50	38.71	41.59	44.35	47.32

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

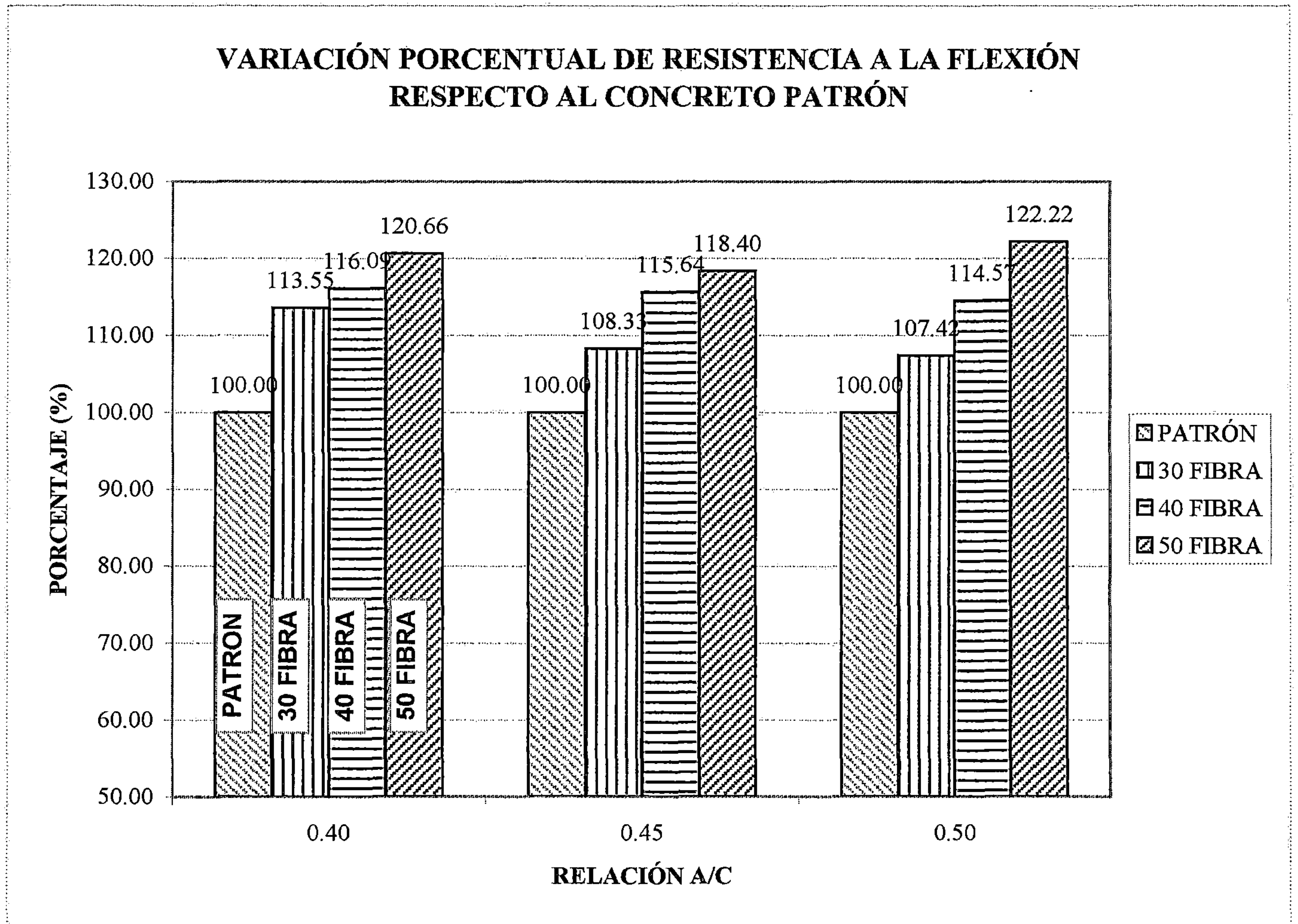
RELACION a/c	**DOSIFICACION DE FIBRA (Kg/m^3)**			
	0	**30**	**40**	**50**
0.40	100.00	113.55	116.09	120.66
0.45	100.00	108.33	115.64	118.40
0.50	100.00	107.42	114.57	122.22

Como podemos observar en los cuadros la Resistencia a la Flexión se incrementa conforme se aumenta proporcionalmente la dosificación de la Fibra de Acero Insonex en el concreto, a continuación detallamos las variaciones respecto al concreto patrón.

Para la relación agua/cemento equivalente a 0.40, se incrementa en 13.5%, 16.09%, 20.66% cuando se le añade Fibra de Acero Insonex proporcionalmente a las dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación agua/cemento equivalente a 0.45, se incrementa en 8.33%, 15.64%, 18.40% cuando se le añade Fibra de Acero Insonex proporcionalmente a las dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación agua/cemento equivalente a 0.50, se incrementa en 7.42%, 14.57%, 22.22% cuando se le añade Fibra de Acero Insonex proporcionalmente a las dosificaciones de 30, 40, 50 Kg/m^3 de concreto respectivamente.



VARIACIÓN PORCENTUAL DE RESISTENCIA A LA FLEXIÓN RESPECTO AL CONCRETO PATRÓN
PORCENTAJE (%)
130.00
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
100.00
113.55
116.09
120.66
100.00
108.33
115.64
118.40
100.00
107.42
114.57
122.22
PATRON
30 FIBRA
40 FIBRA
50 FIBRA
0.40
0.45
0.50
RELACIÓN A/C
PATRÓN
30 FIBRA
40 FIBRA
50 FIBRA

8.8.5 ENSAYO DE RESISTENCIA AL IMPACTO(# de golpes)

- ☐ RELACIÓN A/C=0.40

N° DIAS	DOSIFICACION DE FIBRA (kg/m3)			
	0	30	40	50
28	108	132	153	199
42	112	139	177	200

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRON

N° DIAS	DOSIFICACION DE FIBRA (kg/m3)			
	0	30	40	50
28	100	122	142	185
42	100	125	158	179

- ☐ RELACIÓN A/C=0.45

N° DIAS	DOSIFICACION DE FIBRA (kg/m3)			
	0	30	40	50
28	88	139	151	164
42	105	142	160	184

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

N° DIAS	DOSIFICACION DE FIBRA (kg/m3)			
	0	30	40	50
28	100	158	171	186
42	100	136	153	176

- ☐ RELACIÓN A/C=0.50

N° DIAS	DOSIFICACION DE FIBRA (kg/m3)			
	0	30	40	50
28	72	82	117	125
42	82	92	123	135

- VARIACIÓN PORCENTUAL RESPECTO AL CONCRETO PATRÓN

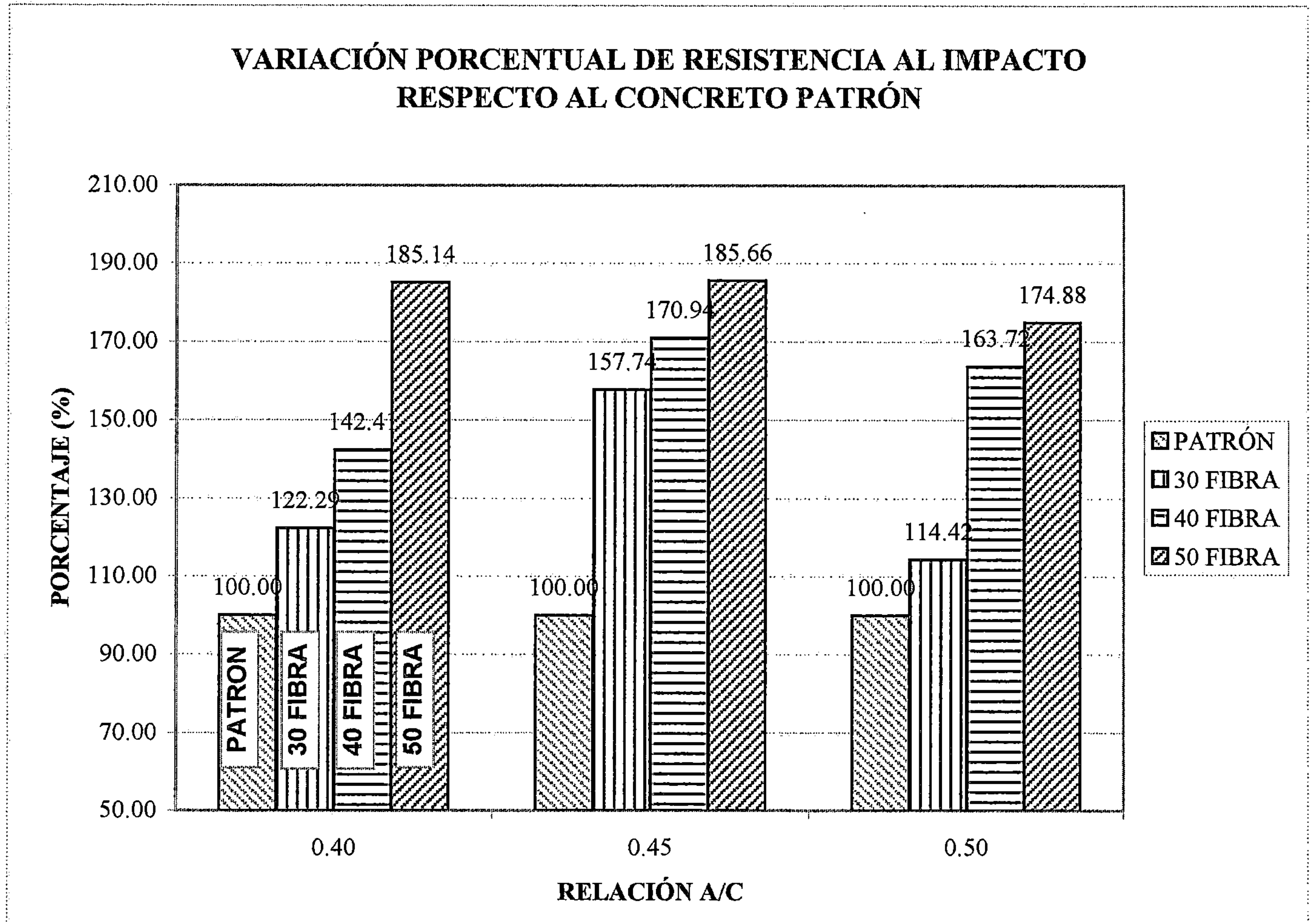
N° DIAS	DOSIFICACION DE FIBRA (kg/m3)			
	0	30	40	50
28	100	114	164	175
42	100	111	150	164

Cabe mencionar que el numero de golpes practicada a los discos de concreto se contabiliza hasta que dicho disco sufra su primera fisuración. Ahora verificando los resultados de los cuadros anteriores, podemos observar, que aumenta la resistencia al Impacto proporcionalmente para las diferentes dosificaciones de fibra.

Para la relación agua/cemento, igual a 0.40 y a una edad de 28 días se incrementa respecto al concreto patrón en: 22%, 42%, 85% cuando se añade fibra de acero insonex en proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente. Y a la edad de 42 días se incrementa en: 25%, 58%,79% con respecto al concreto patrón, para las dosificaciones de: 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación agua/cemento, igual a 0.45 y a una edad de 28 días se incrementa respecto al concreto patrón en: 58%, 71%, 86% cuando se añade fibra de acero insonex en proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente. Y a la edad de 42 días se incrementa en: 36%, 53%,76% con respecto al concreto patrón, para las dosificaciones de: 30, 40, 50 Kg/m^3 de concreto respectivamente.

Para la relación agua / cemento, igual a 0.50 y a una edad de 28 días se incrementa respecto al concreto patrón en: 14%, 64%, 75% cuando se añade fibra de acero insonex en proporciones de 30, 40, 50 Kg/m^3 de concreto respectivamente. Y a la edad de 42 días se incrementa en: 11%, 40%,64% con respecto al concreto patrón, para las dosificaciones de: 30, 40, 50 Kg/m^3 de concreto respectivamente.



VARIACIÓN PORCENTUAL DE RESISTENCIA AL IMPACTO RESPECTO AL CONCRETO PATRÓN

CAPITULO 09

CONCLUSIONES Y RECOMENDACIONES

9.1 ASPECTOS GENERALES

En el presente capitulo, de acuerdo al análisis de resultados del capitulo anterior indicaremos las conclusiones a las que se haya llegado y seguidamente se propondrán algunas recomendaciones.

El concreto utilizado presenta las relaciones agua/cemento equivalente a 0.40, 0.45, 0.50 para un concreto patrón (sin fibras) y concreto con la incorporación de fibras de acero Insonex en dosificaciones de 30, 40, 50 Kg/m^3 de concreto.

Cabe mencionar además que la fibra de acero Insonex utilizado en la presente tesis de investigación es un producto nacional fabricado por la empresa INSOMIN, a continuación mencionamos todas sus características.

CARACTERISTICAS DE LA FIBRA INSONEX	
FORMA GEOMETRICA	ONDULADA
LONGITUD	40mm
DIAMETRO	0.8mm
LONGITUD DE ONDA	5mm
ALTURA DE ONDA	0.65mm
RES. MINIMA A LA TRACCION	76.5Kg/mm^2
PESO PARA SU VENTA	40Kg

9.2 CONCLUSIONES.

1. **El Asentamiento** del concreto en su estado fresco, **disminuye** para todas las relaciones estudiadas cuando se incorpora fibras de acero Insonex, con respecto al concreto patrón; a continuación detallamos.

- En la relación agua/cemento equivalente a 0.40, **disminuye** en: 20%, 25%, 30% para las dosificaciones de fibra de 30, 40, 50Kg/m^3 de concreto respectivamente.
- En la relación agua/cemento equivalente a 0.45, **disminuye** en: 25%, 30%, 35% para las dosificaciones de fibra de 30, 40, 50Kg/m^3 de concreto respectivamente.
- En la relación agua/cemento equivalente a 0.50, **disminuye** en: 25%, 30%, 35% para las dosificaciones de fibra de 30, 40, 50Kg/m^3 de concreto respectivamente.

2. **La Fluidez** del concreto en estado fresco **disminuye** a medida que se incrementa la cantidad de fibra de acero Insonex al concreto; a continuación detallamos.

- Para la relación agua/cemento igual a 0.40, **disminuye** en: 4.87%, 7.28%, 19.23% para las dosificaciones de 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación agua/cemento igual a 0.45, **disminuye** en: 3.88%, 5.67%, 8.65% para las dosificaciones de 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación agua/cemento igual a 0.50, **disminuye** en: 1.61%, 4.84%, 7.41% para las dosificaciones de 30, 40, 50Kg/m^3 de concreto respectivamente.

3. **El Peso Unitario** del concreto en su estado fresco, se **incrementa** a medida que se agrega las dosificaciones de fibra de acero insonex en el concreto; a continuación detallamos para las relaciones de a/c estudiadas.

- Para la relación de agua/cemento igual a 0.40, se **incrementa** en: 0.3%, 0.6%, 0.89% respecto al concreto patrón (sin fibras), cuando se le añade fibras de acero insonex las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

- Para la relación de agua/cemento igual a 0.45, se **incrementa** en: 0.59%, 0.89%, 1.19% respecto al concreto patrón (sin fibras), cuando se le añade fibras de acero insonex las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación de agua/cemento igual a 0.50, se **incrementa** en: 1.18%, 1.48%, 1.78% respecto al concreto patrón (sin fibras), cuando se le añade fibras de acero insonex las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

4. **El Tiempo de Fraguado Inicial** del concreto en su estado fresco **disminuye**, para las relaciones de agua/cemento 0.40, 0.45, 0.50, cuando se le añade fibra de acero insonex las dosificaciones de: 30, 40, 50 Kg/m^3 de concreto respecto al concreto patrón.

- Para la relación de a/c igual a 0.40, **disminuye** en: 2.45%, 4.9%, 7.35% respecto al concreto patrón cuando se le agrega fibra de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación de a/c igual a 0.45, **disminuye** en: 1.03%, 2.56%, 5.13% respecto al concreto patrón cuando se le agrega fibra de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación de a/c igual a 0.50, observamos que **disminuye** en: 1.05%, 2.11%, 4.21% respecto al concreto patrón cuando se le agrega fibra de acero Insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

El Tiempo de Fraguado Final del concreto, en su estado fresco, **disminuye** para todas las relaciones de a/c estudiadas (0.40, 0.45, 0.50), a medida que se incrementa la dosificación de fibra de acero insonex en: 30, 40, 50Kg/m^3 de concreto, a continuación detallamos.

- Para la relación a/c igual a 0.40, **disminuye** en: 1.52%, 3.03%, 3.79% respecto al concreto patrón, cuando se le añade dosificaciones de fibra en: 30, 40, 50Kg/m^3 de concreto respectivamente.

- ☐ Para la relación a/c igual a 0.45, **disminuye** en: 0.78%, 2.33%, 2.88% respecto al concreto patrón, cuando se le añade dosificaciones de fibra en: 30, 40, 50Kg/m^3 de concreto respectivamente.
- ☐ Para la relación a/c igual a 0.50, se **disminuye** en: 0.78%, 1.57%, 2.75% respecto al concreto patrón, cuando se le añade dosificaciones de fibra en: 30, 40, 50Kg/m^3 de concreto respectivamente.

5. El **Contenido de Aire** del concreto en su estado fresco se **incrementa** a medida que se aumenta las dosificaciones de fibra de acero insonex, a continuación detallamos.

- ➢ Para la relación agua/cemento igual a 0.40, se **incrementa** respecto al concreto Patrón (sin fibras) en: 1.48%, 2.96%, 5.19% cuando se le aumenta las dosificaciones de fibra de acero insonex en: 30, 40, 50Kg/m^3 de concreto respectivamente.
- ➢ Para la relación agua/cemento igual a 0.45, se **incrementa** respecto al concreto Patrón (sin fibras) en: 3.62%, 5.80%, 7.97% cuando se le aumenta las dosificaciones de fibra de acero insonex en: 30, 40, 50Kg/m^3 de concreto respectivamente.
- ➢ Para la relación agua/cemento igual a 0.50, se **incrementa** respecto al concreto Patrón (sin fibras) en: 2.76%, 5.52%, 8.97% cuando se le aumenta las dosificaciones de fibra de acero insonex en: 30, 40, 50Kg/m^3 de concreto respectivamente.

6. **La Exudación, disminuye** a medida que se aumenta la dosificación de fibras de acero insonex respecto al concreto patrón para todas las relaciones de agua/cemento, a continuación detallamos.

- ➢ Para la relación a/c = 0.40, **disminuye** en: 4.5%, 13.68%, 18.82% cuando se le adiciona fibra de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

- Para la relación a/c = 0.45, **disminuye** en: 6.32%, 16.69%, 19.90% cuando se le adiciona fibra de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación a/c = 0.50, **disminuye** en: 2.52%, 19.42%, 26.56% cuando se le adiciona fibra de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

7. **La Resistencia a la Compresión** del concreto en su estado endurecido, podemos decir que se **incrementa** respecto al concreto patrón (sin fibras) para todas las relaciones (0.40, 0.45, 0.50), cuando se aumenta la fibra en cada una de las relaciones de a/c con dosificaciones de: 30, 40, 50Kg/m^3 de concreto, cabe mencionar que los incrementos son variables dependiendo de la edad del curado, de la relación a/c y de la dosificación de fibra, a continuación detallamos.

- Para la relación a/c = 0.40, se Incrementa a la edad de 7 días en: 1.31%, 3.12%, 3.19% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Para la edad de 14 días se Incrementa en: 0.24%, 1.43%, 1.65% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Para la edad de 28 días se Incrementa en: 0.6%, 3.71%, 4.14% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Finalmente a la edad de 42 días se Incrementa en: 1.51%, 1.57%, 2.57% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación a/c = 0.45, se incrementa a la edad de 7 días en: 8.78%, 10.88%, 10.91% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Para la edad de 14 días se incrementa en: 0.47%, 0.55%, 2.24% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Para la edad de 28 días se incrementa en: 0.62%, 1.06%, 3.22% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

Finalmente a la edad de 42 días se incrementa en: 0.0%, 0.44%, 1.35% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

- Para la relación a/c = 0.50, se incrementa a la edad de 7 días en: 7.78%, 8.58%, 8.90% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Para la edad de 14 días se incrementa en: 1.24%, 2.15%, 3.78% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Para la edad de 28 días se incrementa en: 1.07%, 2.21%, 2.52% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente. Finalmente a la edad de 42 días se incrementa en: 4.07%, 4.11%, 5.49% respecto al concreto patrón, cuando se aumenta la fibra en dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

8. **La Resistencia a la Tracción por Compresión Diametral** del concreto en su estado endurecido, se **incrementa** a la edad de 28 días, para todos los a/c estudiados respecto al concreto patrón, cuando se aumenta las dosificaciones de fibra en: 30, 40, y 50Kg/m^3 de concreto, a continuación detallamos.

- Para la relación a/c = 0.40 se **incrementa** en: 6.50%, 8.65%, 11.76% respecto al concreto patrón cuando se le añade fibra de acero Insonex para las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación a/c = 0.45 se **incrementa** en: 4.65%, 10.08%, 14.07% respecto al concreto patrón cuando se le añade fibra de acero Insonex para las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación a/c = 0.50 se **incrementa** en: 6.74%, 13.39%, 16.80% respecto al concreto patrón cuando se le añade fibra de acero Insonex para las dosificaciones de:30, 40, 50Kg/m^3 de concreto respectivamente.

9. **El Módulo de Elasticidad Estático** del concreto en su estado endurecido, se **incrementa** para todas las relaciones de a/c estudiadas respecto al concreto patrón, cuando se agrega las dosificaciones de fibra para cada relación a/c en: 30, 40, 50Kg/m^3 de concreto, estos ensayos se realizaron a la edad 28 días.

- Para una relación a/c = 0.40, se **incrementa** en: 1.75%, 4.77%, 7.19% respecto al concreto patrón, cuando se agrega fibras de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para una relación a/c = 0.45, se **incrementa** en: 1.15%, 3.81%, 5.06% respecto al concreto patrón, cuando se agrega fibras de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para una relación a/c = 0.50, se **incrementa** en: 1.38%, 5.49%, 7.20% respecto al concreto patrón, cuando se agrega fibras de acero insonex con dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

10. **La Resistencia a la Flexión en Vigas** del concreto en su estado endurecido, a la edad de 28 días se **Incrementa** para todas las relaciones de a/c estudiadas respecto al concreto patrón, cuando se agrega las dosificaciones de fibra de acero insonex en: 30, 40, 50Kg/m^3 de concreto.

- Para la relación a/c = 0.40, se **incrementa** en: 13.55%, 16.09%, 20.66% respecto al concreto patrón cuando se le añade fibra de acero insonex las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación a/c = 0.45, se **incrementa** en: 8.33%, 15.64%, 18.40% respecto al concreto patrón cuando se le añade fibra de acero insonex las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.
- Para la relación a/c = 0.50, se **incrementa** en: 7.42%, 14.57%, 22.22% respecto al concreto patrón cuando se le añade fibra de acero insonex las dosificaciones de: 30, 40, 50Kg/m^3 de concreto respectivamente.

11. **La Resistencia al Impacto**, a la edad de, 28 y 42 días en general se **incrementa** para todas las relaciones a/c estudiadas respecto al concreto patrón, cuando se aumenta las dosificaciones de fibra de acero en: 30, 40, 50Kg/m3 de concreto, a continuación detallamos.

- Para la relación a/c = 0.40, a la edad de 28 días se **incrementa** en: 22%, 42%, 85% respecto al concreto patrón cuando se añade fibra de acero insonex en dosificaciones de: 30, 40 y 50Kg/m^3 de concreto respectivamente. Finalmente a la edad de 42 días se **incrementa** en: 25%, 58%, 79% respecto al concreto patrón para las mismas dosificaciones de fibra de acero insonex.
- Para la relación a/c = 0.45, a la edad de 28 días se **incrementa** en: 58%, 71%, 86% respecto al concreto patrón cuando se añade fibra de acero insonex en dosificaciones de: 30, 40 y 50Kg/m^3 de concreto respectivamente. Finalmente a la edad de 42 días se **incrementa** en: 36%, 53%, 76% respecto al concreto patrón para las mismas dosificaciones de fibra de acero insonex.
- Para la relación a/c = 0.50, a la edad de 28 días se **incrementa** en: 14%, 64%, 75% respecto al concreto patrón cuando se añade fibra de acero insonex en dosificaciones de: 30, 40 y 50Kg/m^3 de concreto respectivamente. Finalmente a la edad de 42 días se **incrementa** en: 11%, 50%, 64% respecto al concreto patrón para las mismas dosificaciones de fibra de acero insonex.

12. Como conclusión final podemos decir que, el concreto con fibras de acero insonex para las dosificaciones de: 30, 40, 50Kg/m^3 de concreto y para las relaciones a/c de: 0.40, 0.45 y 0.50 mejoran las propiedades en su estado endurecido, con respecto al ensayo a Compresión, Módulo Elástico Estático se incrementa en menores porcentajes respecto a un concreto patrón, en cambio con respecto a los ensayos de: Flexión, Tracción por Compresión Diametral y ensayos por Impacto su incremento es considerable respecto al concreto patrón.

13. De acuerdo a los resultados podemos concluir que, para las relaciones de a/c estudiadas (0.40, 0.45, 0.50), y las dosificaciones de: 30, 40 y 50Kg/m^3 de concreto. La dosificación de fibra de acero insonex que incrementa notablemente los resultados es **50Kg/m^3** de concreto.

14. La forma geométrica que presenta la fibra, sus dimensiones, una adecuada selección de los agregados y una determinada relación de agua/cemento, son determinantes para un buen resultado, a continuación mostramos los resultados del ensayo de resistencia a la compresión entre la fibra "INSONEX" y la fibra "FIBERSTRAN 300" (realizadas en el LEM).

a/c = 0.50; DOSIFICACION DE FIBRA =40Kg/m3 ;ENSAYO A COMPRESION						
MARCA	INSONEX			FIBERSTRAN 300		
LONGITUD	40mm			30mm		
FORMA	ONDULADA			ONDULADA		
EDAD	PATRON. (sin fibras) Kg/cm^2	CON FIBRAS Kg/cm^2	VARIACION (PORCENTUAL)	PATRON. (sin fibras) Kg/cm^2	CON FIBRAS Kg/cm^2	VARIACION (PORCENTUAL)
7 DIAS	272.84	296.25	108.58	266.5	291.4	109.30
14 DIAS	337.16	344.42	102.15	317	305.2	96.30
28 DIAS	376.06	386.79	102.85	356.3	341.6	95.90
42 DIAS	338.79	404.78	104.11	372.5	353.9	95.00

Como podemos observar del cuadro anterior, los incrementos respecto al concreto de la fibra Insonex son mayores al de la fibra FIBERSTRAN 300.

15. En el ensayo de resistencia a la Flexión en vigas, para las relaciones de agua/cemento estudiados y las dosificaciones de fibra podemos decir que, el concreto con fibras presenta doble fluencia, la primera se debe al concreto solo y la segunda se debe a las fibras, en la mayoría de los ensayos la segunda fluencia era significativamente superior a la primera y con respecto a los tiempos, la fluencia del concreto y rotura de la fibra es de 1 a 5 minutos aproximadamente.

9.3 RECOMENDACIONES

1. Como se ha verificado en los resultados, cuando se agrega fibra de acero insonex, el Asentamiento baja considerablemente, en consecuencia es recomendable a que el diseño patrón (sin fibras) se realice en el intervalo de: (4 ½¨ a 5 ½¨), ya que se reduce cuando se añade fibras insonex al concreto hasta un intervalo de: (3¨ a 4¨).

3. Uno de los problemas que se presentó es que las fibras se juntaban entre sí formándose pequeños grupos (erizos) en consecuencia par evitar este inconveniente es recomendable para que la distribución de la fibra sea mas homogénea en el concreto, seguir una secuencia y tiempos de mezclado como se indica a continuación.

   - ☐ Primero mezclar el agregado grueso (piedra), con la fibra y realizar el mezclado en seco durante 1 a 2 minutos, para obtener una uniforme distribución de la fibra.
   - ☐ Posteriormente agregar el agregado fino (arena) + % de agua y proceder al mezclado 1 minuto, luego añadir el cemento + resto de agua. Finalmente proceder al mezclado de 5 a 6 minutos.

3. Otro de los inconvenientes que se presento fue, cuando se añadía las fibras de acero insonex a la mezcladora, algunas de las fibras salían de la mezcla impactando al cuerpo del operador producto de la rotación de la mezcladora, en consecuencia es recomendable usar protector para los ojos y guantes para su manipulación.

4. Hacer un buen análisis de las propiedades en los agregados ya que estos influyen notablemente en la resistencia del concreto, cabe mencionar también que es recomendable controlar constantemente el contenido de humedad de los agregados ya que estos podrían distorsionar la consistencia, asentamiento, del concreto en su estado fresco.

5. Es factible el uso de aditivos con adición de fibras en el concreto, teniendo en cuenta que estos no contengan cloruros, ya que representa un peligro para la fibra.

6. Es recomendable que la longitud de la fibra, sea mayor al tamaño máximo del agregado grueso, para obtener mejores resultados en los ensayos.

7. Es recomendable que las fibras de acero para su uso en el concreto se tenga en cuenta la fecha de vencimiento, verificar también que estas no tengan oxido en su superficie ya que a lago plazo pueden dar resultados no esperados.

8. Es recomendable en el ensayo de impacto que la carga caiga en el centro del disco, para obtener resultados mas coherentes.

9. Es conveniente realizar ensayos de Flexión Compuesta, en muestras de ensayo cuyas dimensiones sean de 50*50 cm y un espesor de 10 cm, en la que se le aplica una carga en el centro mediante un dado de dimensiones 10*10 cm.

10. Es recomendable que se realicen investigaciones para otras formas geométricas y dimensiones distintas, también haciendo uso de aditivos para ver su efectividad respecto a un concreto patrón.

ANEXOS

ANEXO 01

TABLAS GRANULOMETRICAS PARA LOS AGREGADOS

GENERALIDADES

Es de suma importancia que los resultados obtenidos en el laboratorio estén dentro de los limites permisibles, para que de esta manera poder clasificar su comportamiento ó características de los agregados finos (arena), grueso (piedra), global.

A continuación presentamos las siguientes tablas granulométricas para los agregados ya mencionados:

- ☐ GRANULOMETRIA DEL AGREGADO FINO
- ☐ REQUERIMIENTOS DE GRANULOMETRIA DE LOS AGREGADOS GRUESOS
- ☐ GRANULOMETRIA DE AGREGADO GLOBAL
- ☐ LINEAS GRANULOMETRICAS CONTINUAS

TABLA N° 1

GRANULOMETRIA DEL AGREGADO FINO				
Porcentaje de peso (masa) que pasa				
TAMIZ	Limites Totales	C	M	F
9.5 mm (3/8)	100	100	100	100
4.75 mm (No 4)	89 - 100	95 - 100	89 - 100	89 - 100
2.36 mm (No 8)	65 - 100	80 - 100	65 - 100	65 - 100
1.18 mm (No 16)	45 - 100	50 - 85	45 - 100	45 - 100
600 u (No 30)	25 - 100	25 - 60	25 - 100	25 - 100
300 u (No 50)	5 - 70	10 - 30	5 - 70	5 - 70
150 u (No 100)	0 - 12	2 - 10	0 - 12*	0 - 12

* Incrementar a 15% para agregado fino triturado, exepto cuando se use para pavimentos

TABLA N°2

REQUERIMIENTOS DE GRANULOMETRÍA DE LOS AGREGADOS GRUESOS

No ASTM	Tamaño Nominal	% QUE PASA POR LOS TAMICES NORMALIZADOS												
		100mm (4")	90mm (3 1/2")	75mm (3")	63mm (2 1/2")	50mm (2")	37.5mm (1 1/2")	25.0mm (1")	19.0mm (3/4")	12.5mm (1/2")	9.5mm (3/8")	4.75mm (No4)	2.36mm (No8)	1.18mm (No16)
1	90 a 37.5mm (3 1/2" a 1 1/2")	100	90a100		25a60		0 a 15		0 a 5					
2	63 a 37.5mm (2 1/2" a1 1/2")			100	90a100	35a70	0 a 15		0 a 5					
3	50 a25.0mm (2" a 1")				100	90a100	35a70	0a15		0 a 5				
357	50 a4.75mm (2" a No4)				100	95a100		35a70		10a30		0 a 5		
4	37.5 a 19.0mm (1 1/2" a 3/4")					100	90a100	20a55	0a15		0a5			
467	37.5 a 4.75mm (1 1/2" a No4)					100	95a100		35a70		10a30	0a5		
5	25 a 12.5mm 1" a 1/2"						100	90a100	20a55	0a10	0a5			
56	25 a 9.5mm 1" a 3/8"						100	90a100	40a85	10a40	0a15	0a5		
57	25 a 4.75mm (1" a No4)						100	95a100		25a60		0a10	0a5	
6	19.0 a9.5mm (3/4" a 3/8")							100	90a100	20a55	0a15	0a5		
67	19.0 a4.75mm (3/4" a No4)							100	90a100		20a55	0a10	0a5	
7	12.5mma4.75mm (1/2" aNo4)								100	90a100	40a70	0a15	0a5	
8	9.5 a2.36mm (3/8" aNo8)									100	85a100	10a30	0a10	0a5

TABLA N° 03

GRANULOMETRIA DEL AGREGADO GLOBAL

TAMIZ		Tamaño Nominal 37.5 mm (1/2")	Tamaño Nominal 19.0 mm (3/4")	Tamaño Nominal 9.5 mm (3/8")
50,0 mm	2"	100		
37.5 mm	(1 1/2")	95 a 100	100	
19.0 mm	(3/4")	45 a 80	95 a 100	
12.5 mm	(1/2")			100
9.5 mm	(3/8")			95 a 100
4.75 mm	(N° 4)	25 a 50	35 a 55	30 a 65
2.36 mm	(N° 8)			20 a 50
1.18 mm	(N° 16)			15 a 40
600 mm	(N° 30)	8 a 30	10 a 35	10 a 30
300 mm	(N° 50)			5 a 15
150 mm	(N° 100)	0 a 8*	0 a 8*	0 a 8*

* Incrementar a 10% para finos de roca triturada

TABLA N° 4

LINEAS GRANULOMETRICAS CONTINUAS

TAMAÑO MAXIMO = 8mm			
MALLA	FRACCION QUE PASA		
(mm)	A	B	C
8.00	100	100	100
4.00	61	74	85
2.00	36	57	71
1.00	21	42	57
0.50			
0.25	5	11	21

TAMAÑO MAXIMO = 16mm			
MALLA	FRACCION QUE PASA		
(mm)	A	B	C
16.00	100	100	100
8.00	60	76	88
4.00	36	56	74
2.00	21	42	62
1.00	12	32	49
0.50			
0.25	3	8	18

TAMAÑO MAXIMO = 32mm			
HUSO DIN (1045)			
MALLA	FRACCION QUE PASA		
(mm)	A	B	C
31.50	100	100	100
16.00	62	80	89
8.00	38	62	77
4.00	23	47	65
2.00	14	37	53
1.00	8	28	42
0.50			
0.25	2	8	15

TAMAÑO MAXIMO = 63mm			
MALLA	FRACCION QUE PASA		
(mm)	A	B	C
63.00	100	100	100
31.50	67	80	90
16.00	46	64	80
8.00	30	50	70
4.00	19	38	59
2.00	11	30	49
1.00	6	24	39
0.50			
0.25	2	7	14

ANEXO 02

COSTO UNITARIO

GENERALIDADES

A continuación analizaremos el costo que representa la elaboración de 1 m3 de concreto patrón (sin fibras) y de igual modo el costo que representa un concreto adicionándole fibra de acero Insonex las proporciones de 30, 40, 50 Kg/m^3 de concreto para cada una de las relaciones de agua/cemento de 0.40, 0.45, 50. Además los beneficios que genera el uso de la fibra de acero en el concreto.

ANALISIS DE COSTOS

El objetivo de realizar el presente análisis de costo es de obtener un conocimiento aproximado de los efectos económicos que genera el empleo de fibras de acero en el concreto.

Como primer paso, con la información que se posee del capitulo 04 " diseño de mezcla" se evalúa la cantidad de material según la forma común de comercialización, que se necesita para cada diseño de mezcla por metro cúbico. Luego se asigna un precio que corresponde al ámbito de lima metropolitana y así por sumatoria se determina el costo por m3 de cada diseño de concreto.

Para el costo de diseños de 1m^3 de concreto se ha considerado lo siguiente:

- **Fecha noviembre del 2001.**
- **Precio del dólar 3.5 soles.**
- **Cementos Pórtland tipo I andino**. Costo por unidad 17.5 soles
- **Agua** potable distribuida por la red publica. Su costo por litro es 0.005 soles
- **Arena** (cantera gloria). Precio por 1m^3 es 20 soles
- **Piedra** (cantera gloria) Precio por 1m^3 es 40 soles
- **Fibra de acero Insonex**. Precio por Kg 1.5 dólares, su equivalente es 5.25 soles
- **Equipo de Concreto.**
- **Operario (HH).** Su costo es de 8.40 soles por hora.
- **Peón (HH).** Su costo es de 6.78 soles por hora.
- **Combustible (galón).** Su costo es de 6 soles por hora.

Respecto al costo por uso del equipo de concreto a continuación presentamos los precios, estos precios varían de acuerdo al alquiler por día, semana, mes y según la capacidad de dicho equipo, a continuación presentamos sus costos.

Según la publicación mensual del grupo **S10** en su libro **COSTOS** para la industria de la construcción los precios del alquiler son según se indica en los cuadros que a continuación presentamos.

MEZCLADORA DE CONCRETO GASOLINERO DE 9 pies^3 DE CAPACIDAD

ALQUILER		
DIARIO	SEMANAL	MENSUAL
4.24 dol/dia	3.39 dol/dia	2.54 dol/dia

MEZCLADORA DE CONCRETO PETROLERO 18 pies^3 DE CAPACIDAD

ALQUILER		
DIARIO	SEMANAL	MENSUAL
12.73 dol/dia	10.17 dol/dia	7.63 dol/dia

Para el análisis de costo se a tomado en consideración para los cálculos la mezcladora de 18 pies3 (0.5097m^3), el tipo de alquiler será DIARIO entonces para un metro cúbico debe usarse 2 veces la mezcladora. Como se ha indicado en el capitulo 09 "conclusiones y recomendaciones" el tiempo de mezclado total es de 10 minutos, para un concreto con fibras y de 7 minutos, para un concreto simple (sin fibras) en consecuencia para un metro cúbico será de 20 minutos y 14 minutos respectivamente ya que la capacidad de la mezcladora es de 0.5 m^3 .

Como se ha decidido el tipo de alquiler "DIARIO" cuyo costo es de 12.73 dol/hora, entonces para un metro cúbico será de:

- **Para un concreto simple = 12.73*3.5*14/60 = 10.396 soles.**
- **Para un concreto con fibras = 12.73*3.5*20/60 = 14.852 soles.**

OPERADOR HH: Tiene un costo de 8.40 soles por hora en consecuencia para un metro cúbico su costo es de:

- **Concreto simple = 8.40*14/60 = 1.96 soles.**
- **Concreto con fibras = 8.40*20/60 = 2.77 soles.**

PEON HH: Tiene un costo de 6.78 soles por hora en consecuencia para un metro cúbico su costo es de:

- **Concreto simple = 6.78*14/60 = 1.582 soles.**
- **Concreto con fibras = 6.78*20/60 = 2.26 soles.**

COMBUSTIBLE (galón) : Su costo del combustible (petróleo) es de 6 soles por galón y el rendimiento es de 1 galón/hora, en consecuencia para un metro cúbico los costos que genera es como se indica a continuación:

- **Concreto simple = 6*14/60 = 1.40 soles.**
- **Concreto con fibras = 6*20/60 = 2.0 soles.**

Finalmente con estos valores se calcularan el costo final por metro cúbico de concreto normal y el concreto con fibras de acero.

BENEFICIOS QUE SE GENERA CON EL USO DE FIBRAS DE ACERO INSONEX

Los beneficios que se genera cuando se usa las fibras de acero Insonex es que mejora notablemente las propiedades en su estado endurecido como: la resistencia a la flexión, la resistencia al impacto, la resistencia a la tensión. En las múltiples aplicaciones de la fibra de acero Insonex según sea el caso es económico su uso como podemos notar a continuación.

En los prefabricados con la fibra metálicas ahorra tiempo, mano de obra, no hay necesidad de cortar y colocar malla electrosoldada alrededor de los moldes, solamente hay que hay que mezclar y vaciar el concreto reforzando con fibra metálica para obtener mejor comportamiento y control de agrietamiento.

- **EN CONSTRUCCIONES SUBTERRANEAS**

  - Elimina el trabajo de enmallado
  - Ahorra el tiempo de construcción por manipuleo de enmallado.
  - Los consumos de gunita es menor que cuando se realizan con mallas en consecuencia resulta económico.
  - En el concreto lanzado con fibra de acero hay un menor porcentaje de rebotes que cuando se usa malla electrosoldadas.

- **EN LOSAS Y PAVIMENTOS.**

  - incremento de resistencia en el impacto
  - reducción del espesor de la loza.
  - Menor costo de mantenimiento
  - Separa mas las distancias o en algunos casos se elimina las juntas de dilatación.

A continuación presentamos los costos por metro cúbico de concreto para cada relación a/c y sus diferentes dosificaciones de fibra de acero Insonex.

1. RELACION DE AGUA/CEMENTO 0.40

1.1 CONCRETO PATRON

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	15.29	17.50	267.58
Arena Gruesa	m^3	0.273	20.00	5.46
Piedra Chancada de 3/4"	m^3	0.249	40.00	9.96
Agua	lts	268.32	0.005	1.34
Mezcladora	hr	0.233	44.560	10.38
Operario	HH	0.233	8.400	1.96
Peon	HH	0.233	6.780	1.58
Combustible	galon	0.233	6.000	1.40
Costo Total (S/.)				**299.65**

1.2 DOSIFICACION DE FIBRA: 30Kg/m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	15.29	17.50	267.58
Arena Gruesa	m^3	0.273	20.00	5.46
Piedra Chancada de 3/4"	m^3	0.249	40.00	9.96
Agua	lts	268.35	0.005	1.34
Fibra de Acero Insonex	kg	30.00	5.25	157.50
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**463.53**
% Respecto al Patrón		**154.69**	%	

MATERIALES

- **Cemento Pórtland tipo I Andino**
- **Arena de la Cantera Gloria**
- **Piedra chancada de ¾ de la Cantera Gloria.**
- **Fibra de Acero Insonex de 40 mm de longitud.**

1.3 DOSIFICACION DE FIBRA: 40Kg/m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	15.29	17.50	267.58
Arena Gruesa	m^3	0.273	20.00	5.46
Piedra Chancada de 3/4"	m^3	0.249	40.00	9.96
Agua	lts	268.32	0.005	1.34
Fibra de Acero Insonex	kg	40.00	5.25	210.00
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**516.03**
% Respecto al Patrón		**172.21**	%	

1.4 DOSIFICACION DE FIBRA: 50Kg/ m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	15.29	17.50	267.58
Arena Gruesa	m^3	0.273	20.00	5.46
Piedra Chancada de 3/4"	m^3	0.249	40.00	9.96
Agua	lts	268.32	0.005	1.34
Fibra de Acero Insonex	kg	50.00	5.25	262.50
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**568.53**
% Respecto al Patrón		**189.73**	%	

MATERIALES

- **Cemento Pórtland tipo I Andino**
- **Arena de la Cantera Gloria**
- **Piedra chancada de ¾ de la Cantera Gloria.**
- **Fibra de Acero Insonex de 40 mm de longitud.**

2. RELACION DE AGUA/CEMENTO 0.45

2.1 CONCRETO PATRON

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	12.34	17.50	215.95
Arena Gruesa	m^3	0.307	20.00	6.14
Piedra Chancada de 3/4"	m^3	0.28	40.00	11.20
Agua	lts	245.35	0.005	1.23
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.233	6.780	1.58
Combustible	galon	0.233	6.000	1.40
Costo Total (S/.)				**254.97**

2.2 DOSIFICACION DE FIBRA: 30Kg/ m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	12.34	17.50	215.95
Arena Gruesa	m^3	0.307	20.00	6.14
Piedra Chancada de 3/4"	m^3	0.28	40.00	11.20
Agua	lts	245.35	0.005	1.23
Fibra de Acero Insonex	kg	30.00	5.25	157.50
Mez+B48cladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**413.71**
% Respecto al Patrón		**162.26**	%	

MATERIALES

- **Cemento Pórtland tipo I Andino**
- **Arena de la Cantera Gloria**
- **Piedra chancada de ¾ de la Cantera Gloria.**
- **Fibra de Acero Insonex de 40 mm de longitud.**

2.3 DOSIFICACION DE FIBRA: 40Kg/m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	12.34	17.50	215.95
Arena Gruesa	m^3	0.307	20.00	6.14
Piedra Chancada de 3/4"	m^3	0.28	40.00	11.20
Agua	lts	245.35	0.005	1.23
Fibra de Acero Insonex	kg	40.00	5.25	210.00
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**466.21**
% Respecto al Patrón		**182.85**	%	

2.4 DOSIFICACION DE FIBRA: 50Kg/m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	12.34	17.50	215.95
Arena Gruesa	m^3	0.307	20.00	6.14
Piedra Chancada de 3/4"	m^3	0.28	40.00	11.20
Agua	lts	245.35	0.005	1.23
Fibra de Acero Insonex	kg	50.00	5.25	262.50
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**518.71**
% Respecto al Patrón		**203.44**	%	

MATERIALES

- **Cemento Pórtland tipo I Andino**
- **Arena de la Cantera Gloria**
- **Piedra chancada de ¾ de la Cantera Gloria.**
- **Fibra de Acero Insonex de 40 mm de longitud.**

3. RELACION DE AGUA/CEMENTO 0.50

3.1 CONCRETO PATRON

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	10.35	17.50	181.13
Arena Gruesa	m^3	0.329	20.00	6.58
Piedra Chancada de 3/4"	m^3	0.3	40.00	12.00
Agua	lts	230.04	0.005	1.15
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.233	6.780	1.58
Combustible	galon	0.233	6.000	1.40
Costo Total (S/.)				**221.31**

3.2 DOSIFICACION DE FIBRA: 30Kg/m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	10.35	17.50	181.13
Arena Gruesa	m^3	0.329	20.00	6.58
Piedra Chancada de 3/4"	m^3	0.3	40.00	12.00
Agua	lts	230.04	0.005	1.15
Fibra de Acero Insonex	kg	30.00	5.25	157.50
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**375.83**
% Respecto al Patrón		**169.82**	%	

MATERIALES

- **Cemento Pórtland tipo I Andino**
- **Arena de la Cantera Gloria**
- **Piedra chancada de ¾ de la Cantera Gloria.**
- **Fibra de Acero Insonex de 40 mm de longitud.**

3.3 DOSIFICACION DE FIBRA: 40Kg/m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	10.35	17.50	181.13
Arena Gruesa	m^3	0.329	20.00	6.58
Piedra Chancada de 3/4"	m^3	0.3	40.00	12.00
Agua	lts	230.04	0.005	1.15
Fibra de Acero Insonex	kg	40.00	5.25	210.00
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**432.55**
% Respecto al Patrón		**195.45**	%	

3.4 DOSIFICACION DE FIBRA: 50Kg/m^3 de CONCRETO

Materiales	Und	Cantidad	P.U.	Parcial
Cemento Andino tipo I	bls	10.35	17.50	181.13
Arena Gruesa	m^3	0.329	20.00	6.58
Piedra Chancada de 3/4"	m^3	0.3	40.00	12.00
Agua	lts	230.04	0.005	1.15
Fibra de Acero Insonex	kg	50.00	5.25	262.50
Mezcladora	hr	0.33	44.560	14.70
Operario	HH	0.33	8.400	2.77
Peon	HH	0.33	6.780	2.24
Combustible	galon	0.33	6.000	1.98
Costo Total (S/.)				**485.05**
% Respecto al Patrón		**219.17**	%	

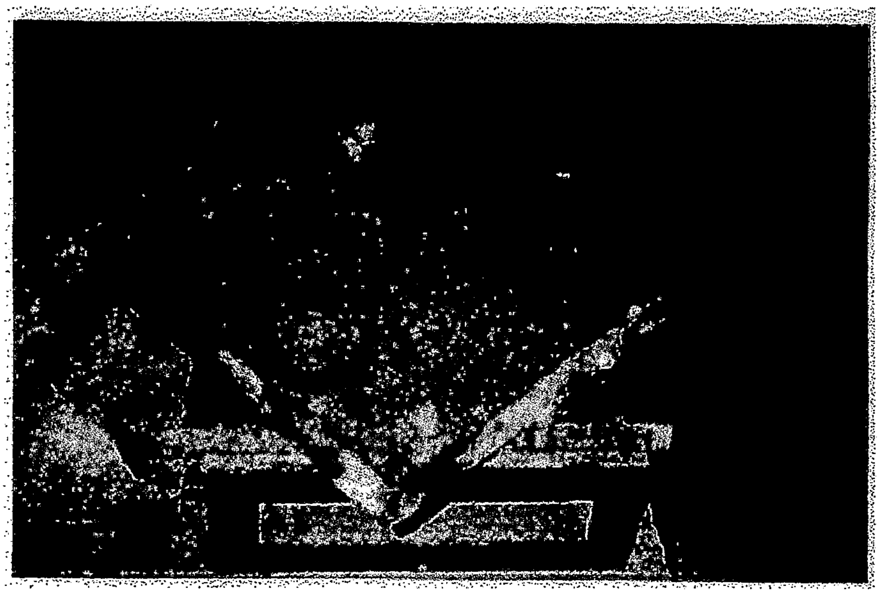
MATERIALES

- **Cemento Pórtland tipo I Andino**
- **Arena de la Cantera Gloria**
- **Piedra chancada de ¾ de la Cantera Gloria.**
- **Fibra de Acero Insonex de 40 mm de longitud.**

ANEXO 03

FOTOGRAFIAS

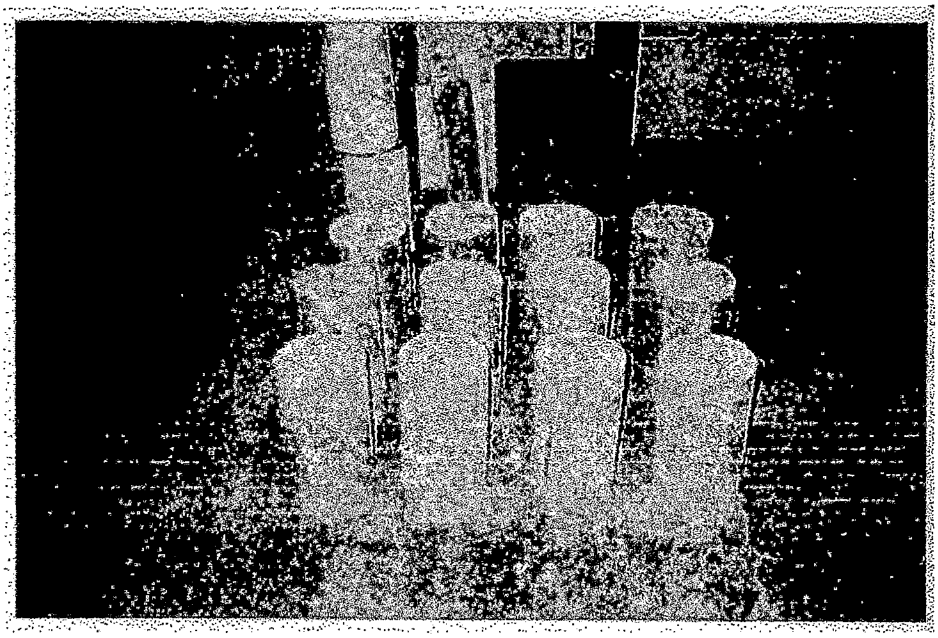
FOTOGRAFÍA 1 : ENSAYO DE FLUIDEZ



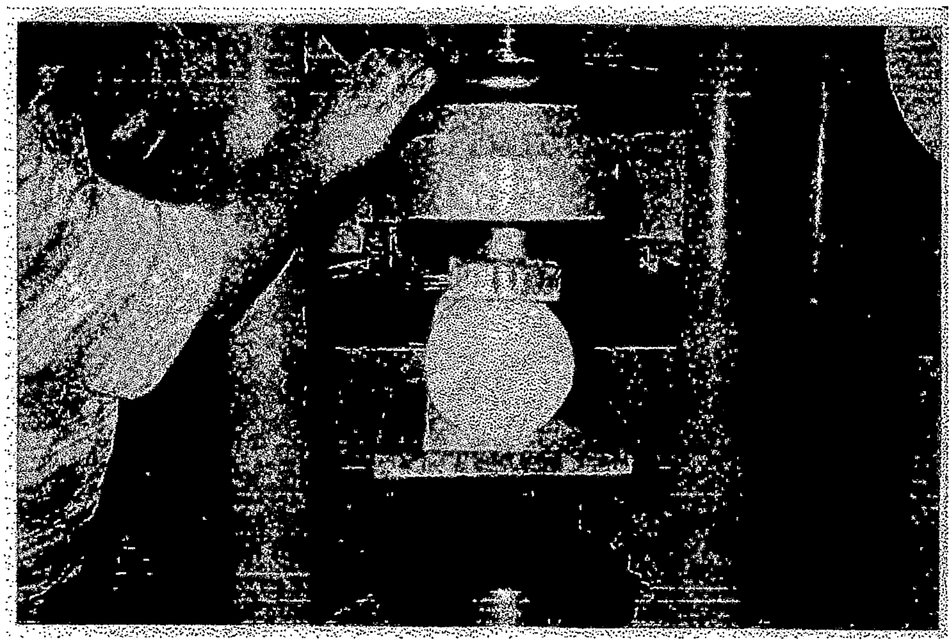
FOTOGRAFÍA 2 : VIBRADO DEL CONCRETO

FOTOGRAFÍA 3 : COMPACTANDO EL CONCRETO PARA EL ENSAYO DE CONTENIDO DE AIRE

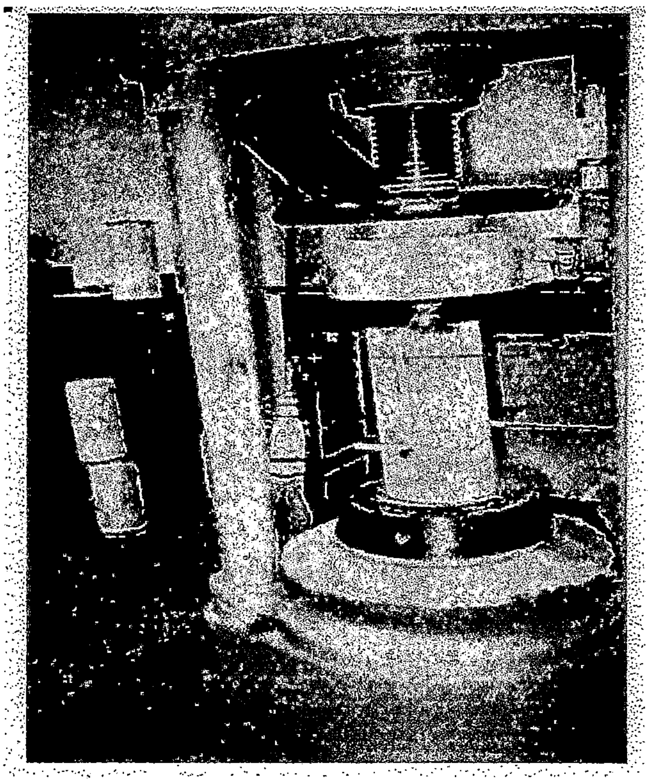
FOTOGRAFÍA 4 : ENSAYO DE TIEMPO DE FRAGUADO



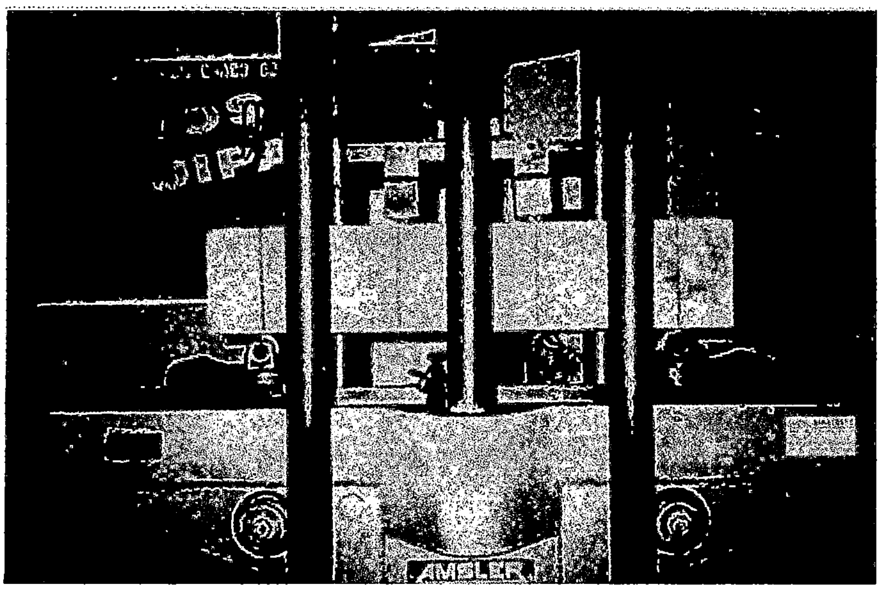
FOTOGRAFÍA 5 : PROBETAS A ENSAYAR



FOTOGRAFÍA 6 : ENSAYO DE TRACCIÓN POR COMPRESIÓN DIAMETRAL

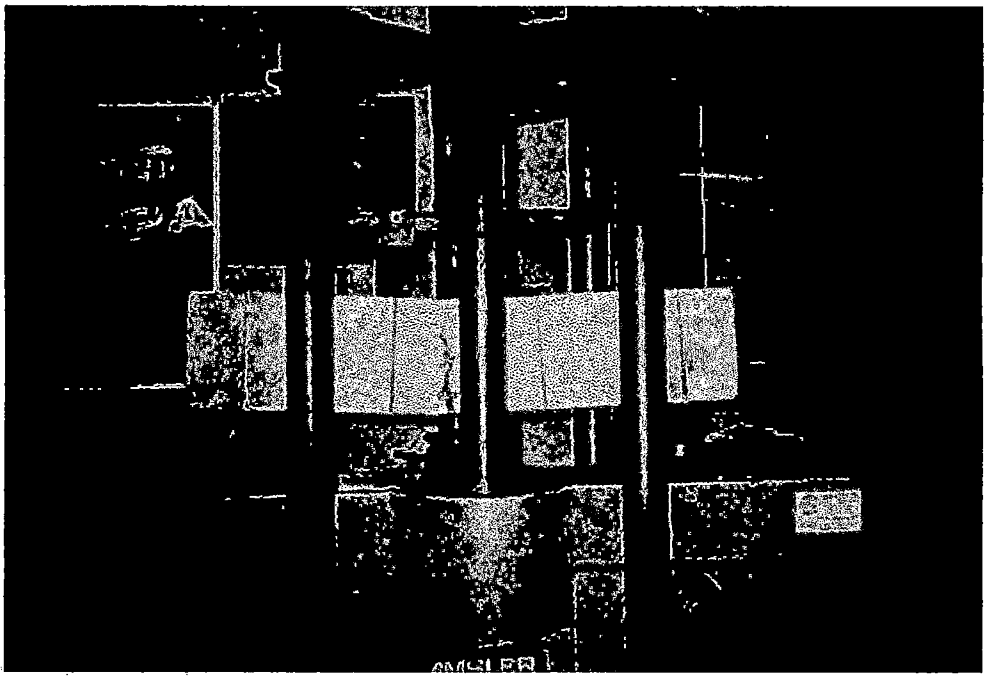


FOTOGRAFÍA 7 : ENSAYO DE MÓDULO ELÁSTICO ESTÁTICO

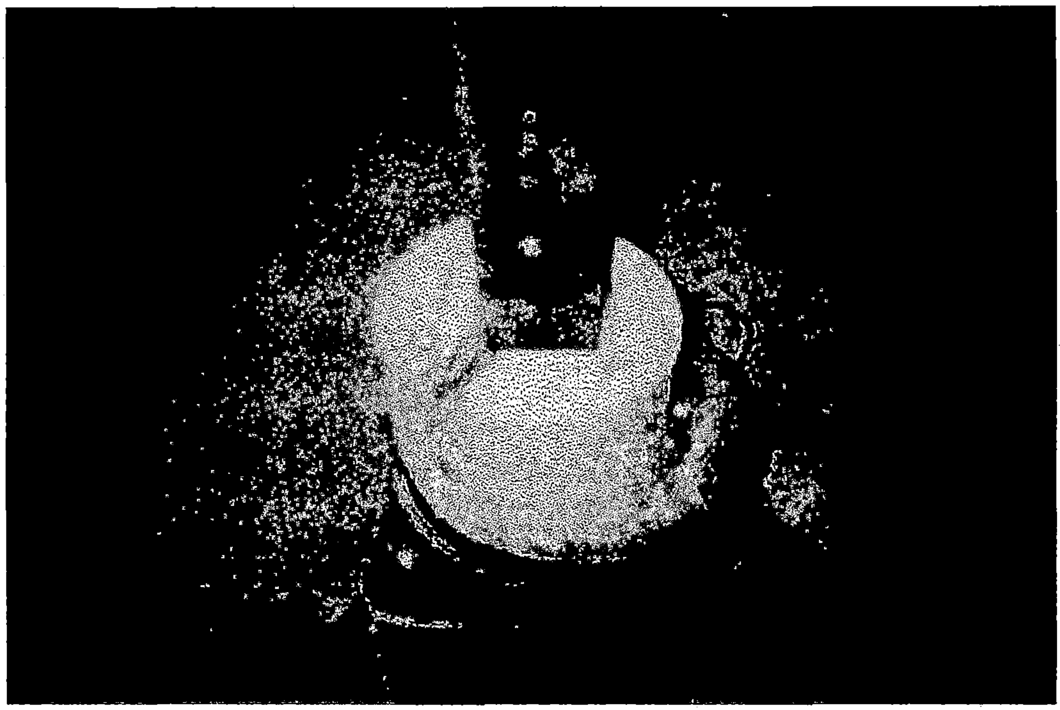


FOTOGRAFÍA 8 : ENSAYO DE FLEXIÓN

FOTOGRAFÍA 9 : FALLA DE LA VIGA SIN FIBRA



FOTOGRAFÍA 10 : FLEXION DE LA VIGA CON FIBRAS



FOTOGRAFIA 11: ENSAYO DE IMPACTO

ANEXO 04

BIBLIOGRAFIA

BIBLIOGRAFÍA

TITULO : TECNOLOGÍA DEL CONCRETO
AUTOR : A. M. NEVILLE Y JJ BROOKS
BIBLIOTECA : PERSONAL
LUGAR – AÑO : MÉXICO 1998
CONTENIDO : USO DEL CONCRETO

TITULO : DISEÑO DE MEZCLA
AUTOR : ING. ENRIQUE RIVERA LOPEZ
BIBLIOTECA : PERSONAL
LUGAR – AÑO : LIMA - PERU 1992
CONTENIDO : DISEÑO DE MEZCLA PARA CONCRETO

TITULO : BOLETINES TÉCNICOS N^{RO} 1 AL 58
AUTOR : ASOCIACIÓN DE PRODUCTORES DE CEMENTO ASOCEM
BIBLIOTECA : PERSONAL
LUGAR – AÑO : LIMA - PERU 1993
CONTENIDO : NORMALIZACION DEL CONCRETO

TITULO : TOPICO DE TECNOLOGÍA DEL CONCRETO EN EL PERU
AUTOR : ENRIQUE PASQUEL, CARBAJAL
BIBLIOTECA : PERSONAL
LUGAR – AÑO : LIMA - PERU 1993
CONTENIDO : EL CEMENTO PÓRTLAND

TITULO : DURABILIDAD DEL CONCRETO
AUTOR : MARIA SALOME AVILA SOTELO
BIBLIOTECA : FIC - UNI
LUGAR – AÑO : LIMA - PERU 1993
CONTENIDO : EFECTOS EXTERNOS CONTRA EL CONCRETO

TITULO : CONCRETO LANZADO
AUTOR : RYON T. S.
BIBLIOTECA : FIC - UNI
LUGAR – AÑO : MEXICO 1990
CONTENIDO : CONCRETO CON INCORPORACION DE FIBRAS DE ACERO

TITULO : TECNOLOGIA DEL CONCRETO
AUTOR : FLAVIO ABANTO CASTILLO
BIBLIOTECA : FIC - UNI
LUGAR – AÑO LIMA-PERU 1995
CONTENIDO : PROPIEDADES DEL CONCRETO.

TITULO : INFLUENCIA DE LA INCORPORACION DE FIBRAS DE VIDRIO
AUTOR : CHOK WONG
BIBLIOTECA : UNI - FIC
LUGAR – AÑO : LIMA – PERU 1984
CONTENIDO : ANALISIS DE RESULTADOS

TITULO : ESTUDIO DE LAS PROPIEDADES DEL CONCRETO UTILIZANDO FIBRAS DE REFUERZO DE ACERO
AUTOR : JULIO CUARESMA CARBAJAL
BIBLIOTECA : UNI - FIC
LUGAR – AÑO : LIMA – PERU 2001
CONTENIDO : ANALISIS DE LOS RESULTADOS.

TITULO : ESTADO ACTUAL Y ULTIMAS TECNOLOGIAS EN EL DISEÑO Y CONTROL DEL CONCRETO.
AUTOR : PROFESORES UNI-FIC
BIBLIOTECA : PERSONAL
LUGAR – AÑO : LIMA – PERU 2001
CONTENIDO : MEJORAMIENTO DEL CONCRETO.

ANEXO 05

INFORMACION SOBRE FIBRAS

Fibercon® Technology Described

Fibercon® steel fibers are manufactured using a method known as "Slit Sheet" processing giving the product a rectangular cross-section. Fibercon® steel fibers are manufactured under a quality plan certified to ISO 9001 standards and ASTM A820-90 type II.

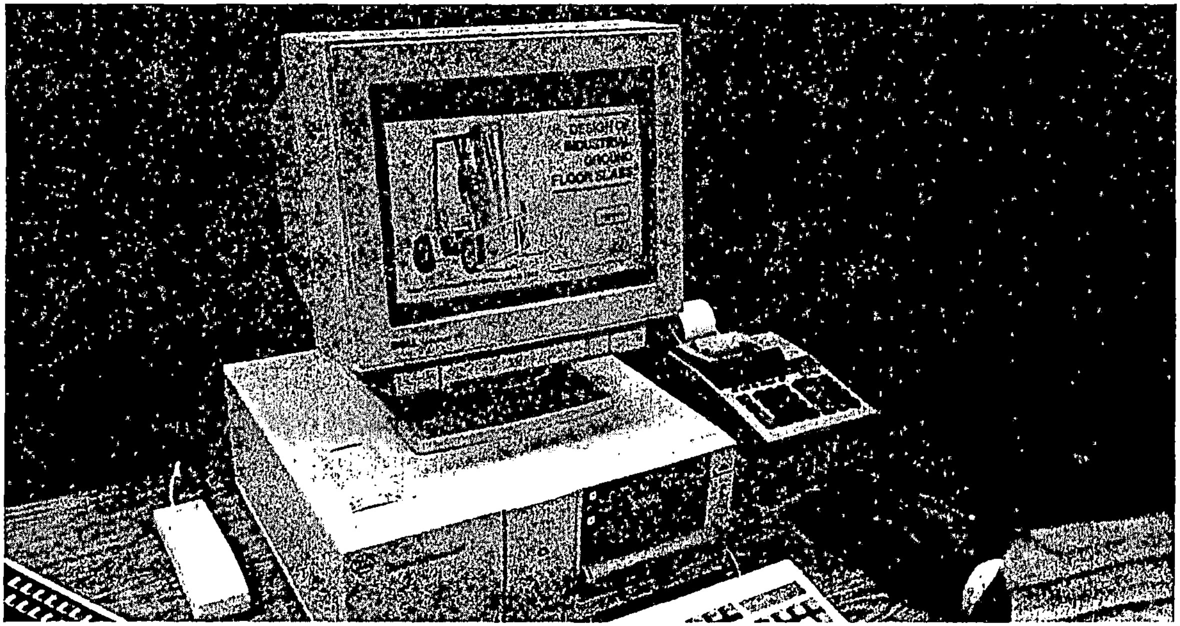
Produced from low carbon steel and various grades of stainless steel, Fibercon® fibers are available in lengths from 1/2" (13mm) to 2.0" (50mm). The fibers are available in straight, wavy, continuously deformed or end-deformed versions.

The following are typical dimensions of the 3 most popular types:

CAR19STR [carbon 19mm straight]
L = 0.75in (19mm), T = 0.01in (0.25mm), W = 0.02in (0.51mm) approx equivalent diameter = 0.0165in (0.42mm), aspect ratio = 45

CAR25CDM [carbon 25mm wavy]
L = 1.0in (25mm), T = 0.013in (0.32mm), W = 0.03in (0.76mm) approx equivalent diameter = 0.022in (0.55mm), aspect ratio = 45

CAR50CDH [carbon 50mm deformed]
L = 2.0 in (50mm), T = 0.02in (0.51mm), W = 0.06in (1.52mm) approx equivalent diameter = 0.039in (1.00mm), aspect ratio = 51



Fibercon® Technology Described

For more precise details of these and other Fibercon® products, please see Mitchell Fibercon material specification sheets.

As a rule of thumb, small fibers tend to be used where control of crack propagation is the most important design consideration. High fiber count (number of fibers per lb or kg) permits finer distribution of steel fiber reinforcement throughout the matrix — and consequently, greater crack control during drying process.

On the other hand, because they exhibit better matrix anchorage at high deformations and large crack widths, longer, heavily deformed fibers afford better post-crack "strength." However, unlike shorter fibers, the dramatically reduced fiber count of longer product yields correspondingly less control of initial crack propagation.

Fibercon® CAR25CDM fiber gives the best compromise between high fiber count and optimal post-crack performance. This makes it ideal for industrial ground floor slabs, highway pavements, precast panels, security applications, shotcrete and other applications. Fibercon® CAR25CDM fiber also handles and finishes easily. A power trowelled industrial floor slab, for example, would not require the use of a supplementary quartz dry shake to hide the fibers - as is typically the case with long deformed fiber products.

FIBERCON®

MITCHELL FIBERCON, INC.
100 South Third St.
Evans City, PA 16033, USA
tel: 800/521-9908
tel: 412/538-5006
fax: 412/538-9118

Improved Strength & Durability

Fibercon® reinforced concrete is a castable or sprayable composite material of hydraulic cements, fine, or fine and coarse aggregates with discrete steel fibers of rectangular cross-section randomly dispersed throughout the matrix.

Fibercon® fibers strengthen concrete by resisting tensile cracking. Fiber reinforced concrete has a higher flexural strength than that of unreinforced concrete and concrete reinforced with welded wire fabric. But unlike conventional reinforcement — which strengthens in one or possibly two directions — Fibercon® fibers reinforce isotropically, greatly improving the concrete's resistance to cracking, fragmentation, spalling and fatigue. When an unreinforced concrete beam is stressed by bending, its deflection increases in proportion with the load to a point at which failure occurs and the beam breaks apart. This is shown in Fig 1. Note that the unreinforced beam fails at point A and a deflection of B.

A Fibercon® reinforced beam will sustain a greater load before the first crack occurs (point C). It will also undergo considerably more deflection before the beam breaks apart (point D). The increased deflection from point B to point D represents the toughness imparted by fiber reinforcement.

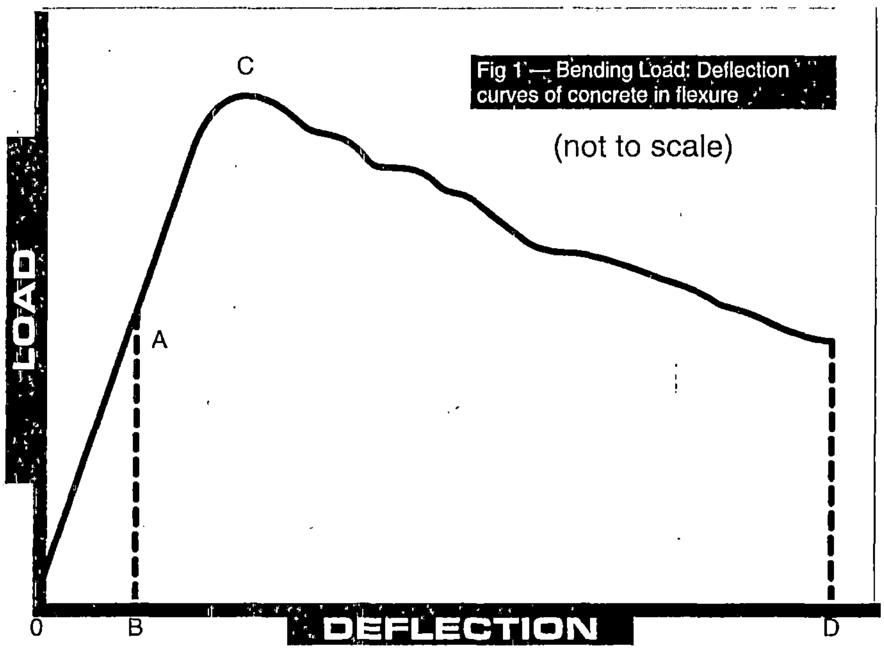


Fig 1 — Bending Load: Deflection curves of concrete in flexure

(not to scale)

Improved Strength & Durability

The load at which the first crack occurs is called the "first crack strength." The first crack strength is generally proportional to the amount of fiber in the mix and the concrete mix design.

Two theories have been proposed to explain the strengthening mechanism. The first proposes that as the spacing between individual fibers becomes closer, the fibers are better able to arrest the propagation of micro cracks in the matrix. Fibercon® brand fibers contain up to 6 times more individual reinforcing elements per pound than competing brands have, minimizing space and maximizing strength.

The second theory holds that the strengthening mechanism of fiber reinforcement relates to the bond between the fibers and the cement. It has been shown that micro cracking of the cement matrix occurs at very small loads. Fibercon® steel fibers, then, serve as small reinforcing bars extending across the cracks.

So as long as the bond between the fibers and cement matrix remains intact, the Fibercon® fibers can carry the tensile load. The surface area of the fiber is also a factor in bond strength. The rectangular cross section of Fibercon® fibers generate 21% more surface area than straight round fibers with the same cross-sectional area — providing greater bond strength. Bond strength can also be enhanced with the use of Fibercon® deformed fibers, which are available from Mitchell Fibercon in a variety of sizes.

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Properties of Reinforcement

When Fibercon® fibers are added to mortar, Portland cement concrete or refractory concrete, the flexural strength of the composite is increased from 25% to 100% — depending on the proportion of fibers added and the mix design. Fibercon® technology actually transforms a brittle material into a more ductile one.

Catastrophic failure of concrete is virtually eliminated because the fibers continue supporting the load after cracking occurs. And while measured rates of improvement vary, Fibercon® reinforced concrete exhibits higher post-crack flexural strength, better crack resistance, improved fatigue strength, higher resistance to spalling, and higher first-crack strength. Figure 2 shows concrete flexural strengths when reinforced at various fiber proportions. Additionally, Fibercon® deformed fibers provide a positive mechanical bond within the concrete matrix to resist pull-out.

Fibercon® fibers are available in lengths from 0.50" (13mm) to 2.0" (50mm) and aspect ratios between 40 and 60. The fibers are manufactured either straight or deformed, and conform to ASTM A-820.

A low carbon, cold rolled sheet steel is used to produce Fibercon® product for concrete applications. This steel has ultimate

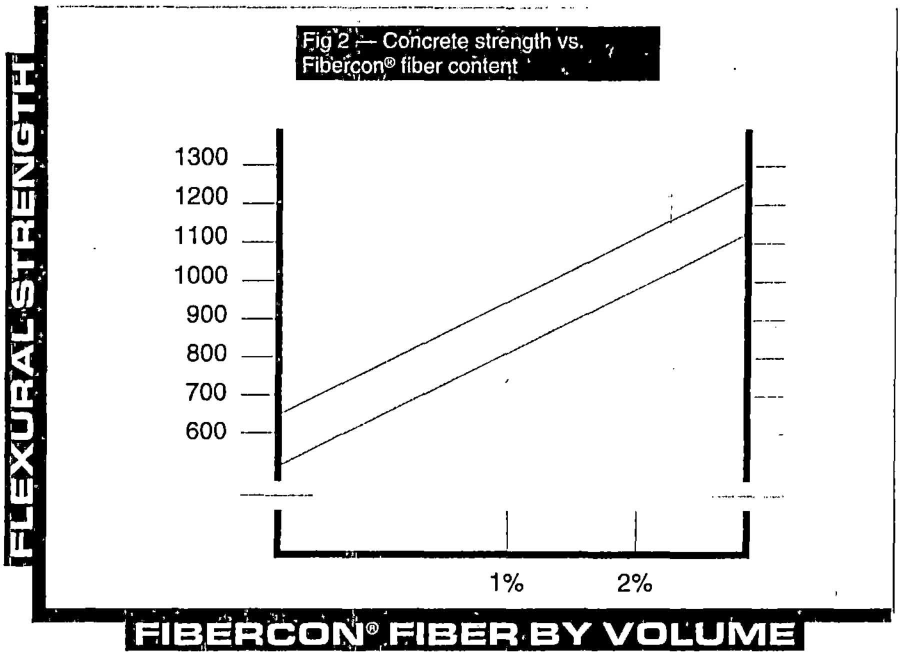
Fig 2 — Concrete strength vs. Fibercon® fiber content

Properties of Reinforcement

tensile strengths from 50 to 120 ksi (345 to 828 MPa) and has sufficient ductility actually to permit 180° bends without rupture. Various stainless steel grades are used for the reinforcement of refractory concretes. Information on these grades for high-temperature applications is available upon request. Fibercon® fiber has more reinforcing elements per pound of product than any of its competitors. There are nominally 21,000 3/4" and 16,000 1" straight fibers per pound, as well as 9,000 1" (254mm) deformed fibers per pound.

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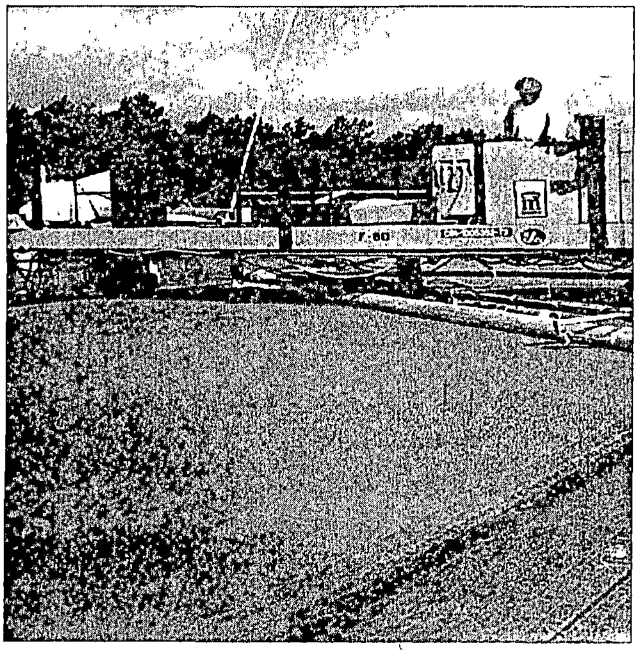
Mixing, Placing & Finishing

The quantity of fibers added to concrete is directly proportional to the ultimate flexural strength of the composite. But fiber contents in excess of 200 lbs./cu. yd. may become more difficult to introduce into the mixture. All fiber additions should be pre-weighed and metered during mixing.

Mixing procedures vary according to the aspect ratio of the Fibercon® steel fiber type specified. Aspect ratios (AR = length/diameter) lower than 50 may be added to the mixer by pouring from its shipping container — as with any bulk material. Aspect ratios above 50 may require additional care and/or equipment for addition to the mix. Fibercon® fibers can be added to concrete at the project site or at the central plant. At the job site, add Fibercon® fibers through the hopper of the transit mixer. Increased mixing revolutions are required. Batch plant addition of fibers and coarse or fine aggregate is normally done by conveyor. No extra mixing time is required if the fiber is added in this manner. Although it is seldom needed, Mitchell Fibercon has fiber-dispensing equipment available upon request.



Because fiber reinforced concrete is usually designed to use less water than ordinary mixes, vibration is frequently necessary to obtain ready flow and consolidation. As is the case with plain concrete, excessive vibration should be avoided. All test samples should be vibrated externally and not rodded.

All conventional, externally vibrated concrete placing and finishing equipment can be used with fiber reinforced concrete. Latest laser screed technology, as well as more conventional, manually moved vibrating screeds can be used to level the concrete. If needed, the surface may be floated soon after screeding and while the concrete is still plastic. Use conventional metal tools and techniques to produce a fiber-free surface. Caution must be exercised to prevent overworking, which might cause the fiber to lose its isotropic orientation.

Use stiff hair or wire brooms, as well as wire comb texturing machines, to score and/

Mixing, Placing & Finishing

or texture the surface. Texturing by dragging wet burlap is not recommended because it tends to pull fibers out of the mixture. All texturing should be delayed until the concrete has set enough to resist fiber pull-out. All standard methods of curing regular concrete can be used for fiber reinforced concrete. However, curing should start as soon as possible. Standard methods to test and control the quality of regular concrete may be applied to fiber reinforced concrete. But fiber reinforced concrete should be vibrated instead of rodded in the molds.

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Fibercon® Product Mix Designs

The proportions of Fibercon® fibers in mix designs usually range from 0.2% to 2.0% of the composite's volume. Key factors to consider largely depend on the application under consideration and/or the physical properties desired in the finished project. Table 1, below, summarizes typical fiber rates for selected common applications.

A successful mix design recently developed and used in several projects is shown in Table 2. This design is economical and has low drying shrinkage. The 28-day strengths of the mix with Fibercon® reinforcement are detailed in Table 3 (over). Table 4 shows a typical shotcrete design mix using Fibercon® deformed fiber. It can be seen in Table 5 (over) that compressive strength and modulus of rupture remain high and that the deformations provide superior toughness.

Mix designs with fiber proportions above 100lbs./yd.^{3} (60 kg/m^3) are usually adjusted to accommodate the presence of millions of steel fiber reinforcing elements. The adjustments are an increase in the cement factor, a reduction in the top size of the coarse aggregate and the addition of a super plasticizer. Prototype testing is recommended to determine the optimum design for each application.

Table 1 — Nominal Fibercon® Proportions In Various Applications

APPLICATIONS	LBS./Y^3 (KG./M^3)
Industrial Floors (new and overlays)	20 to 120 (12 to 72 kg/m^3)
Airports (apron, taxiway & runway)	20 to 160 (12 to 95 kg/m^3)
Dolosse	80 (48 kg/m^3)
Burial Vaults	25 (15 kg/m^3)
Mine Crib Blocks	90 to 120 (54 to 72 kg/m^3)
Shotcrete	40 to 120 (24 to 72 kg/m^3)
Security/Ballistic	160 to 200 (95 to 120 kg/m^3)
Marine	40 to 160 (24 to 36 kg/m^3)
Highway Pavements (Concrete)	50 to 140 (30 to 78 kg/m^3)
Bridge Overlays	50 to 160 (30 to 95 kg/m^3)
Dam Stilling Basins	120 (72 kg/m^3)
Architectural Panels (non-structural)	40 to 60 (24 to 36 kg/m^3)
Architectural Panels (structural)	100 (60 kg/m^3)
Concrete Pipe	100 to 120 (60 to 72 kg/m^3)
Septic Tanks	40 (24 kg/m^3)
Retaining Walls (Poured)	40 to 60 (24 to 36 kg/m^3)
Asphalt Pavements	20 to 25 (12 to 15 kg/m^3)
Tilt-Up Panels	80 to 120 (48 to 72 kg/m^3)

Table 2 — Typical Fibercon® Flooring Mix Design

CONSTITUENT	LBS./Y^3 (KG./M^3)
Cement: Type 1*	564 lbs. (335 kg/m^3)
Sand (SSD)	1490 lbs. (884 kg/m^3)
Coarse Aggregate	1495 lbs. (887 kg/m^3)
3/8" Max. (SSD) (9,5mm)	325 lbs. (193 kg/m^3)
FIBERCON® Fiber	80 lbs. (48 kg/m^3)
Water (total in mixture)	208 lbs. (123 kg/m^3)

*with super plasticizer, per manufacturer

Table 4 — Typical Fibercon® Shotcrete Mix Design

CONSTITUENT	LBS./Y^3 (KG./M^3)
Cement: Type 1	752 lbs. (446 kg/m^3)
Sand (SSD)	1658 lbs. (983 kg/m^3)
Coarse Aggregate	1032 lbs. (612 kg/m^3)
FIBERCON® Fiber (deformed)	100 lbs. (60 kg/m^3)
Silica Fume	50 lbs. (30 kg/m^3)

Fibercon® Product Mix Designs

Table 3 — Fibercon® 28-Day Product Strengths

	COMPRESSIVE		MODULUS OF RUPTURE	
	PSI	MPa	PSI	MPa
	5840	40.26	850	5.85
	5660	39.02	820	5.65
	5660	39.02	870	6.00
Average	5720	39.43	847	5.83

Table 5 — Typical Fibercon® Dry-Mix Shotcrete Strength Results

	COMPRESSIVE		MODULUS OF RUPTURE		TOUGHNESS	
	PSI	MPa	PSI	MPa		
	4060	27.98	985	6.79	I_5	3.6
	4180	28.81	1036	7.14	I_{10}	6.3
			1120	7.72	I_{20}	9.9
Average	4120	28.40	1047	7.22		

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FAQ*'s — Fibercon® Installation

Can steel fibers replace two layers of wire mesh in a floor slab?

In ground-bearing industrial floor slabs, common design practice occasionally dictates using two mesh layers. However, this steel is not acting in a structural capacity and can therefore be readily be replaced with Fibercon® steel fiber reinforcement.

How are the fibers added to concrete?

Fibers can be added at the batching plant by depositing onto an aggregate conveyor. Product can also be added by gantry or lightweight conveyor directly into the back of a transit mixer on site.

*"Frequently Asked Questions"

Don't steel fibers "ball-up" when mixing?

Homogeneous, trouble-free mixing depends on the fiber product's aspect ratio — the ratio of length to diameter. If this number exceeds 55, the risk of fibers bunching together increases. Special packaging methods and/or dispensing machinery might then become necessary. But if the aspect ratio falls below this critical range, fibers can be added directly into the mix at virtually any stage — without fear of balling.

The fibers are made from mild steel - what about rusting?

The relative density of Steel is 7.8, and concrete mortar's is about 2.4. When concrete is vibrated, fibers begin to align themselves in the top layer of laitance. Subsequent operations such as floating and trowelling further embed the fibers. So the number of fibers exposed at the surface of a finished installation is minimal. If subjected to conditions that promote corrosion, these fibers will rust. This, however, will almost certainly not create a cosmetic problem. But in circumstances where finish is critical, such as in architectural panels incorporating white OPC, stainless steel fibers are available from Mitchell Fibercon.

Why doesn't rusting lead to other problems?

The small size of individual steel fibers prevents a build up of expansion stresses

Fibercon® "Frequently Asked Installation Questions"

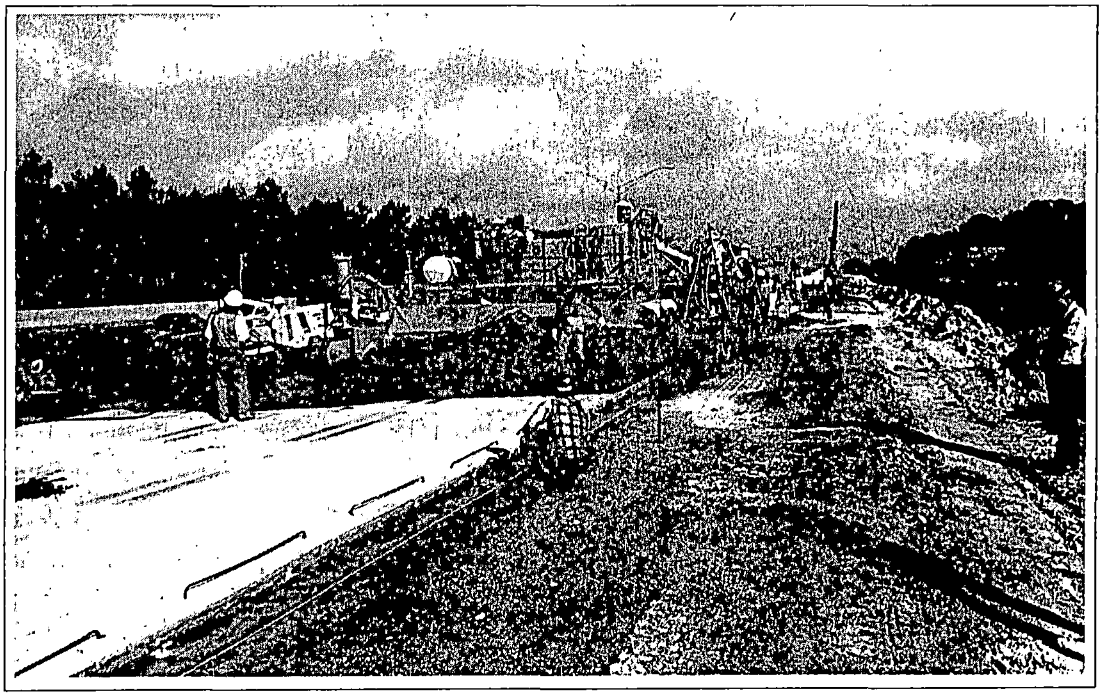
during the corrosion process. The discontinuous nature of steel fiber reinforcement also effectively eliminates galvanic corrosion. Hence, concrete spalling and bursting does not occur. Finally, past studies of structures like bridge decks conclusively prove that fiber corrosion only occurs to the depth of the concrete's carbonation.

Can steel fiber reinforced concrete ("SFRC") be textured?

Yes. Any conventional method can be used — although the use of burlap drag is not recommended. The heavier the texture, the more the fibers will be pulled from the surface. Again, the presence of these fibers will not pose any appearance or safety problem. Successful installations throughout the world — including roads and bridges — bear testimony to this.

Can steel fiber reinforcement be used in the presence of a wire guidance system?

Again, since steel fiber reinforcement is "discontinuous," it does not interfere with wire guidance systems. Unlike conventional reinforcement, no minimum cover is required.



Fibercon® "Frequently Asked Installation Questions"

Do steel fibers affect the slump of concrete?

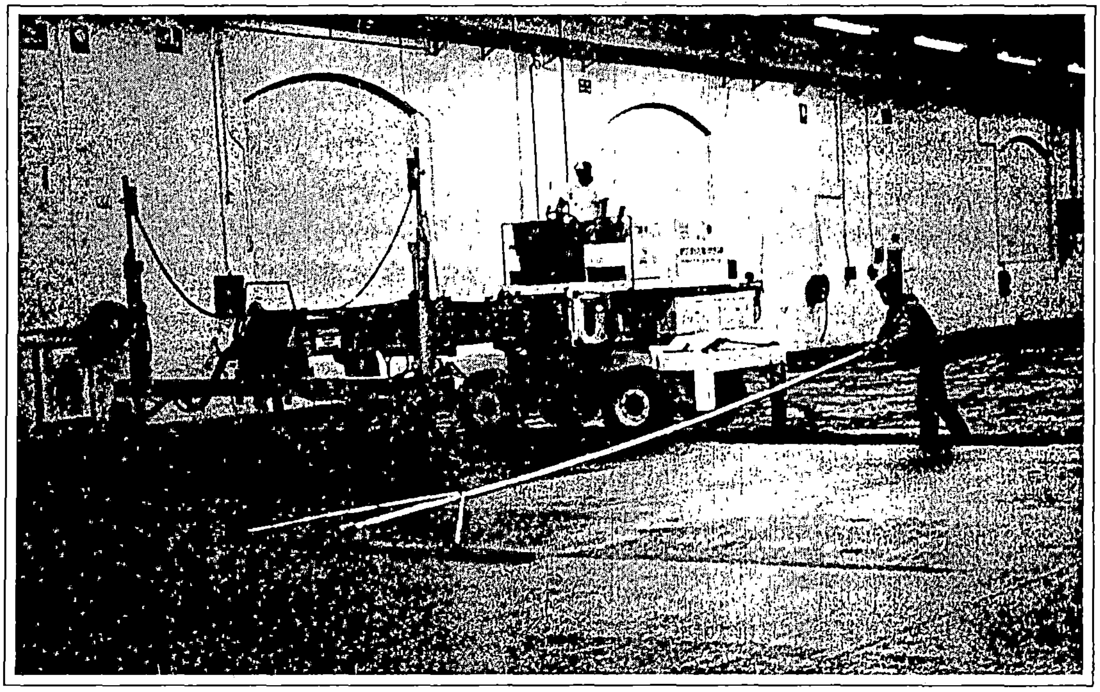
Adding steel fibers, particularly at higher concentrations, will give rise to an apparent loss as measured by the slump test. This results from fibers interlocking — which, when energy is applied, will align and allow concrete to flow more readily. Generally, it is recommended that the base slump of concrete without fiber is 1.0-2.0 in (25-50mm) greater than the final desired target. This is normally achieved by incorporating a small quantity of (super)plasticizer.

Can SFRC be pumped?

Fibercon® SFRC can be readily pumped — providing, as with conventional concrete, that the base mix contains sufficient fines to prevent segregation.

Can SFRC be placed and finished using conventional techniques?

Yes. Use of standard construction methods will yield excellent results. Steel fiber reinforcement also offers a whole new dimension to modern large bay methods of floor construction — such as Laser Screed technology — as well as to more conventional techniques.



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What about joint detailing?

If using long bay construction methods, the longitudinal joints would be tied using dowels, as per conventional design. Transverse joints are typically saw-cut induced to 1/3 the slab's depth. Cutting should take place as early as possible — i.e., within 24 hours of pouring. Spacing between joints not only depends on the incorporation of steel fibers, but also on other considerations — like concrete shrinkage characteristics and the quality of sub-base preparation. Hence, joints will typically be spaced at between 20 ft and 40 ft (6m and 12m) centers, normally to coincide with columns or other intrusions. The length-to-width ratio of panels should not exceed 1:1.5. Construction of "jointless" floors — heavily reinforced slabs cast in bays to 21,500 sq ft (2,000m^2) — is also increasingly popular. There is normally a compromise between number of joints, joint openings and cracking risks. The most suitable jointing regime should be assessed on a case-by-case basis.

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FIBERCON® product performance details

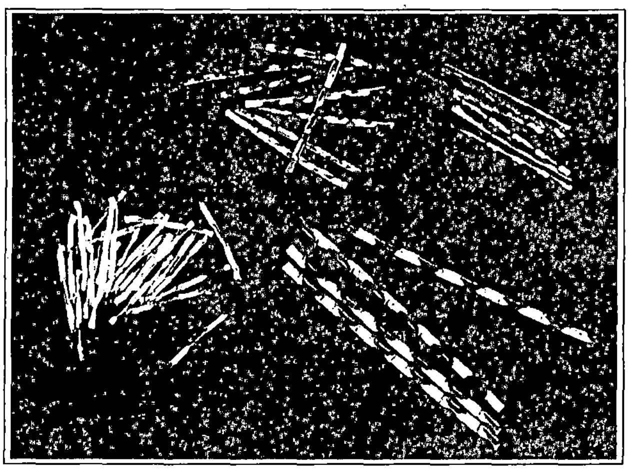
FAQ*'s — Fibercon® Design

What is steel fiber reinforced ("SFRC") concrete?

Steel fiber reinforced concrete ("SFRC") comprises hydraulic cements containing aggregate (fine, or fine and course) and steel fibers. A plasticizer or superplasticizer is often used to enhance mix workability. Steel fiber products ("SFR" or "steel fiber reinforcement") are available in a variety of types and sizes from various manufacturers. However, the underlying principle of all SFRC designs is to provide discrete, discontinuous reinforcement and effective crack control.

How do steel fibers work?

Unlike wire mesh or rebar, steel fibers reinforce in three dimensions throughout the entire concrete matrix. The fiber functions to reinforce and restrain micro-cracking, essentially acting as "miniature reinforcing bars". Thus, the earlier a crack is intercepted and its growth inhibited, the less chance that it will develop into a major flaw.



Are steel fibers a replacement for structural steel?

The sensible answer is "no": nothing takes the place of a properly engineered application to code. In structural applications, sufficient continuous steel reinforcement is required to take the full applied tensile load. Among the exceptions to this rule, however, are certain precast applications. Steel fiber reinforcement may be used in conjunction with structural.

What properties of the concrete are improved by using steel fibers?

Steel fiber reinforced concrete acts as a uniform composite material. Compared to plain or conventionally reinforced concrete, the most immediate differences are improved ductility and post-crack performance. However, the specific affects on matrix mechanical properties greatly depend on the type and quantity of fiber used. Generally speaking, smaller fibers with a high fiber count offer superior first-crack strength and better fatigue endurance. Should a crack open widely, longer fibers with mechanical anchorage mechanisms offer better post-crack performance. For ground-supported slabs,

*"Frequently Asked Questions"

Fibercon® "Frequently Asked Design Questions"

though, we strongly recommend the former: the superior first-crack resistance of an installation with high fiber count.

What are specific concrete properties does Fibercon® technology improve?

FLEXURAL STRENGTH — significant increases (1.5 to 3.0 times) in the first-crack and ultimate flexural (bending) strength can be achieved over plain concrete with higher dosage rates of shorter fiber products.

FATIGUE RESISTANCE — the fatigue strength of steel fiber concrete is far greater (1.6 times) than that of conventional concrete.

IMPACT — steel fibers greatly increase (1.5 to 5.0 times) concrete's resistance to damage from heavy impact.

SHEAR STRENGTH — shear strength is much improved (1.25 to 2.0 times) over unreinforced concrete.

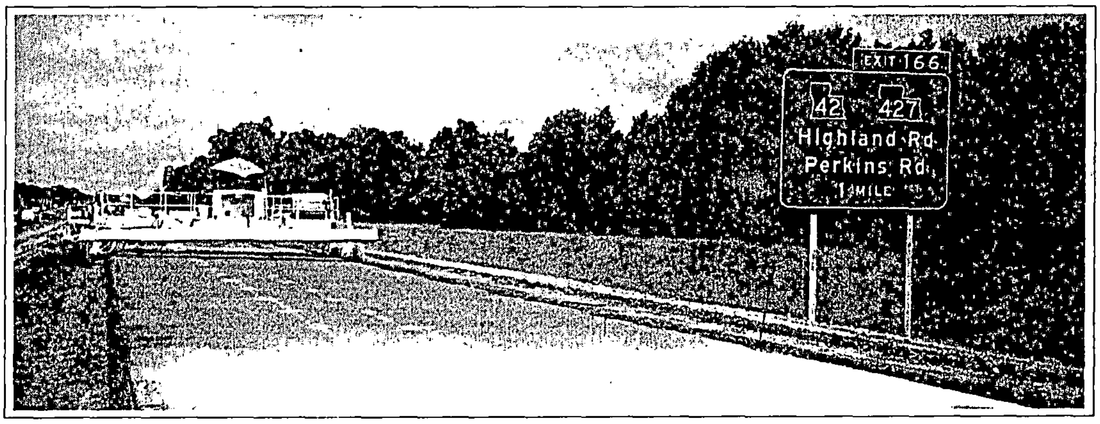
SHRINKAGE — although the steel fibers themselves do not affect shrinkage rate, they can minimize and help eliminate shrinkage cracks, particularly in a restrained situation.

ABRASION — steel fibers do not affect the abrasion rate of concrete mortar itself. But they do offer a high degree (1.2 times) of protection against heavy duty abrasion and gouging. Spalling is dramatically reduced.

PERMEABILITY - again, steel fibers do not directly affect concrete permeability. But by effectively controlling micro-cracking — and the resulting susceptibility to moisture and chemical penetration — SFR can help reduce the overall porosity of the matrix.

If SFRC is so good, will it entirely eliminate cracking?

Nothing protects against bad materials and methods. So nothing can entirely eliminate cracking. SFRC offers an extremely effective means of controlling cracks — and can substantially reduce opportunities for cracking. But concrete is an unpredictable



Fibercon® "Frequently Asked Design Questions"

material. Design and installation practices can also yield equally unpredictable results. That's why optimal attention to product selection, engineering, sub-base preparation, joints, and curing are so essential to overall project performance.

Can steel fiber slabs be substantially thinner?

Steel fiber reinforced floor slabs can be designed in a couple of different ways. Using the more conventional elastic state theory (Westergaard), if the critical load on the slab is static the slab thickness will be much the same as with traditional materials. But if the critical load is dynamic, SFRC's vast improvement in fatigue resistance can justify a lower safety factor. So the resulting slab can be as much as 25% thinner for the same load carrying capacity.

So what about use of a plastic state design method?

Alternatively, the exceptional post-crack performance of SFRC permits use of a plastic state design method, such as Meyerhof. This will, in turn, allow substantial reductions in slab thickness. However, employing this type of design approach will result in radial cracking under the load, as well as increased slab deflection.

What is the typical dosage rate?

SFRC dosage rates depend on the application and the concrete properties required. Typically, 35 - 85 lbs/cu yd (20 - 50kg/m^3) will satisfy most requirements. Lower dosages tend to be used when replacing conventional steel mesh. At higher concentrations, vastly improved mechanical strength properties allow SFRC to be used in the most demanding applications.

How does SFRC lower costs over the installation's life?

Depending on the type, quantity and complexity of reinforcement in traditional design, SFRC can offer substantial cost savings. On occasions, initial costs steel fiber alone might be slightly higher. But when

Fibercon® "Frequently Asked Design Questions"

labor, time, material and activities savings are considered, SFRC costs per sq yd (or m^2) actually diminish. Moreover, the superior performance of Fibercon® concrete often results in reduced maintenance expenses over the installation's life — further lowering "whole life" project costs.

How should a FIBERCON® specification read?

The following phraseology is all you need to secure the benefits of Fibercon® technology: "Steel fiber reinforcement shall be added to the concrete at a rate of _____ lbs/cu yd (_____kg/m^3). Steel fiber shall meet all requirements of ASTM A820-90 type II. The fiber shall be made from cold rolled low carbon steel with a tensile strength in the range of 50 - 120 KSI (400 - 800 N/mm^2) and have sufficient ductility to permit 180 degree bends without rupture. Fibers shall have an aspect ratio in the range of 40 to 50 and a length of 1.0 in (25mm)."

What is the difference between polypropylene and steel fibers?

Polypropylene fibers mainly help control plastic shrinkage cracking, which can occur in the very early stages of concrete life. Steel fibers reinforce the concrete in its hardened state, thereby improving its strength and durability. The major difference between steel and polypropylene is their respective Young's modulus and tensile yield strength. Steel fibers have a sufficiently high modulus of elasticity and tensile strength to assume excess strain across a crack — and hold it tightly.

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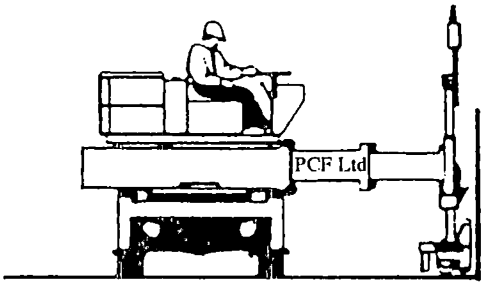

Mega Demonstration

Floor Construction

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Introduction

Concrete floors are everywhere. They form that part of the building between the roof and the ground and as such, are often not given the attention they deserve.

Unfortunately, many floors fail to do their job and are responsible for more user complaints than virtually any other part of the building. One reason for this is that the floor performs a dual role. Not only is it a part of the building structure, it also forms an essential part of the users equipment. Essentially, it is the table on which the client works.

The floor may be a traffic-way for warehouse handling equipment. It may also form part of a flexible manufacturing system controlled by embedded wires for the automatic guidance of robot vehicles. Whatever the function of the floor, each one requires its own individual characteristics in terms of structural capacity, flatness, abrasion resistance, aesthetics, etc

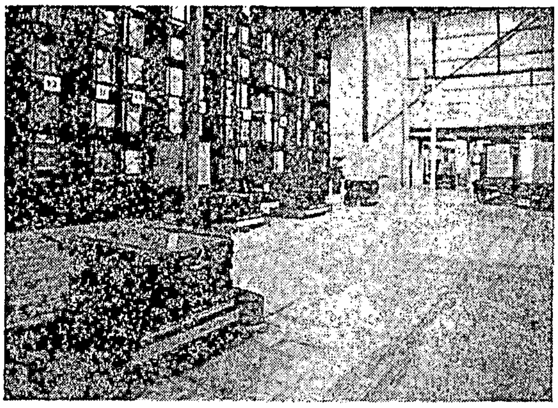

Fig. 1
High production distribution warehouse.

When a floor fails to perform its intended purpose, high costs rapidly accumulate in the loss of production and logistics significantly increasing the overall cost of repair.

Another increasingly important consideration is speed of construction. The system outlined in this paper allows dramatic programme time savings whilst still maintaining quality and reliability.

Common Areas of Complaint

The four main problem areas that occur with concrete floors are:

- Irregular surface tolerance
- Cracking
- Joint breakdown
- Abrasion

Each one of the above can be affected by various factors. For example, floor surface tolerance can be attributed to the construction method in the short term, and in the long term, sub-base/sub-grade movement.

Cracking can be attributed to inadequate design thickness, poor attention to detail, inferior concrete mix design, restraint from sub-base/sub-grade, incorrect use of or wrong type of reinforcement, or deferred curing and provision of stress relief joints.

Joints are prone to accelerated breakdown due to design detail, inferior concrete mix, reinforcement methods and poor workmanship, particularly in the construction/finishing of pre-formed construction joints.

Poor abrasion resistance can be attributed to the design of the concrete mix, improper specification and use of surface finishes, and attention to power trowelling and curing practices.

State-of-the-art

Floors in the UK have traditionally been constructed in narrow strips using concrete reinforced with one or possibly two layers of wire mesh. The method of construction and materials used alone have caused many of the problems highlighted. Coupled with a non sympathetic approach to the client's requirements it is no wonder that concrete ground floor slabs are responsible for so many complaints.

Four years ago, John Kelly (Lasers) Ltd revolutionised the approach to the construction of concrete floors with the introduction of the Laser Screed to Europe and Scandinavia. Precision Concrete Floors Ltd (PCF), having constructed floors using traditional methods for many years, immediately saw the potential that this machine offered.

Having purchased a Laser Screed, PCF embarked on a radical reorganisation of their company and sought the close co-operation of other companies in the materials supply sector, to offer a complete integrated approach to the design and construction of high quality concrete floors. The only area still lacking until recently, was the accurate application of quartz and metallic dry shake toppings. This now, has been answered by the introduction of the STS-130 topping spreader.

Using the knowledge that John Kelly (Lasers) Ltd has developed around laser control systems, steel fibre reinforcement from Fibercon UK Ltd and dry shake toppings and curing compounds from Armorex, PCF can now offer a tailor made floor system from the sub-grade upward; most importantly, with a sympathetic approach to the building user's requirements. Emphasis is always on achieving the highest possible quality within a given budget.

Theory of Laser Level Control

The heart of Precision Concrete Floors systematic approach to floor construction lies in utilising laser control technology in order to maximise speed, and material savings, whilst maintaining a high degree of accuracy.

The basis of the laser control system is the laser transmitter. This unit generates a thin beam of laser light which when rotated through 360 degrees at a constant 300rpm, gives a level reference plane over the entire work area up to a radius of 300 metres.

An important consideration for laser transmitters is that they self-level. Should construction equipment working near the transmitter cause enough vibration to jar it out of level, the laser transmitter will switch off automatically until such time as it has re-levelled itself.

By using a laser receiver to detect the centre of the reference plane, the operator is able, by measuring a constant distance below the reference plane, to establish spot levels enabling control of sub-grade, sub-base and finished floor elevation.

Today's technology allows the totally automatic control of levels of most types of machinery by direct intervention of the machine's hydraulic system. This works on a checking and correction cycle of five times per second, much faster than the human response of an operator.

Sub-base Preparation

Before we get to the point of placing the concrete, the importance of a well prepared sub-base must be recognised. Well compacted sub-base preparation to good tolerances ensures that the slab thickness will be uniform. High areas in the sub-base produce a slab of less thickness locally, undermining the original design calculations. Low areas are at a direct cost to the contractor and client in terms of extra concrete - holes are expensive to fill.

Varying tolerances in the sub-base also give rise to a higher coefficient of friction between the ground and the concrete slab. As a result, there will be a severe increase in the risk of restrained shrinkage cracks occurring and joints failing to perform satisfactorily.

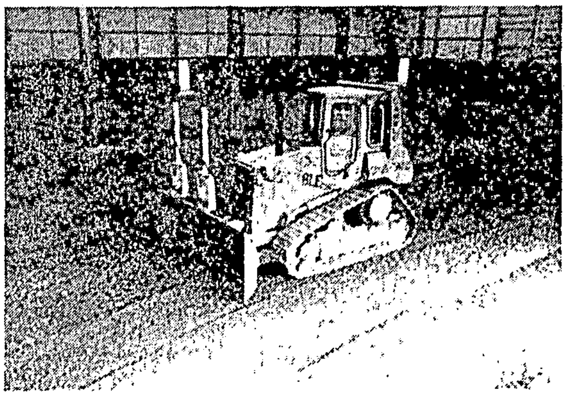

Fig. 2
Sub-base preparation using tilt and lift bulldozer

The use of automatically controlled earth moving plant such as lift and tilt bulldozers can substantially improve the surface tolerance of the sub-base. By using a fully automatic system linked to the machine's hydraulics, as opposed to a manual system, consistent tolerances of +/- 6mm can easily be achieved. As a direct result, money is saved and there is less risk of cracking.

Laser Screed Construction

The Laser Screed is a four wheel drive, four wheel steer/crab steer, laser controlled screeding machine that requires no side forms for level control. Mounted on twin axles, a full circle slewing turntable carries a counterbalanced telescopic boom having a 6.1 metre reach, on the end of which is mounted a 3.66 metre wide screed carriage assembly.

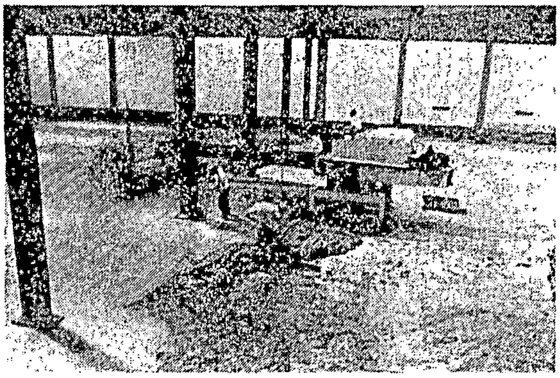

Fig. 3
The Laser Screed

The screed carriage assembly consists of a plough and auger for the removal of surplus concrete, and a vibrator for compaction. Compaction of concrete test results of the Laser Screed have shown that the machine is able to evenly compact concrete to depths in excess of 300mm.

On the end of the screed carriage assembly are mounted two multi-directional laser receivers to refer to the datum from the laser transmitter mounted conveniently on a nearby column or tripod.

Level control of the screed carriage assembly, in relation to the laser datum, is by direct intervention of the machine's hydraulic system. This completely eliminates operator error, enabling high surface regularity to be maintained over widths of 45 metres or more.

The Laser Screed is utilised in conjunction with concrete mixer trucks or a pump, discharging a 5 metre wide strip of concrete across the width of the pour, with a surcharge of 25 - 35mm to finished floor level. The Laser Screed works along the strip from left to right when facing the pour to allow for the working direction of the auger.

The method of operation is to extend the telescopic boom over the newly placed concrete, then lower the screed carriage assembly until it locks on to the finished floor level dictated by the automatic laser control system. The boom is then retracted, thus drawing the screed carriage assembly across the concrete, levelling and compacting as it passes. The machine then tracks right for the next pass, with the operator ensuring an overlap of 300mm on the previous pass. This ensures optimum level and surface regularity is maintained over the entire slab. Once the machine has reached the right hand extent of the face, it will return to the left hand side to proceed with the next pass.

One pass of the Laser Screed provides approximately 22 sq metres of concrete screeded and compacted to floor level in under two minutes. This consistent production ability enables floor areas of up to 5,000 sq metres to be constructed in a single day.

STS 130 Topping Spreader

Dry shake applied surface toppings such as Armorex Quartz are applied to the concrete to increase surface abrasion resistance of the finished floor. They are applied whilst the concrete is still green enough for them to be incorporated monolithically during the power floating operations.

The manual methods of application adopted to date have several draw backs, not least of which are inconsistent dosage rate and risk of delamination. Unless dosage rates can be exactly controlled, surface tolerances are destroyed and inconsistent colour and functional properties from the topping may result.

Launched this year in Europe by John Kelly (Lasers) Ltd was the Somero STS 130 topping spreader, designed specifically to work alongside the Laser Screed and immediately providing a solution to the problems that have been associated with dry shake toppings. Precision Concrete Floors commissioned the second of these machines to be manufactured in the world.

The topping spreader works along a similar principle to the Laser Screed being a highly manoeuvrable unit on which is mounted a telescopic boom. On the end of the 6.1 metre reach boom is a 1.8 metre wide adjustable spreading hopper, with a material capacity of 160 kilos. Positioned on the main chassis of the machine are two main storage compartments with automatic auger feed, having a total material capacity of approximately 1,100 kilos.

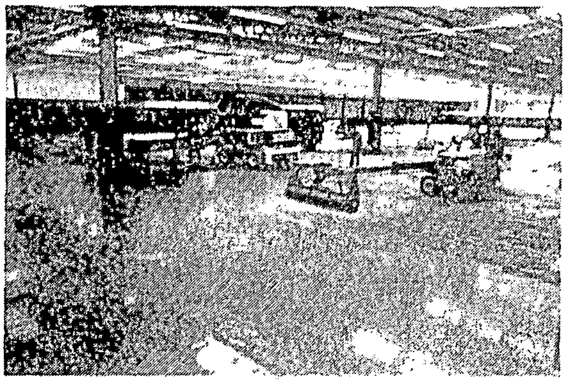

Fig. 4
STS-130 topping spreader working along side the Laser Screed.

Immediately following the completion of a screeding and compaction pass of the Laser Screed, the STS-130 tracks across in place. The telescopic hopper is fast-filled automatically from the main storage compartments. The boom is then extended over the face of the concrete and retracted to initialise the spreading application of the topping material.

The spreading hopper automatically adjusts the distribution rate of the topping material to match the travel speed of the boom during retraction, eliminating any potential error. The extremely early age and precise application of the topping eliminates any risk of delamination, while allowing high regularity tolerances to be maintained. Coloured toppings also have a much more consistent appearance.

Surface Finishing

Once the concrete and topping have been placed, one of the most critical and skilful operations take place, power trowelling. PCF employ a variety of walk behind mono power floats and multi-headed ride on trowels to progressively achieve a hard, dense, flat surface. Power trowelling and supplementary straight edging of the surface are the key to producing a high degree of flatness. To assist in this operation, strict control over concrete slump and water/cement ratio must be achieved. Monitoring of the use of (super)plasticisers to alter the flow characteristics of the concrete is also of vital importance so as not to have any effect on retardation/acceleration of the set. Typically, a concrete slump of 80mm is used.

Fig. 5
Multi-headed ride on power trowels provide a dense and hard surface finish.

Curing

Curing is one of the most simple and often most neglected operations in the construction of concrete ground floor slabs. Without employing a method of keeping the water in the slab for a prolonged period, the continued hydration process of the cement cannot continue. Although concrete hardens within only a few hours of placement, if cured properly, it will continue to gain strength for many weeks. Inadequate curing also creates a weak surface that has poor abrasion resistance and will be prone to crazing and dusting. It can also have a dramatic effect on the spalling of joint edges.

Under most circumstances, PCF adopt the use of Proseal, an acrylic in-surface sealer manufactured by Armorex Ltd. This product is sprayed on to the floor surface as soon as power trowelling has been completed. On a direct power trowelled concrete slab, Proseal also acts as a sealer, surface hardener and anti-dusting compound. If using coloured dry shake toppings, Proseal is also manufactured in a pigmented form that further enhances the consistency of the surface colour and prevents efflorescence.

Joints

A joint is a planned break in the continuity of the floor. An unplanned break is called a crack. Close attention to the design and construction of joints is probably the most singularly important criteria in maintaining a low maintenance floor.

Using the Laser Screed allows the elimination of virtually all preformed construction joints. This is the weakest element in any floor. A 4,000 sq metre building would not have any such joints. To relieve the stress developed during the contraction of the concrete, the slab is cut up in to smaller panels using a wet cut diamond tipped saw. Saw cuts are narrower and far stronger than pre-formed construction joints. There is also no change in surface level from one side of the joint to the other. Consequently, a Laser Screed constructed slab is level and flat in all directions offering a major benefit in the flexibility of the building layout.

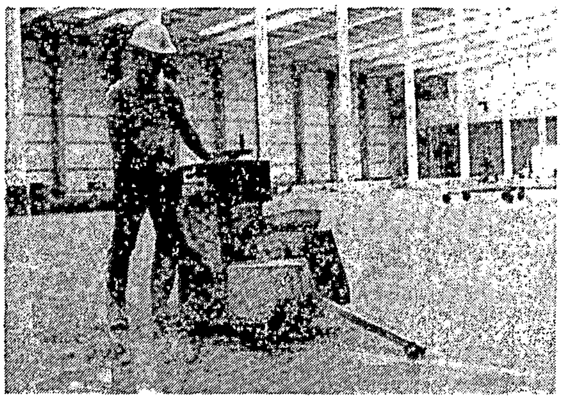

Fig. 6
Wet cut saw induced joints are far less prone to breakdown that pre-formed construction joints.

The use of Fibercon steel fibre reinforcement also gives a great deal of protection to the joint edge, dramatically reducing spalling. It also acts as an effective tie, controlling the opening of the saw cuts and distributing the excess stress to adjacent panels.

The importance of joint detailing and the timing in which the saw cuts are made, cannot be over stressed.

Floor Tolerances

There exists a definite cause and effect relationship between the surface tolerance of a floor and the efficiency of the activity it supports.

For many years the straightedge test has been utilised as a method of checking floor surface regularity. This method has major disadvantages including poor accuracy, repeatability and the inability to produce any permanent record of the surface being measured.

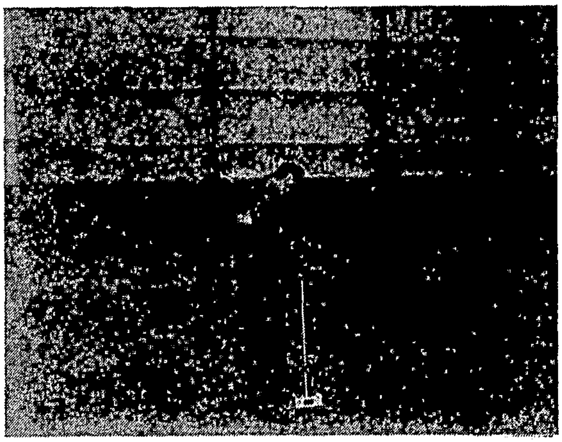

Fig. 7
Measurement of surface tollerance during construction provides valuable quality control.

Having previously agreed the surface tolerance required with the client/engineer/main contractor, PCF use an electronic level developed by the Face Company known as the "Dipstick". This instrument stands on two legs, 300mm apart, and measures the difference in elevation over that distance to an accuracy of +/-0.50mm.

By walking the "Dipstick" across the floor, alternately pivoting on each leg, it is possible to measure a connected series of measurements. These elevation differences are automatically recorded in a data-logger and can later be down loaded to a computer for analysis. A complete surface profile of the floor can be graphically plotted, providing the client and engineer with the necessary information ensuring that the agreed standards have been adhered to. As well as giving the difference in elevation over 300mm and 3 metres, the Dipstick method of measuring the floor profile can produce a complete statistical analysis of the surface tolerance known as the F-Number system.

Steel Fibre Reinforcement

Steel fibre concrete has been around for well over 20 years but it is the arrival of the Laser Screed in the UK which has started a dramatic change in engineers' attitude toward the product.

The high production rates of the Laser Screed, coupled with it's method of operation, make welded wire mesh a most unsatisfactory method of reinforcement. Precision Concrete Floors, having encountered many problems with handling mesh, sought to find an alternative method of reinforcement. Having tried several options, close co-operation was developed with Fibercon UK Ltd for the design and use of steel fibre concrete. Not only was it found that wire mesh could be entirely eliminated from ground bearing slabs (even 2 layer systems) but, that there were also several advantages to be gained in using Fibercon steel fibres over traditional materials.

Fibercon steel fibres; are manufactured in various different forms, from a 19mm straight fibre to a 50mm continuously deformed variety. The 19mm straight is the most preferred product for industrial flooring as it has extremely good handling and finishing characteristics, and has a very high fibre count giving a greater protection against crack development.

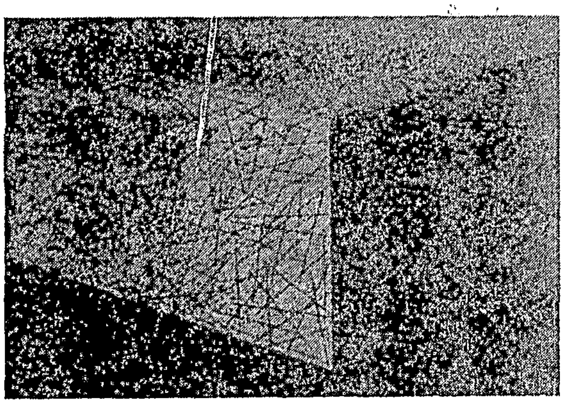

Fig. 8
Fibercon steel fibre concrete provides discrete discontinuous 3-dimensional reinforcement.

Steel fibre concrete provides discrete, discontinuous three dimensional reinforcement throughout the entire depth of the slab. Through the interception of micro cracks during their propagation, concrete is transformed from an extremely brittle building material into a composite that has a degree of ductility. This ductility brings with it improvements in many of the mechanical strength properties of the concrete such as increased fatigue resistance, impact resistance, flexural strength, shear capacity and resistance to thermal shock, etc.

Most importantly, steel fibre reinforcement gives the best possible protection against cracking at all points in the slab, even at the weakest area - joint edges. It cannot be misplaced and also allows the elimination of not only the mesh, but all of the ancillary items such as chairs, spacers, ties, dowel bars, etc.

A concentration of Fibercon steel fibre is determined based on the load type, ground conditions and joint detailing. Typically this is in the region of 20 to 50kg per cubic metre. At the higher concentrations, as a result of improvements in the mechanical strength properties, slab thicknesses may often be reduced for the same load carrying capacity. This may be as much as 25 - 30% depending on the given conditions.

Fig. 9
No special equipment is needed to disperse Fibercon 19mm steel fibres in the concrete.

Fibercon steel fibres can be added to the concrete at an approved batching plant, or on site directly into the transit mixer. If added on site, generally a scaffold tower or forklift truck with a cradle is employed to get the material up to the back of the truck.

The transit mixer is turned up to full mixing revolutions prior to the addition of the fibre. It is then left to mix at full speed for a further 4 - 5 minutes to ensure maximum dispersion. With the 19mm grade, no special equipment is required to prevent balling of the fibres. At higher dosages, steel fibre has a tendency to reduce the apparent slump of the concrete. To overcome this, a small quantity of non-retarding superplasticiser is often added to return the slump to approximately 80mm

From this point on, all that remains is for the concrete to be discharged and the construction process can begin. No special techniques are required to handle or finish concrete containing the Fibercon 19mm fibre. Also, contrary to popular belief, even on a direct power trowelled finish, the steel fibre will not be evident at the surface. As a result, the fibres are protected by the background alkalinity of the concrete and will not corrode and give problems with rust staining. Steel fibre reinforcement is also the preferred method with floors containing wire guidance systems, as being a discontinuous form of reinforcement it does not alter the electrical conductivity of the slab.

Toppings

Direct power trowelled concrete will prove suitable for lighter duty floors. However, there are many instances where specific properties are required that cannot be achieved from concrete alone. Monolithic dry shake toppings may well provide the solution in this case.

Another company that PCF have formed a close co-operation with is Armorex Ltd. Already well known for their range of cementitious and epoxy grouts, sealers and floor toppings, the arrival of the STS-130 topping spreader means that the potential of their monolithic dry shake toppings can now be fully exploited.

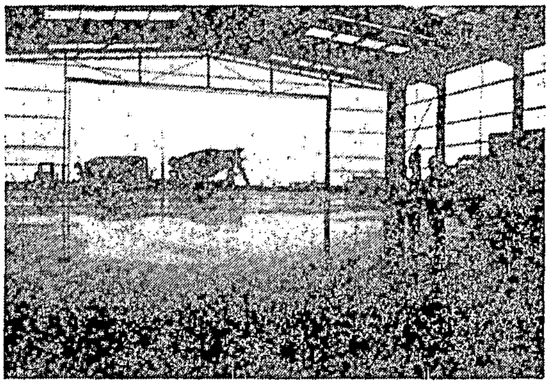

Fig. 10
Armorex monolithic dry shake toppings provide a highly durable surface finish.

Armorex manufacture three main types of sprinkle topping:

- Supertop - a non oxidising metallic grade
- Armorshield - a non metallic compound
- Armorex Quartz - a mineral based range of products

The main benefits to be gained by the application of a monolithic topping are guaranteed abrasion resistance and long life durability. Even after 20 years use, a monolithic topping will still be performing much as the day it was constructed. A monolithic topping is a sealed system. It will not dust. It provides an extremely low porosity surface, resistant to migration of oil, grease and chemical attack. It will also provide an anti-skid surface that cannot be achieved with direct power trowelled concrete.

Another ever increasing reason for using Armorex toppings is that the aesthetics and cosmetic appearance of the floor can play a major part in improving productivity and the harmonious nature of the working environment. The floor slab need no longer be plain concrete grey. Several colours are available, including light light pastel shades for example. Unlike an epoxy paint, a coloured monolithic topping will not wear out in high traffic areas. It is part of the slab, and there for life.

Conclusion

Concrete ground floor slabs do not have to be problematic. If constructed right first time, they will readily last 20 years or more even under the most demanding conditions. Precision Concrete Floors Ltd have realised that there is far more to laying a floor than just pouring strips of concrete. Through investment in the latest and best technology available, and sourcing high quality materials, superior floors can be produced at an affordable cost. Close association with companies such as John Kelly (Lasers) Ltd, Fibercon UK and Armorex allows a complete systematic approach. Utilising the latest computer aided design systems and product knowledge from the above companies, along with the services of their consulting structural engineers, a floor can be rapidly designed and constructed with a sympathetic bias toward what the client requires.

NOTES:

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Special thanks go to the following companies for their assistance:

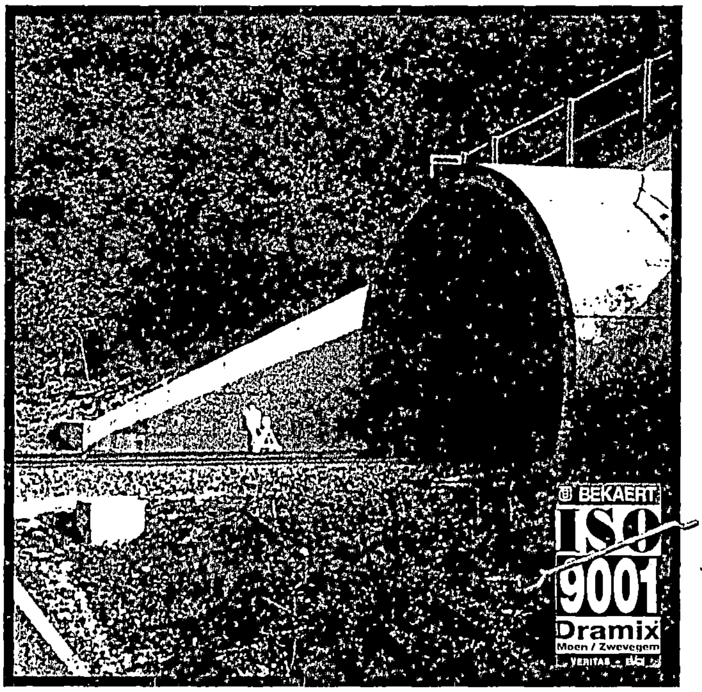
Tarmac Topmix Ltd

SGB International Ltd

World of Concrete International Ltd

BEKAERT

Dramix®



Fibras de acero para la construcción de túneles y obras subterraneas

INVERSIONES MIDAS S.A.
Av. Nicolás [illegible] 3125
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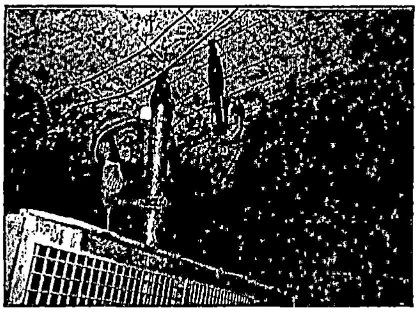
Teléfs. (51-1) [illegible]-326-3389
326-3169
FAX Nr (51-1)326-1133

Dramix®

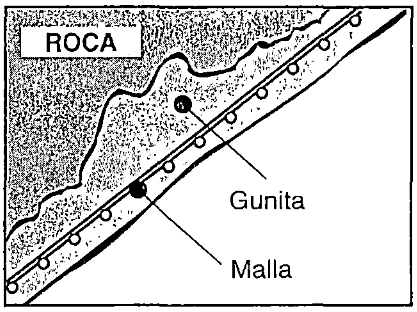
LA IDEA. CONSTRUCTIVA

El otro camino ...



La instalación de la malla es

- ✓ dificultosa
- ✓ lenta
- ✓ arriesgada
- ✓ costosa



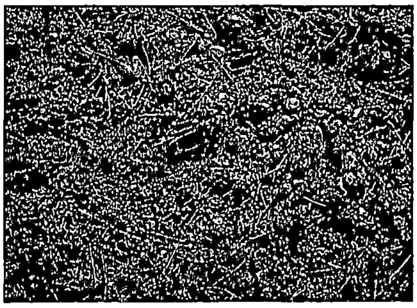
Los consumos de gunita son altos debido

- ✓ a la superficie irregular de la roca
- ✓ al alto procentaje de rebotes contra la malla

La calidad del revestimiento no es siempre la mejor

- ✓ la gunita recubre solo la parte superficial de la malla, dejando huecos entre ésta y la roca
- ✓ suelen quedar sin gunita detrás de las barras de hierro
- ✓ falta de adherencia uniforme entre la gunita y la roca
- ✓ posición irregular de la malla, puntos sobresalientes de la roca. Refuerzo no eficiente

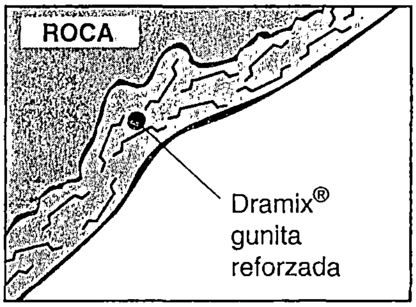
Gunita reforzada con fibras de acero (GRFA): una mejor tecnología



La gunita reforzada con fibras de acero (GRFA) es un hormigón que contiene fibras de acero individuales que crean un refuerzo homogéneo.

Las fibras de acero Dramix® están encoladas en peines, con un pegamento soluble al agua para permitir una fácil manimpulación y una mezcla de alto rendimiento.

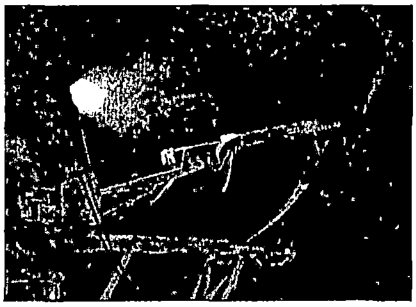
Esto hace que se puedan obtener más altos rendimientos a dosificaciones más bajas que con otras fibras de acero, y es la única manera de garantizar la obtención de una distribución homogénea de la fibra, sin la ayuda de un equipamiento especial.



GRFA puede ser aplicada muy rápido, asegurando un refuerzo inmediato a la roca excavada. El refuerzo homogéneo con fibras permite resistir esfuerzos de flexotracción en cualquier punto de la capa de gunita.

Unos espesores uniformes permiten una reducción importante de los consumos de gunita.

Una capa de GRFA tiene una muy buena adherencia a la roca, la cual es necesaria que se soporte a sí misma.

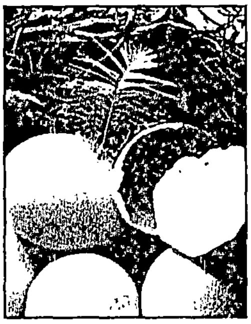


Un brazo de robot es una ventaja considerable en la construcción de túneles, pues permite la utilización de la capacidad total del equipo gunitador y permite llevar a cabo el trabajo desde fuera la área peligrosa y polvorienta.

Tanto la vía seca como la vía húmeda pueden emplearse con las fibras de acero. A fin de poder utilizar las fibras encoladas en la vía seca, se desarrolló una cola especial que se disuelve con la humedad natural de los áridos.

Dramix®

transforma la gunita
de un material **frágil** a uno **dúctil**



Ductilidad significa:

✓ **Seguridad:**
El revestimiento resistirá algunas fisuras locales o cargas inesperadas, pero no colapsara.

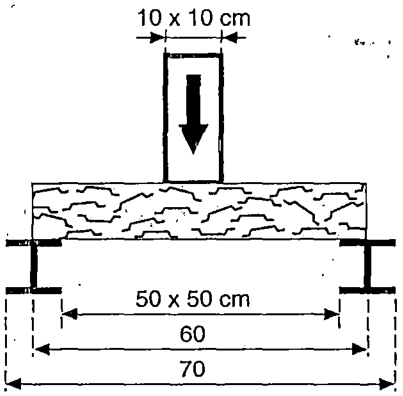
✓ **Redistribución de la carga:**
La capacidad de carga se incrementará y estará determinada por la calidad de la gunita y el grado de dúctilidad.

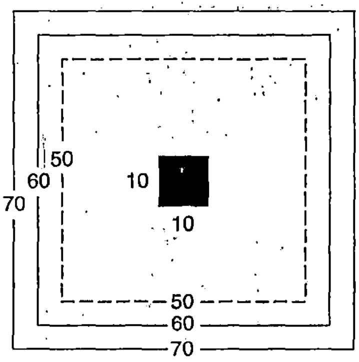
ENSAYO DE PLACA

El ensayo de punzonado-flexión de la placa, desarrollado por la SNCF (Compañía de FFCC Franceses) y el Laboratorio Alpes Essais, es un test ideal para comprobar el comportamiento de la GRFA:

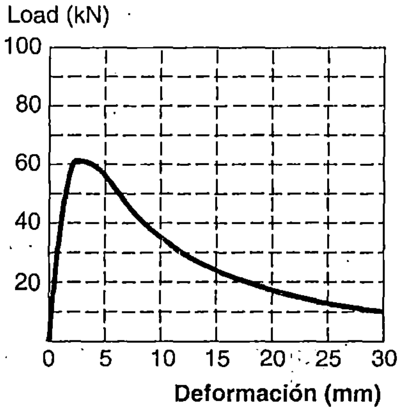
1. El revestimiento de un tunel se comporta como una placa;
2. Las condiciones hiperestáticas del ensayo, permiten la redistribución de las cargas;
3. El ensayo puede realizarse también con las mallas usuales en el sostenimiento.

Del gráfico carga-deformación obtenemos una segunda curva que nos da la energía absorbida.
Los pliegos de especificaciones exigen una absorción de energía dependiendo de las condiciones de carga.
Para los trabajos de reparación de túneles de los FFCC Franceses, se exige una absorción de energía de 500 Joules.

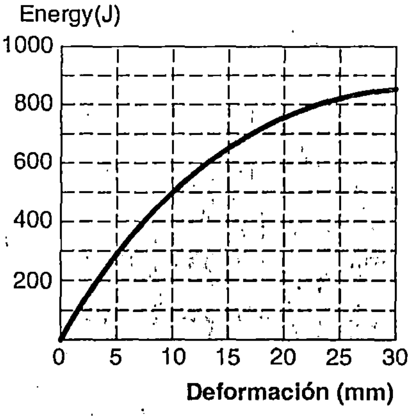




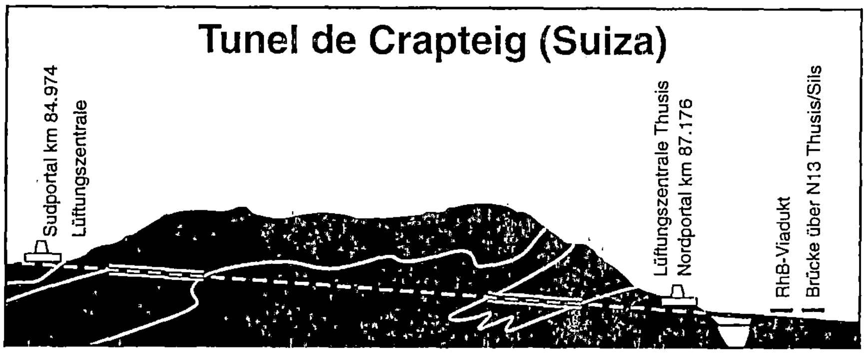
curva de carga de deformación



curva de energía



CASO: Dramix® contra Malla



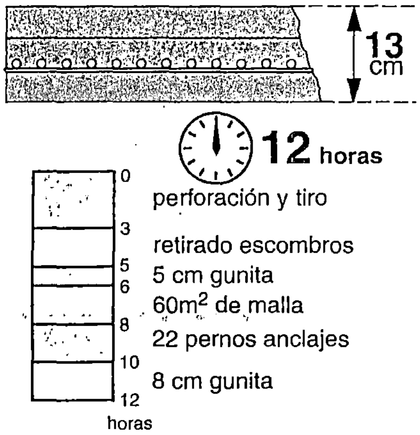
El Tunel de Crapteig en el desfiladero de San Bernardino,Ctra. N-13, cerca de Thusis.

Equivalencia

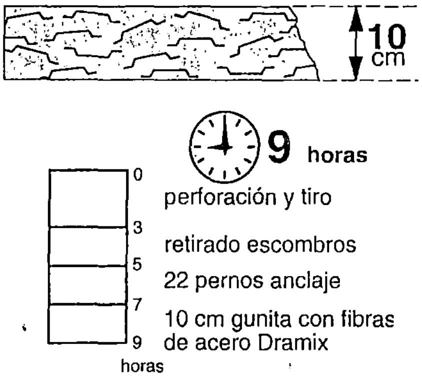
Ensayos comparativos en Versuchstollen Hagerbach han probado la equivalencia de una capa de gunita de 13 cm (incluyendo una malla de alambre Kl 88) y una capa de gunita de 10 cm (reforzada con 40 kg/m³ de fibras de acero Dramix® ZP 30/.50).

Ciclo de trabajo

Malla

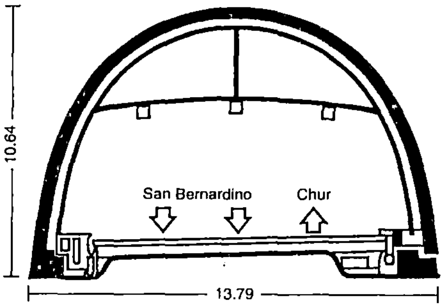


Dramix®



El nuevo método constructivo siempre ha de ser mejor, más seguro y rápido y sobre todo más barato.

El sostenimiento fue diseñado con 5 cm de gunita / 1 malla K 188 / 8 cm de gunita.



Los 3 carriles de 2 km. de longitud del tunel han sido excavados con una sección de 125 m².

Dramix®

en el caso Crapteig

✓ ***mucho menos consumo de gunita***

✓ ***reducción del ciclo de trabajo***

un AHORRO EN EL COSTO de

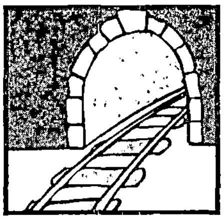
-25%

Unas Referencias de Proyectos

España	: Tren de Alta Velocidad Madrid-Sevilla Ronda Sur de Málaga Tunel de Vallvidrera, Barcelona
Italia	: Carretera de Aosta-Mont Blanc Circunvalación Nápoles
Noruega	: Tunel carretero de Grannfoss Tunel de la ciudad de Oslo Proyecto hidráulico Meraker
Francia	: Tunel carretero de Puymorens, Scetauroute Castelnaud: Tunel hidraulico Tunel de Monaco Moyenne Corniche
Suiza	: Tunel carretero de Monterri, Jura Tunel carretero Mont Russelin, Jura.
Grecia	: Central hidroeléctrica de Tissavros
Suecia	: Tunel ferroviario de Grodinge Tunel de distribución del Aeropuerto de Arlanda.
Finlandia	: Tunel ferroviario Helsinki-Turku
Hongkong	: Tunel carretero de la Carretera 5 Tunel hidráulico
Japón	: Central eléctrica de Sabigawa Tunel de la Carretera 140 de Karizaka
Taiwan	: Proyecto de Estación de bombeo Central hidroeléctrica de Ma'an.
India	: Central hidroeléctrica de URI
EEUU	: Proyecto Carretera Cumberland-Gap
Canadá	: Tunel ferroviario Rogers Pass BC.
Chile	: Planta hidroeléctrica de Alfalfal.

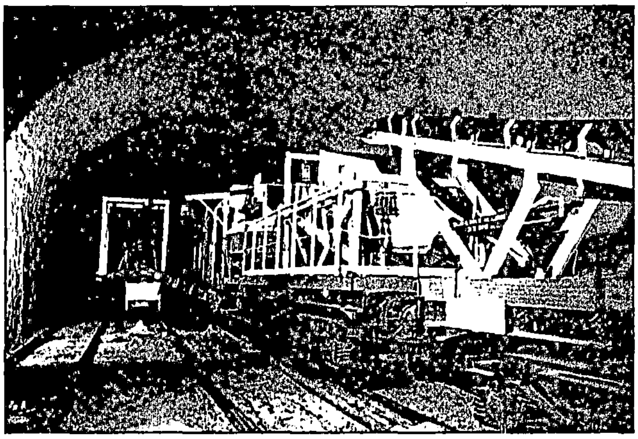
Dramix®: un amplio campo de aplicaciones

1 Réparación de tuneles



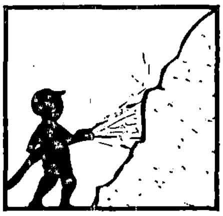
La gunita con fibras de acero es una práctica e interesante técnica para proteger, reparar o reforzar túneles existentes.

Sobre la superficie limpia de un tunel ya existente, se puede aplicar una capa uniforme de gunita homogéneamente reforzada y de un espesor determinado.



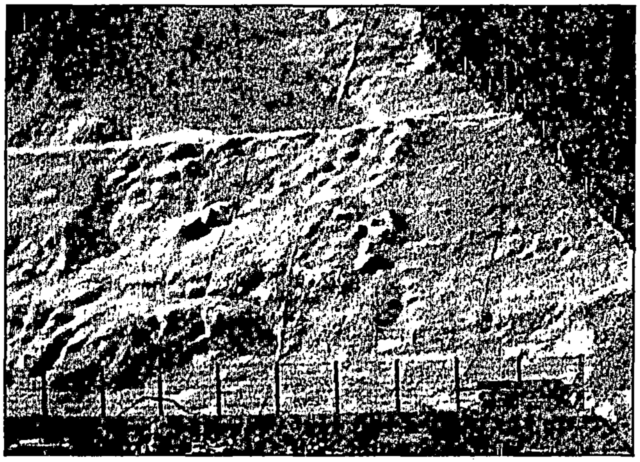
Túnel SNCF de Laifour (France)

2 Estabilización de taludes



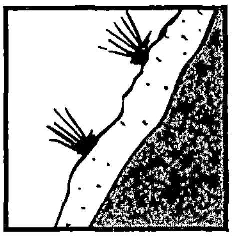
Las gunitas aplicadas en el exterior están expuestas a las heladas y a cambios repentinos de temperatura.

El viento y la exposición a un sol intenso pueden tender a resecarla prematuramente. Bajo estas condiciones, es necesario aplicar una adecuada gunita de refuerzo. El empleo de Dramix® en la gunita permite obtener un producto final con unas propiedades superiores a las obtenidas con el método convencional.



Estabilización de talud - Wakayama Pref. (Japan)

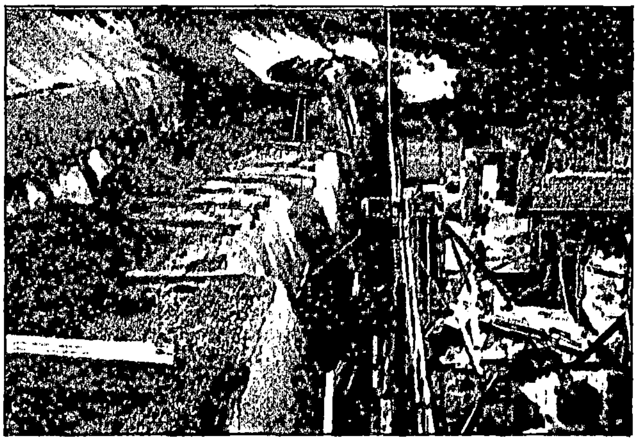
3 Paredes de retencion



Las construcciones urbanas actuales acarrean usualmente grandes excavaciones.

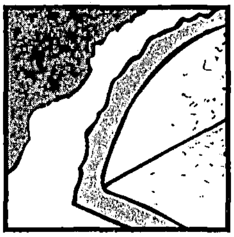
Por ello, se precisan paredes de retención para evitar asentamientos de las estructuras vecinas y también para procurar condiciones de trabajo seguras.

En conjunto, con los pernos de anclaje la gunita con fibras puede emplearse con confianza incluso en grandes excavaciones con paredes altas.



Paroi clouée - Luzern (Suisse)

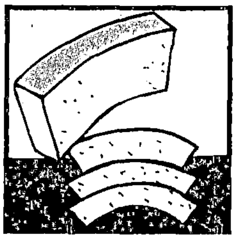
4 Cavernas



Hoy en día encontramos cavernas utilizadas para numerosos propósitos. Desde centrales eléctricas, polideportivos, almacenaje de todo tipo de productos estratégicos, depósitos de basuras, etc...La gunita con fibras de acero usada como un soporte del terreno está actuando como refuerzo eficaz, debido a su gran ductilidad.

Mingtan power house (Taiwan)

5 Dovelas



La ejecución de túneles por TBM permite instalar directamente detrás de la máquina el revestimiento final.

Los elementos prefabricados se ensamblan como un anillo, dando lugar a un revestimiento temporal o definitivo.

Las fibras Dramix, como único refuezo, o combinado con armadura tradicional (redondos o barras normales), dan al segmento la resistencia necesaria para:

* Resistir esfuerzos debidos al acarreo y almacenaje.

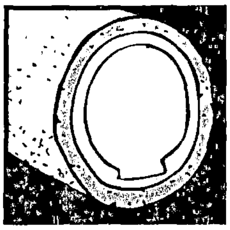
* Evitar fisuras térmicas causadas por los cambios de temperatura.

* Mejorar la durabilidad del hormigón.

* Soportar las grandes cargas producidas por los gatos de la TBM.

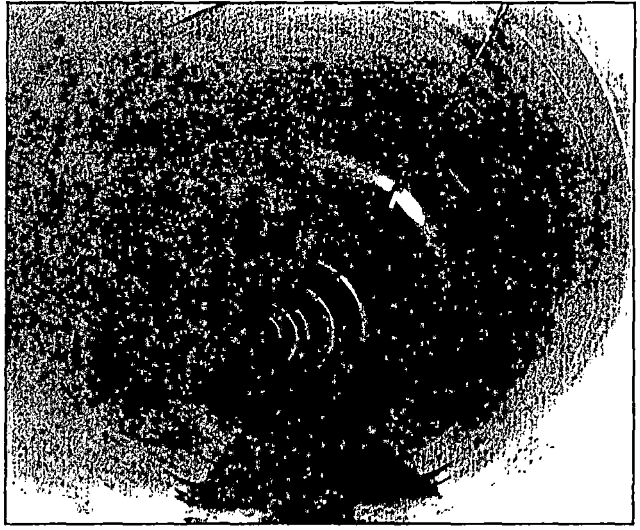
Metro de Nápoles (I) - Línea 1

6 Revestimiento de hormigón extruido



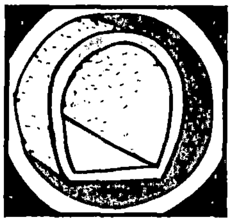
Hochtief, constructor alemán, desarrolló un método de avance de túnel, donde el revestimiento de hormigón reforzado con fibras de acero sale expulsado por la parte de atrás de la máquina tuneladora.

Este sistema moldea el hormigón reforzado con fibras directamente detrás de la tuneladora TBM, formando un tubo de hormigón reforzado con fibras de acero.



Lion, Línea de metro atravesando el Ródano y el Saona

7 Revestimiento interior del tunel

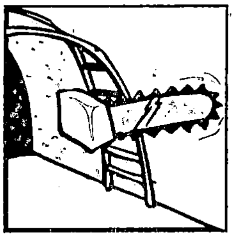


Cuando el sostenimiento de un túnel, generalmente formado por un sistema de dos capas, tiene una función temporal, el único elemento de soporte tenido en cuenta en el diseño de un túnel es el del Revestimiento definitivo.

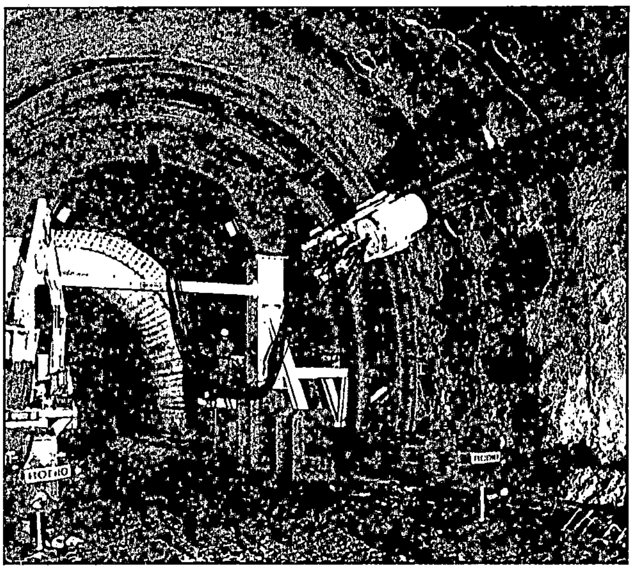
La Compañía Alemana de Ferrocarriles (DB) admitió el uso del hormigón reforzado con fibras de acero (40 kg de Dramix ZC 60/80 por m^3) como un sustituto de la solución estandar de diseño.

City Line S4 (Alemania)

Premill



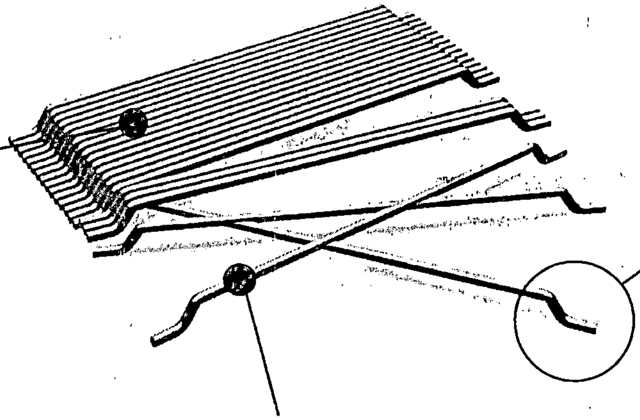
En el frente del tunel se corta una ranura perimetral, a lo largo del perfil del tunel. Se llena la ranura con gunita reforzada con fibras de acero y se crea un presostenimiento previo a la excavación del terreno propiamente dicha.
La ductilidad del presostenimiento con Dramix, garantiza la seguridad de la operación de sostenimiento y permite realizar la excavación del túnel a sección total, con un equipo de tamaño economico.



Valdarno - Arezzo TGV (Italia)

Dramix®

Especialmente diseñado para gunitados



Las fibras de acero Dramix están encoladas en peines, con una cola soluble en agua. Los peines se deshacen en fibras individuales, garantizando una homogénea distribución de las mismas dentro del hormigón o gunita.

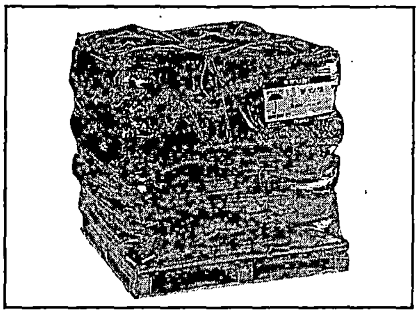
Conformadas en los extremos, para un óptimo anclaje en la gunita.

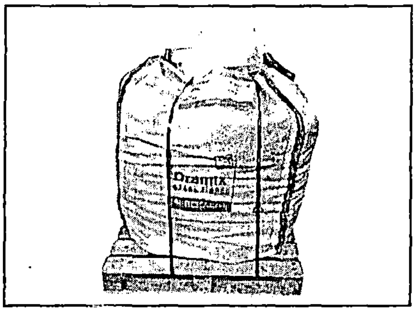
El diseño original de la fibra ha sido desarrollado y mejorado después de 25 años de investigación y experiencia. Se ha creado un balance óptimo entre forma, resistencia, longitud y diámetro.

Las fibras de acero Dramix® están disponibles en diferentes longitudes (20-25-30-35-40-50-60 mm) y en diferentes clases de l/D (45-65-80) según la aplicación, el equipo empleado y la forma de ejecución necesaria.

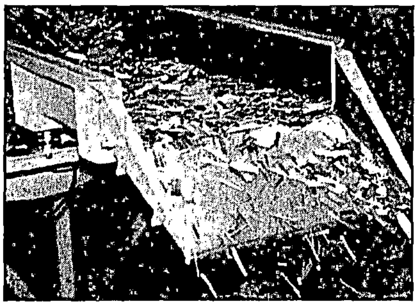
Las fibras de acero Dramix, dentro de la gunita pueden aplicarse sin ningún cambio en las gunitadoras, ya sean de vía seca o de vía húmeda.

Unidades Embalaje


Sacos en una paleta

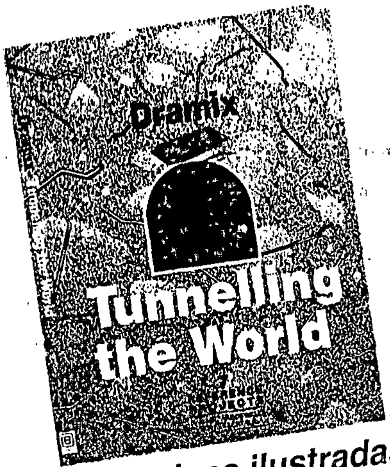

Saco de 1100 kgs

Dosificación automática


Sistema de vibrado

Un argumento contundente a favor de las fibras de acero Dramix®, es la posibilidad demostrada de usar equipos de dosificación automática para una producción automática y en gran volumen de hormigón reforzado con fibras de acero Dramix®, sin problema alguno.

Servicio Bekaert



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Bekaertstraat 2
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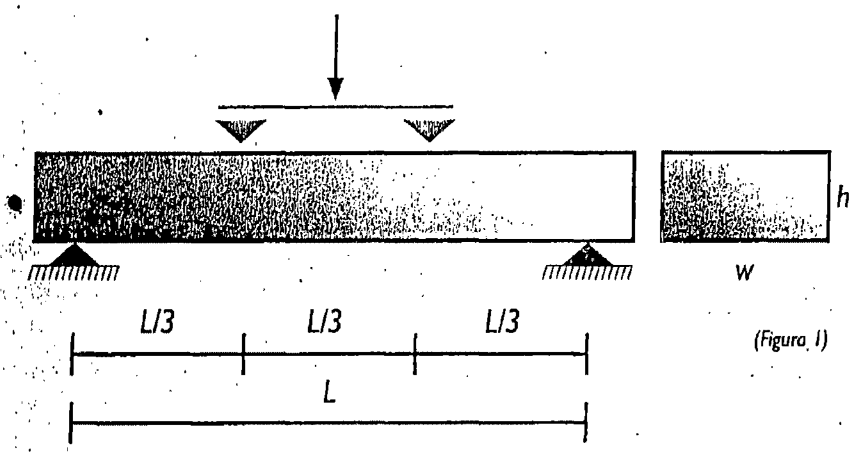
Para pedidos y cálculos se deben usar únicamente las especificaciones y documentos oficiales.

La principal razón para usar fibras de acero en el hormigón, sea éste hormigón convencional o el para ser proyectado (shotcrete), es dar a este quebradizo producto ductilidad y tenacidad. Además, el refuerzo con fibras de acero le da a los hormigones una mayor capacidad de absorción de energía, resistencia al impacto y a la formación de grietas... Agregando fibras de acero, los hormigones podrán soportar cargas aún después de agrietarse.

Diferentes métodos han sido desarrollados para medir estas influencias de la fibra de acero en los hormigones.

A continuación se describen brevemente dos de ellos:

Viga de ensayo para ambos métodos



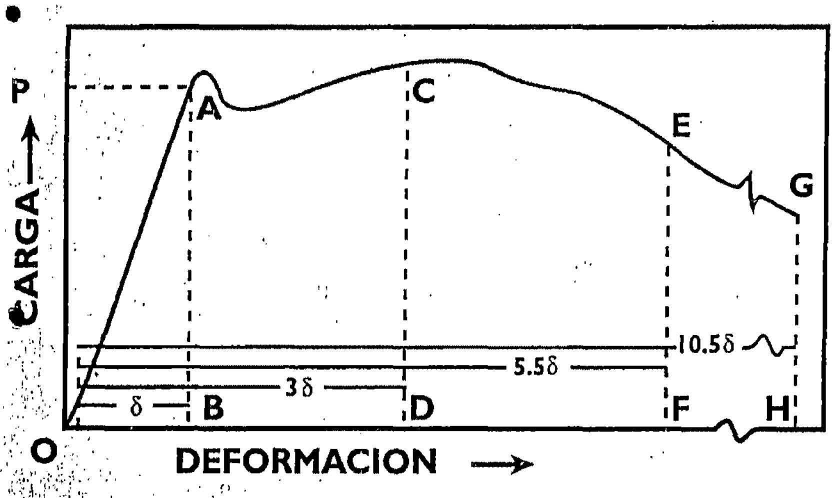
(Figura 1)

La viga de ensayo esta sujeta a una carga central y se registra una curva de Carga - Deformación.

Normas A.S.T.M. C 1018-92

Este método de prueba es para hormigones en general.

Curva de Carga - Deformación.



La resistencia a la flexión (Fs) se define como: $F_s = P \times \frac{L}{w \times h^2}$

La tenacidad se define según varios índices I:

I_5 = OACD/OAB I_{10} = OAEF/OAB I_{20} = OAGH/OAB

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Asociación Noruega para el Hormigón

Estas especificaciones fueron especialmente preparadas para hormigón proyectado.

La resistencia a la flexión (F_s) se define como: $F_s = P \times \frac{L}{w \times h^2}$

Los requerimientos de resistencia a la flexión, según estas especificaciones, son:

	C 30	C 35	C40	C 45	C 50	C 55
Resistencia a la flexión MPa	3,8	4,2	4,4	4,6	4,8	5,0

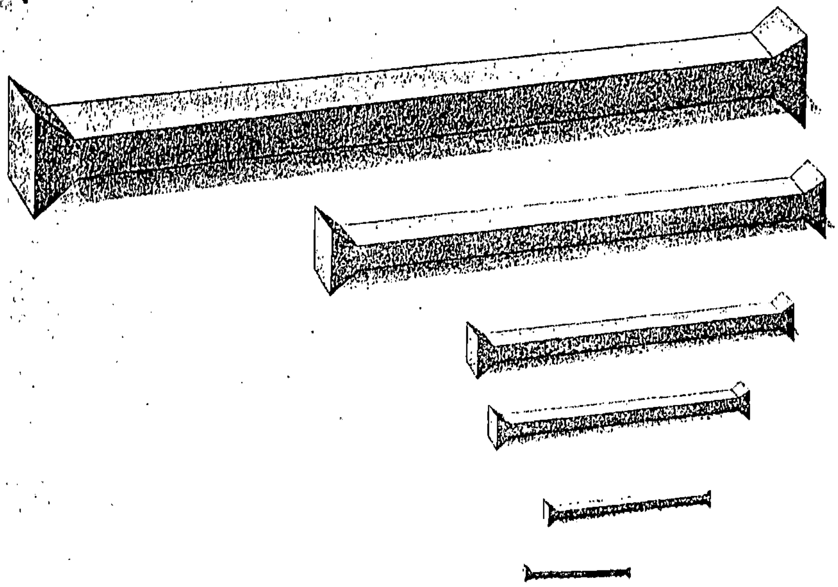
En este método, la tenacidad está dividida en cuatro clases, que reflejan la capacidad del hormigón reforzado con fibras de acero para soportar cargas, después de deflectarse 1 y 3 mms.

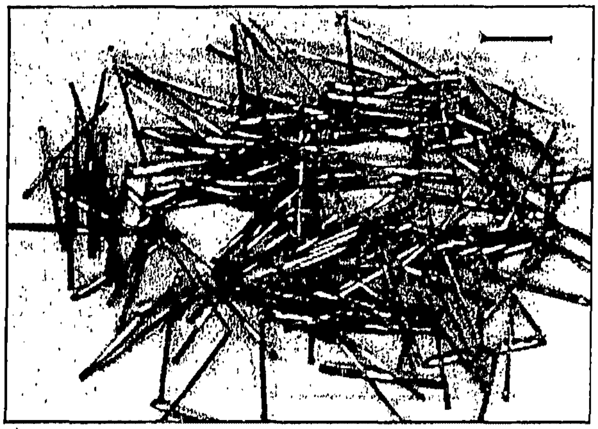
Clases de Tenacidad	Deflexión	
0	Hormigón sin refuero	
1	Tipo y cantidad de Fibras a especificar	
2	2,0 MPa	1,5 MPa
3	3,5 MPa	3,0 MPa

NOTA:

Para todos los ensayos, es imprescindible que las vigas de prueba se obtengan de paneles, los que deberán ser tratados bajo las mismas condiciones que tendrá el proyecto donde se usará el shotcrete.

Fibras de Acero EE





Generalidades

Las fibras de acero EE (Enlarged Ends = Extremos Extendidos) pueden, en la mayoría de los casos, reemplazar los refuerzos tradicionales para concreto. Al usarlas, se consigue para el concreto una mayor tenacidad y distribución de grietas, lo que significa una gama de aplicaciones más amplia para su uso. También resulta en un refuerz distribuído homogeneamente en tod el concreto.

Una de las aplicaciones principales d la fibra de acero es en shotcret (hormigón proyectado) par sostenimiento de roca en túneles cabernas, taludes y trabajos d reparación.

El uso de fibras de acero EE desde 1978 ha entregado a los dueños de proyectos empresas de ingeniería y contratista una bien documentada informació sobre su comportamiento en las má diversas calidades geotécnicas condiciones de roca, después de s aplicación en miles de kilómetros d túneles, cavernas, taludes, canales otros trabajos de reparaciones en tod el mundo.

El Producto

Las fibras de acero EE se producen a partir de acero bobinado de alta calidad. Las fibras son cortadas a su largo y forma final y envasadas en cajas.

El tamaño de los extremos extendidos "cabezas" de las fibras de acero EE está calculado para dar la adherencia óptima en el concreto. Su largo esta determinado por razones prácticas, que tienen relación con su facilidad para ser mezcladas en el concreto, obteniendo la mejor distribución y para su posterior proyección (en el caso de shotcrete) por medio de los modernos equipos robotizados.

Sus medidas de ancho y espesor son las menores posibles, para tener la mayor cantidad de fibras por unidad de peso: con ello se consigue tener un gran número de fibras de acero, incorporadas en el concreto, aún para dosificaciones bajas por metro cúbico.

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La ductibilidad del producto cumple con las normas ASTM A820-85

Tipo	Dimensiones LxAxE (mm)	Relación L/D	Caja (kg)	Palett (kg)	Cabezas EE (mm)	Cantidad aprox Fibras/kg
EE 18	18 x 0,6 x 0,3	37,6	25	1.200	0,6	39500
EE 25	25 x 0,6 x 0,4	45,2	20	960	0,7	21300

Resistencia a la tensión del acero usado en la fabricación, según ensayo DIN 50114 o equivalente de otra norma

EE 18	850 ± 50 Mpa.
EE 25	1050 ± 50 Mpa.

Otras dimensiones, formas y calidades de acero se están desarrollando y probando constantemente.

El Fabricante

FUNDIA BYGG A.S., el productor de acero más grande de Escandinavia, fabrica las fibras de acero EE desde 1986.

La compañía está certificada como "Aprobada bajo ISO 9002 por International Standard Organization".

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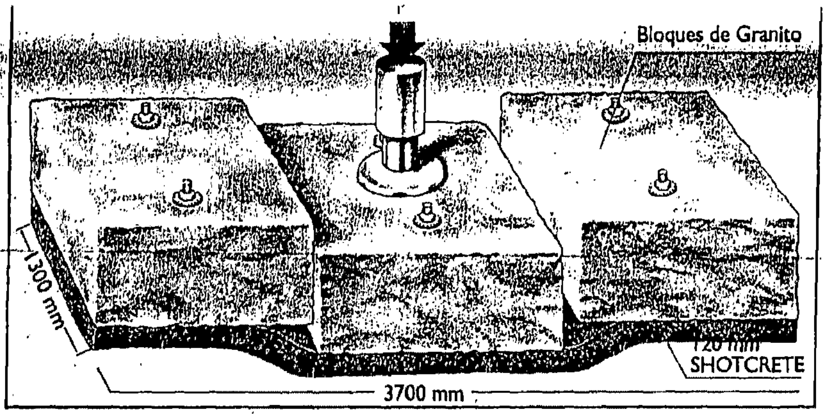
FI Julio '99

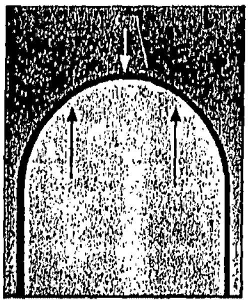
Comparación entre Hormigónes Proyectados refuerzo con malla de acero v/s. Fibras de Acero.

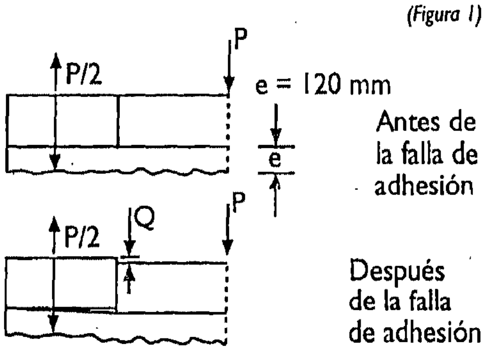
Resultados de "Programa de Investigación a Gran Escala" realizados por el "Consejo Real de Noruega para la investigación

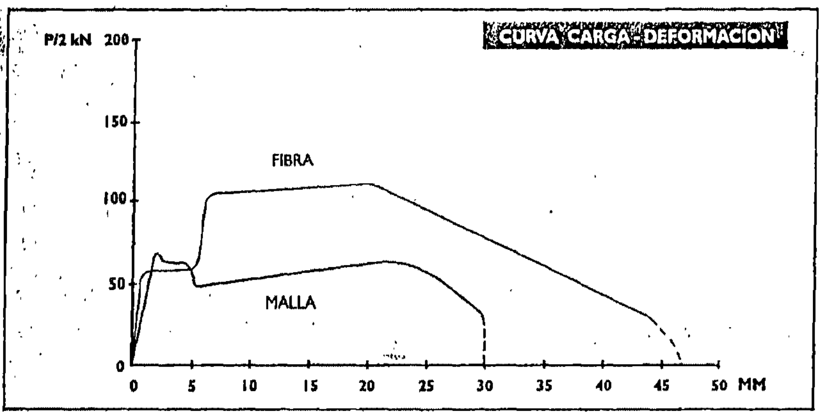
Shotcrete = Hormigón Proyectado
MRS = Shotcrete Reforzado con Malla de Acero
SFRS = Shotcrete Reforzado con Fibras de Acero



(Figura 1)







práctica, al introducirse y perfeccionarse en los países escandinavos el uso del sistema SFRS (shotcrete reforzado con fibras de acero), que desplazó casi completamente al anterior: actualmente, cerca del 100% del sostenimiento de rocas en esos países se realiza con el sistema SFRS, el que también se ha extendido a muchos otros países, para las más diversas calidades geotécnicas de roca. Este cambio ha ocurrido, en general, junto con el uso del método de hormigón proyectado por vía húmeda.

Las razones para este cambio son las importantes ventajas técnicas, económicas, prácticas y de seguridad: el sistema SFRS es suficiente y seguro para todas las condiciones de roca donde se ha especificado la aplicación de shotcrete, sea éste por método vía seca o vía húmeda.

El respaldo para este cambio son los numerosos estudios de investigación realizados en diferentes laboratorios, de diferentes países, y la amplia experiencia ganada gracias al uso intensivo del sistema. En todos los aspectos, los resultados muestran favorables rendimientos para el uso del sistema SFRS.

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Ventajas al Usar el Sistema SFRS

Programas de investigación realizados por el "CENTRO DE INVESTIGACION TECNICA DE FINLANDIA (VTT)" muestran una mayor resistencia del sistema SFRS en lo que se refiere a "Carga Final, Resistencia a la Tensión y Energía de Ruptura", del orden del 20 al 25%. Estas investigaciones se realizaron comparando sistema SFRS, con fibra de acero ROBOCON-FUNDIA EE-25, versus sistema MRS, con malla de acero de 4 mms x 100 x 100 mms.

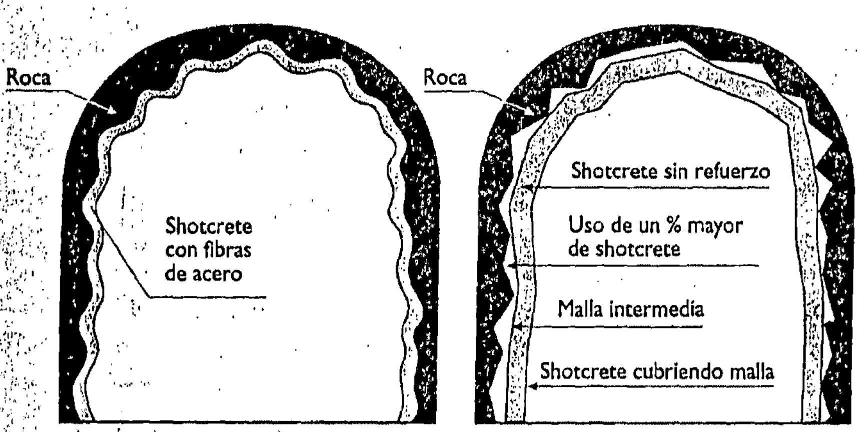
Todos los resultados también muestran que hay un significativo aumento en la adherencia a la roca con el shotcrete reforzado con fibras de acero. Esto se debe, principalmente, al hecho de que la malla de acero a menudo evita el buen contacto entre el shotcrete y la superficie rocosa.

SEGURIDAD

- COLOCACION CON EQUIPOS ROBOTIZADOS, que permiten al operador trabajar retirado de secciones sin sostenimiento de roca previo.

ECONOMIA

- MENOS TRABAJADORES, al eliminar la necesidad de cuadrillas de personal para la instalación de mallas de acero y reducir la cantidad de trabajadores para su colocación: sólo un operador por equipo robotizado para la aplicación.
- AHORRO EN EL TIEMPO DE APLICACION, al eliminar la instalación de las mallas de acero y usar equipos de proyección robotizados de alto rendimiento.
- MENOR USO DE MATERIALES, debido a que el sistema SFRS presenta un bajísimo rebote (entre 5 y 8%) y a que tiene la capacidad de seguir el perfil del túnel sin la necesidad de grandes rellenos, como es el caso del sistema MRS, que usará entre un 40 a 50% más de hormigón para alisar la superficie, previo a la instalación de las mallas de acero, y posteriormente para cubrirla.



Shotcrete con malla de acero

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F3 Mayo '98

Experiencia desde 1978 en Shotcrete Reforzado con Fibras de Acero

SINTEF

TELEFAX

BERGTEKNIKK / ROCK AND MINERAL ENGINEERING

DATE: 1992-03-02 TELEFAX NO: 095-32-56-766785/767950

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ADDRESS: NV BEKAERT INTERNATIONAL TRADE SA
8550 ZWEVEGEM
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FROM: Alf Thidemann, SINTEF Rock and Mineral Eng.

ADDRESS: N-7034 TRONDHEIM
NORWAY

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TELEX: 55620 sintf n

THIS MESSAGE CONTAINS 1 PAGES (including this page)

Dear Mr. Vervaeke,

The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF) is a research organization with approx. 2000 employees, and covers a range of disciplinary areas within technology. The reports are mostly restricted, including those for clients producing steel fibres.

A short state-of-the-art review will be:

1) About 330 km of accessible Norwegian hydro tunnels (from a total of 3500 km) are inspected in a project on long term stability. All damages and defects on support installations are reported. No corrosion problems on steel fibres in shotcrete lining are observed, only corrosion on the free fibre ends in the water stream. However, the most important stability problems are related to faults containing swelling clay in connection with the use of any kind of shotcrete, including 25 cm mesh reinforced shotcrete at zones with extreme swelling pressure.

2) Undersea road tunnels in Norway are investigated. No corrosion of steel fibres inside the shotcrete has been identified in spite of a relatively high chloride content. (A general paper from SINTEF in "Tunnels & Tunnelling", September 1988).

3) Special analyses of steel fibres in shotcrete are carried out. In this review we may say that the results are positive for the clients.

SINTEF Rock and Mineral Engineering will be pleased to be at your service.

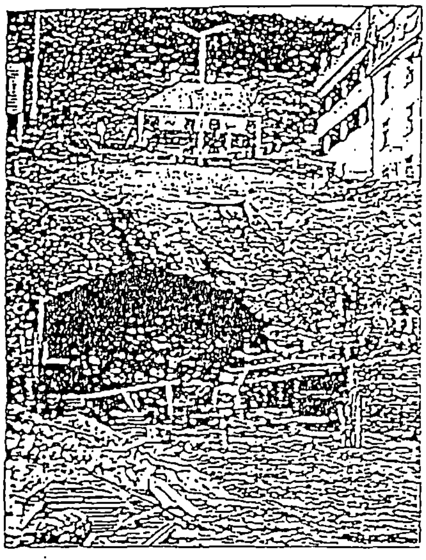
Yours sincerely

Alf Thidemann

Alf Thidemann
Research Manager

Undersea tunnels in Norway: a state-of-the-art review

Bjørn Nilsen, Magne Maage, Tore S Dahlø, Tor Arne Hammer and Sverre Smeplass
SINTEF (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology), Trondheim, Norway



Portal of the Ellingsøy undersea road tunnel (No. 7 in Fig 1 and 7.2 in Fig 2).

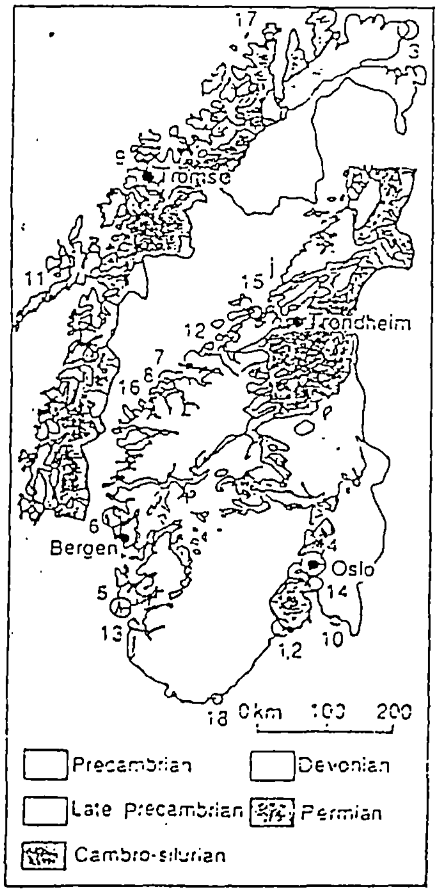


Fig 1. Completed subsea tunnels in Norway (1-7), those under construction (8-10) and those planned (11-18).

The shore line of Norway is characterised by a large number of fjords and straits and the majority of the population lives on the coast. Rock conditions in Scandinavia are generally good, and it is therefore logical that rock tunnels across fjords and straits have become increasingly popular for communication and industrial purposes.

Ten major under sea rock tunnels have been completed in Norway since 1974. A boom in subsea tunnelling, especially road tunnels, has been triggered by the successful completion of these projects. Some of these tunnels have previously been discussed in *Tunnels & Tunnelling*[1-5].

Experience gained from completed projects forms an important basis for the planning of new subsea tunnel projects. A research project was carried out at SINTEF during 1987 to summarise and evaluate the experience gained from Norwegian subsea tunnels. The research programme will be briefly presented here and some of the main results will be discussed.

Summary of tunnels

The state-of-the-art review has considered all the ten major subsea tunnels completed in Norway so far. The majority of these tunnels are related to fjord and strait crossings on the west coast, or are road tunnels or tunnels for oil and gas pipelines (Fig 1 and Table 1).

The total subsea length constructed to date is about 20km, and the greatest depth below sea level is about 250m. Longitudinal sections along the respective tunnels are shown in Fig 2.

For the most recent oil and gas pipeline tunnels the cross-sectional area is about $25m^2$. For two-lane road tunnels the area is about $50m^2$, and for three-lane road tunnels about $70m^2$.

The Norwegian undersea tunnels are situated in a variety of geological structures ranging from typical hard rock such as Precambrian gneiss to less competent phyllite and poor quality schists and shales. All tunnels cross significant zones of weakness under the sea.

Three more undersea tunnels are under construction at present in Norway, and more than 30 are being planned or are under consideration. The majority of these are two- and three-lane road tunnels. Fig 1 indicates the locations of some of the new projects which are most likely to be constructed in the near future.

Research programme

The state-of-the-art study has concentrated in the main on the following topics:

- ☐ Preinvestigations
- ☐ Tunnelling results
- ☐ Behaviour of rock support materials

Among other points, the study includes discussions on the usefulness of the preinvestigations in predicting tunnelling conditions and a study into the effect of saline environments on the condition of rock support materials.

Owners, contractors and consultants for the tunnels which are documented have actively contributed to the study so that a broad overview has been possible. A total of ten technical reports have been published. These reports (in Norwegian) may be ordered from SINTEF.

Preinvestigations

The following preinvestigations are normally used in Norway for subsea tunnels:

1. Review of existing information.
2. Geological engineering field mapping.
3. Acoustic profiling.
4. Refraction seismic profiling.
5. Drilling.

Since most of a subsea tunnel route is normally covered by sea, the planning of such projects is to a great extent based on data from seismic investigations and drilling (Stages 3-5). The planning and performance of such investigations are discussed in detail by Beitnes & Blindheim[6], and Paulsson[7].

The total profile length of acoustic surveying is normally between 20 and 50 times the subsea length of the tunnel, while the total length of refraction seismic profiles is normally between 1.5 and 3.5 times the subsea length. Core drilling is most commonly carried out as inclined holes from the shore and under the sea, and with a drilled length of 30-40% of the subsea length.

Table 1. Norwegian rock tunnels beneath the sea floor completed prior to 1988.

	Project	Year completed	Bedrock	Cross-section	Total length	Subsea length	Lowest level
1.	Vollsfjord, water supply tunnel	1977	Precambrian gneiss	16m^2	9.4km	0.6km	- 80m
2.	Frierfjord, gas pipe tunnel	1977	Precambrian gneiss/Cambro-Silurian sediments	16m^2	3.6km	3.1km	- 252m
3.	Vardo, road tunnel	1981	Late Precambrian sandstone/shale	53m^2	2.6km	1.7km	- 88m
4.	SRV — Slemmestad, sewer tunnel	1982	Cambro-Silurian shale/limestone	10m^2	0.9km	0.7km	- 95m
5.	Karmøy — Kårsto, gas pipe tunnel						
	5.1 Karmsundet	1983	Caledonian greenstone and phyllite/ Precambrian gneiss	27m^2	4.8km	2.1km	-180m
	5.2 Fordesfjord	1983	Precambrian gneiss	27m^2	3.4km	1.6km	-170m
	5.3 Førlandsfjord	1983	Precambrian gneiss/Caledonian phyllite	27m^2	3.9km	1.0km	-160m
6.	Hjartoy, oil pipe tunnel	1986	Precambrian gneiss	26m^2	2.3km	1.8km	-105m
7.	Ålesund, road tunnel						
	7.1 Ellingsoy	1987	Precambrian gneiss	68m^2	3.5km	1.1km	-140m
	Valderoy	1987	Precambrian gneiss	68m^2	4.2km	2.2km	-137m

Though Stages 1 to 4 of the preinvestigations have been carried out for all these tunnels, core drilling has not been performed for three of them (Nos. 2, 7.1 and 7.2). The total cost of preinvestigations is between Nkr 2400-5400 per subsea metre of the tunnel (1987 price levels) (£218-490).

Predictions of rock quality are based on an overall interpretation of results from the various steps of preinvestigations. A major problem during this interpretation is the transformation of seismic data into geological descriptions. For several of the completed projects, such problems have caused considerable discrepancies between prediction and the actual conditions encountered during tunnelling.

One result from the research programme which illustrates this point is shown in Fig 3. Here, the relative lengths of major weakness zones which were estimated from the preinvestigations are plotted against the length of concrete lining in the actual tunnels. The comparison is based on the generally accepted assumption that concrete lining is necessary when a major weakness zone is crossed.

The majority of discrepancies in Fig 3 have geological explanations. For instance, for Tunnel 5.2 (Fødesfjorden) the total zone length was underestimated because of crushed zones running parallel to the tunnel axis. These zones were not identified due to the omission of seismic cross profiles. For Project 7.1 (Ellingsøyfjorden) the major reason for discrepancy was that a combination of systematic rock bolting and steel fibre reinforced shotcrete was used as an alternative to concrete lining.

The estimated costs of rock support and grouting for these tunnels were exceeded by 20-110%. Although part of this discrepancy may have been caused by other factors, geological features are believed to be mainly responsible. A major conclusion from the state-of-the-art reviews is therefore that comprehensive geo-investigations are vital for all subsea projects, and the importance of thorough processing of all investigation result should not be underestimated.

Tunnelling

All projects to date have been tunnelled by using normal drill+blast techniques. The average tunnelled length/wk has varied between 17 and 40m/face (approximately 110 working hours/wk) (see Table 2).

As previously indicated, the rock conditions along the tunnel alignment will generate uncertainties even when comprehensive preinvestigations have been carried out. Continuous probe drilling is therefore necessary during subsea tunnelling to identify changing rock conditions and thereby increase the level of safety. This type of drilling may be regarded as a delayed part of the preinvestigations. Percussive probe drilling is done on a routine basis along the subsea part of the tunnel; typically the length drilled is 3-5 times the tunnel length. Some core drilling is also usual, but only to a lesser extent.

The major problems during tunnelling have occurred during the crossing of significant weakness zones. In many cases

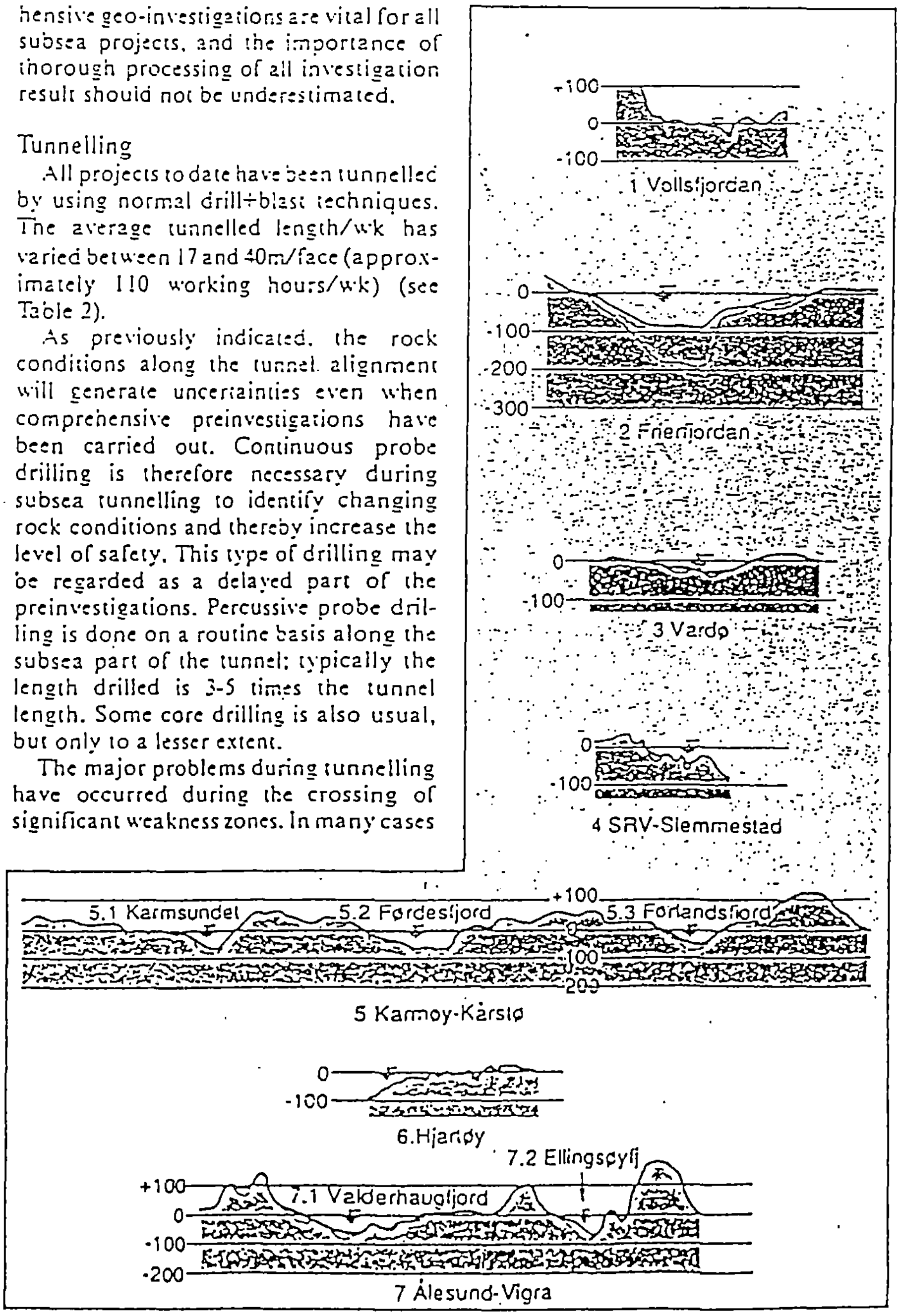


Fig 2. Longitudinal sections along the respective tunnels in Fig 1. Solid lines below water table indicate sea bed; dotted lines indicate rock surface.

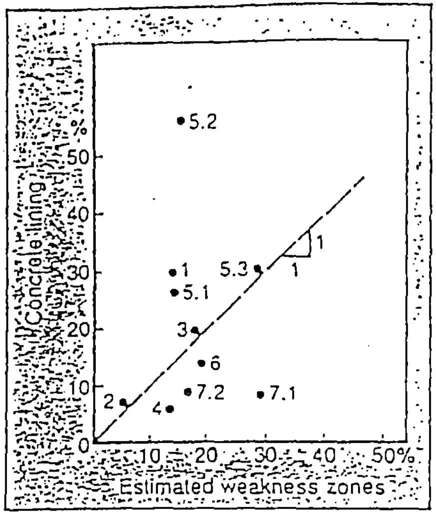


Fig 3. Relative lengths of estimated weakness zones under sea plotted against relative lengths of concrete-lined sections.

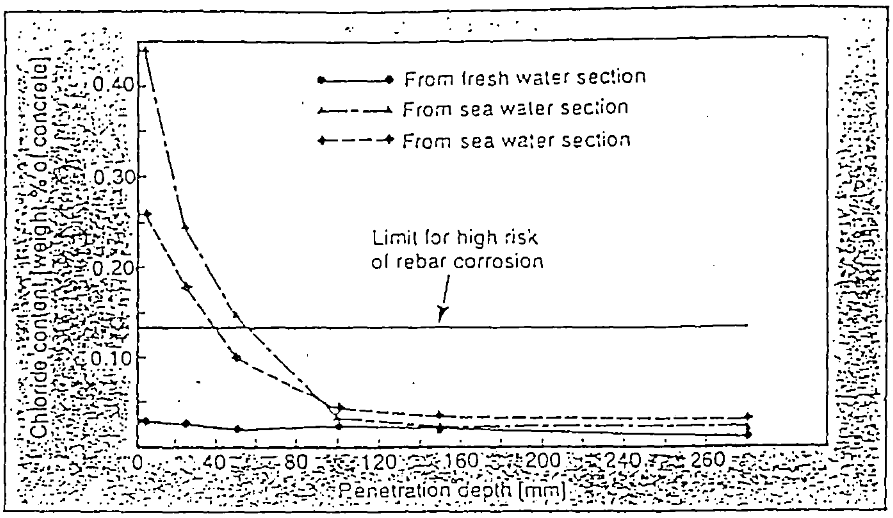


Fig 5. Chloride penetration profiles in cast concrete. Examples from the Vardø Tunnel.

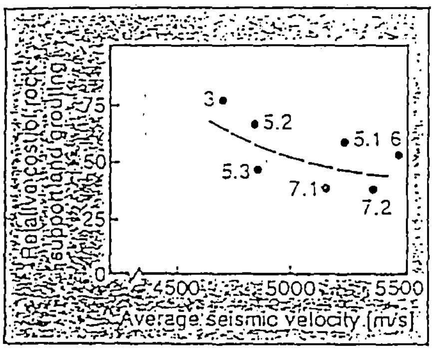


Fig 4. Relative costs of rock support and grouting as a function of average seismic velocity.

these zones contain very active swelling clay. Swelling pressures of up to 2.4MPa have been experienced. In most cases with major weakness zones concrete lining at the working face has been used as rock support.

Because of their high clay content, most weakness zones are practically impermeable. In some cases, however, even zones which are rich in clay may be waterbearing. Such zones represent the most difficult problems. Nevertheless, large, concentrated leakages have not been a major problem so far.

The grouting criterion which is most commonly used is based on measuring the volume of leakage water from the probe drill holes, and grouting is then required if the leakage exceeds a certain limit (normally 5-10 litre/min in a given borehole). The grout consumption per tunnelled metre varies from 2kg/m (Tunnel 5.3) to 98kg/m (Tunnel 7.1). Water leakages and grouting are discussed in more detail by Nilsen[6].

Primary and permanent shotcrete

Some key data concerning tunnelling rate, rock support and grouting are summarised in Table 2.

In Fig 4 the relative costs of rock support and grouting are plotted against the average seismic velocity recorded by refraction seismic profiling. As can be seen, the costs of rock support and grouting in many cases represent the major part of the total tunnelling cost. When the average seismic velocity decreases, there is a distinct tendency for the relative rock support and grouting costs to increase.

Rock support materials

The major types of rock support materials in the reported subsea tunnels are rock bolts, shotcrete (unreinforced and steel fibre reinforced), cast concrete, grout, insulated aluminium sheets and ethafoam (PE-foam). Some key data about the quantities of rock support are summarised in Table 2.

Grouted pipe bolts are most commonly used for rock bolting on the working face. Behind the working face, grouted rebar bolts are usual. All rock bolts are hot dip galvanised. The stipulated requirements for rock bolt types and work specifications have remained unaltered since 1975.

Shotcreting with and without steel fibre reinforcement has been used extensively and in most cases more than planned. Most of the shotcreting has been applied on the working face as combined working and permanent support, but considerable volumes have also been applied behind the working face as permanent support. There has been a considerable development in material quality. Due to higher load capacity and easier performance compared to mesh reinforced shotcreting, the use of steel fibre reinforcement has increased dramatically. The stipulated material requirement today for shotcrete in subsea tunnels is normally grade C45 or a water-cement ratio lower than 0.45.

Cast in-situ concrete linings have been used mainly in poor quality rock situations on the working face. Concrete quality requirements have increased during the period in question, mainly due to environmental loads. For cast in-situ concrete linings, the stipulated requirement today is grade C45 or a water-cement ratio lower than 0.45.

Cement-based materials have been used mainly for grouting. Chemical grouts have been used only in a few cases. All cement grouting has been carried out on the working face. The stipulated requirements for grouting materials have not been increased since 1975.

Sheet vaulting has been used occasionally. In the Vardø Tunnel double aluminium sheets with insulation have

Table 2. Average tunnelling rates and some major data concerning rock support and grouting as recorded on the ten completed undersea tunnels in Norway.

Tunnel	Average tunnelled length (m)	Rock bolts (number/m)	Supported length as percentage of total length Shotcrete (%)	Concrete lining (%)	Grouting (%)
1. Vollsfjord	26	>0.5 2)	6 2)	20	1)
2. Frierfjord	28	0.7 4)	4 2)	6	1)
3. Vardo	17	6.9	50	21	7
4. SRV	1)	1)	62	5	8
5.1. Karmsundet	34	1.5	65	15	9
5.2. Fordesfjord	26	2.3	35	33	6
5.3. Forlandsfjord	35	2.5	28	17	4
6. Hjartoy	40	1.6	33	12	10
7.1 Ellingsoy	28	6.4	20	3	22
7.2 Valderoy	33	5.0	58	5	6

1) No data available. 2) Uncertain data.

been used for water and frost protection. In the Ålesund tunnels PE-foam has been used as protection against water and frost.

Inspection of rock support

Due to the aggressive character of the leakage water in subsea tunnels, the environmental loads on support materials are very high. During the state-of-the-art review the in-situ condition of supporting materials was evaluated by studying the oldest accessible tunnels, i.e. the Vardø and Karmøy-Kårstø tunnels, completed in 1981 and 1983 respectively.

Visual inspections have revealed no notable corrosion of rock bolts. In the subsea section of the Vardø Tunnel, several test-bolts were placed freely in drillholes. After six years of exposure to seawater these bolts are in very good condition. Some permanent rock bolts have been tensioned up to yielding load without any resultant deformation in the bolts or the grout.

In the Vardo Tunnel, shotcreting of strength grade C 25 has deteriorated considerably due to penetration by seawater. The quality of this concrete was not documented and it was only used as a working support. The situation is much better in higher qualities (grade C 35), where no deterioration has been observed. However, on the exposed surface of the concrete, chemical analyses indicate an initial attack where seawater is seeping quite freely on the concrete surface. It is possible that this is only a surface problem since shotcrete normally has a low surface quality due to poor curing. No corrosion of steel fibres inside the shotcrete has been identified in spite of a relatively high chloride content.

Cast in-situ concrete is generally in a better condition than shotcrete when concretes of the same strength grade are compared. In sections with seeping seawater on the concrete surface, initial deterioration due to magnesium has been observed on the exposed surface of the concrete. In the same sections, the chloride content has been found to be higher on the exposed surface than the generally accepted limit for a high risk of rebar corrosion (Fig 5).

Grout materials based on cement may be attacked as a result of a low pH-level, sulphates and magnesium in seawater. The beginning of an attack may result in a tighter grout. However, if there is a process of deterioration, this may be observed by increased water inflow or by changes in the composition of the leakage water. Visual inspections have revealed no increased leakage over time. The chemical composition of leakage water is mainly identical with the composition of ordinary seawater. This indicates that the deterioration of cement-based grouting materials has been negligible.

The aluminium plates in the Vardo Tunnel do not show any general corrosion. At contact points between rails and popnails, however, some corrosion products can be observed, and where there is contact with concrete there is local corrosion due to the alkalinity of the concrete and the aggressiveness of seawater on aluminium. This problem may be avoided by preventing electrical contact between concrete and alumina plates.

Plans for further research

This state-of-the-art review provides a sound foundation for a further programme of research which is planned to include the following topics:

- ☐ A further evaluation of possibilities for improving and rationalising existing preinvestigation procedures.
- ☐ A comprehensive study of cases of roof-instability and major rockfalls.
- ☐ A review of criteria for optimising the rock cover.
- ☐ A closer study of the durability of rock bolts and grouts.
- ☐ The preparation of recommendations for rock support and shotcrete works.

References

1. Beitnes, A & Blindheim, O T (1987). Investigation strategy for subsea rock tunnels. *Tunnels & Tunnelling*, Sept '87, pp35-39.
2. Martin, D. Vardø Tunnel — an undersea unlined road tunnel Norwegian style. *Tunnels & Tunnelling*, Dec '81, pp20-22.
3. Martin, D. Undersea tunnels carry Norwegian "Pluto" ashore. *Tunnels & Tunnelling*, Dec '87, pp 24-26.
4. Martin, D. Undersea tunnel brings Norway's North Sea oil ashore. *Tunnels & Tunnelling*, Oct '86, pp 13-15.
5. Martin, D. Undersea road links Ålesund with its airport. *Tunnels & Tunnelling*, Mar '87, pp 20-24.
6. Nilsen, B. Norwegian subsea tunnels, a review with emphasis on water leakages. *Proc. Int. Congress on tunnels and water*, Madrid, June 12-15 1988, 6p (in print).
7. Paulsson, S. Refraction seismic survey for subsea rock tunnels down to 500 metres water depth. *Proc. Int. Symp. on Strait Crossings*, Stavanger 1986, Tapir Publishers. pp 833-845.

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OBITUARY

Leopold Müller, Salzburg, Austria
Jan 9, 1908 — Aug 1, 1988

Univ.-Prof.
Baurat h.c. Dipl.-
Ing. Dr. techn.
Dr. mont. h.c.
Honorary Citizen
of Salzburg

Holder of The Ring of Salzburg County, Holder of The Golden Ring of Salzburg, Holder of The Golden Plate of Salzburg County, Holder of the Salzburg Science Award; Honorary Member of the Austrian Academy of Science, Corresponding member of the Bologna Academy of Science, Past-President of the International Society of Rock Mechanics, Honorary President of the Austrian Society of Geomechanics, Honorary Member of the Austrian Society of Engineering and Architecture, Honorary lecturer of the Universities of Salzburg and Munich, Associate lecturer of the University of Lahore, Holder of the Rock Mechanics Award, Holder of the Carl-Friedrich-Gauß-Medal, the Hans-Cloos-Medal, the Haidinger-Medal and the Ritter-von-Prechtl-Medal.

His international recognition did not come by chance. A very humane engineer and scientist, he not only founded geomechanics as the missing link between geology and civil engineering; he also brought a paralysed society of engineers of all disciplines to think and work together.

He often invited us, his pupils, and friends and colleagues from all technical and academic disciplines round his table, guiding those lost in mathematical ravines and mountains of steel and concrete back to the fruitful way of overall thinking. The stimulating and sometimes very open discussions in his Salzburg Geomechanics Colloquy, which was founded in his own living-room 37 years ago, are still proving his philosophical approach.

Not all of us accepted or appreciated his points of view and this did, on occasion, give rise to bitter remarks, as on the last afternoon of the Geomechanics Colloquy in October 1987 when he said: It is nonsense to specify a 40 to 50cm thickness of shotcrete for shallow tunnels based purely on computer calculation, and it is even more absurd to build it!

He will be forever remembered as a sharp thinker, always encouraging, a warm friend, colleague and teacher. He crowned the numerous awards and tributes given on the occasion of his 80th birthday with a three-week trip to China.

This year, the 37th Geomechanics Colloquy, named the Leopold Müller Colloquy in his honour, will take place without him.

G Sauer

ACI STRUCTURAL JOURNAL COMMITTEE REPORT

Title no. 85-S52 ACI 544.4R

Design Considerations for Steel Fiber Reinforced Concrete

reported by ACI Committee 544

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The present state of development of design practices for fiber reinforced concrete and mortar using steel fibers is reviewed. Mechanical properties are discussed, design methods are presented, and typical applications are listed.

Keywords: beams (supports;) cavitation; compressive strength; concrete slabs; creep properties; fatigue (materials); fiber reinforced concretes; fibers; flexural strength; freeze-thaw durability; metal fibers; mortars (material); structural design.

CONTENTS

CHAPTER 1—INTRODUCTION

Steel fiber reinforced concrete (SFRC) and mortar made with hydraulic cements and containing fine or fine and coarse aggregates along with discontinuous discrete steel fibers are considered in this report. These materials are routinely used in only a few types of ap-

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[*] Members of the subcommittee that prepared the report.

[†] Co-chairmen of the subcommittee that prepared the report.

[‡] Deceased.

Pertinent discussion will be published in the May-June 1989 *ACI Structural Journal* if received by Dec. 1, 1988.

plications at present (1988), but ACI Committee 544 believes that many other applications will be developed once engineers become aware of the beneficial properties of the material and have access to appropriate design procedures. The contents of this report reflect the experience of the committee with design procedures now in use.

The concrete used in the mixture is of a usual type, although the proportions should be varied to obtain good workability and take full advantage of the fibers. This may require limiting the aggregate size, optimizing the gradation, increasing the cement content, and perhaps adding fly ash or other admixtures to improve workability. The fibers may take many shapes. Their cross sections include circular, rectangular, half-round, and irregular or varying cross sections. They may be straight or bent, and come in various lengths. A convenient numerical parameter called the aspect ratio is used to describe the geometry. This ratio is the fiber length divided by the diameter. If the cross section is not round, then the diameter of a circular section with the same area is used.

The designer may best view fiber reinforced concrete as a concrete with increased strain capacity, impact resistance, energy absorption, and tensile strength. However, the increase in these properties will vary from substantial to nil depending on the quantity and type of fibers used; in addition, the properties will not increase at the same rate as fibers are added.

Several approaches to designing members with steel fiber reinforced concrete (SFRC) are available that are based on conventional design methods supplemented by special procedures for the fiber contribution. These methods generally modify the internal forces in the member to account for the additional tension from the fibers. When supported by full-scale test data, these approaches can provide satisfactory designs. The major differences in the proposed methods are in the determination of the magnitude of the tensile stress increase due to the fibers and in the manner in which the total force is calculated. Other approaches that have been used are often empirical, and they may apply only in certain cases where limited supporting test data have been obtained. They should be used with caution in new applications, only after adequate investigation.

Generally, for structural applications, steel fibers should be used in a role supplementary to reinforcing bars. Steel fibers can reliably inhibit cracking and improve resistance to material deterioration as a result of fatigue, impact, and shrinkage, or thermal stresses. A conservative but justifiable approach in structural members where flexural or tensile loads occur, such as in beams, columns, or elevated slabs (i.e., roofs, floors, or slabs not on grade), is that reinforcing bars must be used to support the total tensile load. This is because the variability of fiber distribution may be such that low fiber content in critical areas could lead to unacceptable reduction in strength.

In applications where the presence of continuous reinforcement is not essential to the safety and integrity of the structure, e.g., floors on grade, pavements, overlays, and shotcrete linings, the improvements in flexural strength, impact resistance, and fatigue performance associated with the fibers can be used to reduce section thickness, improve performance, or both.

ACI 318 does not provide for use of the additional tensile strength of the concrete in building design and, therefore, the design of reinforcement must follow the usual procedure. Other applications provide more freedom to take full advantage of the improved properties of SFRC.

There are some applications where steel fibers have been used without bars to carry flexural loads. These have been short-span elevated slabs, e.g., a parking garage at Heathrow Airport with slabs 3 ft-6 in. (1.07 m) square by 2½ in. (10 cm) thick, supported on four sides (Anonymous 1971). In such cases, the reliability of the members should be demonstrated by full-scale load tests, and the fabrication should employ rigid quality control.

Some full-scale tests have shown that steel fibers are effective in supplementing or replacing the stirrups in beams (Williamson 1978; Craig 1983; Sharma 1986). Although it is not an accepted practice at present, other full-scale tests have shown that steel fibers in combination with reinforcing bars can increase the moment capacity of reinforced concrete beams (Henager and Doherty 1976; Henager 1977a).

Steel fibers can also provide an adequate internal restraining mechanism when shrinkage-compensating cements are used, so that the concrete system will perform its crack control function even when restraint from conventional reinforcement is not provided. Fibers and shrinkage-compensating cements are not only compatible, but complement each other when used in combination (Paul et al. 1981). Guidance concerning shrinkage-compensating cement is available in ACI 223.1R.

ASTM A 820 covers steel fibers for use in fiber reinforced concrete. The design procedures discussed in this report are based on fibers meeting that specification.

Additional sources of information on design are available in a selected bibliography prepared by Hoff (1976-1982), in ACI publications SP-44 (1974) and SP-81 (1984), in proceedings of the 1985 U.S.-Sweden joint seminar edited by Shah and Skarendahl (1986), and the recent ACI publication SP-105 edited by Shah and Batson (1987).

For guidance regarding proportioning, mixing, placing, finishing, and testing for workability of steel fiber reinforced concrete, the designer should refer to ACI 544.3R.

CHAPTER 2—MECHANICAL PROPERTIES USED IN DESIGN

2.1—General

The mechanical properties of steel fiber reinforced concrete are influenced by the type of fiber; length-to-diameter ratio (aspect ratio); the amount of fiber; the

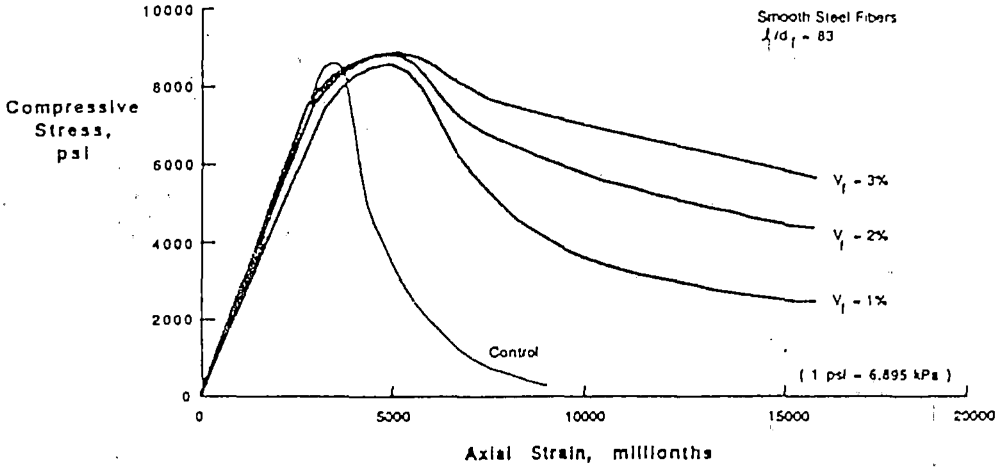

Fig. 2.2—Influence of the volume fraction of fibers on the compressive stress-strain curve

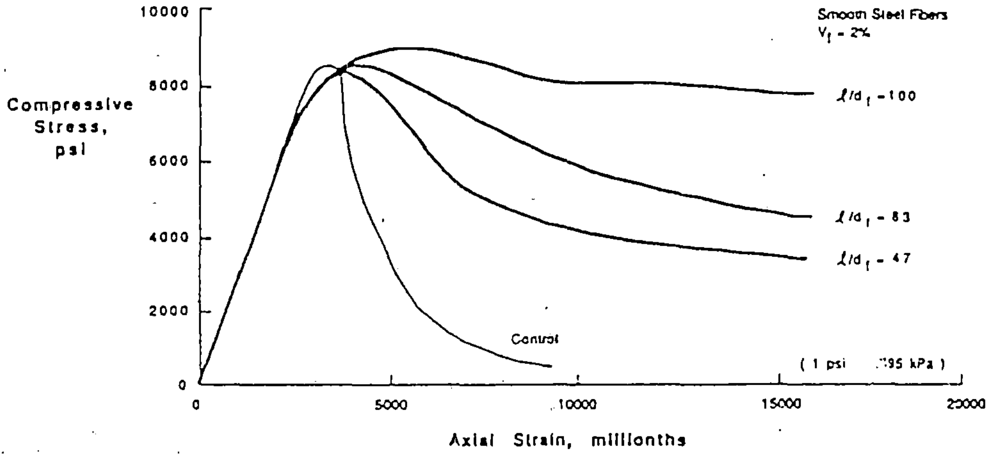

Fig. 2.3—Influence of the aspect ratio of fibers on the stress-strain curve

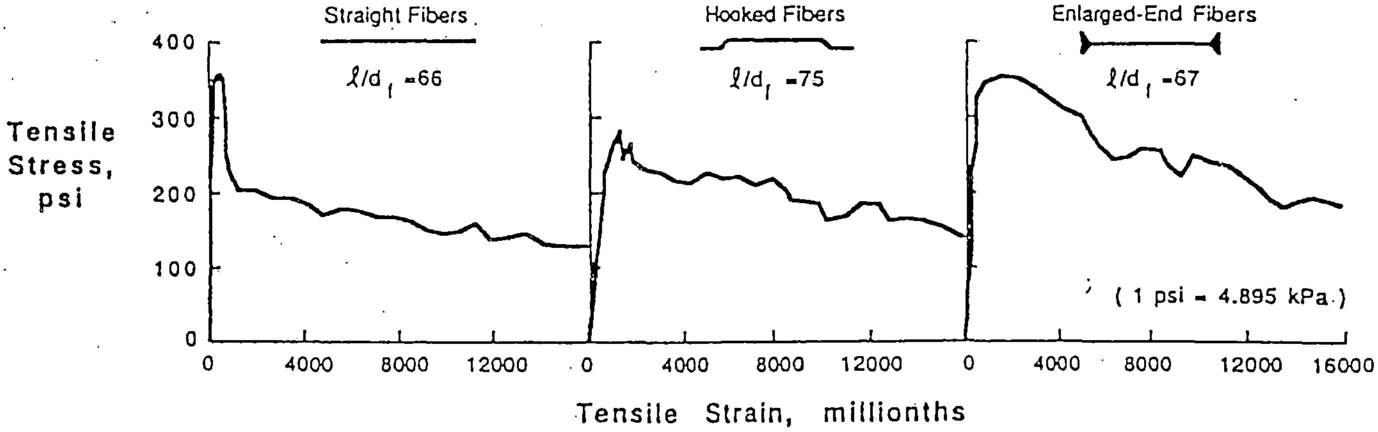

Fig. 2.4—Stress-strain curves for steel fiber reinforced mortars in tension (1.73 percent fibers by volume) (Shah 1978)

preventing sudden and explosive failure under static loading, and in absorbing energy under dynamic loading.

2.3—Direct tension

No standard test exists to determine the stress-strain curve of fiber reinforced concrete in direct tension. The observed curve depends on the size of the specimen, method of testing, stiffness of the testing machine, gage length, and whether single or multiple cracking occurs within the gage length used. Typical examples of stress-strain curves (with strains measured from strain gages) for steel fiber reinforced mortar are shown in Fig. 2.4 (Shah et al. 1978). The ascending part of the curve up to first cracking is similar to that of unreinforced mortar. The descending part depends on the fiber reinforcing parameters, notably fiber shape, fiber amount and aspect ratio.

strength of the matrix; the size, shape, and method of preparation of the specimen; and the size of the aggregate. For this reason, mixtures proposed for use in design should be tested, preferably in specimens representing the end use, to verify the property values assumed for design.

SFRC mixtures that can be mixed and placed with conventional equipment and procedures use from 0.5 to 1.5 volume percent* fibers. However, higher percentages of fibers (from 2 to 10 volume percent) have been used with special fiber addition techniques and placement procedures (Lankard 1984). Most properties given in this chapter are for the lower fiber percentage range. Some properties, however, are given for the higher fiber percentage mixtures for information in applications where the additional strength or toughness may justify the special techniques required.

Fibers influence the mechanical properties of concrete and mortar in all failure modes (Gopalaratnam and Shah 1987a), especially those that induce fatigue and tensile stress, e.g., direct tension, bending, impact, and shear. The strengthening mechanism of the fibers involves transfer of stress from the matrix to the fiber by interfacial shear, or by interlock between the fiber and matrix if the fiber surface is deformed. Stress is thus shared by the fiber and matrix in tension until the matrix cracks, and then the total stress is progressively transferred to the fibers.

Aside from the matrix itself, the most important variables governing the properties of steel fiber reinforced concrete are the fiber efficiency and the fiber content (percentage of fiber by volume or weight and total number of fibers). Fiber efficiency is controlled by the resistance of the fibers to pullout, which in turn depends on the bond strength at the fiber-matrix interface. For fibers with uniform section, pullout resistance increases with an increase in fiber length; the longer the fiber the greater its effect in improving the properties of the composite.

Also, since pullout resistance is proportional to interfacial surface area, nonround fiber cross sections and smaller diameter round fibers offer more pullout resistance per unit volume than larger diameter round fibers because they have more surface area per unit volume. Thus, the greater the interfacial surface area (or the smaller the diameter), the more effectively the fibers bond. Therefore, for a given fiber length, a high ratio of length to diameter (aspect ratio) is associated with high fiber efficiency. On this basis, it would appear that the fibers should have an aspect ratio high enough to insure that their tensile strength is approached as the composite fails.

Unfortunately, this is not practical. Many investigations have shown that use of fibers with an aspect ratio greater than 100 usually causes inadequate workability of the concrete mixture, non-uniform fiber distribution, or both if the conventional mixing techniques are used (Lankard 1972). Most mixtures used in practice employ fibers with an aspect ratio less than 100, and failure of the composite, therefore, is due primarily to fiber pullout. However, increased resistance to pullout without increasing the aspect ratio is achieved in fibers with deformed surfaces or end anchorage; failure may involve fracture of some of the fibers, but it is still usually governed by pullout.

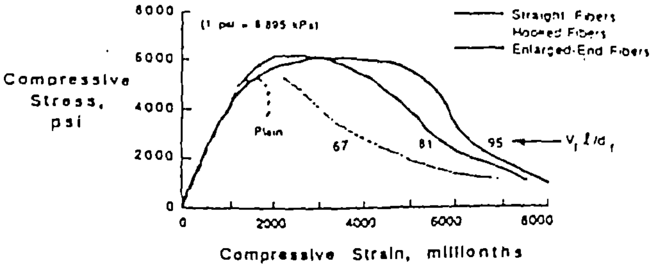

Fig. 2.1—Stress-strain curves for steel fiber reinforced concrete in compression, ⅜-in. (9.5-mm) aggregate mixtures (Shah 1978)

An advantage of the pullout type of failure is that it is gradual and ductile compared with the more rapid and possibly catastrophic failure that may occur if the fibers break in tension. Generally, the more ductile the steel fibers, the more ductile and gradual the failure of the concrete. Shah and Rangan (1970) have shown that the ductility provided by steel fibers in flexure was enhanced when the high-strength fibers were annealed (a heating process that softens the metal, making it less brittle).

An understanding of the mechanical properties of SFRC and their variation with fiber type and amount is an important aspect of successful design. These properties are discussed in the remaining sections of this chapter.

2.2—Compression

The effect of steel fibers on the compressive strength of concrete is variable. Documented increases for concrete (as opposed to mortar) range from negligible in most cases to 23 percent for concrete containing 2 percent by volume of fiber with $\ell/d = 100$, ¾-in. (19-mm) maximum-size aggregate, and tested with 6 x 12 in. (150 x 300 mm) cylinders (Williamson 1974). For mortar mixtures, the reported increase in compressive strength ranges from negligible (Williamson 1974) to slight (Fanella and Naaman 1985).

Typical stress-strain curves for steel fiber reinforced concrete in compression are shown in Fig. 2.1 (Shah et al. 1978). Curves for steel fiber reinforced mortar are shown in Fig. 2.2 and 2.3 (Fanella and Naaman 1985). In these curves, a substantial increase in the strain at the peak stress can be noted, and the slope of the descending portion is less steep than that of control specimens without fibers. This is indicative of substantially higher toughness, where toughness is a measure of ability to absorb energy during deformation, and it can be estimated from the area under the stress-strain curves or load-deformation curves. The improved toughness in compression imparted by fibers is useful in

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* Percent by volume of the total concrete mixture.

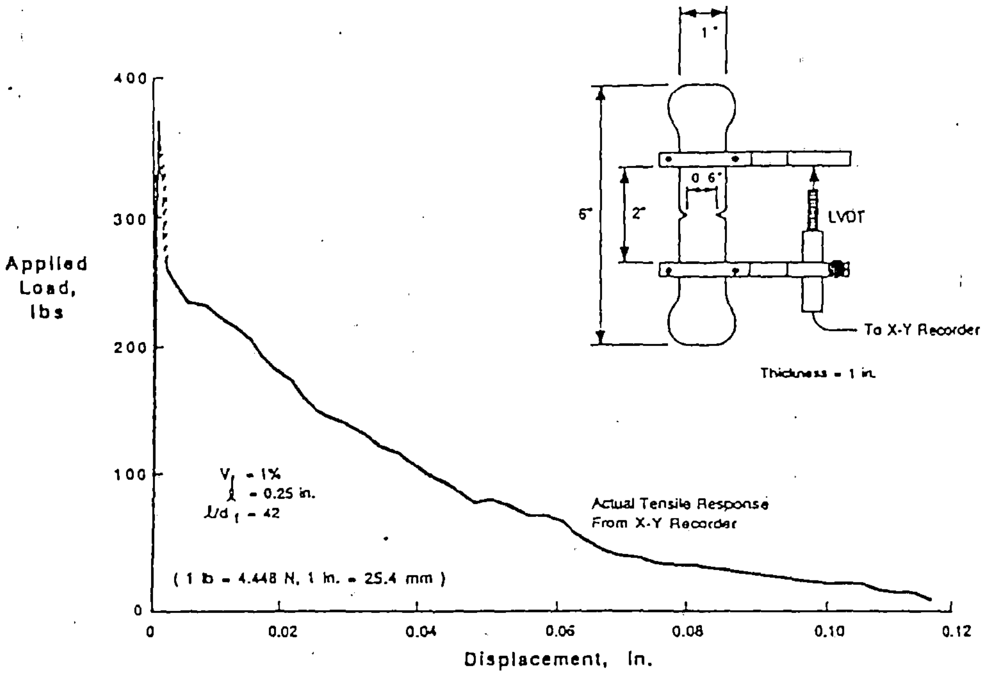

Fig. 2.5—Typical tensile load-versus-displacement curve of steel fiber reinforced mortar (Visalvanich and Naaman 1983)

An investigation of the descending, or post-cracking, portion of the stress-strain curve has led to the data shown in Fig. 2.5 and 2.6 and the prediction equation shown in Fig. 2.6 (Visalvanich and Naaman 1983). If only one crack forms in the tension specimen, as in the tests in Fig. 2.5, deformation is concentrated at the crack, and calculated strain depends on the gage length. Thus, post-crack strain information must be interpreted with care in the post-crack region (Gopalaratnam and Shah 1987b).

The strength of steel fiber reinforced concrete in direct tension is generally of the same order as that of unreinforced concrete, i.e., 300 to 600 psi (2 to 4 MPa). However, its toughness (as defined and measured according to ASTM C 1018) can be one to two orders of magnitude higher, primarily because of the large frictional and fiber bending energy developed during fiber pullout on either side of a crack, and because of deformation at multiple cracks when they occur (Shah et al. 1978; Visalvanich and Naaman 1983; Gopalaratnam and Shah 1987b).

2.4—Flexural strength

The influence of steel fibers on flexural strength of concrete and mortar is much greater than for direct tension and compression. Two flexural strength values are commonly reported. One, termed the first-crack flexural strength, corresponds to the load at which the load-deformation curve departs from linearity (Point A on Fig. 2.7). The other corresponds to the maximum load achieved, commonly called the ultimate flexural strength or modulus of rupture (Point C on Fig. 2.7). Strengths are calculated from the corresponding load using the formula for modulus of rupture given in ASTM C 78, although the linear stress and strain distributions on which the formula is based no longer apply after the matrix has cracked.

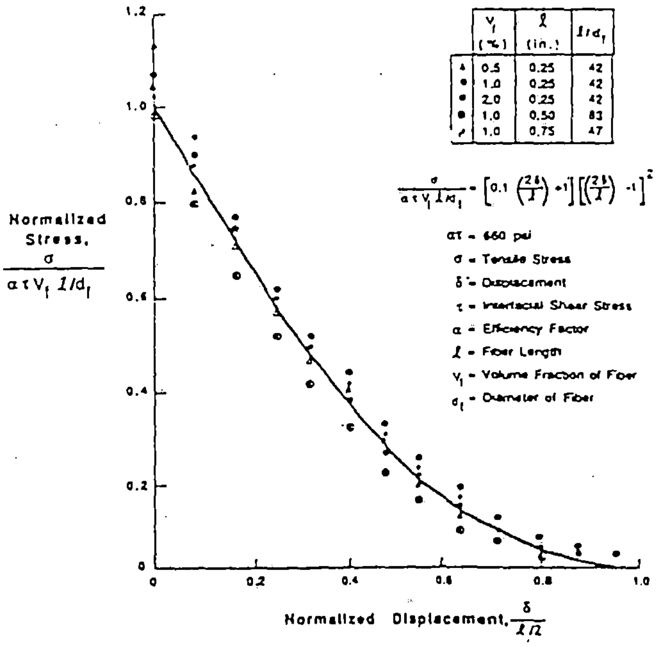

Fig. 2.6—Normalized stress-displacement law of steel fiber reinforced mortar (all cases) (Visalvanich and Naaman 1983)

Fig. 2.8 shows the range of flexural load-deflection curves that can result when different amounts and types of fibers are used in a similar matrix and emphasizes the confusion that can occur in reporting of first-crack and ultimate flexural strength. For larger amounts of fibers the two loads are quite distinct (upper curve), but for smaller fiber volumes the first-crack load may be the maximum load as well (lower curves). The shape of

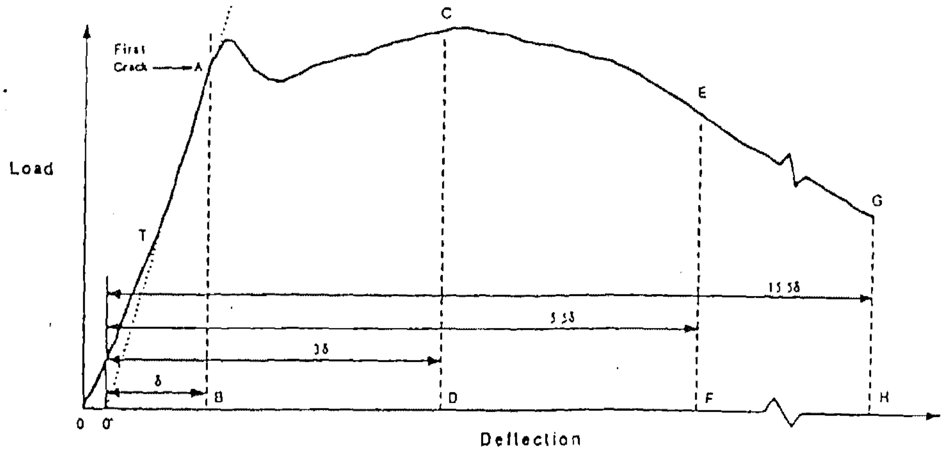

Fig. 2.7—Important characteristics of the load-deflection curve (ASTM C 1018)

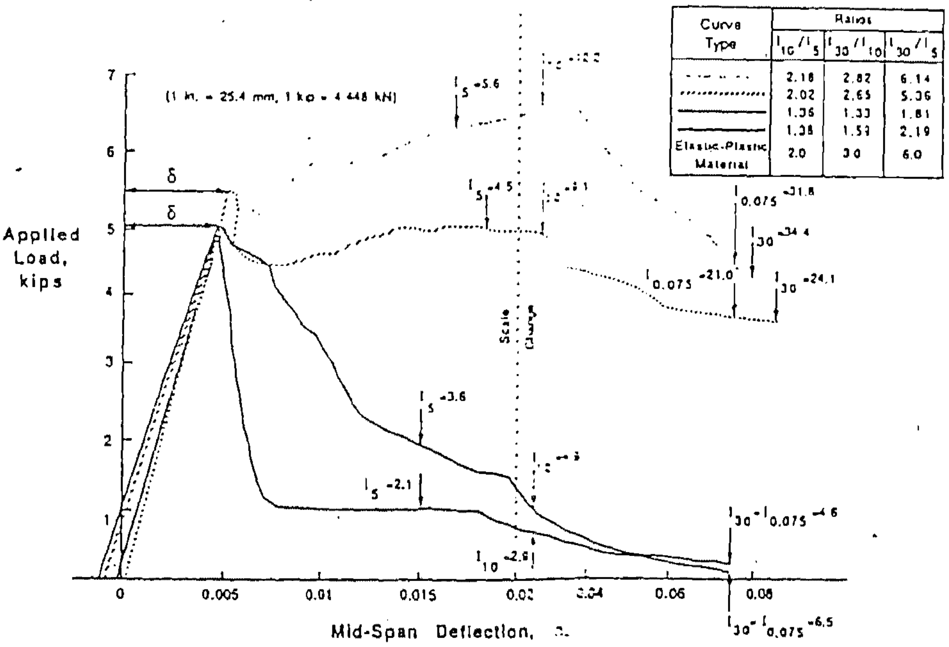

Fig. 2.8—Load-deflection curves illustrating the range of material behavior possible for four mixtures containing various amounts and types of fibers (Johnston 1982b)

the post-cracking curve is an important consideration in design, and this will be discussed relative to the calculation of flexural toughness. It is important, however, that the assumptions on which strength calculations are based be clearly indicated.

Procedures for determining first-crack and ultimate flexural strengths, as published in ACI 544.2R and ASTM C 1018, are based on testing 4 x 4 x 14 in. (100 x 100 x 350 mm) beams under third-point loading for quality control. Other sizes and shapes give higher or lower strengths, depending on span length, width and depth of cross section, and the ratio of fiber length to the minimum cross-sectional dimension of the test specimen.

It is possible, however, to correlate the results obtained in different testing configurations to values for standard beams tested under third-point loading, even when centerpoint loading is employed (Johnston 1982a). This is necessary when attempting to relate the performance of a particular design depth or thickness of material, e.g., a sample obtained from a pavement overlay or shotcrete lining, to the performance of standard 4 x 4 x 14 in. (100 x 100 x 350 mm) beams. The requirements relating cross-sectional size to design thickness of fiber reinforced concrete and to fiber length in ASTM C 1018 state that, for normal thickness of sections or mass concrete applications, the minimum cross-sectional dimension shall be at least three times the fiber length and the nominal maximum aggregate size.

Ultimate flexural strength generally increases in relation to the product of fiber volume concentration v and aspect ratio ℓ/d. Concentrations less than 0.5 volume percent of low aspect ratio fibers (say less than 50) have negligible effect on static strength properties. Prismatic fibers or hooked or enlarged end (better anchorage) fibers have produced flexural strength increases over unreinforced matrices of as much as 100 percent

(Johnston 1980). Post-cracking load-deformation characteristics depend greatly on the choice of fiber type and the volume percentage of the specific fiber type used. The cost effectiveness of a particular fiber type/amount combination should therefore be evaluated by analysis or prototype testing.

High flexural strengths are most easily achieved in mortars. Typical values for mortars (w/c ratio = 0.45 to 0.55) are in the range of 1000 to 1500 psi (6.5 to 10 MPa) for 1.5 percent by volume of fibers depending on the ℓ/d and the type of fiber, and may approach 1900 psi (13 MPa) for 2.5 percent by volume of fibers (Johnston 1980).

For fiber reinforced concretes, strengths decrease with increases in the maximum size and proportion of coarse aggregate present. In the field, workability considerations associated with conventional placement equipment and practices usually limit the product of fiber concentration by volume percent and fiber aspect ratio $v\ell/d$ to about 100 for uniform straight fibers. Twenty-eight day ultimate flexural strengths for concretes containing 0.5 to 1.5 percent by volume of fibers with ¼ to ¾ in. (8 to 19 mm) aggregate are typically in the range of 800 to 1100 psi (5.5 to 7.5 MPa) depending on $v\ell/d$, fiber type, and water-cement ratio.

Crimped fibers, surface-deformed fibers, and fibers with end anchorage produce strengths above those for smooth fibers of the same volume concentration, or allow similar strengths to be achieved with lower fiber concentrations. The use of a superplasticizing admixture may increase strengths over the value obtained without the admixture if the w/c ratio is reduced (Ramakrishnan and Coyle 1983).

Flexión

2.5—Flexural toughness

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Toughness is an important characteristic for which steel fiber reinforced concrete is noted. Under static loading, flexural toughness may be defined as the area under the load-deflection curve in flexure, which is the total energy absorbed prior to complete separation of the specimen (ACI 544.1R). Typical load-deflection curves for concrete with different types and amounts of fiber are shown in Fig. 2.8 (Johnston 1982b). Flexural toughness indexes may be calculated as the ratio of the area under the load-deflection curve for the steel fiber concrete to a specified endpoint, to the area up to first crack, as shown in ASTM C 1018, or to the area obtained for the matrix without fibers.

Some examples of index values computed using a fixed deflection of 0.075 in. (1.9 mm) to define the test endpoint for a 4 x 4 x 14 in. (100 x 100 x 350 mm) beam are shown in Fig. 2.8. Examples of index values I_5, I_{10}, and I_{30}, which can be computed for any size or shape of specimen, are also shown in Fig. 2.8.

These indexes, defined in ASTM C 1018, are obtained by dividing the area under the load-deflection curve, determined at a deflection that is a multiple of the first-crack deflection, by the area under the curve up to the first crack. I_5 is determined at a deflection 3 times the first-crack deflection, I_{10} is determined at 5.5, and I_{30} at 15.5 times the first-crack deflection. For example, for the second highest curve of Fig. 2.8, the first-crack deflection is 0.0055 in. (0.014 mm). I_5 is therefore determined at a deflection of 0.0165 in. (0.042 mm). The other values are computed similarly. ASTM C 1018 recommends that the end-point deflection and the corresponding index be selected to reflect the level of serviceability required in terms of cracking and deflection.

Values of the ASTM C 1018 toughness indexes depend primarily on the type, concentration, and aspect ratio of the fibers, and are essentially independent of whether the matrix is mortar or concrete (Johnston and Gray 1986). Thus, the indexes reflect the toughening effect of the fibers as distinct from any strengthening effect that may occur, such as an increase in first-crack strength.

Strengthening effects of this nature depend primarily on matrix characteristics such as water-cement ratio. In general, crimped fibers, surface-deformed fibers, and fibers with end anchorage produce toughness indexes greater than those for smooth straight fibers at the same volume concentration, or allow similar index values to be achieved with lower fiber concentrations. For concrete containing the types of fiber with improved anchorage such as surface deformations, hooked ends, enlarged ends, or full-length crimping, index values of 5.0 for I_5 and 10.0 for I_{10} are readily achieved at fiber volumes of 1 percent or less. Such index values indicate a composite with plastic behavior after first crack that approximates the behavior of mild steel after reaching its yield point (two upper curves in Fig. 2.8). Lower fiber volumes or less effectively anchored fibers produce correspondingly lower index values (two lower curves in Fig. 2.8).

2.6—Shrinkage and creep

Tests have shown that steel fibers have little effect on free shrinkage of SFRC (Hannant 1978). However, when shrinkage is restrained, tests using ring-type concrete specimens cast around a restraining steel ring have shown that steel fibers can substantially reduce the amount of cracking and the mean crack width (Malmberg and Skarendahl 1978; Swamy and Stavrides 1979). However, compression-creep tests carried out over a loading period of 12 months showed that the addition of steel fibers does not significantly reduce the creep strains of the composite (Edgington 1973). This behavior for shrinkage and creep is consistent with the low volume concentration of fiber when compared with an aggregate volume of approximately 70 percent.

2.7—Freeze-thaw resistance

Steel fibers do not significantly affect the freeze-thaw resistance of concrete, although they may reduce the severity of visible cracking and spalling as a result of freezing in concretes with an inadequate air-void system (Aufmuth et al. 1974). A proper air-void system (ACI 201.2R) remains the most important criterion needed to insure satisfactory freeze-thaw resistance, just as with plain concrete.

2.8—Abrasion/cavitation/erosion resistance

Both laboratory tests and full-scale field trials have shown that SFRC has high resistance to cavitation forces resulting from high-velocity water flow and the damage caused by the impact of large waterborne debris at high velocity (Schrader and Munch 1976a; Houghton et al. 1978; ICOLD 1982). Even greater cavitation resistance is reported for steel fiber concrete impregnated with a polymer (Houghton et al. 1978).

It is important to note the difference between erosion caused by impact forces (such as from cavitation or from rocks and debris impacting at high velocity) and the type of erosion that occurs from the wearing action of low velocity particles. Tests at the Waterways Experiment Station indicate that steel fiber additions do not improve the abrasion/erosion resistance of concrete caused by small particles at low water velocities. This is because adjustments in the mixture proportions to accommodate the fiber requirements reduce coarse aggregate content and increase paste content (Liu 1981).

2.9—Performance under dynamic loading

The dynamic strength of concrete reinforced with various types of fibers and subjected to explosive charges; dropped weights; and dynamic flexural, tensile, and compressive loads is 3 to 10 times greater than that for plain concrete (Williamson 1965; Robins and Calderwood 1978; Suaris and Shah 1984). The higher energy required to pull the fibers out of the matrix provides the impact strength and the resistance to spalling and fragmentation under rapid loading (Suaris and Shah 1981; Gokoz and Naaman 1981).

An impact test has been devised for fibrous concrete that uses a 10-lb (4.54-kg) hammer dropped onto a steel ball resting on the test specimen. The equipment used to compact asphalt concrete specimens according to ASTM D 1559 can readily be adapted for this test; this is described in ACI 544.2R. For fibrous concrete, the number of blows to failure is typically several hundred compared to 30 to 50 for plain concrete (Schrader 1981b).

Steel fiber reinforced beams have been subjected to impact loading in instrumented drop-weight and Charpy-type systems (Suaris and Shah 1983; Naaman and Gopalaratnam 1983; Gopalaratnam, Shah, and John 1984; Gopalaratnam and Shah 1986). It was observed that the total energy absorbed (measured from the load-deflection curves) by SFRC beams can be as much as 40 to 100 times that for unreinforced beams.

CHAPTER 3—DESIGN APPLICATIONS

3.1—Slabs

The greatest number of applications of steel fiber reinforced concrete (SFRC) has been in the area of slabs, bridge decks, airport pavements, parking areas, and cavitation/erosion environments. These applications have been summarized by Hoff (1976-1982), Schrader and Munch (1976b), Lankard (1975), Johnston (1982c), and Shah and Skarendahl (1986).

Wearing surfaces have been the most common application in bridge decks. Between 1972 and 1982, fifteen bridge deck surfaces were constructed with fiber contents from 0.75 to 1.5 volume percent. All surfaces but one were either fully or partially bonded to the existing deck, and most of these developed some cracks. In most cases, the cracks have remained tight and have not adversely affected the riding quality of the deck. A 3 in. (75 mm) thick unbonded overlay on a wooden deck was virtually crack-free after three years of traffic (ACI Committee 544, 1978). Periodic examination of the 15 projects has shown that the SFRC overlays have performed as designed in all but one case. Recently, latex-modified fiber reinforced concrete has been used successfully in seven bridge deck rehabilitation projects (Morgan 1983).

3.1.1 *Slabs on grade*—SFRC projects that are slabs on grade fall into two categories: overlays and new slabs on prepared base.

Many of the bonded or partially bonded experimental overlays placed to date without proper transverse control joints developed transverse cracks within 24 to 36 hours after placement. There are several causes for this. One is that there is greater drying shrinkage and heat release in the SFRC mixtures used because of the higher cement contents [of the order 800 lb/yd^3 (480 kg/m^3)] and the increased water demand. Recent designs have used much lower cement contents, thus reducing drying shrinkage.

It has been suggested that restrained shrinkage occurs in the overlay at a time when bond between the fiber and matrix is inadequate to prevent crack formation. In these cases, a suggested remedy is to use high-range water reducer technology and cooler placing temperatures. A study at the South Dakota School of Mines showed that drying shrinkage is reduced when the use of superplasticizers in SFRC results in a lower water-cement ratio. SFRC mixtures with w/c ratios less than 0.4 had lower shrinkage than conventional structural concrete mixtures (Ramakrishnan and Coyle 1983).

The most extensive and well monitored SFRC slab-on-grade project to date was an experimental highway overlay project in Green County, Iowa, constructed in September and October 1973 (Betterton and Knutson 1975). The project was 3.03 miles (4.85 km) long and included thirty-three 400 x 20 ft (122 x 6.1 m) sections of SFRC overlays 2 and 3 in. (50 and 75 mm) thick on badly broken pavement. Many major mixture and design variables were studied under the same loading and environmental conditions, and performance continues to be monitored.

Early observations on the Green County project indicated that the use of debonding techniques has greatly minimized the formation of transverse cracks. However, later examinations indicated that the bonded sections had outperformed the unbonded sections (Betterton and Knutson 1978). The 3 in. (75 mm) thick overlays are performing significantly better than those that are 2 in. (50 mm) thick. In the analysis of the Green County project, it was concluded that fiber content was the parameter that had the greatest impact on performance, with the higher fiber contents performing the best.

There are few well documented examples of the comparison of SFRC with plain concrete in highway slabs on grade. However, in those projects involving SFRC slabs subjected to heavy bus traffic, there is evidence that SFRC performed as well as plain concrete without fibers at SFRC thicknesses of 60 to 75 percent of the unreinforced slab thickness (Johnston 1984).

The loadings and design procedures for aircraft pavements and warehouse floors are different from those used for highway slabs. For nonhighway uses, the design methods for SFRC are essentially the same as those used for nonfiber concrete except that the improved flexural properties of SFRC are taken into account (AWI c. 1978; Schrader 1984; Rice 1977; Parker 1974; Marvin 1974; BDC 1975).

Twenty-three airport uses (Schrader and Lankard 1983) of SFRC and four experimental test slabs for aircraft-type loading have been reported. Most uses are overlays, although a few have been new slabs cast on prepared base. The airport overlays of SFRC have been constructed considerably thinner (usually by 20 to 60 percent) than a comparable plain concrete overlay would have been, and, in general, have performed well, as reported by Schrader and Lankard (1983) in a study on curling of SFRC. In those cases where comparison with a plain concrete installation was possible, as in the experimental sections, the SFRC performed significantly better.

The majority of the SFRC placements have shown varying amounts of curling at corners or edges (Schrader and Lankard 1983). The curling is similar to that evidenced by other concrete pavements of the same thickness reinforced with bar or mesh. Depending upon the amount of curling, a corner or edge crack may eventually form because of repeated bending. Thinner sections, less than 5 in. (125 mm), are more likely to exhibit curling.

The design of SFRC slabs on grade involves four considerations: (1) flexural stress and strength; (2) elastic deflections; (3) foundation stresses and strength; and (4) curl. The slab must be thick enough to accommodate the flexural stresses imposed by traffic and other loading. Since traffic-induced stresses are repetitive, a reasonable working stress must be established to insure performance under repeated loading.

In comparison with conventional concrete slabs, a fibrous concrete slab is relatively flexible due to its reduced thickness. The magnitude of anticipated elastic deflections must be assessed, because excessive elastic deflections increase the danger of pumping in the subgrade beneath the slab.

Stresses in the underlying layers are also increased due to the reduced thickness, and these must be kept low enough to prevent introduction of permanent deformation in the supporting materials.

Specific recommendations to minimize curl are available (Schrader and Lankard 1983). They include reducing the cement content, water content, and temperature of the plastic concrete, and using Type II portland cement, water reducing admixtures, and set-retarding admixtures. Other recommendations cover curing and construction practices and joint patterns.

The required slab thickness is most often based on a limiting tensile stress in flexure, usually computed by the Westergaard analysis of a slab on an elastic foundation. Selection of an appropriate allowable stress for the design is difficult without laboratory testing, because the reduction factor to account for fatigue and variability of material properties may be different for each mixture, aggregate, water-cement ratio, fiber type, and fiber content.

Parker (1974) has developed pavement thickness design curves for SFRC similar to the design curves for conventional concrete. For general SFRC, the ultimate flexural strength (modulus of rupture) is of the order 1.5 times that of ordinary concrete. A working value of 80 percent of the modulus of rupture obtained from the laboratory SFRC specimen has been conservatively suggested as a design parameter for aircraft pavements (Parker 1974). A value of two-thirds the modulus of rupture has been suggested for highway slabs.

Typical material property values for SFRC that has been used for pavements and overlays are: flexural strength = 900 to 1100 psi (6.2 to 7.6 MPa), compressive strength = 6000 psi (41 MPa), Poisson's ratio = 0.2, and modulus of elasticity = 4.0 x 10^6 psi (27,600 MPa). Typical mixtures that achieve properties in these ranges are shown in ACI 544.3R. Schrader (1984) has developed additional guidance for adapting existing pavement design charts for conventional concrete to the design of fiber reinforced concretes.

Flexural fatigue is an important parameter affecting the performance of pavements. The available data indicate that steel fibers increase the fatigue resistance of the concrete significantly. Batson et al. (1972b) found that a fatigue strength of 90 percent of the first-crack strength at 2 x 10^6 cycles to 50 percent at 10 x 10^6 cycles can be obtained with 2 to 3 percent fiber volume in mortar mixtures for nonreversal type loading. Morse and Williamson (1977), using 1.5 percent fiber volume, obtained 2 x 10^6 cycles at 65 percent of the first-crack stress without developing cracks, also for a nonreversal loading. Zollo (1975) found a dynamic stress ratio [ratio of first-crack stress that will permit 2 x 10^6 cycles to the static (one cycle) first-crack stress] for overlays on steel decks between 0.9 and 0.95 at 2 million cycles.

Generally, fatigue strengths are 65 to 95 percent at one to two million cycles of nonreversed load, as compared to typical values of 50 to 55 percent for beams without fibers. Fatigue strengths are lower for fully reversed loading. For properly proportioned high-quality SFRC, a fatigue value of 85 percent is often used in pavement design. The designer should use fatigue strengths that have been established for the fiber type, volume percent, approximate aggregate size, and approximate mortar content of the materials to be used. Mortar mixtures can accept higher fiber contents and do not necessarily behave the same as concrete mixtures.

3.1.2 *Structural floor slabs*—For small slabs of steel fiber reinforced concrete, Ghalib (1980) presents a design method based on yield line theory. This procedure was confirmed and developed from tests on one-way slabs ¾ in. thick by 6 in. wide by 20 in. long (19 x 150 x 508 mm) on an 18-in. (457-mm) span line loaded near the third points, and on two-way slabs 1.3 in. x 37.8 in. square (33 x 960 mm square) on a 35.4-in. (900-mm) span point loaded at the center. The design method applies to slabs of that approximate size only, and the designer is cautioned not to attempt extrapolation to larger slabs. Design examples given by Ghalib (1980) are for slabs about 0.78 in. (20 mm) thick.

3.1.3 *Bridge decks*—Deterioration of concrete bridge decks due to cracking, scaling, and spalling is a critical maintenance problem for the nation's highway system. One of the main causes of this deterioration is the intrusion of deicing salts into the concrete, causing rapid corrosion of the reinforcing. As discussed in Section 3.1, SFRC overlays have been used on a number of projects in an attempt to find a practical and effective method of prevention and repair of bridge deck deterioration. The ability of steel fibers to control the frequency and severity of cracking, and the high flexural and fatigue strength obtainable with SFRC can provide significant benefit to this application.

However, the SFRC does not stop all cracks, nor does it decrease the permeability of the concrete. As a consequence, SFRC by itself does not solve the problem of intrusion of deicing salts, although it may help by limiting the size and number of cracks. The corrosion of fibers is not a problem in sound concrete. They will corrode in the presence of chlorides, but their small size precludes their being a cause of spalling (Morse and Williamson 1977; Schupack 1985). See ACI 544.1R for additional data on steel fiber corrosion.

3.2—Flexure in beams

3.2.1 *Static flexural strength prediction for beams with fibers only*—Several methods have been developed to predict the flexural strength of small beams reinforced only with steel fibers (Schrader and Lankard 1983; Lankard 1972; Swamy et al. 1974). Some use empirical data from laboratory experiments. Others use the fiber bond area or the law of mixtures, plus a random distribution factor, bond stress, and fiber stress.

Equations developed by Swamy et al. (1974) have a form based on theoretical derivation with the coefficients obtained from a regression analysis of that data. Although the coefficient of correlation for the regression analysis (of the laboratory data analyzed) was 0.98, the predictions may be as much as 50 percent high for field-produced mixtures.

Concrete and mortar, a wide range of mixture proportions, fiber geometries, curing methods, and cement of two types were represented in data from several authors. The first coefficient in each equation should theoretically be 1.0. The equations are applicable only to small [4 x 4 x 12 in. (100 x 100 x 305 mm)] beams, such as those used in laboratory testing or as small minor secondary members in a structure. The designer should not attempt extrapolation to larger beams or to fiber volumes outside the normal range of the data used in the regression analysis. The equations are
first-crack composite strength, psi

$$\sigma_{cf} = 0.843\, f_r\, V_m + 425\, V_f\, \ell/d_f \quad (3\text{-}1)$$

ultimate composite flexural strength, psi

$$\sigma_{cu} = 0.97\, f_r\, V_m + 494\, V_f\, \ell/d_f \quad (3\text{-}2)$$

where

f_r = stress in the matrix (modulus of rupture of the plain mortar or concrete), psi
V_m = volume fraction of the matrix = $1 - V_f$
V_f = volume fraction of the fibers = $1 - V_m$
ℓ/d_f = ratio of the length to diameter of the fibers (aspect ratio)

These equations correlate well with laboratory work. However, as previously noted, if they are used to predict strengths of field placements, the predictions will generally be higher than the actual values by up to 50 percent.

3.2.2 *Static flexural analysis of beams containing bars and fibers*—A method has been developed (Henager and Doherty 1976) for predicting the strength of beams reinforced with both bars and fibers. This method is similar to the ACI ultimate strength design method. The tensile strength computed for the fibrous concrete is added to that contributed by the reinforcing bars to obtain the ultimate moment.

The basic design assumptions made by Henager and Doherty (1976) are shown in Fig. 3.1, and the equation for nominal moment M_n of a singly reinforced steel fibrous concrete beam is

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) + \sigma_t\, b\,(h - e)\left(\frac{h}{2} + \frac{e}{2} - \frac{a}{2}\right) \quad (3\text{-}3)$$

$$e = [\epsilon_s\,(\text{fibers}) + 0.003]\, c/0.003 \quad (3\text{-}4)$$

where

$$\sigma_t = 1.12\, \ell/d_f\, \rho_f\, F_{be} \text{ (inch/pound units, psi) or} \quad (3\text{-}5)$$

$$\sigma_t = 0.00772\, \ell/d_f\, \rho_f\, F_{be} \text{ (SI units, MPa)} \quad (3\text{-}6)$$

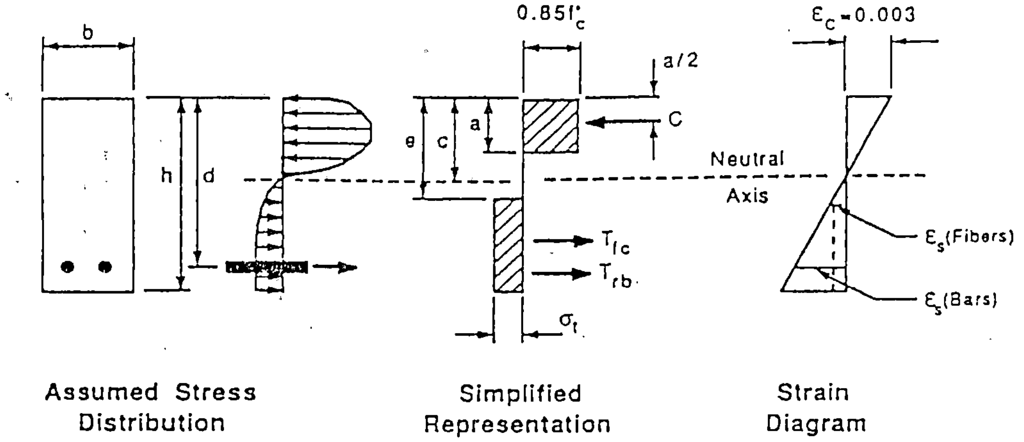

Fig. 3.1—Design assumptions for analysis of singly reinforced concrete beams containing steel fibers (Henager and Doherty 1976)

where

ℓ = fiber length
d_f = fiber diameter
ρ_f = percent by volume of steel fibers
F_{be} = bond efficiency of the fiber which varies from 1.0 to 1.2 depending upon fiber characteristics
a = depth of rectangular stress block
b = width of beam
c = distance from extreme compression fiber to neutral axis found by equating the internal tension and compression forces
d = distance from extreme compression fiber to centroid of tension reinforcement
e = distance from extreme compression fiber to top of tensile stress block of fibrous concrete (Fig. 3.1)
ϵ_s = tensile strain in steel at theoretical moment strength of beam, for bars = f_y/E_s; for fibers = σ_f/E_s based on fiber stress developed at pullout (dynamic bond stress of 333 psi) (Fig. 3.1)
ϵ_c = compressive strain in concrete
f'_c = compressive strength of concrete
f_y = yield strength of reinforcing bar
A_s = area of tension reinforcement
C = compressive force
h = total depth of beam
σ_t = tensile stress in fibrous concrete
E_s = modulus of elasticity of steel
T_{fc} = tensile force of fibrous concrete = $\sigma_t b (h - e)$
T_{rb} = tensile force of bar reinforcement = $A_s f_y$

In this analysis, the maximum usable strain at the extreme concrete compression fiber is taken to be 0.003. There are some data that indicate 0.003 may be conservative. Work by Williamson (1973) and Pearlman (1979) indicates that 0.0033 may be more realistic for steel fiber concrete. Swamy and Al-Ta'an (1981) recommend 0.0035. Based on a study of plastic hinges, Hassoun and Sahebjam (1985) recommend a failure strain of 0.0035 for concrete with 1.0 percent steel fibers, and 0.004 for 1 to 3 percent fibers.

The question arises as to whether the load factors and the capacity-reduction factor for flexure used in ACI 318 are still applicable. Normally, a smaller capacity-reduction factor would be used in the calculation of design strength when concrete tension is a major part of the resisting mechanism. In this use, however, the concrete tension contributes only about 5 to 15 percent of the resisting moment, which is significant but not a major part. Additional research is needed to define the reliability of the concrete tension force before a factor can be assigned to this type of member. It would be reasonable, however, to maintain a $\phi = 0.9$ for the part of the resistance attributed to the deformed bar reinforcement [first term in Eq. (3-3)], and a smaller ϕ for the concrete tension contribution [second term in Eq. (3-3)].

The ratios of the calculated moments [using Eq. (3-3)] to actual moments in test beams ranged from 1.001 to 1.017 for a series of 6 beams reported by Henager and Doherty (1976). In these tests, a SFRC mortar mixture containing 940 lb of cement/yd^3 (557 kg/m^3), 2256 lb (1337 kg) of ¼-in. (6-mm) maximum size aggregate, and a w/c ratio of 0.45 or less was used. The method has also been applied successfully to fiber reinforced beams using a normal cement content [420 lb/yd^3 (250 kg/m^3)] and to beams of fiber reinforced lightweight aggregate concrete (Henager 1977a).

Eq. (3-5) and (3-6) incorporate a factor for bond stress of the fibers; this was chosen because it correlated with these tests. The selection of 333 psi (2.3 MPa) for bond stress was based on reported values in the range of 213 to 583 psi (1.5 to 4 MPa) for smooth, straight, round, high-strength fibers with embedment lengths of ½ to 1¼ in. (12 to 32 mm) (Williamson 1974; Aleszka and Beaumont 1973; Naaman and Shah 1976). This was combined with calculations that showed that 333 psi (2.3 MPa) would not cause fracture of the fibers used in the beams.

Fiber fracture rarely occurs in SFRC flexure loading.

with the fiber proportions and anchorage provisions normally available and with ℓ/d = 100 or less. In this derivation the strain in the fibers is limited to the amount that produces about 333 psi, and it does not increase because the fibers slip and pull out. It is the pullout resistance that produces the toughness characteristic of SFRC during fracture. Other methods for static flexural analysis of beams containing bars and fibers have been proposed by Schrader (1971), Williamson (1973), Swamy and Al-Ta'an (1981), and Jindal (1984). There have been studies on combined axial load and flexure that deal with the same problem of including the effect of fibers on the tension force in the concrete (Craig et al. 1984b).

3.2.3 *Beam-to-column joints*—Additional studies related to flexure have been performed on beam-to-column connections. Henager (1977b) investigated the performance of a seismic-resistant beam-column joint using steel fibers in lieu of hoops in the joint region. Longitudinal steel bars were used in both the beam and the column. Deformed steel fibers 1½ x 0.020 in. (38 x 0.51 mm) were used at a fiber content of 1.67 percent by volume in the joint region, an area of high shear stresses.

In comparison to a conventional joint using hoop ties at 4 in. (100 mm) on centers, the SFRC joint showed no cracking in the joint region, whereas the conventional joint showed some hairline cracking. The SFRC joint developed a maximum moment of 56.5 kip-ft (76.7 kN-m) compared to 45.9 kip-ft (62.2 kN-m) for the conventional joint. The 28-day compressive strengths were 5640 psi (38.9 MPa) for the SFRC and 5915 psi (40.8 MPa) for the conventional concrete in the joint regions. Flexural strengths were 1419 psi (9.8 MPa) for the SFRC and 450 psi (3.1 MPa) for the conventional concrete.

Craig et al. (1984a) tested 10 joints, 5 of which contained steel fibers and a reduced quantity of deformed bar hoops. He also noted considerable improvement in the joint strength, ductility, and energy absorption with the steel fibers.

3.2.4 *Flexural fatigue considerations*—Batson et al. (1972b) recommended that 67 percent of the first-crack stress be used for 10^6 cycles of load in conventionally reinforced SFRC beams. Schrader (1971) has shown that the post-fatigue load-carrying capacity of SFRC beams is improved, but that the presence of conventional reinforcing bars overshadows the fatigue and static strength improvements obtained when comparing SFRC beams to beams with no conventional reinforcing.

Kormeling, Reinhardt, and Shah (1980) tested conventionally reinforced concrete beams with and without fibers in fatigue loading up to 10 million cycles. It was observed that the addition of fibers to conventionally reinforced concrete beams increased the fatigue life and decreased deflections and crack widths for a given number of dynamic cycles. The beneficial effect of fibers decreased with increasing volume of conventional reinforcement.

3.3—Shear in beams

There are considerable laboratory data indicating that fibers substantially increase the shear (diagonal tension) capacity of concrete and mortar beams. Steel fibers show several potential advantages when used to supplement or replace vertical stirrups or bent-up steel bars. These advantages are: (1) the fibers are randomly distributed through the volume of the concrete at much closer spacing than can be obtained with reinforcing bars; (2) the first-crack tensile strength and the ultimate tensile strength are increased by the fibers; and (3) the shear-friction strength is increased.

It is evident from a number of tests that stirrup and fiber reinforcement can be used effectively in combination. However, although the increase in shear capacity has been quantified in several investigations it has not yet been used in practical applications. This section presents the results of some of the studies dealing with the effect of steel fibers on shear strength in beams and slabs. It is important to identify the type and size of fiber upon which the design is based.

Batson et al. (1972a), using mortar beams 4 x 6 x 78 in. (100 x 150 x 2000 mm), conducted a series of tests to determine the effectiveness of straight steel fibers as web reinforcement in beams with conventional flexural reinforcement. In tests of 96 beams, the fiber size, type, and volume concentration were varied, along with the shear-span-to-depth ratio a/d, where a = shear span (distance between concentrated load and face of support) and d = the depth to centroid of reinforcing bars. (Shear capacity of rectangular beams may be considered a function of moment-to-shear ratio a/d or M/Vd.) Third-point loading was used throughout the test program.

It was found that, for a shear-span-to-depth ratio of 4.8, the nonfiber beams failed in shear and developed a shear stress at failure of 277 psi (1.91 MPa). For a fiber volume percent of 0.88, the average shearing stress at failure was 310 psi (2.14 MPa) with a moment-shear failure; for 1.76 volume percent, 330 psi (2.28 MPa) with a moment failure; and for 2.66 volume percent, 352 psi (2.43 MPa), also with a moment failure. The latter value represents an increase of 27 percent over the nonfiber beams. The shear stress at failure for beams with #3 [⅜-in. (9.5-mm) diameter] stirrups at 2-in. (50-mm) spacing in the outer thirds averaged 315 psi (2.17 MPa). All shearing stresses were computed by the equation $v = VQ/Ib$.

It was found that as the shear-span ratio decreased and fiber volume increased, higher shear stresses were developed at failure. For example, for an a/d of 3.6 and a volume percent of fiber of 0.88, the shear stress at failure was 444 psi (3.06 MPa) with a moment failure; for an a/d of 2.8 and a fiber volume percent of 1.76, the shear stress at failure was 550 psi (3.79 MPa) and a moment failure.

Paul and Sinnamon (1975) studied the effect of straight steel fibers on the shear capacity of concrete in a series of seven tests similar to those of Batson et al. (1972a). The objective was to determine a procedure for

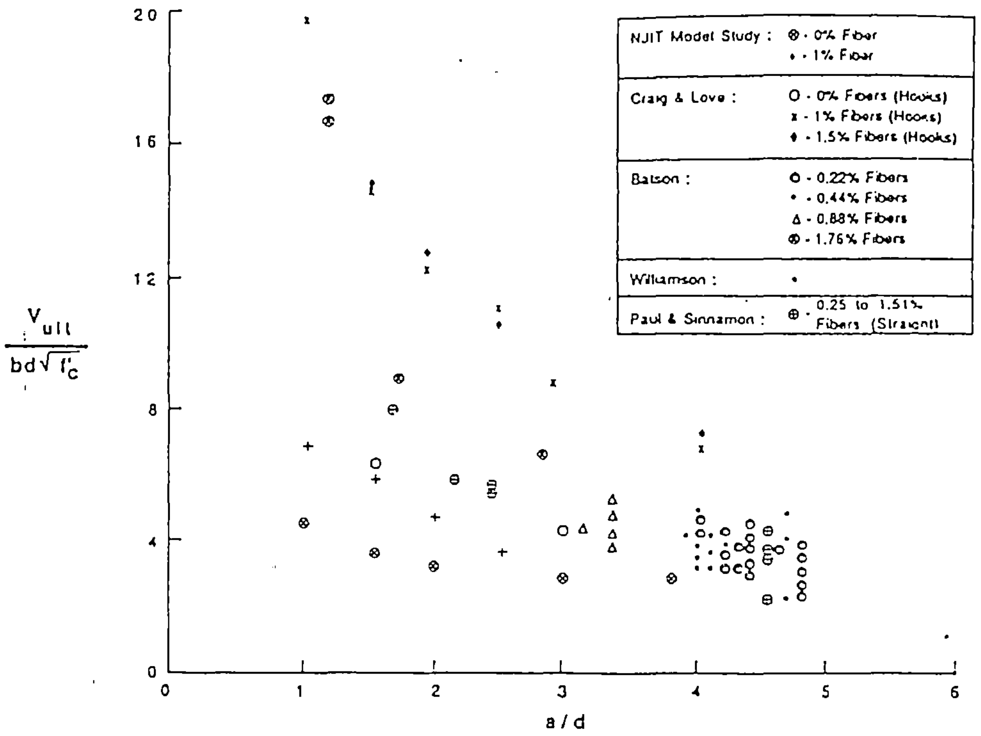

Fig. 3.2—Shear behavior of reinforced fibrous concrete beams

predicting the shear capacity of segmented concrete tunnel liners made with steel fiber reinforced concrete. Their results agreed closely with Batson, especially for beams with similar a/d ratios.

Williamson (1978), working with conventionally reinforced beams 12 x 21.5 in. x 23 ft (305 x 546 x 7010 mm), found that when 1.66 percent by volume of straight steel fibers were used in place of stirrups, the shear capacity of the beams was increased 45 percent over a beam without stirrups. Nevertheless, the beams failed in shear. This is consistent with the results of other investigators. When steel fibers with deformed ends were used (1.1 percent by volume), the shear capacity was increased by 45 to 67 percent and the beams failed in flexure.

Williamson (1978) concluded that, based upon the use of steel fibers with deformed ends, steel fibers can increase the shear strength of concrete beams enough to prevent catastrophic diagonal tension failure and to force the beam to fail in flexure. In his report, Williamson (1978) presents an analysis showing that steel fibers can present an economical alternative to the use of stirrups in reinforced concrete design.

Tests of crimped-end fibers have shown considerable increase in the shear capacity of reinforced concrete in other studies. Some of the tests at the New Jersey Institute of Technology (Craig 1983) have shown increases of more than 100 percent. Twelve full-scale test beams with 1.0 and 1.5 percent by volume of 0.020 x 1.18 in. (0.5 x 30 mm) long crimped-end fibers were tested with the following span-to-depth ratios: a/d = 1.0, 1.5, 2.0, 2.5, and 3.0. The beams had a 6 x 12 in. (150 x 300 mm) section. The increases in shear capacity for the 1.0
and 1.5 percent fiber content with a/d = 1.5 were 1
and 140 percent, respectively. Similarly, the increase
a/d = 3.0 was 108 percent for 1.0 volume percent
fiber. The combination of stirrups and fibers showe
slow and controlled cracking and better distribution
tensile cracks, and minimized the penetration of she
cracks into the compression zone.

It was also found that when fibers with crimped en
were the only shear reinforcement, there was a signif
cant decrease in diagonal tension cracking in the beam
Fig. 3.2 shows the results of the tests reported by Crai
(1983) and compares them with other test results.

Bollano (1980) investigated the behavior of steel f
bers as shear reinforcement in two-span continuous
reinforced concrete beams. These tests indicate the b
havior in shear for the common range of M/Vd rati
for negative moment regions (M/Vd = 2 to 3, equiva
lent to a/d for simple beams). It is generally assume
that the M/Vd concept can be used equally well in sim
ply supported and continuous beams, but this is n
entirely true for the beams investigated. The a/d rati
was 4.8 and the M/Vd ratio was 3.0. The regular rei
forced concrete beam $V/bd\sqrt{f'_c}$ ranged from 3 to
whereas this parameter for the beams with straight an
crimped-end fibers ranged from 5 to 8, showing signi
icant improvement with the addition of fibers.

Criswell (1976) conducted a number of differen
shear tests, all of which demonstrated an increase
shear capacity with the use of steel fibers. All of hi
tests were made with concrete containing 1.0 percent b
volume of straight fibers. The results of four shear
friction specimens showed a 20 percent increase in shea
strength; bolt pullout tests showed a shear strength i

excess of 64 percent greater than that for the nonfiber concrete; slab-column connection specimens developed shearing strengths 27 percent greater than the nonfiber specimens; and beam-column shear tests resulted in shear strengths up to 60 percent greater.

Sharma (1986) tested 7 beams with steel fiber reinforcement, of which 4 also contained stirrups. The fibers had deformed ends. Based on these tests and those by Batson et al (1972a) and Williamson and Knab (1975), he proposed the following equation for predicting the average shear stress v_{cf} in the SFRC beams. (In the equation that follows, a typographical error in Sharma's 1986 paper has been corrected.)

$$v_{cf} = \frac{2}{3} f_t' \left(\frac{d}{a}\right)^{0.25} \qquad (3\text{-}7)$$

where f_t' is the tensile strength of concrete obtained from results of indirect tension tests of 6 x 12 in. (150 x 300 mm) cylinders, and d/a is the effective depth-to-shear-span ratio. Straight, crimped, and deformed-end fibers were included in the analysis and the average ratio of experimental to calculated shear stress was 1.03 with a mean deviation of 7.6 percent. The influence of different fiber types and quantities is considered through their influence on the parameter f_t'. The proposed design approach follows the method of ACI 318 for calculating the contribution of stirrups to the shear capacity, to which is added the resisting force of the concrete calculated from the shear stress given by Eq. (3-7).

An additional design procedure for shear and torsion in composite reinforced concrete beams with fibers has been published by Craig (1986).

3.4—Shear in slabs

The influence of steel fiber reinforcement on the shear strength of reinforced concrete flat plates was investigated by Swamy et al. (1979) in a test series on four slabs with various fiber contents (0, 0.6, 0.9, and 1.2 percent by volume). The slabs were 72 x 72 x 5 in. (1830 x 1830 x 125 mm) with load applied through a square column stub 6 x 6 x 10 in. (150 x 150 x 250 mm). All slabs had identical tension and compression reinforcement, and the steel fibers had crimped ends and were 0.02 x 2 in. (0.5 x 50 mm) long. The shear strength increases were 22, 35, and 42 percent for the 0.6, 0.9, and 1.2 percent by volume fiber contents, respectively.

3.5—Shotcrete

Steel fiber shotcrete has been used in the construction of dome-shaped structures using the inflation/foam/shotcrete process (Williamson et al. 1977; Nelson and Henager 1981). Design of the structures follows the conventional structural design procedures for concrete domes, taking into account the increased compressive, shear, and flexural properties of fibrous concrete.

This material is also used for underground support and linings, rock slope stabilization, repair of deteriorated concrete, etc. (Kobler 1966; Shah and Skarendahl 1986; Morgan and McAskill 1984). A research effort carried out in a side chamber of an Atlanta subway station to examine shotcrete support in loosening rock is reported by Fernandez-Delgado et al. (1981).

A significant quantity of steel fiber reinforced shotcrete has been used throughout the world, and a state-of-the-art report has been prepared by ACI Committee 506 (ACI 506.1R). That report also contains information on material properties, application procedures, and mixtures.

3.6—Cavitation erosion

Failure of hydraulic concrete structures is often precipitated by cavitation-erosion failure of the concrete. SFRC was used to repair severe cavitation-erosion damage that occurred in good quality conventional concrete after relatively short service at Dworshak, Libby, and Tarbella Dams (ICOLD 1982; Schrader and Munch 1976a). All three are high-head structures capable of large flows and discharge velocities in excess of 100 fps (30.5 mps).

At Libby and Dworshak, both the outlet conduits and stilling basins were repaired. At Tarbella, fiber concrete was used as topping in the basin and ogee curve leading from the outlet conduit to the basin. All three projects have performed well since the repairs. It should be noted, however, that while SFRC improves resistance to erosion from cavitation, it does not improve resistance to erosion from abrasion or scouring (see Section 2.8).

3.7—Additional applications

There are several applications of SFRC that have involved a considerable volume of material, but which do not have well defined design methods specifically for SFRC. Among these are fence posts, sidewalks, embankment protection, machinery foundations, machine tool frames, manhole covers, dolosse, bridge deck expansion joints (nosings at joints to improve wear and impact resistance), dams, electric power manholes, ditch linings, mine cribbing, liquid storage tanks, tilt-up wall construction, and thin precast members (see also Shah and Batson 1987).

CHAPTER 4—REFERENCES

4.1—Specified and/or recommended references

The standards of the American Society for Testing and Materials and the standards and reports of the American Concrete Institute referred to in this report are listed below with their serial designation, including the year of adoption or revision. The standards and reports listed were the latest editions at the time this report was prepared. Since some of these publications are revised frequently, generally in minor details only, the user of this report should check directly with the sponsoring group to refer to the latest edition.

American Concrete Institute

201.2R-77 Reapproved 1982	Guide to Durable Concrete
223-83	Standard Practice for the Use of Shrinkage-Compensating Concrete
318-83 (Revised 1986)	Building Code Requirements for Reinforced Concrete
506R-85	Guide to Shotcrete
506.1R-84	State-of-the-Art Report on Fiber Reinforced Shotcrete
506.2-77	Standard Specification for Materials, Proportioning, and Application of Shotcrete
544.1R-82 (Reapproved 1986)	State-of-the-Art Report on Fiber Reinforced Concrete
544.2R-78 (Revised 1983)	Measurement of Properties of Fiber Reinforced Concrete
544.3R-84	Guide for Specifying, Mixing, Placing and Finishing Steel Fiber Reinforced Concrete
549R-82	State-of-the-Art Report on Ferrocement

ASTM

A 820-85	Standard Specification for Steel Fibers for Use in Fiber Reinforced Concrete
C 78-84	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C 143-78	Standard Test Method for Slump of Portland Cement Concrete
C 157-80	Standard Test Method for Length Change of Hardened Cement Mortar and Concrete
C 666-84	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C 995-86	Standard Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone
C 1018-85	Standard Test Method for Flexural Toughness and First Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)
D 1559-82	Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

The above publications may be obtained from the following organizations:

American Concrete Institute
P. O. Box 19150
Detroit, MI 48219-0150

ASTM
1916 Race Street
Philadelphia, PA 19103

4.2—Cited references

ACI Committee 544, Feb. 15, 1978, "Listing of Fibrous Concrete Projects," American Concrete Institute, Detroit, 232 pp.

ACI Publication SP-44, 1974, *Fiber Reinforced Concrete*, American Concrete Institute, Detroit, 554 pp.

ACI Publication SP-81, 1984, *Fiber Reinforced Concrete—Properties and Applications*, American Concrete Institute, Detroit, 600 pp.

Aleszka, J. C., and Beaumont, P. W., Dec. 1973, "The Fracture Behavior of Plain, Polymer-Impregnated, and Fiber-Reinforced Concrete," *Report* No. UCLA-ENG-7396, University of California, Los Angeles.

Anonymous, Dec. 1971, "Wire-Reinforced Precast Concrete Decking Panels," *Precast Concrete* (London), V. 2, No. 12, pp. 703-708.

Aufmuth, R. E.; Naus, D. J.; and Williamson, G. R., Nov. 1974, "Effects of Aggressive Environments on Steel Fiber Reinforced Concrete," *Letter Report* No. M-113, U.S. Army Construction Engineering Research Laboratory, Champaign.

AWI, c. 1978, "Design Manual for Pavements and Industrial Floors," Australian Wire Industries, Pty., Ltd., Five Dock, NSW.

Batson, G.; Jenkins, E.; and Spatney, R., Oct. 1972a, "Steel Fibers as Shear Reinforcement in Beams," ACI JOURNAL, *Proceedings* V. 69, No. 10, pp. 640-644.

Batson, G; Ball, C.; Bailey, L.; Landers, E.; and Hooks, J., "Flexural Fatigue Strength of Steel Fiber Reinforced Concrete Beams," ACI JOURNAL, *Proceedings* V. 69, No. 11, Nov. 1972, pp. 673-677.

BDC, 1975, "Design Manual for Factory and Warehouse Floor Slabs," Battelle Development Corp., Columbus.

Betterton, R. H., and Knutson, M. J., Dec. 5, 1978, "Fibrous PC Concrete Overlay Research in Green County, Iowa," *Final Report*, Iowa Highway Research Board, Research Project HR-165, Office of County Engineer, Green County.

Bollano, R. D., May 1980, "Steel Fibers as Shear Reinforcement in Two Span Continuous Reinforced Concrete Beams," MS thesis, Civil and Environmental Engineering, Clarkson College of Technology, Potsdam.

Craig, R. J., Mar. 4, 1983, "Design Procedures for Fibrous Concrete—Shear, Moment and Torsion," *Proceedings*, Structural Concrete Design Conference, New Jersey Institute of Technology, Newark, pp. 253-284.

Craig, R. J., Apr. 1986, "Design for Shear and Torsion in Composite Reinforced Concrete Beams with Fibers," Proceedings, Southeastern Conference on Theoretical and Applied Mechanics (SECTAMXIII), Columbia, South Carolina, pp. 476-484.

Craig, R. John; Mahadev, Sitaram; Patel, C.C.; Viteri, Manuel; and Kertesz, Czaba, 1984a, "Behavior of Joints Using Reinforced Fibrous Concrete," *Fiber Reinforced Concrete—International Symposium*, SP-81, American Concrete Institute, Detroit, pp. 125-167.

Craig, R. John; McConnell, J.; Germann, H.; Dib, N.; and Kashani, F., 1984b, "Behavior of Reinforced Fibrous Concrete Columns," *Fiber Reinforced Concrete—International Symposium*, SP-81, American Concrete Institute, Detroit, pp. 69-105.

Criswell, M. E., Aug. 1976, "Shear in Fiber Reinforced Concrete," National Structural Engineering Conference, Madison.

Edgington, J., 1973, "Steel-Fibre-Reinforced- Concrete," PhD thesis, University of Surrey.

Fanella, David A., and Naaman, Antoine E., July-Aug. 1985, "Stress-Strain Properties of Fiber Reinforced Concrete in Compression," ACI JOURNAL, *Proceedings* V. 82, No. 4, pp. 475-483.

Fernandez-Delgado, G., et al., 1981, "Thin Shotcrete Linings in Loosening Rock," *Report* No. UMTA-GA-06-0007 81-1, U.S. Department of Transportaion, Washington, D.C., 525 pp.

Ghalib, Mudhafar A., July-Aug. 1980, "Moment Capacity of Steel Fiber Reinforced Small Concrete Slabs," ACI JOURNAL, *Proceedings* V. 77, No. 4, pp. 247-257.

Gokoz, U. N., and Naaman, A. E., Aug. 1981, "Effect of Strain Rate on the Pull-Out Behavior of Fibers in Mortar," *International Journal of Cement Composites* (Harlow), V. 3, No. 3, pp. 187-202.

Gopalaratnam, V. S., and Shah, S. P., Jan.-Feb. 1986, "Properties of Steel Fiber Reinforced Concrete Subjected to Impact Loading," ACI JOURNAL, *Proceedings* V. 83, No. 1, pp. 117-126.

Gopalaratnam, V. S., and Shah, S, 1987a, "Failure Mechanisms and Fracture of Fiber Reinforced Concrete," *Fiber Reinforced Concrete—Properties and Applications*, SP-105, American Concrete Institute, Detroit, pp. 1-25.

Gopalaratnam, V. S., and Shah, S. P., May 1987b, "Tensile Failure of Steel Fiber Reinforced Mortar," *Journal of Engineering Mechanics*, ASCE, V. 113, No. 5, May 1987, pp. 635-652.

Gopalaratnam, V. S.; Shah, S. P.; and John, R., June 1984, "A Modified Instrumented Charpy Test for Cement Based Composites," *Experimental Mechanics*, V. 24, No. 2, pp. 102-110.

Hannant, D. J., Mar. 1984, *Fibre Cements and Fibre Concretes*, Wiley & Sons, Chichester, 219 pp.

Hassoun, M. N., and Sahebjam, K., May 1985, "Plastic Hinge in Two-Span Reinforced Concrete Beams Containing Steel Fibers," *Proceedings*, Canadian Society for Civil Engineering, Montreal, pp. 119-139.

Henager, C. H., 1977a, "Ultimate Strength of Reinforced Steel Fibrous Concrete Beams," *Proceedings*, Conference on Fiber-Reinforced Materials: Design and Engineering Applications, Institution of Civil Engineers, London, pp. 165-173.

Henager, C. H., 1977b, "Steel Fibrous, Ductile Concrete Joint for Seismic-Resistant Structures," *Reinforced Concrete in Seismic Zones*, SP-53, American Concrete Institute, Detroit, pp. 371-386.

Henager, Charles H., and Doherty, Terrence J., Jan. 1976, Analysis of Reinforced Fibrous Concrete Beams," *Proceedings*, ASCE, V 12, ST-1, pp. 177-188.

Hoff, George C., 1976-1982, "Selected Bibliography on Fiber-Reinforced Cement and Concrete," *Miscellaneous Paper* No. C-76-6, and Supplements 1-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg. Also, Chapter 9, *Report* No. FHWA-RD-77-110, V. 2, Federal Highway Administration, Washington, D.C., Apr. 1977.

Houghton, D. L.; Borge, O. E.; and Paxton, J. A., Dec. 1978, "Cavitation Resistance of Some Special Concretes," ACI JOURNAL, *Proceedings* V. 75, No. 12, pp. 664-667.

ICOLD, 1982, "Fiber Reinforced Concrete," *Bulletin* No. 40, International Commission on Large Dams, Paris.

Jindal, Roop L., 1984, "Shear and Moment Capacities of Steel Fiber Reinforced Concrete Beams," *Fiber Reinforced Concrete—International Symposium*, SP- 81, American Concrete Institute, Detroit, pp. 1-16.

Johnston, C. D., 1980, "Properties of Steel Fibre Reinforced Mortar and Concrete," *Proceedings*, International Symposium on Fibrous Concrete (CI-80), Construction Press, Lancaster, pp. 29-47.

Johnston, Colin D., Mar.-Apr. 1982a, "Steel Fiber Reinforced and Plain Concrete: Factors Influencing Flexural Strength Measurement," ACI JOURNAL, *Proceedings* V. 79, No. 2, pp. 131-138.

Johnston, C. D., Winter 1982b, "Definition and Measurement of Flexural Toughness Parameters for Fiber Reinforced Concrete," *Cement, Concrete, and Aggregates*, V. 4, No. 2, pp. 53-60.

Johnston, C. D., Apr. 1982c, "Steel Fibre Reinforced Concrete—Present and Future in Engineering Construction," *Composites* (Butterworth & Co., London), pp. 113-121.

Johnston, Colin D., Dec. 1984, "Steel Fiber Reinforced Pavement Trials," *Concrete International: Design & Construction*, V. 6, No. 12, pp. 39-43.

Johnston, C. D., and Gray, R. J., July 1986, "Flexural Toughness and First-Crack Strength of Fibre-Reinforced Concrete," *Proceedings*, 3rd RILEM International Symposium on Fiber Reinforced Cement Composites, Sheffield.

Kobler, Helmut G., 1966, "Dry-Mix Coarse-Aggregate Shotcrete as Underground Support," *Shotcreting*, SP-14, American Concrete Institute, Detroit, pp. 33-58.

Kormeling, H. A.; Reinhardt, H. W.; and Shah, S. P., Jan.-Feb. 1980, "Static and Fatigue Properties of Concrete Beams Reinforced with Bars and Fibers," ACI JOURNAL, *Proceedings* V. 77, No. 1, pp. 36-43.

Lankard, D. R., May 1972, "Prediction of the Flexural Strength Properties of Steel Fibrous Concrete," *Proceedings*, CERL Conference on Fibrous Concrete, Construction Engineering Research Laboratory, Champaign, pp. 101-123.

Lankard, D. R., 1975, "Fibre Concrete Applications," *Fibre Reinforced Cement and Concrete*, RILEM Symposium 1975, Construction Press, Lancaster, pp. 3-19.

Lankard, D. R., Dec. 1984, "Properties, Applications: Slurry Infiltrated Fiber Concrete (SIFCON)," *Concrete International: Design & Construction*, V. 61, No. 12, pp. 44-47.

Liu, T. C., Nov. 1981, "Abrasion-Erosion Resistance of Concrete," *Miscellaneous Paper* No. SL-81-32, U.S Army Engineer Waterways Experiment Station, Vicksburg.

Malmberg, Bo, and Skarendahl, Ake, 1978, "Method of Studying the Cracking of Fibre Concrete under Restrained Shrinkage," *Testing and Test Methods of Fibre Cement Composites*, RILEM Symposium 1978, Construction Press, Lancaster, pp. 173-179.

Marvin, E., Dec. 1974, "Fibrous Concrete Overlay Thickness Design," *Technical Note*, U.S. Army Construction Engineering Research Laboratory, Champaign.

Morgan, D. R., Sept. 1983, "Steel Fibre Concrete for Bridge Rehabilitation—A Review;" Annual Conference, Roads and Transportation Association of Canada, Edmonton.

Morgan, Dudley R., and McAskill, Neil, Dec. 1984, "Rocky Mountain Tunnels Lined with Steel Fiber Reinforced Shotcrete," *Concrete International: Design & Construction*, V. 6, No. 12, pp. 33-38.

Morse, D. C., and Williamson, G. R., May 1977, "Corrosion Behavior of Steel Fiber Concrete," *Report* No. CERL-TR-M-217, U.S. Army Construction Engineering Research Laboratory, Champaign, 37 pp.

Moustafa, S. E., July 1974, "Use of Steel Fibrous Concrete Shear Reinforcement in T-Beam Webs," paper presented at a short course on Steel Fibrous Concrete, Joint Center for Graduate Study, Richland, Washington.

Naaman, A. E., and Gopalaratnam, V. S., Nov. 1983, "Impact Properties of Steel Fiber Reinforced Concrete in Bending," *International Journal of Cement Composites and Lightweight Concrete* (Harlow), V. 5, No. 4, pp. 225-237.

Naaman, Antoine E., and Shah, Surendra P., Aug. 1976, "Pull-Out Mechanism in Steel Fiber Reinforced Concrete," *Proceedings*, ASCE, V. 102, ST8, pp. 1537-1548.

Nelson, K. O., and Henager, C. H., Oct. 1981, "Analysis of Shotcrete Domes Loaded by Deadweight," *Preprint* No. 81-512, American Society of Civil Engineers, New York.

Parker, F., Jr., Nov. 1974, "Steel Fibrous Concrete for Airport Pavement Applications," *Technical Report* No. S-74-12, U.S. Amy Engineer Waterways Experiment Station, Vicksburg.

Paul, B. K.; Polivka, M.; and Mehta, P. K., Dec. 1981, "Properties of Fiber Reinforced Shrinkage-Compensating Concrete," ACI JOURNAL, *Proceedings* V. 78, No. 6, pp. 488-492.

Paul, S. L., and Sinnamon, G. K., Aug. 1975, "Concrete Tunnel Liners: Structural Testing of Segmented Liners," *Final Report* No. FRA-ORD-75-93, U.S. Department of Transportation/University of Illinois, Urbana, 170 pp.

Pearlman, S. L., Apr. 1979, "Flexural Performance of Reinforced Steel Fiber Concrete Beams," MS thesis, Carnegie-Mellon University, Pittsburgh.

Ramakrishnan, V., and Coyle, W. V., Nov. 1983, "Steel Fiber Reinforced Superplasticized Concretes for Rehabilitation of Bridge Decks and Highway Pavements," *Report* No. DOT/RSPA/DMA-50/84-2, Office of University Research, U.S. Department of Transportation, Washington, D.C., 408 pp. (Available from NTIS, Springfield).

Rice, J. L., Jan. 1975, "Fibrous Concrete Pavement Design Summary," *Final Report* No. CERL-TR-M-134, U.S. Army Construction Engineering Research Laboratory, Champaign.

Robins, P. J., and Calderwood, R. W., Jan. 1978, "Explosive Testing of Fibre-Reinforced Concrete," *Concrete* (London), V. 12, No. 1, pp. 26-28.

Schrader, E. K., Apr. 1971, "Studies in the Behavior of Fiber-Reinforced Concrete," MS thesis, Clarkson College of Technology, Potsdam.

Schrader, Ernest K., Mar.-Apr. 1981, "Impact Resistance and Test Procedure for Concrete," ACI JOURNAL, *Proceedings* V. 78, No. 2, pp. 141-146.

Schrader, Ernest K., 1984, "Design Methods for Pavements with Special Concretes," *Fiber Reinforced Concrete—International Symposium*, SP-81, American Concrete Institute, Detroit, pp. 197-212.

Schrader, E. K., and Lankard, D. R., Apr. 13, 1983, "Inspection and Analysis of Curl in Steel Fiber Reinforced Concrete Pavement Applications," Bekaert Steel Wire Corp., Pittsburgh, 9 pp.

Schrader, Ernest K., and Munch, Anthony V., June 1976a, "Fibrous Concrete Repair of Cavitation Damage," *Proceedings*, ASCE, V. 102, CO2, pp. 385-399.

Schrader, Ernest K., and Munch, Anthony V., Mar. 1976b, "Deck Slab Repaired by Fibrous Concrete Overlay," *Proceedings*, ASCE, V. 102, CO1, pp. 179-196.

Schupack, Morris, 1985, "Durability of SFRC Exposed to Severe Environments," *Steel Fiber Concrete* (US-Sweden Joint Seminar, Stockholm), Swedish Cement and Concrete Research Institute, Stockholm, pp. 479-496.

Shah, S. P., and Batson, G. B., Editors, 1987, *Fiber Reinforced Concrete—Properties and Applications*, SP-105, American Concrete Institute, Detroit, 597 pp.

Shah, Surendra P., and Rangan, B. Vijaya, June 1970, "Effects of Reinforcements on Ductility of Concrete," *Proceedings*, ASCE, V. 96, ST6, pp. 1167-1184.

1 Shah, Surendra P., and Skarendahl, Ake, Editors, 1986, *Steel Fiber Concrete*, Elsevier Applied Science Publishers, London, 520 pp.

Shah, S. P.; Stroeven, P.; Dalhuisen, D.; and Van Stekelenburg, P. "Complete Stress-Strain Curves for Steel Fibre Reinforced Concrete in Uniaxial Tension and Compression," *Testing and Test Methods of Fibre Cement Composites*, RILEM Symposium 1978, Construction Press, Lancaster, pp. 399-408.

Sharma, A. K., July-Aug. 1986, "Shear Strength of Steel Fiber Reinforced Concrete Beams," ACI JOURNAL, *Proceedings* V. 83, No. 4, pp. 624-628.

Suaris, W., and Shah, S. P., Winter 1981, "Inertial Effects in the Instrumented Impact Testing of Cementitious Composites," *Cement, Concrete, and Aggregates*, V. 3, No. 2, pp. 77-83.

Suaris, Wimal, and Shah, Surendra P., July 1983, "Properties of Concrete Subjected to Impact," *Journal of Structural Engineering*, ASCE, V. 109, No. 7, pp. 1727-1741.

Suaris, W., and Shah, S. P., 1984, "Test Method for Impact Resistance of Fiber Reinforced Concrete," *Fiber Reinforced Concrete;—International Symposium*, SP-81, American Concrete Institute, Detroit, pp. 247-260.

Swamy, R. N., and Al-Ta'an, Sa'ad A., Sept.-Oct. 1981, "Deformation and Ultimate Strength in Flexure of Reinforced Concrete Beams Made with Steel Fiber Concrete," ACI JOURNAL, *Proceedings* V. 78, No. 5, pp. 395-405.

Swamy, R. N.; Al-Ta-an, S. A.; and Ali, Sami A. R., Aug. 1979, "Steel Fibers for Controlling Cracking and Deflection," *Concrete International: Design & Construction*, V. 1, No. 8, pp. 41-49.

Swamy, R. N., and Bahia, H. M., Mar. 1985, "The Effectiveness of Steel Fibers as Shear Reinforcement," *Concrete International: Design & Construction*, V. 7, No. 3, pp. 35-40.

Swamy, R. N.; Mangat, P. S.; and Rao, C. V. S. K., 1974, "The Mechanics of Fiber Reinforcement of Cement Matrices," *Fiber Reinforced Concrete*, SP-44, American Concrete Institute, Detroit, pp. 1-28.

Swamy, R. N., and Stavrides, H., Mar. 1979, "Influence of Fiber Reinforcement on Restrained Shrinkage and Cracking," ACI JOURNAL, *Proceedings* V. 76, No. 3, pp. 443-460.

Visalvanich, Kitisak, and Naaman, Antoine E., Mar.-Apr. 1983, "Fracture Model for Fiber Reinforced Concrete," ACI JOURNAL, *Proceedings* V. 80, No. 2, pp. 128-138.

Williamson, G. R.; Smith, A.; Morse, D.; Woratzeck, M.; and Barrett, H., May 1977, "Inflation/Foam/Shotcrete System for Rapid Shelter Construction," *Technical Report* No. M-214, U.S. Army Construction Engineering Research Laboratory, Champaign.

Williamson, G. R., Aug. 1965, "The Use of Fibrous Reinforced Concrete in Structures Exposed to Explosives Hazards," *Miscellaneous Paper* No. 5-5, U.S. Army Ohio River Division Laboratories.

Williamson, G. R., Dec. 1973, "Compression Characteristics and Structural Beam Design Analysis of Steel Fiber Reinforced Concrete," *Technical Report* No. M-62, U.S. Army Construction Engineering Research Laboratory, Champaign.

Williamson, Gilbert R., 1974, "The Effect of Steel Fibers on the Compressive Strength of Concrete," *Fiber Reinforced Concrete*, SP-44, American Concrete Institute, Detroit, pp. 195-207.

Williamson, G. R., June 1978, "Steel Fibers as Web Reinforcement in Reinforced Concrete," *Proceedings*, U.S. Army Science Conference, West Point, V. 3, pp. 363-377.

Williamson, G. R., and Knab, L. I., 1975, "Full Scale Fibre Concrete Beam Tests," *Fibre Reinforced Cement and Concrete*, RILEM Symposium 1975, Construction Press, Lancaster, pp. 209-214.

Zollo, Ronald F., Oct. 1975, "Wire Fiber Reinforced Concrete Overlays for Orthotropic Bridge Deck Type Loadings," ACI JOURNAL, *Proceedings* V. 72, No. 10, pp. 576-582.

4.3—Uncited references (additional publications concerning design)

Balaguru, P. N., and Ramakrishnan, V., May-June 1986, "Freeze-Thaw Durability of Fiber Reinforced Concrete," ACI JOURNAL, *Proceedings* V. 83, No. 3, pp. 374-382.

Craig, R. John; Parr, James A.; Germain, Eddy; Mosquera, Victor; and Kamilares, Stavros, Nov.-Dec. 1986, "Fiber Reinforced Beams in Torsion," ACI JOURNAL, *Proceedings* V. 83, No. 6, pp. 934-942.

Hannant, D. J., Mar. 1984, "Fiber Reinforced Cement and Concrete, Part 2—Practical Composites," *Concrete* (London), V. 18, No. 3, pp. 21-22.

Mansur, M. A., and Paramasivam, P., Jan.-Feb. 1985, "Fiber Reinforced Concrete Beams in Torsion, Bending, and Shear," ACI JOURNAL, *Proceedings* V. 82, No. 1, pp. 33-39.

Patton, Mark E., and Whittaker, W. L., Jan.-Feb. 1983, "Effects of Fiber Content and Damaging Load on Steel Fiber Reinforced Concrete Stiffness," ACI JOURNAL, *Proceedings* V. 80, No. 1, pp. 13-16.

Ramakrishnan, V.; Brandshaug, Terje; Coyle, W. V.; and Schrader, Ernest K., May 1980, "A Comparative Evaluation of Concrete Reinforced with Straight Steel Fibers and Fibers with Deformed Ends Glued Together in Bundles," ACI JOURNAL, *Proceedings* V. 77, No. 3, pp. 135-143.

Ramakrishnan, V.; Coyle, W. V.; Kulandaisamy, V.; and Schrader, Ernest K., 1981, "Performance Characteristics of Fiber Reinforced Concretes with Low Fiber Contents," ACI JOURNAL, *Proceedings* V. 78, No. 5, pp. 388-394.

Snyder, M. Jack, and Lankard, David R., Feb. 1972, "Factors Affecting the Flexural Strength of Steel Fibrous Concrete," ACI JOURNAL, *Proceedings* V. 69, No. 2, pp. 96-100.

Zollo, Ronald F., Sept-Oct. 1980, "Fibrous Concrete Flexural Testing—Developing Standardized Techniques," ACI JOURNAL, *Proceedings* V. 77, No. 5, pp. 363-368.

CHAPTER 5 — NOTATION

a = depth of rectangular stress block
a = shear span, distance between concentrated load and face of support
A_s = area of tension reinforcement bars
b = width of beam

b_w = web or width of a rectangular beam
c = distance from extreme compression fiber to neutral axis
C = compressive force
d = distance from extreme compression fiber to centroid of tension reinforcement
d_f = fiber diameter (for a noncircular fiber, an equivalent fiber diameter is the diameter of a circle with the same area as the fiber)
e = distance from extreme compression fiber to top of tensile stress block of fibrous concrete
E = modulus of elasticity
E_s = modulus of elasticity of steel
f'_c = compressive strength of concrete
f_{sp} = splitting tensile strength
f_r = modulus of rupture
f_y = yield strength of reinforcing bar
F_{be} = bond efficiency factor
h = total depth of beam
I = moment of inertia of section
M_n = nominal moment capacity of section
M_u = factored moment at beam section
ℓ = fiber length
ℓ/d_f = aspect ratio = fiber length/fiber diameter
Q = first statical moment of an area about the neutral axis
T_{fc} = tensile force of fibrous concrete = $\sigma_t b (h - e)$
T_{rb} = tensile force of bar reinforcement = $A_s f_y$
v = fiber volume concentration or volume fraction (not percentage)
v = shear stress at section
v_{cf} = average shear stress in SFRC beam
V = shear force at section
V_c = nominal shear strength provided by concrete
V_f = volume fraction of fibers $(1 - V_m)$
V_m = volume fraction of the matrix $(1 - V_f)$
V_u = factored shear force at beam section
ϵ_c = compressive strain in concrete
ϵ_s = tensile strain in steel
σ_{cf} = first crack composite flexural strength
σ_{cu} = ultimate composite flexural strength
σ_f = tensile stress in fiber
σ_t = tensile stress in fibrous concrete
τ_d = dynamic bond stress between fiber and matrix
ρ_f = percent by volume of fibers
ρ_w = $A_s/b_w d$
ϕ = capacity reduction factor

This report was submitted to letter ballot of the committee and was approved in accordance with ACI balloting requirements.

Guide For Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete

Reported by ACI Committee 544

This guide describes the current technology in specifying, mixing, placing, and finishing of steel fiber reinforced concrete (SFRC). Much of the current conventional concrete practice applies to SFRC. The emphasis in this guide is to describe the differences between conventional concrete and SFRC and how to deal with them. Guidance is provided in mixing techniques to achieve uniform mixtures, placement techniques to assure adequate compaction, and finishing techniques to assure satisfactory surface textures. Sample mix proportions are tabulated. A listing of references is provided covering proportioning, properties, refractory uses, shotcrete technology, and general information on SFRC.

Keywords: compacting; concrete construction; concrete finishing (fresh concrete); fiber reinforced concretes; mixing; mix proportioning; metal fibers; placing; specifications.

CONTENTS

CHAPTER 1 — GENERAL

1.1 — Scope

This guide covers specifying, mixing, placing, and finishing of steel fiber reinforced concrete (SFRC).

1.2 — Steel fiber reinforced concrete—General

Steel fiber reinforced concrete is a composite material made of hydraulic cements, fine or fine and coarse aggregate, and a dispersion of discontinuous, small, steel fibers. It may also contain pozzolans and additives commonly used with conventional concrete.

The addition of these fibers in amounts from 50 to 200 lb/yd³ (30 to 118 kg/m³)* can provide significant

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*0.38 to 1.5 percent by volume (for normal weight concrete - 145 lb/ft³).

improvements in many of the engineering properties of mortars and concrete. Impact strength is greatly improved as is the toughness. The flexural strength, fatigue strength, and the ability to resist cracking and spalling are also enhanced. More detailed information on properties may be found in references listed in Chapter 8.

1.3 — Typical uses of steel fiber reinforced concrete

Generally, when used in structural applications, steel fiber reinforced concrete should only be used in a supplementary role to inhibit cracking, to improve resistance to impact or dynamic loading, and to resist material disintegration. In structural members where flexural or tensile loads will occur, such as in beams, columns, suspended floors, (i.e., floors or slabs not on grade) the reinforcing steel must be capable of supporting the total tensile load. In applications where the presence of continuous reinforcement is not essential to the safety and integrity of the structure, e.g., pavements, overlays, and shotcrete linings, the improvements in flexural strength associated with the fibers can be used to reduce section thickness or improve performance, or both. The following are some examples of structural and nonstructural uses of SFRC:

- Hydraulic structures — Dams, spillways, stilling basins, and sluiceways as new or replacement slabs or overlays to resist cavitation damage. See Reference 5.
- Airport and highway paving and overlays — Particularly where a thinner than normal slab is desired.
- Industrial floors — For impact resistance and resistance to thermal shock.
- Refractory concrete — Using high-alumina cement in both castable and shotcreted applications. See References 6 and 7.
- Bridge decks — As an overlay or topping where the primary structural support is provided by an underlying reinforced concrete deck.
- In shotcrete linings — For underground support in tunnels and mines, usually with rock bolts.
- In shotcrete coverings — To stabilize aboveground rock or soil slopes, e.g., highway and railway cuts and embankments. See Reference 8.
- Thin shell structures — Shotcreted "foam domes."
- Explosion-resistant structures — Usually in combination with reinforcing bars.
- A possible future use is in seismic-resistant structures.

1.4 — Specifying steel fiber reinforced concrete

1.4.1 *General* — Steel fiber reinforced concrete is usually specified by strength and fiber content. The flexural strength is normally specified for paving applications while compressive strength is normally specified for structural applications. A flexural strength of 700 to 1000 psi (4.8 to 6.9 MPa) at 28 days and a compressive strength of 5000 to 7000 psi (34.5 to 48.3 MPa) are typical values. In general the addition of fibers does not significantly increase compressive strength but does increase the compressive strain at ultimate load. The changes in mixture proportions to accommodate the fibers do have a significant influence on the compressive strength.

For normal weight concrete, fiber contents have been used from as low as 50 lb/yd^3 (30 kg/m^3) to as high as 265 lb/yd^3 (157 kg/m^3) although the high range limit is usually about 160 to 200 lb/yd^3 (95 to 118 kg/m^3). Steel fibers have also been used in lightweight concrete, but data are not generally available. The amount that can be used, and the amount needed for a particular application, depends upon the fiber shape and aspect ratio* as well as the end use. See References 1 through 4 and 10 or consult fiber manufacturers for additional information. In terms of volume percentage for normal weight concrete, 50 lb/yd^3 = 0.38 percent by volume; 160 lb/yd^3 = 1.2 percent by volume; and 265 lb/yd^3 = 2.0 percent by volume.

Toughness, which is the area under a load-deflection curve, or a toughness index, which is a function of that area, may be determined to help define the performance requirements of SFRC intended for use where post-cracking energy absorption or resistance to failure after cracking is important. These properties would be important in applications such as structures subjected to earthquakes or explosive blasts, impact loads, cavitation loads, thermal shock, and other dynamic loads. A standard test for flexural toughness is being prepared by the ASTM subcommittee on Fiber Reinforced Concrete. After such a standard test has been adopted and more experience gained in the relationship of toughness to performance, it may be practical to use toughness as a performance standard for SFRC.

As noted in subsequent chapters, the manufacture and placing of SFRC is very similar to conventional concrete. Most existing concrete specifications can be used for the manufacture and placement of SFRC with some added requirements to account for the differences in materials and techniques. The subsequent chapters point out those differences.

1.4.2 *Guidelines for specifying ready-mixed SFRC using ASTM C 94* — ASTM C 94 may be used to specify steel fiber reinforced concrete. When using ASTM C 94, the purchaser should state that mixture proportions should be in accordance with Alternative No. 1, 2, or 3, except that flexural strength at 28 days may be specified for the strength requirement instead of compressive strength. For structures, however, the compressive strength may govern. See Section 1.4.1. Flexural strength should be determined in accordance with ASTM C 78 using 4 × 4 × 14 in. specimens on a 12-in. span (100 × 100 × 350 mm - 300 mm span) as recommended in ACI 544.2R. See ACI 544.2R for additional guidance on testing, e.g., specimens representing the design depth. The alternative methods in ASTM C 94 as applied to this guide are

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*The aspect ratio of a fiber is its length divided by its diameter, *l/d*.

Alternative 1: The purchaser assumes responsibility for mixture proportions and specifies them including cement content, maximum allowable water content, and the type, name, and dosage of admixtures, if admixtures are to be used.

Alternative 2: The purchaser requires the concrete supplier to assume responsibility for selecting mixture proportions and specifies a minimum flexural or compressive strength.

Alternative 3: The purchaser requires the concrete supplier to assume responsibility for selecting mixture proportions, but with a minimum allowable cement content specified, along with the required minimum flexural or compressive strength and the type, name, and dosage of admixtures to be used.

For those projects electing to use Alternative 1, typical airfield paving mixtures are shown in Chapter 3 as examples of mixtures that have been used for paving and similar applications. Note that the amount of fiber to suit the particular application must be selected and specified. Adjustments to these mixtures, as may be required for workability, placeability, surface texture, yield, or other properties, should be made and evaluated during trial mixture or preconstruction testing, and final mixture proportions should be selected during the first day or so of actual construction.

CHAPTER 2 — MATERIALS

2.1 — General

Cement, pozzolans, aggregates, water, admixtures, reinforcing steel, and other conventional materials to be used for steel fiber reinforced concrete should conform to the same nationally recognized specifications used for conventional concrete. Since these specifications are named in other ACI publications, many are not repeated here. Titles for those that are referenced in this guide are shown in Chapter 8 — Information Sources.

2.2 — Aggregates

The fine aggregate should meet the gradation requirement given in ASTM C 33. The coarse aggregate should be ASTM C 33 size No. 8 or equivalent for nominal ⅜ in. (9 mm) maximum size aggregate mixtures and should be size No. 67 or equivalent for ¾ in. (19 mm) maximum size aggregate mixtures. Aggregate sizes larger than ¾ in. (19 mm) are not generally used in SFRC.

2.3 — Fibers

A specification for steel fibers (A 820) is being prepared by the ASTM but has not yet been published. In the interim, fibers are commonly specified by brand name or, for public works, by a short specification description which usually includes a minimum ultimate tensile strength (they are available from 50,000 psi up to 300,000 psi), a minimum desired aspect ratio ℓ/d, and any other desired features such as end anchorage provisions, deformations, or collating. The specifier should consult the fiber manufacturers for details.

Steel fibers should be clean, free of rust, oil, and deleterious materials. Steel fibers should have an aspect ratio, i.e., fiber length divided by diameter (or equivalent diameter,* in the case of nonround fibers), in the range of 30 to 100 for lengths of 0.5 to 2.5 in. (12.7 to 63.5 mm).

2.4 — Admixtures

- Calcium chloride should not be added to steel fiber reinforced concrete in excess of amounts permitted to be added to conventional structural concrete as shown in ACI 318-83, Table 4.5.4.
- Water-reducing admixtures are recommended. Both regular and high-range (superplasticizer) water reducers are suitable.
- Air-entraining admixtures are recommended for SFRC exposed to freezing and thawing conditions.

2.5 — Storage of fibers

Care should be taken to see that steel fibers are stored in a manner that will prevent their deterioratio or the intrusion of moisture or foreign matter. If fiber deteriorate or become contaminated, they should not b used.

CHAPTER 3 — TYPICAL MIXTURE PROPORTIONS

3.1 — Mixture proportions

As with conventional concrete, SFRC mixtures employ a variety of mixture proportions depending upo the end use. They may be specially proportioned for project or selected to be the same as a mixture use previously. In either case, they must be adjusted fo yield, workability, and other factors as noted in Section 1.4.2.

A procedure for proportioning of SFRC mixtures with emphasis on good workability, is available.[9] Typical proportions that have been used for airfield pavin mixtures are shown in Table 1. In addition, AC 544.1R, Chapter 3, discusses SFRC mixtures and includes a table showing the range of proportions fo normal weight fiber reinforced concrete.

CHAPTER 4 — FORMWORK AND REINFORCING STEEL

4.1 — Formwork

Design and construction of formwork should be don according to ACI 347. Normal weight SFRC with a f ber content up to two percent by volume has a density i the same range as normal weight conventional concret — 144 to 150 lb/ft³ (2306 to 2403 kg/m³). The fibers i steel fiber reinforced concrete have a tendency to pr trude from sharp corners of formed concrete. The may be hazardous to personnel. To minimize thi sharp corners should be chamfered. Alternately, rounded corner may be formed by applying a pressur

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*The equivalent diameter of a fiber is the diameter of a round fiber havi the same cross-sectional area A as the fiber in question; equivalent diameter $\sqrt{4A/\pi}$.

sensitive tape to the inside of sharp corners in the forms. On formed surfaces, use of a form vibrator will cause the fibers to back away from the form leaving them covered by about ⅛ in. (3 mm) of concrete. Formwork must be designed for the additional stress caused by the vibration. Consult ACI 347 for further information.

4.2 — Reinforcing steel

Fabricating and placing reinforcing steel should be in accordance with ACI 301. Steel fiber reinforced concrete is routinely used in conjunction with reinforcing steel.

CHAPTER 5 — BATCHING, MIXING, DELIVERY, AND SAMPLING

5.1 — General

Batching, mixing, delivery, and sampling of steel fiber reinforced concrete should be in accordance with ASTM C 94, Ready-Mixed Concrete, or applicable portions of ACI 304, Measuring, Mixing, Transporting, and Placing Concrete, as modified and supplemented by the following.

The contractor should supply appropriate equipment or develop a suitable technique for dispersing the fibers in the mixer free of fiber clumps. The equipment and/or method of adding the fibers to the mix should be reviewed and accepted by the project engineer before any placement of SFRC takes place.

The batching procedure is critical to obtaining a good blend of the fibers with the concrete. Several methods have previously been used with success, and information to assist the contractor in the choice of a suitable procedure may be obtained from fiber manufacturers. Any SFRC which is not properly batched and which develops dry clumps of fibers or a significant number of wet fiber balls (which include fibers and matrix) should be discarded and removed from the site.

The contractor should perform a full-scale trial batching, charging, and mixing operation with a minimum of 80 percent of the planned operational batch size at least eight days[*] prior to the first SFRC placement. The owner's engineer should observe the operation and recommend adjustments in the mixture proportions at the time to help obtain a workable mixture at a low water-cement ratio. Additional batches may be necessary to verify the mixture adjustments and plant efficiency. The contractor should conduct quality control tests for the trial batches and the owner may elect to cast test specimens for quality assurance. At the time of the test batch, the contactor should have on hand a working vibrator of the type to be used in the actual placements. The behavior of the trial batch under this vibration should be observed to provide guidance under actual construction operations.

Mixers generally should not be batched over 85 percent of their rated capacity[1] for SFRC. The mixing time should be sufficient to uniformly distribute the fibers in the mixture.

Table 1 — Steel fiber reinforced concrete mixtures used in the construction of airfield paving[*]

	Mixture Number 1, ⅜ in. (9 mm) aggregate with pozzolan or fly ash	Mixture Number 2, ¾ in. (19 mm) aggregate with pozzolan or fly ash
Cement	500 lb/yd^3 (296 kg/m^3)	525 lb/yd^3 (311 kg/m^3)
Fly ash or pozzolan	235 lb/yd^3 (139 kg/m^3)	250 lb/yd^3 (148 kg/m^3)
Steel fibers[†]		
Coarse aggregate[‡]		
[⅜ in. (9 mm) max]	1470 lb/yd^3 (872 kg/m^3)	
[¾ in. (19 mm) max]		1330 lb/yd^3 (789 kg/m^3)
Sand	1370 lb/yd^3 (812 kg/m^3)	1440 lb/yd^3 (854 kg/m^3)
Water[§]	255 lb/yd^3 (151 kg/m^3)	283 lb/yd^3 (168 kg/m^3)
Additives		
Water reducers (normal or high range)	Per manufacturer's instructions.	
Air-entraining agent	Per manufacturer's recommendation for 6 percent air when subject to freezing and thawing conditions.	

[*] These mixture proportions are given as examples. The exact mixture proportions required to produce 1 yd^3 (or 1 m^3) for any given project will depend on a number of factors, such as the specific gravity of the materials and the water and air content of the mixture. Each mixture should be designed to yield correctly. These mixtures have been placed by slipform pavers.

[†] Fiber content of these airfield paving mixtures varied from 83 lb/yd^3 to 140 lb/yd^3 (49 to 83 kg/m^3). Flexural strengths ranged from 1050 to 1100 psi (7.2 to 7.6 MPa) at 28 days.

[‡] Aggregates larger than ¾ in. (19 mm) are not generally used in steel fiber concrete. If larger aggregates are used, the use of longer fibers should be considered.

[§] Water content varies depending upon amount and type of water reducer, workability achieved with the aggregates used, and other factors. Field adjust to optimum for strength and workability.

5.2 — Mixing

There are some important differences in mixing SFRC in a transit mixer or revolving drum mixer compared to conventional concrete. One of these is that to obtain good dispersion of the fibers and to prevent fiber clumping, the fibers should be added to a fluid mix.

Methods 1 and 2, which follow, describe procedures used to mix SFRC by adding the fibers to a fluid mix. These methods generally apply to uncollated, individual fibers. Fibers collated into bundles of about 30 fibers per bundle using a water-reactive glue may be dumped directly into a fluid mix as the last step (i.e., similar to Method 1 below) with little or no likelihood of fiber clumping. Also, certain types of individual fibers of large diameter, [e.g., 0.035 in. (0.9 mm) equivalent diameter half round fibers up to 2½ in. (63 mm) long] and conventional round or rectangular fibers with an aspect ratio less than 50 may generally be added to a fluid mix as the last step with little or no likelihood of fiber clumping.

Method 1: Add fibers last to transit mix truck

1. The wet mixture to be used is prepared first without the fibers. The slump of the concrete before fiber addition should be 2 to 3 in. (51 to 76 mm) greater than the final slump desired. Normally, the mixture would be prepared using the water-cement ratio found to give the best results and meeting the mixture design specifications for the job.

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[*] To allow time to make appropriate 7-day tests.

[1] This figure may be raised to 100 percent if it can be shown that the equipment is capable of producing a uniformly mixed product.

2. With the mixer operating at normal charging speed, add the fibers as described in 3.

3. Add the individual fibers, clump-free (i.e., as a rain of individual fibers), to the mixer. A convenient way to do this is to dump the fibers through a 4 in. (100 mm) mesh screen into a hopper which opens onto a moving conveyor belt going to the mixer. It is important that no clumps be introduced; once a clump is introduced into the mixture, it will remain a clump. The drum must rotate fast enough to carry away the fibers as they enter the mixture, and the fibers should land on the mixture. With all fibers introduced into the mixer, it should be slowed to the rated mixing speed and mixed for approximately 30-40 revolutions.

Method 2: Add fibers to aggregate on a conveyor belt

In a plant set up to charge a central mixer or transit mixers, add the fibers by a shaker or through a hopper to the fine aggregate on a conveyor belt during aggregate addition and mix in the normal manner. This method does not require the same care as Method 1 as to where the fibers land in the mixer, but they should not be allowed to pile up and form clumps on their way to the mixer. If possible, the operator should stretch out the addition of aggregate so that fibers go in with the aggregate and not by themselves. A fiber feeder or shaker is useful in reducing the time for fiber handling and addition. Method 2 has been used for the majority of fibrous concrete projects where large quantities of concrete were mixed using bulk individual fibers.

5.3 — Causes of fiber clumping

The following listing of causes of fiber clumping may be useful in designing a plant or mixing sequence for fibrous concrete or correcting the problem in a mixing operation. Most fiber clumping occurs somewhere before the fibers get into the mixture. Once the fibers get into a mixture clump-free, they nearly always stay clump-free. This means that if clumps form, it's because fibers were added so that they fell on each other and they stacked up (in the mixer, on the belt, on the vanes, etc.). This normally happens when the fibers are added too fast at some point in the procedure. The mixer, whatever type, must carry the fibers away into the mixture as fast as they are added. Clumps can also form by hanging up on a rough loading chute at the back of a mixer truck. Fibers should not be allowed to pile up or slide down the vanes of a partially filled drum; this will form clumps.

Other causes of clumping are adding too many fibers to a mixture (more than about 2 percent by volume or even 1 percent of a fiber with a high aspect ratio); adding fibers too fast to a harsh mixture (mixture is not fluid enough or workable enough and the fibers don't get mixed in fast enough; therefore, they pile up on each other in the mixer); adding fibers first to the mixer (fibers have nothing to keep them apart, they fall on each other and form clumps); and using equipment with worn out mixing blades. The most common causes of wet fiber balls are overmixing and using a mixture with too much coarse aggregate (more than about 50 percent).

CHAPTER 6 — PLACING AND FINISHING

6.1 — General

Conventional concrete equipment is adequate for the placing and finishing of nearly all steel fiber reinforced concrete. Internal or external vibrators (including vibrating screeds) should always be used or the concrete will have excessive pockets of entrapped air voids. Even if a superplasticizer has been used, some vibration is needed around reinforcing steel to avoid reduction of bond to the bars.

The basic guide for placing concrete, ACI 304, should be used for placing and finishing SFRC along with the different techniques noted in the following.

6.2 — Workability and consistency measurements

Because of the unique properties of SFRC, workability measurements or slump requirements will be somewhat different from those of conventional concrete. Acceptable workability of SFRC should be determined by one of the following methods, and its use should be specified in the contractual documents.

6.2.1 *Time of flow through the inverted slump cone* — The inverted slump cone procedure (ASTM C 995) may be used to determine the workability of SFRC. This test apparatus consists of a conventional slump cone inverted, centered, and rigidly held by external supports so that the small end of the cone is 3 in. (7 mm) off the bottom of a one cubic foot yield bucket (ASTM C 29). The slump cone is loosely filled with an uncompacted concrete sample. The test uses a vibrator conforming to ASTM C 31 or C 192 with a 1 ± ⅛ in. (25 ± 3 mm) diameter probe. The probe of the operating vibrator is allowed to fall under its own weight through the concrete in the slump cone to the bottom of the bucket and its end is allowed to rest on the bottom of the bucket. The elapsed time from when the vibrator first makes contact with the concrete until the slump cone first becomes emptied is recorded as the inverted-slump-cone time. The inverted-slump-cone time for SFRC should preferably be not more than about 3 seconds nor less than about 10 seconds. These times may not suit all mixtures. Changes in fiber length and amount, cement content, sand content, air content, aggregate shape, and other factors may produce a different acceptable time. Also, the test is not applicable to concrete that flows freely through the cone.

6.2.2 *Slump test* — The slump test may be specified in the contractual documents to serve as a control test for consistency of SFRC from batch to batch. (In addition to the slump test described in ASTM C 143, it may be appropriate to perform the tests described in ASTM C 138, C 173, and C 231 also.)

In general, the slump for steel fiber reinforced concrete per ASTM C 143 should be at least 1 in. but not greater than 4 in. (25 mm to 100 mm). However, the same factors that influence inverted-slump-cone tim also influence the slump. When these factors are changed, a different range may be acceptable. In any event the specified water-cement ratio should be maintained.

6.3 — Placing

Because of fibers, SFRC with the proper water-cement ratio appears very stiff and unworkable until subjected to vibration. Then it usually places very easily. The material tends to "hang together" and resist movement or compaction if an attempt is made to handle it without vibration. Batch plant operators and transit truck drivers must be instructed not to add additional water to the mixture based on its appearance and their experience with conventional concrete.

Water-cement ratios for fibrous mixtures must be carefully controlled. It is very easy to add unnecessary water to the mixture and lose many of the beneficial properties obtained from the addition of fibers. Ratios on the order of about 0.43 to 0.50 are normal. Paving mixtures and some special structural applications may benefit from less workable, but much higher quality concrete with the water-cement ratios in the range of 0.40 to 0.43. At the upper end of the water-cement spectrum, tests have shown that further addition of water causes an increase in slump without a change in workability under vibration. This water addition reduces the quality of the mixture without improving the placeability.

There are no special measures to take for placing SFRC around reinforcing steel except to use vibration to properly consolidate it. In a very thin wall or beam form, e.g., 4 in. (100 mm) or less, which also contains bars or mesh, placement of the concrete may be difficult, especially with longer fibers. This is similar to the difficulties of placing conventional mixtures with larger aggregate in thin, congested sections. When SFRC mixtures are used in congested areas, a ⅜ in. (9 mm) maximum aggregate size should be specified to reduce placing difficulties.

6.4 — Transporting and handling equipment

Transporting and placing of SFRC can be accomplished with most conventional equipment that is properly designed, maintained, and clean.

6.4.1 *Transit trucks* — Discharging from transit trucks is usually accomplished with little trouble. Too stiff a mixture or a truck in poor condition will prevent the mixture from easily discharging from the back of the drum onto the chute. A well-proportioned mixture usually just barely slides down the chute by itself and may need to be pushed by the truck operator. When an especially stiff mixture is used, the truck can be driven up on blocks or a ramp to help discharging.

6.4.2 *Concrete buckets* — Concrete buckets should have steep hopper slopes, be clean and smooth inside, and have a minimum gate opening dimension of 12 in. (300 mm). The fibers will bridge smaller gate openings and the mix will not fall out of its own weight. A remedy for bridging and an aid to placement is to provide a vibrator at the bucket when discharging. To facilitate placement of especially stiff mixtures, a form vibrator can be attached to the side of the bucket and activated when the gate is opened. Another procedure is to weld pieces of pipe to the bucket exterior. Internal vibrators can then be placed into the pipes to assist in emptying the bucket.

6.4.3 *Pumping* — Pumping has been used to transport SFRC on a number of projects. A good fiber mixture generally has proportions of sand and admixtures which make it well-suited for pumping. Gradations suited to SFRC are also compatible with pumping. Although a mixture may appear stiff and unworkable, it may pump surprisingly well. Because of its composition, a SFRC mixture will move through the line without slugs and has been reported to pump more easily and more trouble-free than conventional concrete. Some important points about pumping SFRC are (1) use a pump capable of handling the volume and pressures needed; (2) use a large diameter line, preferably at least 6 in. (150 mm); (3) avoid flexible hose if possible; (4) provide a screen over the pump hopper to prevent any fiber clumps from entering the line. About a 2 × 3 in. (50 × 75 mm) mesh is adequate; and (5) do not try to pump a fibrous mix that is too wet. Pump pressures can cause the fluid paste and fine mortar to squeeze out ahead of the rest of the mixture, resulting in a mat of fibers and coarse aggregate without mortar. It must be noted that this is the result of a mixture that is too wet, not too dry. The same type of plugging can occur with conventional concrete with the plug consisting of coarse aggregate devoid of paste and fine mortar. Additional information on pumping is available in ACI 304.2R. Reference 10 describes proportioning of SFRC mixes for pumping.

6.5 — Finishing

Steel fiber reinforced concrete can be finished with conventional equipment, but minor refinements in techniques and workmanship are needed. For flat formed surfaces, normally no special attention is needed. The surface will normally be smooth and not show fibers when the forms are stripped. If chamfers or rounds have been provided at the edges and in corners the ends of fibers will not protrude at these points when forms are stripped. To provide added compaction and bury surface fibers, open slab surfaces should first be struck off with a vibrating screed. The screed should have slightly rounded edges and preferably should be metal. In areas where a screed is not practical, a jitterbug* can be used for compaction and to establish rough grade control. Magnesium floats can be used to establish a surface and close up any tears or open areas which are caused by the screed. Wood floats tend to tear the surface and should not be used.

Throughout all finishing operations, care must be taken not to overwork the surface. Overworking will bring excessive fines to the surface and may result in

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*A grate tamper that forces aggregate and fibers below the surface.

crazing which normally shows up after the curing period. If bleeding occurs or excessive fines are at the surface, the material should be screeded off and discarded.

After completion of any float work, the surface should be left until it can be worked further without damage. This is usually about the time of initial set. Where a careful finish is not required for appearance or exact tolerance, no further work is needed after floating. If a texture is required, a broom or roller can be used prior to initial set. Burlap drags should not be used because they will lift up the fibers and tear up the surface. When additional finishing is needed, the next step should be done with magnesium floats. Power equipment or hand equipment may be used. When done by hand, the float should be held flat and not on edge. It should be moved with a sawing motion (short, quick, back-and-forth movements) as it is drawn across the surface. The magnesium float can be used to obtain a nearly perfect, flat surface, bury or cover all the fibers, and leave a slight texture. This can be followed by hard steel troweling if a smooth surface is desired. The trowel must be kept flat or the edge will cause fibers to spring out of the surface. Using these techniques, some excellent finishes of SFRC have been obtained. An example of this is at Tarbela Dam where a curved spillway invert and flat stilling basin floor were completed to close tolerances.

Slipform pavers have been used on several projects, such as airport runways and taxiways, with excellent results.

The proper time to execute a broom finish following a screed finish or paving machine finish is just prior to application of curing compounds when the water sheen has practically disappeared.

6.6 — Hot and cold weather requirements

Placement of steel fiber reinforced concrete should be done according to the recommendations of ACI 305R for hot weather and ACI 306R for cold weather.

6.7 — Repair of defects

The repair of defects such as voids and honeycombing is done much the same as for plain concrete. However, if removal of some SFRC is required, the removal operation will be significantly more difficult because of the greater toughness of SFRC.

Removal by jackhammers is hindered because the material does not fracture easily. Sawing is a more effective method of cutting or removing steel fiber reinforced concrete.

6.8 — Contraction joints

Contraction joints in slabs are more easily made if they are sawed rather than cast or formed. The sawing can be done shortly after final set. At joints where it is desired to have a controlled shrinkage crack occur below the sawed portion of the joint, it has been found that the saw cut should extend from one-half to two-thirds of the way through the slab. If it does not, the higher tensile strength of the SFRC tends to preven cracking at the joint and random cracking occurs else where in the slab. A joint sealing compound should b used to seal the sawed joint to prevent water infiltra tion to the subgrade, and to prevent the corrosion c those fibers and fiber ends that become exposed i the saw cut and the crack below.

CHAPTER 7 — CURING AND PROTECTION

7.1 — General

Curing of steel fiber reinforced concrete and protec tion from freezing or excessively hot or cold tempera tures should be done the same as for conventional cor crete. One aspect deserves special attention. Sinc SFRC is often placed in thin sections, as overlays fc example, and has a high cement content, it is partict larly vulnerable to plastic shrinkage cracking. This wi occur on warm days where it is exposed to direct sun c a breeze. Such placements must be shaded from the su and sheltered from the wind to prevent this type c damage.

CHAPTER 8 — INFORMATION SOURCES

8.1 — Specified and/or recommended reference

The standards of the American Society for Testir and Materials and the standards and reports of t American Concrete Institute referred to in this repo are listed below with their serial designation, includir the year of adoption or revision. The standards and r ports listed were the latest editions at the time this r port was prepared. Since some of these publications a revised frequently, generally in minor details only, t user of this report should check directly with the spor soring group to refer to the latest edition.

American Concrete Institute

ACI 301-72 (Revised 1982)	Specifications for Structural Co crete for Buildings
ACI 304-73 (Reaffirmed 1978)	Recommended Practice for Me suring, Mixing, Transporting, ar Placing Concrete
ACI 304.2R-71 (Revised 1982)	Placing Concrete by Pumpi Methods
ACI 305R-77	Hot Weather Concreting
ACI 306R-78	Cold Weather Concreting
ACI 318-83	Building Code Requirements f Reinforced Concrete
ACI 347-78	Recommended Practice for Co crete Formwork
ACI 544.1R-82	State-of-the-Art Report on Fib Reinforced Concrete
ACI 544.2R-78	Measurement of Properties of Fi Reinforced Concrete

American Society for Testing and Materials

A 820 (To be published)	Standard Specification for Steel bers for Fiber Reinforced Concre
C 29-78	Standard Test Methods for U Weight and Voids in Aggregate

C 31-83	Standard Method for Making and Curing Concrete Test Specimens in the Field
C 33 82	Standard Specification for Concrete Aggregates
C 78-75 (Reapproved 1982)	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C 94-81	Standard Specification for Ready-Mixed Concrete
C 138-81	Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
C 143-78	Standard Test Method for Slump for Portland Cement Concrete
C 173-78	Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
A 192-81	Standard Method of Making and Curing Concrete Test Specimens in the Laboratory
C 231-82	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C 995-83	Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone

The above publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

8.2 — Cited references

General

1. ACI Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete," (ACI 544.1R-82), American Concrete Institute Detroit, 1982, 16 pp. Also, *ACI Manual of Concrete Practice*, Pa 5.

2. "Fibre Concrete Materials: A Report Prepared by RILEM Technical Committee 19-FRC," *Materials and Structures/Researc and Testing* (RILEM, Paris), V. 10, No. 56, Mar.-Apr. 1977, pp. 103 120.

Properties of steel fiber concrete

3. Johnston, C. D., "Properties of Steel Fibre Reinforced Morta and Concrete," *Proceedings*, Symposium on Fibrous Concrete (CI80 London, 1980), The Construction Press, Lancaster, 1980, pp. 29-47

4. Henager, C. H., "Steel Fibrous Concrete—A Review of Testin Procedures," *Proceedings*, Symposium on Fibrous Concrete (CI80 London, 1980), The Construction Press, Lancaster, 1980, pp. 16-28

5. Houghton, D. L.; Borge, O. E.; and Paxton, J. H., "Cavitation Resistance of Some Special Concretes," ACI JOURNAL, *Proceedings* V. 75, No. 12, Dec. 1978, pp. 664-667.

Refractory concrete

6. Lankard, D. R., "Steel Fiber Reinforced Refractory Concrete," *Refractory Concrete*, SP-57, American Concrete Institute, Detroit 1978, pp. 241-263.

7. Hackman, L. E., "Application of Steel Fiber to Refractory Reinforcement," *Proceedings*, Symposium on Fibrous Concrete (CI80 London, 1980), The Construction Press, Lancaster, 1980, pp. 137 152.

Shotcrete

8. Henager, Charles H., "Steel Fibrous Shotcrete: A Summary o the State-of-the-Art," *Concrete International: Design & Construction*, V. 3, No. 1, Jan. 1981, pp. 50-58.

Proportioning of steel fiber concrete mixes

9. Schrader, Ernest K., and Munch, Anthony V., "Deck Slab Repaired by Fibrous Concrete Overlay," *Proceedings*, ASCE, V. 102 CO1, Mar. 1976, pp. 179-196. (Includes Appendix: Mix Design Procedures.)

10. Ounanian, Douglas W., and Kesler, Clyde E., "Design of Fiber Reinforced Concrete for Pumping," *Report* No. DOT-TST 76T 17, Federal Railroad Administration, Washington, D. C., 1976, 5 pp.

ACI COMMITTEE 544
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Designation: A 820 – 90

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Specification for Steel Fibers for Fiber Reinforced Concrete[1]

This standard is issued under the fixed designation A 820; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers minimum standards for steel fibers intended for use in fiber reinforced concrete. Steel fibers for this purpose are defined as pieces of smooth or deformed cold drawn wire; smooth or deformed cut sheet; melt-extracted fibers; or other steel fibers that are sufficiently small to be dispersed at random in a concrete mixture.

1.2 This specification provides for measurement of dimensions, tolerances from specified dimensions, and required minimum physical properties, and prescribes testing procedures to establish conformance to these requirements.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of material purchase form a part of this specification to the extent referenced herein.

2.2 *ASTM Standards:*

A 370 Methods and Definitions for Mechanical Testing of Steel Products[2]

C 94 Specification for Ready-Mixed Concrete[3]

2.3 *ACI Standard:*

544.1 R-82 State-of-the-Art Report on Fiber Reinforced Concrete[4]

3. Terminology

3.1 *Symbols*—The following symbols used in this specification are defined as:

3.1.1 A—cross-sectional area, in.^{2} (mm^2).

3.1.2 d—diameter, in. (mm).

3.1.3 f_u—ultimate tensile strength, psi (MPa).

3.1.4 l—length, in. (mm).

3.1.5 λ—l/d = aspect ratio.

3.1.6 The subscript "n" on dimensional units indicates "nominal" and the subscript "e" indicates "equivalent". "Nominal" and "equivalent" dimensions are calculated from other measurable dimensions or average weights.

4. Classification

4.1 Four general types of steel fibers are identified in this specification based upon the product used as a source of the steel fiber material.

4.1.1 Type I, cold drawn wire.

4.1.2 Type II, cut sheet.

4.1.3 Type III, melt-extracted.

4.1.4 Type IV, other fibers.

4.2 Fibers may be straight or deformed.

5. Ordering Information

5.1 Orders for material under this specification should include the following:

5.1.1 ASTM designation and year of issue,

5.1.2 Quantity in pounds or tons,

5.1.3 Type or types permissible (4.1),

5.1.4 Diameter or equivalent diameter (8.1), or range of equivalent diameters (8.1.5),

5.1.5 Length or nominal length (8.1),

5.1.6 Deformations, if required, and

5.1.7 Whether certification by the producer or supplier is required including whether a report is to be furnished (15.1).

NOTE 1—For information on satisfactory sizes and aspect ratios, see ACI 544.1R-82, and contact producer regarding availability.

6. Material and Manufacture

6.1 The materials and manufacturing methods used shall be such that the fibers produced conform to the requirements in this specification.

7. Responsibility for Quality Assurance

7.1 *Responsibility for Inspection*—Unless otherwise specified in the contract or purchase order, the producer is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract or order, the producer may use his own or any other suitable facility for the performance of the inspection and test requirements specified herein unless disapproved by the purchaser. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

8. Dimensions and Tolerances

8.1 *Dimensions:*

8.1.1 Straight cold-drawn wire fibers are specified by diameter (d) or equivalent (d_e) and length (l), that establish a specified aspect ratio (l/d) or (l/d_e).

8.1.2 Deformed cold-drawn wire fibers are specified by the diameter (d) or equivalent diameter (d_e) and length (out-to-out) after bending (l_n). Nominal aspect ratio (λ_n) is established as (l_n/d) or (l_n/d_e). See Fig. 1.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.

Current edition approved Apr. 27, 1990. Published June 1990. Originally published as A 820 – 85. Last previous edition A 820 – 85.

[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] Available from American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, MI 48219.

8.1.3 Cut sheet fibers are specified by thickness (t), width (w), and length (l). Nominal aspect ratio (λ_n) can be computed as $l/\sqrt{4A/\pi} = l/d_e$, where $A = tw$ and d_e = equivalent diameter. See Fig. 2.

8.1.4 Deformed cut sheet fibers are specified by thickness (t), width (w), and out-to-out length after deformation (l_n). Nominal aspect ratio (λ_n) can be computed as $l_n\sqrt{4A/\pi} = l_n/d_e$. See Fig. 3.

8.1.5 Melt-extracted or other fibers are specified by a range of equivalent diameters, (d_e), and length (l). Equivalent diameter is computed from measured average length and the weight of a known quantity of fibers, based upon 0.2836 lb/in.^{3} (7850 kg/m^3). See Fig. 4.

8.2 *Tolerances:*

8.2.1 The length shall not vary from its specified value more than ±10 %.

8.2.2 The diameter or equivalent diameter shall not vary from its specified value more than ±10 %.

8.2.3 The aspect ratio shall not vary from its specified value more than ±15 %.

Tensile Requirements

9.1 The average tensile strength, f_u, shall not be less than 50 000 psi (345 MPa).

10. Bending Requirements

10.1 Fibers shall withstand bending around a 0.125-in. (3.18-mm) inside diameter to an angle of 90° at temperatures not less than 60°F (16°C) without breaking.

NOTE 2—The bending requirements of this specification provide a general indication of fiber ductility, as may be important in resisting breakage during handling and mixing operations. Ductility measures of fiber reinforced concrete are outside the scope of this specification; see ACI 544.1R-82.

11. Surface Condition

11.1 Seams and surface irregularities shall not be cause for rejection provided that tensile properties are not less than requirements of this specification and mixing performance in concrete is not adversely affected.

11.2 Rust, mill scale, or other coatings shall not be cause for rejection provided that the individual fibers separate when mixed in concrete in accordance with Specification C 94, and tensile and bending properties are not less than the requirements of this specification.

12. Measurement of Dimensions

12.1 Measurement of dimensions shall be performed on not less than 10 randomly selected specimens for each test to establish the average for conformance to specified tolerances. At least 90 % of the specimens in each test shall meet the specified tolerances for length, diameter or equivalent diameter, and aspect ratio.

12.2 At least one test shall be performed for each 5 tons (4.5 Mg) of material or each shipment if less than 5 tons (4 Mg).

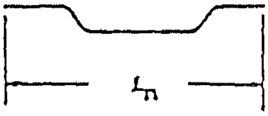

FIG. 1 Deformed Cold-Drawn Fibers

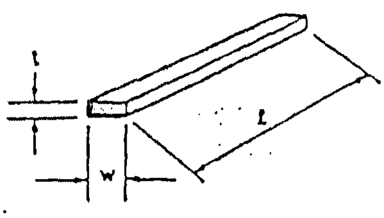

FIG. 2 Cut Sheet Fibers

13. Tests

13.1 At least one tensile test, consisting of 10 randorr selected finished fibers, shall be performed for each 5 tons (4.5 Mg) of material or each shipment if less than 5 tons (4 Mg). The average value of f_u in these tests must not be le than 50 000 psi (345 MPa). The tensile strength of any one the ten specimens shall not be less than 45 000 psi (3 MPa). Where the parent source material consists of sheet wire, tensile tests by the producer may be performed larger samples of source material. One sample of ea different source material used shall then be tested for eaci tons (4.5 Mg) of material or each shipment if less than 5 to (4.5 Mg). The tensile strength of a single sample of sou material shall not be less than 50 000 psi (345 MPa).

13.1.1 The cross-sectional area used to compute t tensile strength shall be carried out to five decimal places, units of square inches, and shall be: *(1) for drawn wire fibe* the area calculated from the actual diameter of the pare source material or finished fibers; *(2) for cut sheet fibers*, t area calculated from the actual thickness and width of t parent source specimen, or if fibers are tested, the area each individual fiber calculated from the measured len and weight of the fiber, weighed to the nearest 0.0001 based on a density of 0.2836 lb/in.^{3} (7850 kg/m^3); and *(3) melt-extraction fibers or other fibers specified by equival diameter*, the area calculated from the equivalent diameter the fibers. See 8.1.5. The breaking load in pounds-force individual fibers shall be measured to at least three sign cant figures. Testing shall be in accordance with Metho and Definitions A 370, where applicable.

13.2 Ten randomly selected specimens of finished fib shall be bent 90° around a 0.125-in. (3.18-mm) ins diameter without breaking. The test may be done by ha At least one test consisting of 10 specimens shall be made each 5 tons (4.5 Mg) of material or each shipment if less th 5 tons (4.5 Mg). At least 90 % of the specimens must pass test.

14. Rejection and Retest

14.1 If any test fails to conform to the requirements of t specification, it shall be cause for rejection of the mate represented by the test. When any test fails to meet t requirements of tension, bending, or dimensional toleranc a retest will be allowed. This retest shall be performed twice the number of randomly selected specimens origin tested. The retest shall meet the requirements of the spec cation or the lot shall be rejected.

14.2 Also, material in which defects are discovered dur

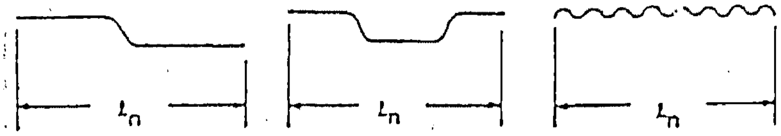

FIG. 3 Deformed Cut Sheet Fibers

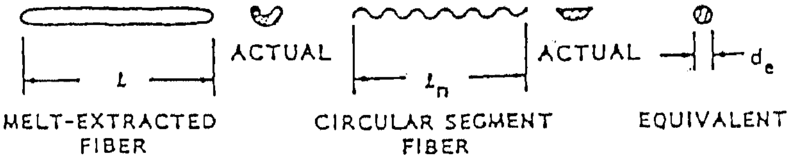

FIG. 4 Melt-Extracted and Other Fibers

subsequent manufacturing operation may be rejected. If rejected, the producer or supplier shall be responsible only for replacement of material to the purchaser. As much as possible of the rejected material shall be returned to the producer or supplier.

14.3 Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

15. Certification

15.1 The producer or supplier shall on request furnish to the purchaser a certificate stating that each lot has been sampled, tested, and inspected in accordance with this specification and has met the requirements. When specified in the purchase order or contract, a report of the test results shall be furnished.

16. Packaging and Marking

16.1 The material shall be packaged to provide adequate protection during normal handling and transportation and each package shall contain only one type and size of material unless otherwise agreed upon. The type of packaging and gross weight of containers shall, unless otherwise agreed upon, be at the producer's or supplier's discretion provided that they are such as to ensure acceptance by common or other carriers for safe transportation at the lowest rate to the delivery point.

16.2 Each shipping container shall be marked with the purchase order number, material, size, type, specification designation, net weight, and the producer's name or trademark.

ACI 544.3R-84

Guide For Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete

Reported by ACI Committee 544

This guide describes the current technology in specifying, mixing, placing, and finishing of steel fiber reinforced concrete (SFRC). Much of the current conventional concrete practice applies to SFRC. The emphasis in this guide is to describe the differences between conventional concrete and SFRC and how to deal with them. Guidance is provided in mixing techniques to achieve uniform mixtures, placement techniques to assure adequate compaction, and finishing techniques to assure satisfactory surface textures. Sample mix proportions are tabulated. A listing of references is provided covering proportioning, properties, refractory uses, shotcrete technology, and general information on SFRC.

Keywords: compacting; concrete construction; concrete finishing (fresh concrete); fiber reinforced concretes; mixing; mix proportioning; metal fibers; placing; specifications.

CONTENTS

CHAPTER 1 — GENERAL

1.1 — Scope

This guide covers specifying, mixing, placing, and finishing of steel fiber reinforced concrete (SFRC).

1.2 — Steel fiber reinforced concrete—General

Steel fiber reinforced concrete is a composite material made of hydraulic cements, fine or fine and coarse aggregate, and a dispersion of discontinuous, small, steel fibers. It may also contain pozzolans and additives commonly used with conventional concrete.

The addition of these fibers in amounts from 50 to 200 lb/yd^3 (30 to 118 kg/m^3)* can provide significant

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*0.38 to 1.5 percent by volume (for normal weight concrete = 145 lb/ft^3).

also influence the slump. When these factors are changed, a different range may be acceptable. In any event the specified water-cement ratio should be maintained.

6.3 — Placing

Because of fibers, SFRC with the proper water-cement ratio appears very stiff and unworkable until subjected to vibration. Then it usually places very easily. The material tends to "hang together" and resist movement or compaction if an attempt is made to handle it without vibration. Batch plant operators and transit truck drivers must be instructed not to add additional water to the mixture based on its appearance and their experience with conventional concrete.

Water-cement ratios for fibrous mixtures must be carefully controlled. It is very easy to add unnecessary water to the mixture and lose many of the beneficial properties obtained from the addition of fibers. Ratios on the order of about 0.43 to 0.50 are normal. Paving mixtures and some special structural applications may benefit from less workable, but much higher quality concrete with the water-cement ratios in the range of 0.40 to 0.43. At the upper end of the water-cement spectrum, tests have shown that further addition of water causes an increase in slump without a change in workability under vibration. This water addition reduces the quality of the mixture without improving the placeability.

There are no special measures to take for placing SFRC around reinforcing steel except to use vibration to properly consolidate it. In a very thin wall or beam form, e.g., 4 in. (100 mm) or less, which also contains bars or mesh, placement of the concrete may be difficult, especially with longer fibers. This is similar to the difficulties of placing conventional mixtures with larger aggregate in thin, congested sections. When SFRC mixtures are used in congested areas, a ⅜ in. (9 mm) maximum aggregate size should be specified to reduce placing difficulties.

6.4 — Transporting and handling equipment

Transporting and placing of SFRC can be accomplished with most conventional equipment that is properly designed, maintained, and clean.

6.4.1 *Transit trucks* — Discharging from transit trucks is usually accomplished with little trouble. Too stiff a mixture or a truck in poor condition will prevent the mixture from easily discharging from the back of the drum onto the chute. A well-proportioned mixture usually just barely slides down the chute by itself and may need to be pushed by the truck operator. When an especially stiff mixture is used, the truck can be driven up on blocks or a ramp to help discharging.

6.4.2 *Concrete buckets* — Concrete buckets should have steep hopper slopes, be clean and smooth inside, and have a minimum gate opening dimension of 12 in. (300 mm). The fibers will bridge smaller gate openings and the mix will not fall out of its own weight. A remedy for bridging and an aid to placement is to provide a vibrator at the bucket when discharging. To facilitate placement of especially stiff mixtures, a form vibrator can be attached to the side of the bucket and activated when the gate is opened. Another procedure is to weld pieces of pipe to the bucket exterior. Internal vibrators can then be placed into the pipes to assist in emptying the bucket.

6.4.3 *Pumping* — Pumping has been used to transport SFRC on a number of projects. A good fiber mixture generally has proportions of sand and admixtures which make it well-suited for pumping. Gradations suited to SFRC are also compatible with pumping. Although a mixture may appear stiff and unworkable, it may pump surprisingly well. Because of its composition, a SFRC mixture will move through the line without slugs and has been reported to pump more easily and more trouble-free than conventional concrete. Some important points about pumping SFRC are (1) use a pump capable of handling the volume and pressures needed; (2) use a large diameter line, preferably at least 6 in. (150 mm); (3) avoid flexible hose if possible; (4) provide a screen over the pump hopper to prevent any fiber clumps from entering the line. About a 2 × 3 in. (50 × 75 mm) mesh is adequate; and (5) do not try to pump a fibrous mix that is too wet. Pump pressures can cause the fluid paste and fine mortar to squeeze out ahead of the rest of the mixture, resulting in a mat of fibers and coarse aggregate without mortar. It must be noted that this is the result of a mixture that is too wet, not too dry. The same type of plugging can occur with conventional concrete with the plug consisting of coarse aggregate devoid of paste and fine mortar. Additional information on pumping is available in ACI 304.2R. Reference 10 describes proportioning of SFRC mixes for pumping.

6.5 — Finishing

Steel fiber reinforced concrete can be finished with conventional equipment, but minor refinements in techniques and workmanship are needed. For flat formed surfaces, normally no special attention is needed. The surface will normally be smooth and not show fibers when the forms are stripped. If chamfers or rounds have been provided at the edges and in corners, the ends of fibers will not protrude at these points when forms are stripped. To provide added compaction and bury surface fibers, open slab surfaces should first be struck off with a vibrating screed. The screed should have slightly rounded edges and preferably should be metal. In areas where a screed is not practical, a jitterbug* can be used for compaction and to establish rough grade control. Magnesium floats can be used to establish a surface and close up any tears or open areas which are caused by the screed. Wood floats tend to tear the surface and should not be used.

Throughout all finishing operations, care must be taken not to overwork the surface. Overworking will bring excessive fines to the surface and may result in

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*A grate tamper that forces aggregate and fibers below the surface.

Alternative 1: The purchaser assumes responsibility for mixture proportions and specifies them including cement content, maximum allowable water content, and the type, name, and dosage of admixtures, if admixtures are to be used.

Alternative 2: The purchaser requires the concrete supplier to assume responsibility for selecting mixture proportions and specifies a minimum flexural or compressive strength.

Alternative 3: The purchaser requires the concrete supplier to assume responsibility for selecting mixture proportions, but with a minimum allowable cement content specified, along with the required minimum flexural or compressive strength and the type, name, and dosage of admixtures to be used.

For those projects electing to use Alternative 1, typical airfield paving mixtures are shown in Chapter 3 as examples of mixtures that have been used for paving and similar applications. Note that the amount of fiber to suit the particular application must be selected and specified. Adjustments to these mixtures, as may be required for workability, placeability, surface texture, yield, or other properties, should be made and evaluated during trial mixture or preconstruction testing, and final mixture proportions should be selected during the first day or so of actual construction.

CHAPTER 2 — MATERIALS

2.1 — General

Cement, pozzolans, aggregates, water, admixtures, reinforcing steel, and other conventional materials to be used for steel fiber reinforced concrete should conform to the same nationally recognized specifications used for conventional concrete. Since these specifications are named in other ACI publications, many are not repeated here. Titles for those that are referenced in this guide are shown in Chapter 8 — Information Sources.

2.2 — Aggregates

The fine aggregate should meet the gradation requirement given in ASTM C 33. The coarse aggregate should be ASTM C 33 size No. 8 or equivalent for nominal ⅜ in. (9 mm) maximum size aggregate mixtures and should be size No. 67 or equivalent for ¾ in. (19 mm) maximum size aggregate mixtures. Aggregate sizes larger than ¾ in. (19 mm) are not generally used in SFRC.

2.3 — Fibers

A specification for steel fibers (A 820) is being prepared by the ASTM but has not yet been published. In the interim, fibers are commonly specified by brand name or, for public works, by a short specification description which usually includes a minimum ultimate tensile strength (they are available from 50,000 psi up to 300,000 psi), a minimum desired aspect ratio ℓ/d, and any other desired features such as end anchorage provisions, deformations, or collating. The specifier should consult the fiber manufacturers for details.

Steel fibers should be clean, free of rust, oil, and deleterious materials. Steel fibers should have an aspect ratio, i.e., fiber length divided by diameter (or equivalent diameter,[*] in the case of nonround fibers), in the range of 30 to 100 for lengths of 0.5 to 2.5 in. (12.7 to 63.5 mm).

2.4 — Admixtures

- Calcium chloride should not be added to steel fiber reinforced concrete in excess of amounts permitted to be added to conventional structural concrete as shown in ACI 318-83, Table 4.5.4.
- Water-reducing admixtures are recommended. Both regular and high-range (superplasticizer) water reducers are suitable.
- Air-entraining admixtures are recommended for SFRC exposed to freezing and thawing conditions.

2.5 — Storage of fibers

Care should be taken to see that steel fibers are stored in a manner that will prevent their deterioration or the intrusion of moisture or foreign matter. If fibers deteriorate or become contaminated, they should not be used.

CHAPTER 3 — TYPICAL MIXTURE PROPORTIONS

3.1 — Mixture proportions

As with conventional concrete, SFRC mixtures employ a variety of mixture proportions depending upon the end use. They may be specially proportioned for a project or selected to be the same as a mixture used previously. In either case, they must be adjusted for yield, workability, and other factors as noted in Section 1.4.2.

A procedure for proportioning of SFRC mixtures, with emphasis on good workability, is available.[9] Typical proportions that have been used for airfield paving mixtures are shown in Table 1. In addition, ACI 544.1R, Chapter 3, discusses SFRC mixtures and includes a table showing the range of proportions for normal weight fiber reinforced concrete.

CHAPTER 4 — FORMWORK AND REINFORCING STEEL

4.1 — Formwork

Design and construction of formwork should be done according to ACI 347. Normal weight SFRC with a fiber content up to two percent by volume has a density in the same range as normal weight conventional concrete — 144 to 150 lb/ft^3 (2306 to 2403 kg/m^3). The fibers in steel fiber reinforced concrete have a tendency to protrude from sharp corners of formed concrete. These may be hazardous to personnel. To minimize this, sharp corners should be chamfered. Alternately, a rounded corner may be formed by applying a pressure-

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[*] The equivalent diameter of a fiber is the diameter of a round fiber having the same cross-sectional area A as the fiber in question; equivalent diameter = $\sqrt{4A/\pi}$.

sensitive tape to the inside of sharp corners in the forms. On formed surfaces, use of a form vibrator will cause the fibers to back away from the form leaving them covered by about ⅛ in. (3 mm) of concrete. Formwork must be designed for the additional stress caused by the vibration. Consult ACI 347 for further information.

4.2 — Reinforcing steel

Fabricating and placing reinforcing steel should be in accordance with ACI 301. Steel fiber reinforced concrete is routinely used in conjunction with reinforcing steel.

CHAPTER 5 — BATCHING, MIXING, DELIVERY, AND SAMPLING

5.1 — General

Batching, mixing, delivery, and sampling of steel fiber reinforced concrete should be in accordance with ASTM C 94, Ready-Mixed Concrete, or applicable portions of ACI 304, Measuring, Mixing, Transporting, and Placing Concrete, as modified and supplemented by the following.

The contractor should supply appropriate equipment or develop a suitable technique for dispersing the fibers in the mixer free of fiber clumps. The equipment and/or method of adding the fibers to the mix should be reviewed and accepted by the project engineer before any placement of SFRC takes place.

The batching procedure is critical to obtaining a good blend of the fibers with the concrete. Several methods have previously been used with success, and information to assist the contractor in the choice of a suitable procedure may be obtained from fiber manufacturers. An SFRC which is not properly batched and which develops dry clumps of fibers or a significant number of wet fiber balls (which include fibers and matrix) should be discarded and removed from the site.

The contractor should perform a full-scale trial batching, charging, and mixing operation with a minimum of 80 percent of the planned operational batch size at least eight days[*] prior to the first SFRC placement. The owner's engineer should observe the operation and recommend adjustments in the mixture proportions at the time to help obtain a workable mixture at a low water-cement ratio. Additional batches may be necessary to verify the mixture adjustments and plant efficiency. The contractor should conduct quality control tests for the trial batches and the owner may elect to cast test specimens for quality assurance. At the time of the test batch, the contactor should have on hand a working vibrator of the type to be used in the actual placements. The behavior of the trial batch under this vibration should be observed to provide guidance under actual construction operations.

Mixers generally should not be batched over 85 percent of their rated capacity[†] for SFRC. The mixing time should be sufficient to uniformly distribute the fibers in the mixture.

Table 1 — Steel fiber reinforced concrete mixtures used in the construction of airfield paving[*]

	Mixture Number 1, ⅜ in. (9 mm) aggregate with pozzolan or fly ash	Mixture Number 2, ¾ in. (19 mm) aggregate with pozzolan or fly ash
Cement	500 lb/yd^3 (296 kg/m^3)	525 lb/yd^3 (311 kg/m^3)
Fly ash or pozzolan	235 lb/yd^3 (139 kg/m^3)	250 lb/yd^3 (148 kg/m^3)
Steel fibers[†]		
Coarse aggregate[‡]		
[⅜ in. (9 mm) max]	1470 lb/yd^3 (872 kg/m^3)	
[¾ in. (19 mm) max]		1330 lb/yd^3 (789 kg/m^3)
Sand	1370 lb/yd^3 (812 kg/m^3)	1440 lb/yd^3 (854 kg/m^3)
Water[§]	255 lb/yd^3 (151 kg/m^3)	283 lb/yd^3 (168 kg/m^3)
Additives		
Water reducers (normal or high range)	Per manufacturer's instructions.	
Air-entraining agent	Per manufacturer's recommendation for 6 percent air when subject to freezing and thawing conditions.	

[*] These mixture proportions are given as examples. The exact mixture proportions required to produce 1 yd^3 (or 1 m^3) for any given project will depend on a number of factors, such as the specific gravity of the materials and the water and air content of the mixture. Each mixture should be designed to yield correctly. These mixtures have been placed by slipform pavers.

[†] Fiber content of these airfield paving mixtures varied from 83 lb/yd^3 to 140 lb/yd^3 (49 to 83 kg/m^3). Flexural strengths ranged from 1050 to 1100 psi (7.2 to 7.6 MPa) at 28 days.

[‡] Aggregates larger than ¾ in. (19 mm) are not generally used in steel fiber concrete. If larger aggregates are used, the use of longer fibers should be considered.

§Water content varies depending upon amount and type of water reducer, workability achieved with the aggregates used, and other factors. Field adjust to optimum for strength and workability.

5.2 — Mixing

There are some important differences in mixing SFRC in a transit mixer or revolving drum mixer compared to conventional concrete. One of these is that to obtain good dispersion of the fibers and to prevent fiber clumping, the fibers should be added to a fluid mix.

Methods 1 and 2, which follow, describe procedures used to mix SFRC by adding the fibers to a fluid mix. These methods generally apply to uncollated, individual fibers. Fibers collated into bundles of about 30 fibers per bundle using a water-reactive glue may be dumped directly into a fluid mix as the last step (i.e., similar to Method 1 below) with little or no likelihood of fiber clumping. Also, certain types of individual fibers of large diameter, [e.g., 0.035 in. (0.9 mm) equivalent diameter half round fibers up to 2½ in. (63 mm) long] and conventional round or rectangular fibers with an aspect ratio less than 50 may generally be added to a fluid mix as the last step with little or no likelihood of fiber clumping.

Method 1: Add fibers last to transit mix truck

1. The wet mixture to be used is prepared first without the fibers. The slump of the concrete before fiber addition should be 2 to 3 in. (51 to 76 mm) greater than the final slump desired. Normally, the mixture would be prepared using the water-cement ratio found to give the best results and meeting the mixture design specifications for the job.

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[*] To allow time to make appropriate 7-day tests.

[†] This figure may be raised to 100 percent if it can be shown that the equipment is capable of producing a uniformly mixed product.

2. With the mixer operating at normal charging speed, add the fibers as described in 3.

3. Add the individual fibers, clump-free (i.e., as a rain of individual fibers), to the mixer. A convenient way to do this is to dump the fibers through a 4 in. (100 mm) mesh screen into a hopper which opens onto a moving conveyor belt going to the mixer. It is important that no clumps be introduced; once a clump is introduced into the mixture, it will remain a clump. The drum must rotate fast enough to carry away the fibers as they enter the mixture, and the fibers should land on the mixture. With all fibers introduced into the mixer, it should be slowed to the rated mixing speed and mixed for approximately 30-40 revolutions.

Method 2: Add fibers to aggregate on a conveyor belt

In a plant set up to charge a central mixer or transit mixers, add the fibers by a shaker or through a hopper to the fine aggregate on a conveyor belt during aggregate addition and mix in the normal manner. This method does not require the same care as Method 1 as to where the fibers land in the mixer, but they should not be allowed to pile up and form clumps on their way to the mixer. If possible, the operator should stretch out the addition of aggregate so that fibers go in with the aggregate and not by themselves. A fiber feeder or shaker is useful in reducing the time for fiber handling and addition. Method 2 has been used for the majority of fibrous concrete projects where large quantities of concrete were mixed using bulk individual fibers.

5.3 — Causes of fiber clumping

The following listing of causes of fiber clumping may be useful in designing a plant or mixing sequence for fibrous concrete or correcting the problem in a mixing operation. Most fiber clumping occurs somewhere before the fibers get into the mixture. Once the fibers get into a mixture clump-free, they nearly always stay clump-free. This means that if clumps form, it's because fibers were added so that they fell on each other and they stacked up (in the mixer, on the belt, on the vanes, etc.). This normally happens when the fibers are added too fast at some point in the procedure. The mixer, whatever type, must carry the fibers away into the mixture as fast as they are added. Clumps can also form by hanging up on a rough loading chute at the back of a mixer truck. Fibers should not be allowed to pile up or slide down the vanes of a partially filled drum; this will form clumps.

Other causes of clumping are adding too many fibers to a mixture (more than about 2 percent by volume or even 1 percent of a fiber with a high aspect ratio); adding fibers too fast to a harsh mixture (mixture is not fluid enough or workable enough and the fibers don't get mixed in fast enough; therefore, they pile up on each other in the mixer); adding fibers first to the mixer (fibers have nothing to keep them apart, they fall on each other and form clumps); and using equipment with worn out mixing blades. The most common causes of wet fiber balls are overmixing and using a mixture with too much coarse aggregate (more than about 50 percent).

CHAPTER 6 — PLACING AND FINISHING

6.1 — General

Conventional concrete equipment is adequate for the placing and finishing of nearly all steel fiber reinforced concrete. Internal or external vibrators (including vibrating screeds) should always be used or the concrete will have excessive pockets of entrapped air voids. Even if a superplasticizer has been used, some vibration is needed around reinforcing steel to avoid reduction of bond to the bars.

The basic guide for placing concrete, ACI 304, should be used for placing and finishing SFRC along with the different techniques noted in the following.

6.2 — Workability and consistency measurements

Because of the unique properties of SFRC, workability measurements or slump requirements will be somewhat different from those of conventional concrete. Acceptable workability of SFRC should be determined by one of the following methods, and its use should be specified in the contractual documents.

6.2.1 *Time of flow through the inverted slump cone* — The inverted slump cone procedure (ASTM C 995) may be used to determine the workability of SFRC. This test apparatus consists of a conventional slump cone inverted, centered, and rigidly held by external supports so that the small end of the cone is 3 in. (75 mm) off the bottom of a one cubic foot yield bucket (ASTM C 29). The slump cone is loosely filled with an uncompacted concrete sample. The test uses a vibrator conforming to ASTM C 31 or C 192 with a 1 ± ⅛ in. (25 ± 3 mm) diameter probe. The probe of the operating vibrator is allowed to fall under its own weight through the concrete in the slump cone to the bottom of the bucket and its end is allowed to rest on the bottom of the bucket. The elapsed time from when the vibrator first makes contact with the concrete until the slump cone first becomes emptied is recorded as the inverted-slump-cone time. The inverted-slump-cone time for SFRC should preferably be not more than about 30 seconds nor less than about 10 seconds. These times may not suit all mixtures. Changes in fiber length and amount, cement content, sand content, air content, aggregate shape, and other factors may produce a different acceptable time. Also, the test is not applicable to concrete that flows freely through the cone.

6.2.2 *Slump test* — The slump test may be specified in the contractural documents to serve as a control test for consistency of SFRC from batch to batch. (In addition to the slump test described in ASTM C 143, it may be appropriate to perform the tests described in ASTM C 138, C 173, and C 231 also.)

In general, the slump for steel fiber reinforced concrete per ASTM C 143 should be at least 1 in. but not greater than 4 in. (25 mm to 100 mm). However, the same factors that influence inverted-slump-cone time improvements in many of the engineering properties of mortars and concrete. Impact strength is greatly improved as is the toughness. The flexural strength, fatigue strength, and the ability to resist cracking and spalling are also enhanced. More detailed information on properties may be found in references listed in Chapter 8.

1.3 — Typical uses of steel fiber reinforced concrete

Generally, when used in structural applications, steel fiber reinforced concrete should only be used in a supplementary role to inhibit cracking, to improve resistance to impact or dynamic loading, and to resist material disintegration. In structural members where flexural tensile loads will occur, such as in beams, columns, suspended floors, (i.e., floors or slabs not on grade) the reinforcing steel must be capable of supporting the total tensile load. In applications where the presence of continuous reinforcement is not essential to the safety and integrity of the structure, e.g., pavements, overlays, and shotcrete linings, the improvements in flexural strength associated with the fibers can be used to reduce section thickness or improve performance, or both. The following are some examples of structural and nonstructural uses of SFRC:

- Hydraulic structures — Dams, spillways, stilling basins, and sluiceways as new or replacement slabs or overlays to resist cavitation damage. See Reference 5.
- Airport and highway paving and overlays — Particularly where a thinner than normal slab is desired.
- Industrial floors — For impact resistance and resistance to thermal shock.
- Refractory concrete — Using high-alumina cement in both castable and shotcreted applications. See References 6 and 7.
- Bridge decks — As an overlay or topping where the primary structural support is provided by an underlying reinforced concrete deck.
- In shotcrete linings — For underground support in tunnels and mines, usually with rock bolts.
- In shotcrete coverings — To stabilize aboveground rock or soil slopes, e.g., highway and railway cuts and embankments. See Reference 8.
- Thin shell structures — Shotcreted "foam domes."
- Explosion-resistant structures — Usually in combination with reinforcing bars.
- A possible future use is in seismic-resistant structures.

1.4 — Specifying steel fiber reinforced concrete

1.4.1 *General* — Steel fiber reinforced concrete is usually specified by strength and fiber content. The flexural strength is normally specified for paving applications while compressive strength is normally specified for structural applications. A flexural strength of 700 to 1000 psi (4.8 to 6.9 MPa) at 28 days and a compressive strength of 5000 to 7000 psi (34.5 to 48.3 MPa) are typical values. In general the addition of fibers does not significantly increase compressive strength but does increase the compressive strain at ultimate load. The changes in mixture proportions to accommodate the fibers do have a significant influence on the compressive strength.

For normal weight concrete, fiber contents have been used from as low as 50 lb/yd^3 (30 kg/m^3) to as high as 265 lb/yd^3 (157 kg/m^3) although the high range limit is usually about 160 to 200 lb/yd^3 (95 to 118 kg/m^3). Steel fibers have also been used in lightweight concrete, but data are not generally available. The amount that can be used, and the amount needed for a particular application, depends upon the fiber shape and aspect ratio[*] as well as the end use. See References 1 through 4 and 10 or consult fiber manufacturers for additional information. In terms of volume percentage for normal weight concrete, 50 lb/yd^3 = 0.38 percent by volume; 160 lb/yd^3 = 1.2 percent by volume; and 265 lb/yd^3 = 2.0 percent by volume.

Toughness, which is the area under a load-deflection curve, or a toughness index, which is a function of that area, may be determined to help define the performance requirements of SFRC intended for use where post-cracking energy absorption or resistance to failure after cracking is important. These properties would be important in applications such as structures subjected to earthquakes or explosive blasts, impact loads, cavitation loads, thermal shock, and other dynamic loads. A standard test for flexural toughness is being prepared by the ASTM subcommittee on Fiber Reinforced Concrete. After such a standard test has been adopted and more experience gained in the relationship of toughness to performance, it may be practical to use toughness as a performance standard for SFRC.

As noted in subsequent chapters, the manufacture and placing of SFRC is very similar to conventional concrete. Most existing concrete specifications can be used for the manufacture and placement of SFRC with some added requirements to account for the differences in materials and techniques. The subsequent chapters point out those differences.

1.4.2 *Guidelines for specifying ready-mixed SFRC using ASTM C 94* — ASTM C 94 may be used to specify steel fiber reinforced concrete. When using ASTM C 94, the purchaser should state that mixture proportions should be in accordance with Alternative No. 1, 2, or 3, except that flexural strength at 28 days may be specified for the strength requirement instead of compressive strength. For structures, however, the compressive strength may govern. See Section 1.4.1. Flexural strength should be determined in accordance with ASTM C 78 using 4 × 4 × 14 in. specimens on a 12-in. span (100 × 100 × 350 mm - 300 mm span) as recommended in ACI 544.2R. See ACI 544.2R for additional guidance on testing, e.g., specimens representing the design depth. The alternative methods in ASTM C 94 as applied to this guide are

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[*] The aspect ratio of a fiber is its length divided by its diameter, l/d.

crazing which normally shows up after the curing period. If bleeding occurs or excessive fines are at the surface, the material should be screeded off and discarded.

After completion of any float work, the surface should be left until it can be worked further without damage. This is usually about the time of initial set. Where a careful finish is not required for appearance or exact tolerance, no further work is needed after floating. If a texture is required, a broom or roller can be used prior to initial set. Burlap drags should not be used because they will lift up the fibers and tear up the surface. When additional finishing is needed, the next step should be done with magnesium floats. Power equipment or hand equipment may be used. When done by hand, the float should be held flat and not on edge. It should be moved with a sawing motion (short, quick, back-and-forth movements) as it is drawn across the surface. The magnesium float can be used to obtain a nearly perfect, flat surface, bury or cover all the fibers, and leave a slight texture. This can be followed by hard steel troweling if a smooth surface is desired. The trowel must be kept flat or the edge will cause fibers to spring out of the surface. Using these techniques, some excellent finishes of SFRC have been obtained. An example of this is at Tarbela Dam where a curved spillway invert and flat stilling basin floor were completed to close tolerances.

Slipform pavers have been used on several projects, such as airport runways and taxiways, with excellent results.

The proper time to execute a broom finish following a screed finish or paving machine finish is just prior to application of curing compounds when the water sheen has practically disappeared.

6.6 — Hot and cold weather requirements

Placement of steel fiber reinforced concrete should be done according to the recommendations of ACI 305R for hot weather and ACI 306R for cold weather.

6.7 — Repair of defects

The repair of defects such as voids and honeycombing is done much the same as for plain concrete. However, if removal of some SFRC is required, the removal operation will be significantly more difficult because of the greater toughness of SFRC.

Removal by jackhammers is hindered because the material does not fracture easily. Sawing is a more effective method of cutting or removing steel fiber reinforced concrete.

6.8 — Contraction joints

Contraction joints in slabs are more easily made if they are sawed rather than cast or formed. The sawing can be done shortly after final set. At joints where it is desired to have a controlled shrinkage crack occur below the sawed portion of the joint, it has been found that the saw cut should extend from one-half to two-thirds of the way through the slab. If it does not, the higher tensile strength of the SFRC tends to prevent cracking at the joint and random cracking occurs elsewhere in the slab. A joint sealing compound should be used to seal the sawed joint to prevent water infiltration to the subgrade, and to prevent the corrosion of those fibers and fiber ends that become exposed in the saw cut and the crack below.

CHAPTER 7 — CURING AND PROTECTION

7.1 — General

Curing of steel fiber reinforced concrete and protection from freezing or excessively hot or cold temperatures should be done the same as for conventional concrete. One aspect deserves special attention. Since SFRC is often placed in thin sections, as overlays for example, and has a high cement content, it is particularly vulnerable to plastic shrinkage cracking. This will occur on warm days where it is exposed to direct sun or a breeze. Such placements must be shaded from the sun and sheltered from the wind to prevent this type of damage.

CHAPTER 8 — INFORMATION SOURCES

8.1 — Specified and/or recommended references

The standards of the American Society for Testing and Materials and the standards and reports of the American Concrete Institute referred to in this report are listed below with their serial designation, including the year of adoption or revision. The standards and reports listed were the latest editions at the time this report was prepared. Since some of these publications are revised frequently, generally in minor details only, the user of this report should check directly with the sponsoring group to refer to the latest edition.

American Concrete Institute

ACI 301-72 (Revised 1982)	Specifications for Structural Concrete for Buildings
ACI 304-73 (Reaffirmed 1978)	Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete
ACI 304.2R-71 (Revised 1982)	Placing Concrete by Pumping Methods
ACI 305R-77	Hot Weather Concreting
ACI 306R-78	Cold Weather Concreting
ACI 318-83	Building Code Requirements for Reinforced Concrete
ACI 347-78	Recommended Practice for Concrete Formwork
ACI 544.1R-82	State-of-the-Art Report on Fiber Reinforced Concrete
ACI 544.2R-78	Measurement of Properties of Fiber Reinforced Concrete

American Society for Testing and Materials

A 820 (To be published)	Standard Specification for Steel Fibers for Fiber Reinforced Concrete
C 29-78	Standard Test Methods for Unit Weight and Voids in Aggregate

C 31-83	Standard Method for Making and Curing Concrete Test Specimens in the Field
C 33 82	Standard Specification for Concrete Aggregates
C 78-75 (Reapproved 1982)	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C 94-81	Standard Specification for Ready-Mixed Concrete
C 138-81	Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
C 143-78	Standard Test Method for Slump for Portland Cement Concrete
C 173-78	Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
A 192-81	Standard Method of Making and Curing Concrete Test Specimens in the Laboratory
C 231-82	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C 995-83	Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone

The above publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219

American Society for Testing and Materials
19 [illegible] ace Street
Philadelphia, PA 19103

8.2 — Cited references

General

1. ACI Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete," (ACI 544.1R-82), American Concrete Institute, Detroit, 1982, 16 pp. Also, *ACI Manual of Concrete Practice*, Part 5.

2. "Fibre Concrete Materials: A Report Prepared by RILEM Technical Committee 19-FRC," *Materials and Structures/Research and Testing* (RILEM, Paris), V. 10, No. 56, Mar.-Apr. 1977, pp. 103-120.

Properties of steel fiber concrete

3. Johnston, C. D., "Properties of Steel Fibre Reinforced Mortar and Concrete," *Proceedings*, Symposium on Fibrous Concrete (Ci80, London, 1980), The Construction Press, Lancaster, 1980, pp. 29-47.

4. Henager, C. H., "Steel Fibrous Concrete—A Review of Testing Procedures," *Proceedings*, Symposium on Fibrous Concrete (Ci80, London, 1980), The Construction Press, Lancaster, 1980, pp. 16-28.

5. Houghton, D. L.; Borge, O. E.; and Paxton, J. H., "Cavitation Resistance of Some Special Concretes," ACI JOURNAL, *Proceedings* V. 75, No. 12, Dec. 1978, pp. 664-667.

Refractory concrete

6. Lankard, D. R., "Steel Fiber Reinforced Refractory Concrete," *Refractory Concrete*, SP-57, American Concrete Institute, Detroit, 1978, pp. 241-263.

7. Hackman, L. E., "Application of Steel Fiber to Refractory Reinforcement," *Proceedings*, Symposium on Fibrous Concrete (Ci80, London, 1980), The Construction Press, Lancaster, 1980, pp. 137-152.

Shotcrete

8. Henager, Charles H., "Steel Fibrous Shotcrete: A Summary of the State-of-the-Art," *Concrete International: Design & Construction*, V. 3, No. 1, Jan. 1981, pp. 50-58.

Proportioning of steel fiber concrete mixes

9. Schrader, Ernest K., and Munch, Anthony V., "Deck Slab Repaired by Fibrous Concrete Overlay," *Proceedings*, ASCE, V. 102, CO1, Mar. 1976, pp. 179-196. (Includes Appendix: Mix Design Procedures.)

10. Ounanian, Douglas W., and Kesler, Clyde E., "Design of Fiber Reinforced Concrete for Pumping," *Report* No. DOT-TST 76T-17, Federal Railroad Administration, Washington, D. C., 1976, 53 pp.

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BEAM TEST

Designation: C 1018 – 94b

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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If not listed in the current combined index, will appear in the next edition.

Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)[1]

This standard is issued under the fixed designation C 1018; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method evaluates the flexural performance of toughness parameters derived from fiber-reinforced concrete in terms of areas under the load-deflection curve obtained by testing a simply supported beam under third-point loading.

NOTE 1—Toughness determined in terms of areas under the load-deflection curve is an indication of the energy absorption capability of the particular test specimen, and, consequently, its magnitude depends directly on the geometrical characteristics of the test specimen and the loading system.

1.2 This test method provides for the determination of a number of ratios called toughness indices that identify the pattern of material behavior up to the selected deflection criteria. These indices are determined by dividing the area under the load-deflection curve up to a specified deflection criterion, by the area up to the deflection at which first crack is deemed to have occurred. Residual strength factors that represent the average post-crack load retained over a specific deflection interval as a percentage of the load at first crack are derived from these indices.

NOTE 2—Index values may be increased by preferential alignment of fibers parallel to the longitudinal axis of the beam caused by fiber contact with the mold surfaces or by external vibration. However, index values appear to be independent of geometrical specimen and testing variables, such as span length, which do not directly affect fiber alignment.

1.3 This test method provides for the determination of the first-crack flexural strength using the load corresponding to the point on the load-deflection curve defined in 3.1.1 as first crack, and the formula for modulus of rupture given in Test Method C 78.

1.4 Values of flexural toughness and first-crack flexural strength stated in inch-pound units are to be regarded as the standard. Values of toughness indices and residual strength factors are independent of the system of units used to measure load and deflection.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]
C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]
C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)[2]
C 172 Practice for Sampling Freshly Mixed Concrete[2]
C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]
C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]
C 823 Practice for Examination and Sampling of Hardened Concrete in Constructions[2]

3. Terminology

3.1 *Descriptions of Terms Specific to This Standard:*

3.1.1 *first crack*—the point on the load-deflection curve at which the form of the curve first becomes nonlinear (approximates the onset of cracking in the concrete matrix).

3.1.2 *first-crack deflection*—the deflection value on the load-deflection curve at first crack.

3.1.3 *first-crack strength*—the stress obtained when the load corresponding to first crack is inserted in the formula for modulus of rupture given in Test Method C 78.

3.1.4 *first-crack toughness*—the energy equivalent to the area under the load-deflection curve up to the first-crack deflection.

3.1.5 *toughness*—the energy equivalent to the area under the load-deflection curve up to a specified deflection.

3.1.6 *toughness indices*—the numbers obtained by dividing the area up to a specified deflection by the area up to first crack.

NOTE 3—Values of 5.0, 10.0, and 20.0 for I_5, I_{10}, and I_{20} respectively, as defined below, correspond to linear elastic material behavior up to first crack and perfectly plastic behavior thereafter (see Appendix X1).

3.1.6.1 *toughness index* I_5—the number obtained by dividing the area up to a deflection of 3.0 times the first-crack deflection by the area up to first crack.

3.1.6.2 *toughness index* I_{10}—the number obtained by dividing the area up to a deflection of 5.5 times the first-crack deflection by the area up to first crack.

3.1.6.3 *toughness index* I_{20}—the number obtained by

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[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.42 on Fiber-Reinforced Concrete.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

dividing the area up to a deflection of 10.5 times the first-crack deflection by the area up to first crack.

3.1.6.4 *residual strength factor* $R_{5,10}$—the number obtained by calculating the value of $20\,(I_{10} - I_5)$.

3.1.6.5 *residual strength factor* $R_{10,20}$—the number obtained by calculating the value of $10\,(I_{20} - I_{10})$.

4. Summary of Test Method

4.1 Molded or sawn beams of fiber-reinforced concrete are tested in flexure using the third-point loading arrangement specified in Test Method C 78. Load and beam deflection are monitored either continuously by means of an X-Y plotter, or incrementally by means of dial gages read at sufficiently frequent intervals to ensure accurate reproduction of the load-deflection curve. A point termed first crack which corresponds approximately to the onset of cracking in the concrete matrix is identified on the load deflection curve. The first-crack load and deflection are used to determine the first-crack flexural strength and to establish end-point deflections for toughness calculations. Computations of toughness and toughness indices are based on areas under the load-deflection curve up to the first-crack deflection and up to the specified end-point deflection.

5. Significance and Use

5.1 The first-crack strength characterizes the behavior of the fiber-reinforced concrete up to the onset of cracking in the matrix, while the toughness indices characterize the toughness thereafter up to specified end-point deflections. Residual strength factors, which are derived directly from toughness indices, characterize the level of strength retained after first crack simply by expressing the average post-crack load over a specific deflection interval as a percentage of the load at first crack. The importance of each depends on the nature of the proposed application and the level of serviceability required in terms of cracking and deflection. Toughness and first-crack strength are influenced in different ways by the amount and type of fiber in the concrete matrix. In some cases, fibers may greatly increase the toughness, toughness indices, and residual strength factors determined by this test method while producing a first-crack strength only slightly greater than the flexural strength of the plain concrete matrix. In other cases, fibers may significantly increase the first-crack strength with only relatively small increases in toughness, toughness indices, and residual strength factors.

5.2 The toughness indices and residual strength factors determined by this test method reflect the post-crack behavior of fiber-reinforced concrete under static flexural loading. The absolute values of toughness determined to compute the toughness indices are of little practical significance since they are directly dependent upon geometrical variables associated with the specimen and the loading arrangement.

NOTE 4—In applications where the energy absorption capability of a structural concrete element is important, it may be possible to obtain some indication of its performance by testing a specimen equivalent to the element in terms of size, span, and mode of loading.

5.3 In determining which toughness index is most appropriate as a measure of material performance for a specific application, the level of serviceability required in terms of cracking and deflection shall be considered, and an index appropriate to the service conditions shall be selected in accordance with the rationale described in 9.6 and in Appendix X1.

5.4 Values of toughness indices, residual strength factors, and first-crack strength may be used for comparing the performance of various fiber-reinforced concretes during the mixture proportioning process or in research and development work. They may also be used to monitor concrete quality, to verify compliance with construction specifications, or to evaluate the quality of concrete already in service.

NOTE 5—Values of toughness index at different ages may not be comparable.

5.5 Values of toughness indices, residual strength factors, and first-crack strength obtained using the 14 by 4 by 4 in. (350 by 100 by 100 mm) preferred standard size of molded specimen may not necessarily correspond with the performance of larger or smaller molded specimens, concrete in large structural units, or specimens sawn from such units, because of differences in the degree of preferential fiber alignment parallel to the longitudinal axis of the specimen. For molded specimens, they tend to increase as the degree o preferential fiber alignment increases.

5.5.1 Preferential fiber alignment is likely to occur in molded specimens when fibers in the vicinity of the mold surfaces tend to align in the plane of the surface, and is most pronounced in specimens of small cross-section containing long fibers.

5.5.2 In thin concrete sections, such as overlays and shotcrete linings, fibers tend to align in the plane of the section, so in-place performance is best evaluated using either molded or sawn specimens of depth equal to the thickness of the section. Consequently, toughness indices, residual strength values, and first-crack strengths for thin sections may differ from those for standard molded specimens of nominally identical concrete.

5.5.3 External vibration promotes preferential alignment of fibers parallel to the vibrating surface of the form or screeding device used, while internal vibration does not have this effect. Consequently, toughness indices, residual strength values, and first-crack strengths for identical concrete specimens prepared using the two kinds of vibration may differ.

5.5.4 Preferential fiber alignment is negligible in mass concrete because the aligning effect of mold surfaces i absent and because internal vibration is often used, so toughness indices, residual strength values, and first-crack strengths for standard molded specimens may differ from those for sawn specimens of nominally identical concrete.

NOTE 6—The degree of preferential fiber alignment may be less fo fibers that are flexible enough to be bent by contact with aggregat particles or mold surfaces than for fibers rigid enough to remain straigh during mixing and specimen preparation.

6. Apparatus

6.1 *Testing Machine*—The testing machine shall be i accordance with Test Method C 78 and shall, in addition, b capable of operating in a manner which produces a controlled and constant rate of increase of deflection of th specimen. A testing machine capable only of producing constant rate of increase of load is not suitable for establishing the post-crack portion of the load-deflection cur after the first-crack load has been reached.

6.2 *Deflection-Measuring Equipment*—Devices such as lectronic transducers or mechanical dial gages shall be ocated in a manner that ensures accurate determination of he net deflection at the mid-span exclusive of any effects lue to seating or twisting of the specimen on its supports. wo alternative arrangements for measuring net mid-span leflection have evolved. In the first arrangement three lectronic transducers or similar digital devices mounted on a supporting frame are positioned along the centerline of the op surface of the test specimen, one at the mid-span and one at each support (Fig. 1). The average of the support deflec-ions is electrically subtracted from the mid-span deflection. The second arrangement employs a rectangular jig which surrounds the specimen and is clamped to it at the supports Fig. 2). Two transducers or similar digital devices mounted on the jig at mid-span, one on each side, measure deflection through contact with appropriate brackets attached to the specimen. The average of the measurements represents net mid-span deflection.

6.3 *X-Y Plotter*—An X-Y plotter coupled directly to electronic outputs of load and deflection is the preferred means of expediently and accurately obtaining the relationship between load and net mid-span deflection, subsequently termed the load-deflection curve. If an X-Y plotter is not available, incremental tabulations of load and deflection may be used to manually plot the curve.

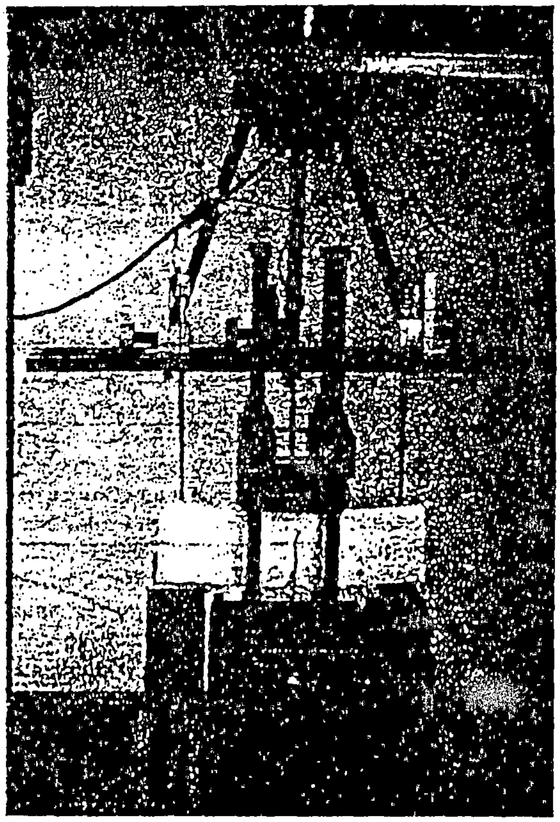


FIG. 1 Arrangement Using 3 Transducers

NOTE 7—Accurate determination of the areas under the load-deflection curve subsequently needed for computation of toughness indices is only possible when the scales initially chosen for load and deflection are reasonably large. A load scale on which 1 in. (25 mm) corresponds to a flexural stress of the order of 150 psi (1 MPa), or no more than 20 % of the estimated first-crack strength, is recommended. For the preferred 14 by 4 by 4 in. (350 by 100 by 100 mm) specimen size, where first-crack deflection is of the order of 0.002 in. (0.05 mm), a deflection scale on which 1 in. (25 mm) corresponds to about 10 % of the estimated end-point deflection for I-20 is recommended. When testing is continued to a higher end-point deflection, the scale may have to be reduced to avoid excessively large load-deflection plots. With some plotting equipment it is possible to use a relatively large scale up to the I_{10} criterion and switch to a smaller scale at higher deflections without interrupting the test. This keeps the size of the plot reasonable without adversely affecting the ability to accurately determine the area up to first crack and the areas up to the I_5 and I_{10} deflection criteria. For test specimens that exhibit a very rapid decrease in load and increase in

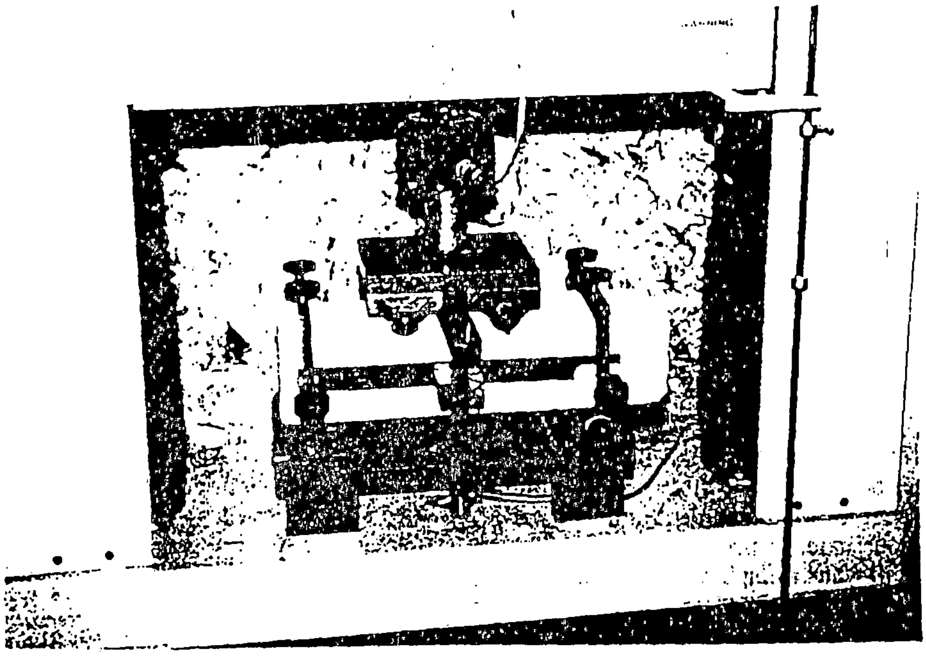
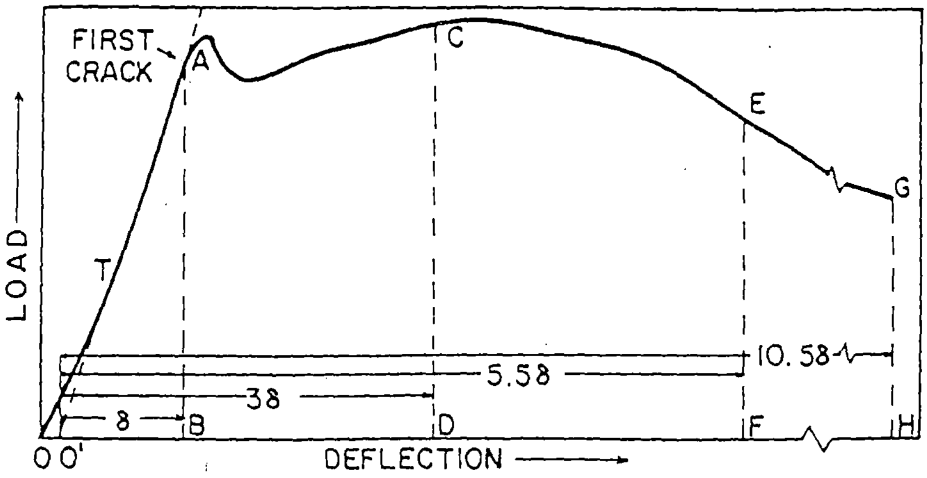
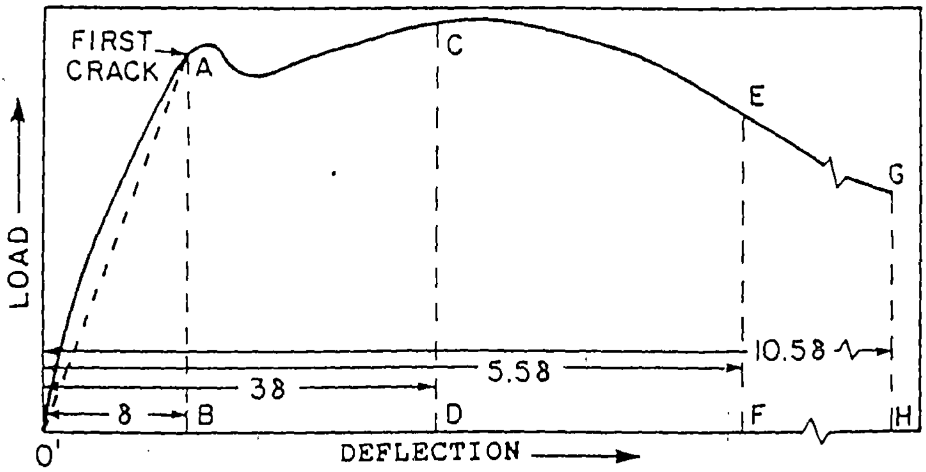


FIG. 2 Arrangement Using Rectangular Jig



(a) Concave upwards to first crack



(b) Convex upwards to first crack

FIG. 3 Important Characteristics of the Load-Deflection Curve

deflection immediately after first crack, the shape of the portion of the load-deflection curve immediately following first crack may be affected by the response rate of the data recording and plotting system.

7. Sampling, Test Specimens, and Test Units

7.1 *General Requirements*—The nominal maximum size of aggregate and cross-sectional dimensions of test specimens shall be in accordance with Practice C 31 or Practice C 192 when using molded specimens, or in accordance with Test Method C 42 when using sawn specimens, except when the following specific requirements are contravened:

7.1.1 The length of test specimens shall be at least 2 in. (50 mm) greater than three times the depth, and in any case not less than 14 in. (350 mm).

7.1.2 The width of test specimens shall be at least three times the maximum fiber length. The three times maximum fiber length requirement for width and depth may be waived at the option of the purchaser to permit specimen width or depth of 6 in. (150 mm) when using fibers of length 2 to 3 in. (50 to 75 mm).

7.1.3 The depth and size of test specimens shall conform to either of the following two sets of requirements:

7.1.3.1 *Thick Sections*—The depth of test specimens shall be at least three times the maximum fiber length. Subject to meeting this requirement and the requirements of 7.1, 7.1.1, and 7.1.2, the preferred specimen size is 14 by 4 by 4 in. (350 by 100 by 100 mm). When the preferred size is not large enough to meet all of these requirements, specimens of square cross-section large enough to meet the requirements shall be tested. The three times maximum fiber length requirement for width and depth may be waived at the option of the purchaser to permit specimen width or depth of 6 in. (150 mm) when using fibers of length 2 to 3 in. (50 to 75 mm).

7.1.3.2 *Thin Sections*—When the requirements of 7.1 and 7.1.3.1 are not met in the application in which the concrete is to be used, as for example in overlays or shotcrete linings, specimens of depth equal to the section thickness actually used shall be tested.

NOTE 8—When testing freshly mixed fiber-reinforced concrete, it may be desirable to prepare additional specimens of the preferred standard size in order to make proper comparisons of their performance with results obtained on other jobs or reported in the literature. The results of tests of beams with steel fibers longer than one-third the width or depth of the beam may not be comparable to test results of similar-sized beams with fibers shorter than one-third the width or depth because of possible preferential fiber alignment, and different size beams may not be comparable because of size effects.

7.2 *Freshly Mixed Concrete*—Samples of freshly mixed fiber-reinforced concrete for the preparation of test specimens shall be obtained in accordance with Practice C 172.

7.2.1 Specimens shall be molded in accordance with Practice C 31 or Practice C 192, except that compaction shall be by external vibration, as internal vibration or rodding may produce nonuniform fiber distribution. Make sure that the time of vibration is sufficient to ensure adequate consolidation, as fiber-reinforced concrete requires a longer vibration time than concrete not containing fibers, especially when the fiber concentration is relatively high. Take care to avoid placing the concrete in a manner which produces lack of fiber continuity between successive placements by using a wide shovel or scoop and placing each lift of concrete uniformly along the length of the mold. Use a single layer for specimens of depth 3 in. (75 mm) or less and two layers for specimens of depth greater than 3 in. (75 mm).

7.2.2 In placing the final layer, attempt to add an amount of concrete that will exactly fill the mold after compaction. When trowelling the top surface, continue vibration in order to ensure that fibers do not protrude from the finished surface.

7.2.3 Curing shall be in accordance with Practice C 31 or Practice C 192.

7.3 *Hardened Concrete*—Samples of hardened fiber-reinforced concrete from structures shall be selected in accordance with Practice C 823.

7.3.1 Sawn specimens shall be prepared and cured in accordance with Test Method C 42.

7.4 *Test Unit*—At least three specimens from each sample of fresh or hardened concrete shall be prepared for testing.

8. Conditioning

8.1 When the time between removal of test specimens from their curing environment and the start of testing is likely to exceed 15 min, drying shall be minimized by applying a curing compound or by other appropriate techniques.

9. Procedure

9.1 Molded or sawn specimens representing thick sections, as defined in 7.1.3.1, shall be turned on their side with respect to the position as cast before placing on the support system. Molded or sawn specimens representing thin sections, as defined in 7.1.3.2, shall be tested as cast without turning. Specimens representing shotcrete panels of any thickness shall be tested as placed without turning.

9.2 Arrange the specimen and the loading system so that the specimen is loaded at the third points in accordance with Test Method C 78. The span length shall be three times the specimen depth or 12 in. (300 mm), whichever is greater. If before loading, full contact is not obtained between the specimen, the load-applying devices, and the supports, grind or cap the contact surfaces of the specimen in accordance with Test Method C 78.

9.3 Operate the testing machine so that the deflection of the specimen at the mid-span increases at a constant rate. For 14 by 4 by 4 in. (350 by 100 by 100 mm) specimen size, the rate of increase of Net Mid-Span deflection shall be within the range 0.002 to 0.004 in./min (0.05 to 0.10 mm/min) until the specified end-point deflection is reached. The corresponding rate for other sizes and shapes of specimens shall be based on reaching the first-crack deflection 30 to 60 s after the start of the test. First-crack deflection for third-point loading is estimated assuming elastic behavior up to first crack from the equation:

$$\delta = 23\,PL^3/1296\,EI\left[1 + \frac{216\,D^2(1+\mu)}{115\,L^2}\right]$$

where P is the first-crack load, L is the span, E is the estimated modulus of elasticity of the concrete, I is the cross-sectional moment of inertia, D is the specimen depth, and μ is Poisson's ratio.

NOTE 9—Testing machines capable of automatically controlling the rate of movement of the loading heads are well suited but not essential to this procedure.

9.4 Exercise care to ensure that the measured deflections are the net values exclusive of any extraneous effects due to seating or twisting of the specimen on its supports or deformation of the support system. At regular intervals or when using test equipment for the first time, or after major alterations or maintenance, confirm the reliability of net mid-span deflection values by comparing the value of first-crack deflection determined experimentally with the value derived from the formula given in 9.3.

NOTE 10—Location of deflection-measuring devices at the mid-width of the specimen minimizes the effect of twisting and reduces the number of devices needed to determine the net deflection at the mid-span. When deflection is measured on the sides of the specimen, deflection-measuring devices are needed on both sides of the specimen to eliminate the possible effects of twisting of the specimen on deflection values.

9.5 Unless otherwise specified by the purchaser, terminate the test at a deflection large enough to ensure that the area up to the end-point deflection of 5.5 times the first-crack deflection specified for the I_{10} index can be determined.

9.6 When the level of serviceability appropriate to the particular application in terms of permissible deflection and cracking indicates that the specified end-point deflection should be higher, further testing to an appropriate deflection criterion shall be specified at the option of the purchaser. In general, the end-point deflection for an index I_n is $(n + 1)/2$ times the first-crack deflection. Rationale for selection of end-point deflection is given in X1.3 of Appendix X1.

9.7 Make two measurements of the specimen depth and width adjacent to the fracture (one at each face) to the nearest 0.05 in. (1.0 mm) to determine the average depth and width.

9.8 Determine the position of the fracture by measuring the distance along the middle of the tension face from the fracture to the nearest end of the specimen.

9.9 When the fracture occurs outside the middle third of the span by more than 5 % of the span length, discard the results.

10. Calculation

10.1 If the load-deflection curve is slightly concave upwards throughout its initial portion, determine first crack by placing a straightedge coincident with that portion of the load-deflection curve which is essentially linear, and identifying the point at which the curvature first increases sharply and the slope of the curve exhibits a definite change, as at point A in Fig. 3(a). To correct for the extraneous effects identified in 9.4, extend the straight line, AT, representing the linear portion of the load-deflection curve from the point, T, at which it departs from the experimental curve to a new origin at point O', as shown in Fig. 3(a). The line $O'TA$ in Fig. 3(a) is used in subsequent area computations rather than the curve OTA.

10.2 If the load-deflection curve is slightly convex upwards throughout its initial portion, that is like the stress-strain curve for plain concrete in tension or compression, first crack is the point at which the curvature first increases sharply and the slope of the curve exhibits a definite change, as at A in Fig. 3 (b). The straight line O'A in Fig. 3(b) is used in subsequent area computations rather than the O'A portion of the curve.

Note 11—Small ripples or fluctuations in the load-deflection curve due to electronic noise or mechanical vibration should not be confused with a definite change in overall slope and curvature, particularly when the portion of the curve in question is artificially magnified.

10.3 Calculate the first-crack strength using the load corresponding to first crack on the load-deflection curve and the formula for modulus of rupture given in Test Method C 78.

Note 12—When the flexural strength is required, it may be determined using the maximum load attained on the load-deflection curve and the formula for modulus of rupture given in Test Method C 78. The value thus obtained may differ from the flexural strength obtained using the constant-rate-of-loading procedure specified in Test Method C 78.

10.4 Determine the first-crack deflection as the deflection corresponding to the length $O'B$ in Fig. 3.

10.5 Determine the area under the load-deflection curve up to the first-crack deflection. This is the triangular area corresponding to $O'AB$ in Fig. 3. If required, calculate the corresponding first-crack toughness in inch-pound or SI units.

10.6 Determine the area under the load-deflection curve up to a deflection of 3.0 times the first-crack deflection. This corresponds to the area $O'ACD$ in Fig. 3 where $O'D$ equals 3.0 times the first-crack deflection. Divide this area by the area up to first crack, obtained in accordance with 10.4, and report the number rounded to the nearest 0.1 as the toughness index I_5.

Note 13—Determination of the irregularly shaped areas needed to implement the instructions of this and subsequent sections 10.6 to 10.9 requires a planimeter, or application of Simpson's rule, or the counting of squares or other suitable elements of known area. When different deflection scales are used on the same plot, care must be taken to ensure that this is taken into account when converting physical area measurements to toughness indices.

10.7 Determine the area under the load-deflection curve up to a deflection of 5.5 times the first-crack deflection (area $O'AEF$ in Fig. 3). Divide it by the area up to first crack, and report the number rounded to the nearest 0.1 as the toughness index I_{10}.

10.8 When required, determine the area under the load-deflection curve up to a deflection of 10.5 times the first-crack deflection (area $O'AGH$ in Fig. 3). Divide it by the area up to first crack, and report the number rounded to the nearest 0.1 as the toughness index I_{20}.

10.8 Determine the residual strength factor $R_{5,10}$ as $20(I_{10} - I_5)$, and, when required, the residual strength factor $R_{10,20}$ as $10(I_{20} - I_{10})$.

Note 14—While the foregoing calculations presume that the load-deflection curve is determined in graphical form, it is not inconceivable that electronic equipment capable of digitally recording load and deflection may be developed, and that the recorded data may be analyzed by computer to determine relevant areas and toughness indices.

11. Report

11.1 Report the following information:

11.1.1 Type of specimen (molded or sawn) and specimen identification numbers or symbols,

11.1.2 Average width of specimen to the nearest 0.05 in. (1.0 mm),

11.1.3 Average depth of specimen to the nearest 0.05 in. (1.0 mm),

11.1.4 Span length to the nearest 0.1 in. (2.0 mm),

11.1.5 First-crack load and, when required, the maximum load, lbf(N),

11.1.6 First-crack deflection, in. (mm) to the nearest 0.0001 in. (0.002 mm), and the location where deflection was measured (mid-span or loading points),

11.1.7 First-crack strength and, when required, flexural strength to the nearest 5 psi (0.05 MPa),

11.1.8 First-crack toughness, lbf·in. (N·m), to the nearest 0.1 lbf·in. (0.01 N·m), when required,

11.1.9 Toughness indices I_5 and I_{10}, and the residual strength factor $R_{5,10}$,

11.1.10 Toughness index I_{20} and the residual strength factor $R_{10,20}$ when required,

11.1.11 Age of specimens at test,

11.1.12 Curing history and moisture condition of specimens at test,

11.1.13 Whether specimen was capped, or ground, and

11.1.14 Defects in specimen prior to test and abnormalities in specimen behavior during test.

12. Precision and Bias

12.1 *Within-Laboratory Precision*—Single-operator values of the one-sigma limit in percent (1s %), defined in accordance with Practice C 670, have been determined for concretes containing steel fibers as follows:

Parameter	Within-Batch 1s %	Overall 1s %[A]
First-crack strength	5	7
First-crack toughness	10	12
Toughness index I_5	12	13
Toughness index I_{10}	14	16
Toughness index I_{20}	16	20
Flexural strength	5 to 8[B]	8 to 10[B]

[A] Inclusive of batch-to-batch variability, but not variability due to changes in specimen geometry, test span, and mode of loading.

[B] Upper limit appears applicable to relatively high fiber concentrations, 200 lb/yd^3 (120 kg/m^3) or more of straight uniform fibers, or 70 lb/yd^3 (42 kg/m^3) or more of deformed fibers.

NOTE 15—These levels of precision are based on data from a small number of investigations[3,4] conducted by experienced operators using good, but not necessarily the best possible equipment. The levels of precision achievable probably depend on the nature of the equipment used to produce the load-deflection curve, and the care exercised in computing the areas under this curve. As more sophisticated deflection-measuring and plotting devices become available, it may be possible to achieve 1s % values lower than those indicated.

12.2 No data are yet available to indicate whether the levels of precision for concretes containing other types of fibers, such as glass or polypropylene, differ from those quoted in 12.1.

12.3 *Multilaboratory Precision*—No data suitable for the evaluation of multilaboratory precision are yet available.

12.4 *Bias*—This test method has no bias since the properties determined can only be defined in terms of this test method.

APPENDIX

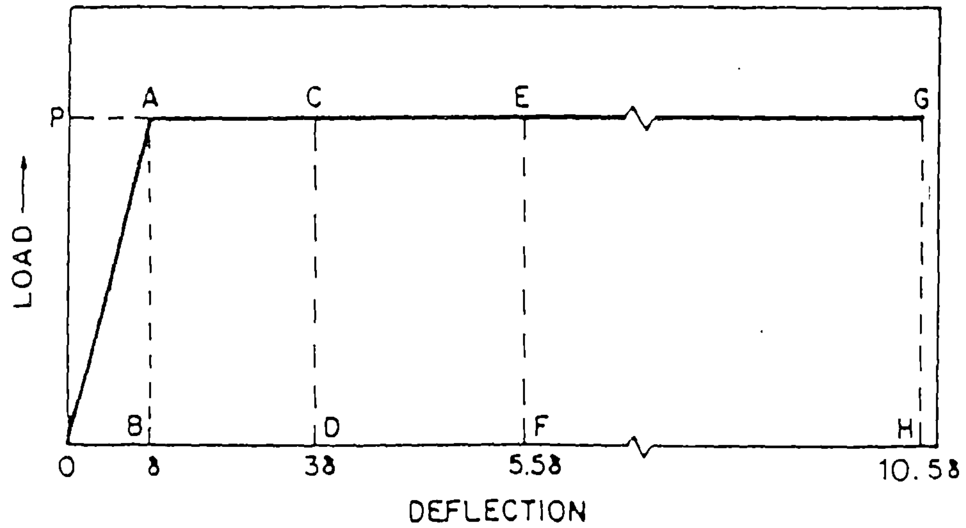
(Nonmandatory Information)

X1. RATIONALE FOR THE METHOD

X1.1 Absolute values of toughness up to the first-crack or other specified deflections depend entirely on geometrical variables associated with the specimen and the testing arrangement, and bear no direct relationship to the energy absorption capability of a structural element made with a fibrous concrete identical to that used to prepare specimens for testing according to this test method.

X1.2 Toughness indices I_5, I_{10}, and I_{20} enable actual performance to be compared with a readily understood reference level of performance. In this regard, values of 5.0, 10.0 and 20.0 for I_5, I_{10}, and I_{20} correspond to linear elastic material behavior up to first crack and perfectly plastic behavior thereafter[5] (Fig. X1.1). Such behavior is desirable for many applications requiring high toughness, and can be reached or exceeded only by careful selection of fiber type, fiber concentration, and concrete matrix parameters. The indices have the same meaning regardless of the cross-sectional size and span of the test specimen.

X1.3 When the conditions of serviceability or the purchaser's needs require a specified end-point deflection higher than that identified in 9.5, it is recommended that the



Area Basis[A]	Index Designation	Deflection Criterion	Values of Toughness Indices		
			Plain Concrete	Elastic-Plastic Material	Observed Range for Fibrous Concrete
OACD	I_5	3δ	1.0	5.0	1 to 6
OAEF	I_{10}	5.5δ	1.0	10.0	1 to 12
OAGH	I_{20}	10.5δ	1.0	20.0	1 to 25

[A] Indices calculated by dividing this area by the area to the first crack OAB.

FIG. X1.1 Definition of Toughness Indices in Terms of Multiples of First-Crack Deflection and Elastic-Plastic Material Behavior

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[3] Johnston, C. D., "Effects of Testing Rate and Age on ASTM C 1018 Toughness Parameters and Their Precision for Steel Fiber-Reinforced Concrete," *Cement Concrete and Aggregates*, CCAGDP, Vol 15, No. 1, Summer 1993, pp 50-58.

[4] Johnston, C. D. and Skarendahl, A., "Comparative Flexural Performance Evaluation of Steel Fibre-Reinforced Concretes According to ASTM C 1018 Shows Importance of Fibre Parameters," *RILEM Materials and Structures*, Vol 25, May 1992, pp 191-200.

[5] Johnston, C. D., "Definition and Measurement of Toughness Parameters for Fiber-Reinforced Concrete," *Cement, Concrete, and Aggregates*, CCAGDP, Vol 4, No. 2, Winter 1982, pp 53-60.

end-point deflection be specified as a multiple of the first-crack deflection and that it be consistent with the rationale in X1.2. For example, an end-point deflection of 10.5 times the first-crack deflection permits calculation of the I_{20} index.

X1.4 The residual strength factors $R_{5,10}$ and $R_{10,20}$ represent the average level of strength retained after first crack as a percentage of the first-crack strength for the deflection intervals *CE* and *EG* respectively in Fig. 3 (a). Values of 100 correspond to perfectly plastic behavior (Fig. X1.1). Lower values indicate inferior performance. Plain concrete has residual strength factors of zero.

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Standard Specification for Fiber-Reinforced Concrete and Shotcrete[1]

This standard is issued under the fixed designation C 1116; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers all forms of fiber-reinforced concrete that are delivered to a purchaser with the ingredients uniformly mixed, and that can be sampled and tested at the point of delivery. It does not cover the placement, consolidation, curing, or protection of the fiber-reinforced concrete after delivery to the purchaser.

1.2 Certain sections of this specification are also applicable to fiber-reinforced concrete intended for shotcreting by the dry-mix process when sampling and testing of concrete is possible only at the point of placement. In this case, the sections dealing with batching plant, mixing equipment, mixing and delivery, and measurement of workability and air content, are not applicable.

1.3 This specification does not cover thin-section glass fiber-reinforced concrete manufactured by the spray-up process that is under the jurisdiction of ASTM Subcommittee C27.40.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 The following precautionary statement pertains only to the test method portion, Sections 16 and 19, of this specification: *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 820 Specification for Steel Fibers for Fiber-Reinforced Concrete[2]
C 31 Practice of Making and Curing Concrete Test Specimens in the Field[3]
C 33 Specification for Concrete Aggregates[3]
C 39 Test Method for Strength of Cylindrical Concrete Specimens[3]
C 42 Methods of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[3]
C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)[3]
C 94 Specification for Ready-Mixed Concrete[3]
C 109 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-/in. or 50-/mm Cube Specimens)[4]
C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[3]
C 143 Test Method for Slump of Portland Cement Concrete[3]
C 150 Specification for Portland Cement[2]
C 172 Method of Sampling Freshly Mixed Concrete[3]
C 173 Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[3]
C 191 Test Method for Time of Setting of Hydraulic Cement by Vicat Needle[4]
C 192 Practice of Making and Curing Concrete Test Specimens in the Laboratory[3]
C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[3]
C 260 Specification for Air-Entraining Admixtures for Concrete[3]
C 330 Specification for Lightweight Aggregates for Structural Concrete[3]
C 387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete[3]
C 494 Specification for Chemical Admixtures for Concrete[3]
C 567 Test Method for Unit Weight of Structural Lightweight Concrete[3]
C 595 Specification for Blended Hydraulic Cements[3]
C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete[3]
C 637 Specification for Aggregates for Radiation-Shielding Concrete[3]
C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing[3]
C 684 Method of Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens[3]
C 685 Specification for Concrete Made by Volumetric Batching and Continuous Mixing[3]
C 887 Specification for Packaged, Dry, Combined Materials for Surface Bonding Mortar[5]
C 995 Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone[3]
C 1017 Specification for Chemical Admixtures for Use in Producing Flowing Concrete[3]
C 1018 Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using

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[1] This specification is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.03.04 on Fiber Reinforced Concrete.

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[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.01.

[5] *Annual Book of ASTM Standards*, Vol 04.05.

Beam with Third-Point Loading)[3]

C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[3]

D 512 Test Methods for Chloride Ion in Water[6]

D 516 Test Methods for Sulfate Ion in Water[6]

2.2 *ACI Standards and Reports:*

211.1 Standard Practice for Selecting Proportions for Normal and Heavyweight Concrete[7]

211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete[7]

214 Recommended Practice for Evaluation of Strength Test Results of Concrete[7]

506.1R, State-of-the-Art Report on Fiber-Reinforced Shotcrete[7]

506.2 Specification for Materials, Proportioning and Application of Shotcrete[7]

506 R. Guide for Shotcreting[7]

544.3R Guide for Specifying, Mixing, Placing and Finishing Steel Fiber-Reinforced Concrete[7]

2.3 *AASHTO Standard:*

T26 Test Method for Solids Content of Wash Water[8]

3. Terminology

3.1 *Descriptions of Terms Specific to This Standard:*

3.1.1 *fibers*—slender and elongated filaments in the form of bundles, networks, or strands of any natural or manufactured material that can be distributed throughout freshly mixed concrete.

3.1.2 *manufacturer*—the contractor, subcontractor, supplier, or producer who furnishes the fiber-reinforced concrete.

3.1.3 *purchaser*—the owner or representative thereof.

4. Classification

4.1 This specification classifies fiber-reinforced concrete or shotcrete by the material type of the fiber incorporated. The performance of a fiber-reinforced concrete or shotcrete depends strongly upon the susceptibility of the fibers to physical damage during the mixing or shotcreting process, their chemical compatibility with the normally alkaline environment within cement paste, and their resistance to service conditions encountered within uncracked concrete or as a consequence of cracking, involving, for example, carbon dioxide, chlorides or sulphates in solution with water and oxygen or ultraviolet light in the atmosphere. The magnitude of improvements in the mechanical properties of the concrete or shotcrete imparted by fibers also reflects the material characteristics of the fiber type with fibers having a high modulus of elasticity and tensile strength being more effective on an equivalent volume basis than fibers of low modulus and strength.

4.1.1 *Type I Steel Fiber-Reinforced Concrete or Shotcrete*—Contains stainless steel, alloy steel, or carbon steel fibers, (see Note 1).

NOTE 1—Steel fibers are not easily damaged by the mixing or shotcreting processes and are chemically compatible with the normally alkaline environment within cement paste. Carbon steel fibers will rust under conditions that cause rusting of conventional steel, for example, in the near-surface portion of concrete subject to carbonation.

4.1.2 *Type II Glass Fiber-Reinforced Concrete or Shotcrete*—Contains alkali-resistant glass fibers, (see Note 2).

NOTE 2—Glass fibers in concrete or shotcrete subjected to wetting, humid atmosphere, or contact with moist ground have the potential to react with the alkalies present in cement paste thereby weakening the fibers. They also tend to become embrittled by hydration products penetrating the fiber bundles and filling the interstitial spaces between the individual glass filaments. Both mechanisms cause reductions in strength, toughness, and impact resistance with age. The alkali-resistant (AR) types of glass fiber developed for use with cement are more resistant to alkalies than the E-glass and other types not marketed specifically for use in cement, and should be used in conjunction with established techniques for suppressing the alkali-silica reaction, for example, use of a low-alkali cement or a mineral admixture, or both. However, even the use of AR-glass fibers does not prevent deterioration in glass fiber-reinforced concrete exposed to moisture for a long period of time, but only slows the rate at which it occurs.

Glass fibers can be damaged by conventional concrete mixing processes employing coarse aggregate, but have been used in shotcrete and in other cementitious matrices such as mechanically mixed masonry mortar (see Specification C 887) and thin-section glass fiber-reinforced concrete prepared by the spray-up process (under the jurisdiction of ASTM Subcommittee C27.40).

4.1.3 *Type III Synthetic Fiber-Reinforced Concrete or Shotcrete*—Contains virgin homopolymer polypropylene fibers or other synthetic fibers for which documentary evidence can be produced confirming their long-term resistance to deterioration when in contact with the moisture and alkalies present in cement paste or the substances present in air-entraining and chemical admixtures, (see Note 3 and 4.2).

NOTE 3—Virgin homopolymer polypropylene fibers are not attacked by the constituents of cement or the substances encountered in most air-entraining and chemical admixtures. Fibers made with some other polymers may deteriorate when in contact with moisture, alkalies, the detergents present in some air-entraining admixtures, or some of the ingredients of chemical admixtures.

4.2 When the purchaser chooses to permit the use of fibers other than those complying with the classifications in 4.1, for example: natural fibers, metallic fibers other than steel, carbon fibers, etc., the producer shall show evidence satisfactory to the purchaser that the type of fiber proposed for use does not react adversely with the concrete or shotcrete matrix, including the constituents of any admixtures present, or with the surrounding environment in the cracked matrix, causing deterioration in mechanical properties with age under the exposure conditions anticipated in the application.

5. Basis of Purchase

5.1 The basis of purchase for conventionally mixed fiber-reinforced concrete shall be the cubic yard or cubic metre of freshly mixed and unhardened material as discharged from the mixer.

5.2 The volume of freshly mixed and unhardened material in a given batch shall be determined from the total weight of the batch divided by the unit weight in pounds per cubic foot or kilograms per cubic metre. The total weight of the batch shall be calculated either as the sum of the weights

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[6] *Annual Book of ASTM Standards*, Vol 11.01.

[7] Available from American Concrete Institute, PO Box 19150, Detroit, MI 48219.

[8] Available from American Association of State Highway and Transportation Officials, Washington DC.

of all materials, including water, entering the batch, or as the net weight of the concrete in the batch as delivered. The unit weight shall be determined in accordance with Method C 138 or C 567 for the average of at least three measurements, each on a different sample. Sampling shall be in accordance with Practice C 172.

NOTE 4—It should be understood that the volume of hardened concrete may be, or may appear to be, less than expected due to waste and spillage, over-excavation, spreading forms, some loss of entrained air, or settlement of wet mixtures, none of which are the responsibility of the manufacturer.

5.3 The basis of purchase for fiber-reinforced shotcrete shall normally be the cubic yard or cubic metre. For wet-mix shotcrete, the volume shall be calculated from the quantities delivered and the unit weight. For dry-mix shotcrete, the volume shall be calculated from the weights of constituent materials mixed and their respective specific gravities. At the option of the purchaser, where the surface to be shotcreted is plane and a uniform finished thickness of shotcrete is specified, the basis of purchase shall be the square yard or square metre.

6. Ordering Information

6.1 The purchaser shall specify the following:

6.1.1 Type of cement at the purchaser's option, otherwise the cement shall be Type I meeting the requirements of Specification C 150;

6.1.2 Types of fine and coarse aggregate at the purchaser's option, otherwise the aggregates shall be normal weight meeting the requirements of Specification C 33;

6.1.3 Slump or time of flow required at the point of delivery, or when appropriate the point of placement, subject to the tolerances hereinafter specified;

6.1.3.1 Slump shall be specified when it is anticipated to be 2 in. (50 mm) or more, and time of flow shall be specified when slump is anticipated to be less than 2 in. (50 mm). Slump or time of flow shall not be specified for shotcrete placed by the dry process.

NOTE 5—The time of flow of fiber-reinforced concrete through an inverted slump cone, determined in accordance with Method C 995, is a better indicator than slump (Method C 143) of the appropriate level of workability for fiber-reinforced concrete placed by vibration because such concrete can exhibit very low slump due to the presence of fibers and still be easily consolidated. Mixtures with a time of flow of 8 to 15 s are readily consolidated by vibration. Consolidation becomes more difficult with increase in time of flow, and is extremely difficult even when using internal vibration if the time of flow exceeds 30 s. Mixtures with a time of flow less than 8 s should be evaluated in terms of slump because the time of flow is too short to determine with satisfactory precision, or may not be determinable because the fiber-reinforced concrete flows freely through the inverted cone.

6.1.4 Air content when air-entrainment is required, ba on the air content of samples taken at the point of discha or when appropriate the point of placement, subject to tolerances hereinafter specified;

6.1.4.1 Air-entrainment shall not be specified for s crete placed by the dry process.

NOTE 6—In selecting the specified air content, the purchaser sh consider the exposure conditions to which the concrete will be subje Air contents less than shown in Table 1 may not produce adec resistance to freezing and thawing. Air contents higher than the l shown may reduce strength without contributing further to freeze-resistance.

6.1.5 When structural lightweight concrete is speci the purchaser shall specify the unit weight as wet we air-dry weight, or oven-dry weight.

NOTE 7—The unit weight of freshly mixed lightweight concrete. is the only unit weight determinable at the time of delivery, is a higher than the air-dry or oven-dry weight. Definitions of, and me for determining or calculating air-dry and oven-dry weights of weight concrete are covered in Method C 567.

6.1.6 One of the following Alternatives, 1, 2, or 3, sha used as the basis for determining the proportions of fiber-reinforced concrete or fiber-reinforced shotcrete o quality required.

6.2 *Alternative Number 1:*

6.2.1 When the purchaser assumes responsibility for ture proportioning, the following parameters shall als specified by the purchaser:

6.2.1.1 The cement content in pounds per cubic yarc kilograms per cubic metre),

6.2.1.2 If mineral admixtures are required, the type, amounts to be used in pounds per cubic yard (or kilog per cubic metre), or in percentages by weight of cement

6.2.1.3 The maximum allowable amount of mixing in gallons per cubic yard or litres per cubic metre, inclu surface moisture on the aggregates, but excluding absorbed by the aggregate,

6.2.1.4 If air-entraining admixtures are required, the name, and dosage range to be used to achieve the spe air content, (see 6.1.4),

6.2.1.5 If chemical admixtures are required, the name, and dosage range to be used, and:

6.2.1.6 The type of fibers to be used and the amou pounds per cubic yard (or kilograms per cubic metre), Classification Section).

NOTE 8—The dosage of air-entraining, water-reducing (incl high-range), accelerating, and retarding admixtures needed to satis material performance requirements varies. Therefore, dosage r should be specified to ensure that the material performance re- ments can be met.

TABLE 1 Recommended Total Air Content for Air-Entrained Concrete[A,B]

Exposure Condition[C]	Total Air Content, %						
	Nominal Maximum Sizes of Aggregate, in. (mm)						
	3/8 (9.5)	1/2 (12.5)	3/4 (19.0)	1 (25.0)	1 1/2 (37.5)	2 (50.0)	3 (75.C
Mild	4.5	4.0	3.5	3.0	2.5	2.0	1.5
Moderate	6.0	5.5	5.0	4.5	4.5	4.0	3.5
Severe	7.5	7.0	6.0	6.0	5.5	5.0	4.5

[A] For air-entrained concrete, when specified.

[B] Unless exposure conditions dictate otherwise, air contents recommended above may be reduced by up to 1 % for concretes with specified compressive stren of 5000 psi (34.5 MPa) or above.

[C] For description of exposure conditions, refer to ACI 211.1, Table 5.3.3 with attention to accompanying footnotes.

NOTE 9—The purchaser, in selecting requirements for which he assumes responsibility should give consideration to requirements for workability, placeability, durability, surface texture, and density. The purchaser is referred to ACI Practices 211.1 and 211.2 for selecting proportions that will result in concrete suitable for various types of structures and conditions of exposure, and to ACI Report 544.3R for selecting concrete and fiber parameters suitable for fiber-reinforced concrete. For guidance on selecting proportions for fiber-reinforced shotcrete, the purchaser is referred to ACI Reports 506.1R and 506.R and ACI Specification 506.2.

6.2.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of concrete, furnish a statement to the purchaser giving the sources, specific gravities, sieve analyses, and saturated surface-dry weights of fine and coarse aggregates, and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser.

6.3 *Alternative Number 2:*

6.3.1 When the purchaser requires the manufacturer to assume full responsibility for mixture proportioning (see Note 9), the purchaser shall also specify the following:

6.3.1.1 Requirements for flexural toughness, or first-crack strength, or both, determined in accordance with Method C 1018, or, at the option of the purchaser, for flexural strength determined in accordance with Method C 78, using samples obtained at the point of discharge, or when appropriate at the point of placement. At the option of the purchaser, compressive strength (Method C 39) shall be specified when the flexural requirements are considered inadequate for ensuring the quality of the matrix of the fiber-reinforced concrete. Unless accelerated curing and testing in accordance with the warm water or boiling water procedures of Method C 684 is specified, tests shall be performed after standard moist curing in accordance with Practices C 31 or C 192 at 28 days, or such other ages as are specified by the purchaser.

NOTE 10—The level of toughness achieved in any mixture is primarily a function of the type, length, and amount of fibers employed, so it is recommended that, when specifying requirements for flexural toughness, the requirements be stated in terms of one of the four levels of performance identified in the Performance Requirements section of this Specification.

NOTE 11—While first-crack strength is affected by the type and amount of fibers, it is more dependent on the characteristics of the mortar or concrete matrix, so it is recommended that the purchaser, when specifying first-crack strength, consider factors known to influence the strength of normal concrete such as, water-cement ratio, aggregate maximum size, and the presence of chemical or mineral admixtures.

6.3.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of concrete, furnish a statement to the purchaser giving the sources, specific gravities, sieve analyses, and saturated surface-dry weights of fine and coarse aggregates, the dry weights of cement and mineral admixtures, the type, dimensions, and weight of fibers, the quantities, types and names of chemical and air-entraining admixtures (if any), and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser. The manufacturer shall also furnish evidence satisfactory to the purchaser that the materials to be used and the proportions selected will produce fiber-reinforced concrete or shotcrete of the quality specified.

6.4 *Alternative Number 3:*

6.4.1 When the purchaser requires the manufacturer to assume responsibility for mixture proportioning with the minimum allowable cement content specified (see Note 9), the purchaser shall also specify the following:

6.4.1.1 Requirements for flexural toughness, or first-crack strength, or both, determined in accordance with Method C 1018, or, at the option of the purchaser, for flexural strength determined in accordance with Method C 78, using samples obtained at the point of discharge, or when appropriate the point of placement. At the option of the purchaser, compressive strength (Method C 39) shall be specified when the flexural requirements are considered inadequate for ensuring the quality of the matrix of the fiber-reinforced concrete. Unless accelerated curing and testing in accordance with the warm water or boiling water procedures of Method C 684 is specified, tests shall be performed after standard moist curing in accordance with Practices C 31 or C 192 at 28 days, or such other ages as are specified by the purchaser (see Notes 10 and 11).

6.4.1.2 Minimum cement content in pounds per cubic yard (or kilograms per cubic metre).

6.4.1.3 If admixtures are required, the type, name, and dosage to be used. The cement content shall not be reduced when admixtures are used.

NOTE 12—Alternative Number 3 can be distinctive and useful only if the designated minimum cement content is at about the same level that would ordinarily be required for the mechanical properties, aggregate size, and workability specified. It must be an amount that will be sufficient to ensure durability under expected service conditions, as well as satisfactory surface texture and density. For additional information refer to ACI Practices 211.1 and 211.2.

6.4.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser giving the sources, specific gravities, sieve analyses and saturated surface-dry weights of fine and coarse aggregates, the dry weights of cement and mineral admixtures, the type, dimensions, and weight of fibers, the quantities, types and names of chemical and air-entraining admixtures (if any), and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser. The manufacturer shall also furnish evidenc satisfactory to the purchaser that the materials to be used an the proportions selected will produce fiber-reinforced concrete or shotcrete of the quality specified.

6.5 The proportions arrived at by Alternatives 1, 2, or for each class of fiber-reinforced concrete or shotcret approved for use in a project shall be assigned a designatio to facilitate identification of each mixture delivered to th project. A certified copy of the proportions of all mixtures a established in Alternatives 1, 2, and 3 shall be kept on file b the manufacturer.

7. Materials and Manufacture

7.1 In the absence of designated applicable specificatio covering requirements for quality of materials, the followi specifications shall govern:

7.1.1 *Cement*—Cement shall conform to Specificati C 150 or C 595.

7.1.2 *Aggregates*—Aggregates shall conform to Specific tions C 33, C 330, or C 637 consistent with the type of concrete required.

7.1.3 *Water:*

7.1.3.1 The mixing water shall be clear and apparently clean. If it contains quantities of substances that discolor it or make it smell or taste unusual or objectionable or cause suspicion, it shall not be used unless service records of concrete made with it or other information indicates that it is not injurious to the quality of the concrete. Water of questionable quality shall be subject to the acceptance criteria of Table 2.

7.1.3.2 Wash water from mixer washout operations may be used as mixing water provided tests of wash water comply with the physical tests of Table 2. Wash water shall be tested at a weekly interval for approximately 4 weeks, and thereafter at a monthly interval provided that no single test exceeds the applicable limit. Optional chemical requirements in accordance with Table 3 may be specified by the purchaser when appropriate for the construction. The testing frequency for chemical limits shall be as given above unless otherwise specified by the purchaser.

NOTE 13—When recycled wash water is used, attention should be given to effects on the dosage rate and batching sequence of air-entraining and other chemical admixtures, and a uniform amount should be used in consecutive batches.

7.1.4 *Admixtures*—Admixtures for conventionally mixed fiber-reinforced concrete shall conform to Specifications C 260, C 618, C 494, or C 1017 whichever is applicable.

7.1.5 *Fibers*—Fibers shall be capable of producing fiber-reinforced concrete meeting the requirements of this specification. Steel fibers shall conform to Specification A 820.

8. Measuring Materials

8.1 Except as otherwise specifically permitted by the purchaser, cement, pozzolans, fine and coarse aggregates, mixing water, and admixtures shall be measured in accordance with the applicable requirements of Specification C 94 or C 685.

8.2 Fibers shall be measured by weight. When approved by the purchaser, fibers may be measured in bags, boxes, or like containers. Such bags, boxes, or containers shall be sealed by the fiber manufacturer and shall have the weight contained therein clearly marked. No fraction of an unsealed bag, box or like container delivered unsealed, or left over from previous work, shall be used unless weighed.

8.3 Prepackaged, dry, combined materials, including fibers, shall comply with the packaging and marking requirements of Specification C 387 and shall be accepted for use provided that after addition of water, the resulting fiber-reinforced concrete or shotcrete meets the performance requirements of this specification.

TABLE 2 Acceptance Criteria for Questionable Water Suppliers

	Limits	Test Method
Compressive strength, min % control at 7 days	90	C 109[A]
Time of set deviation from control, h:min	from 1.00 early to 1.30 later	C 191[A]

[A] Comparisons shall be based on fixed proportions and the same volume of test water compared to control mix using city water or distilled water.

TABLE 3 Chemical Limitations for Wash Water Used as Mixin Water

	Limits	Test Methoc
Chemical requirements, maximum concentration in mixing water, ppm[B]		
Chloride as Cl, ppm:		D 512
Prestressed concrete or in bridge decks	500[C]	
Other reinforced concrete in most environments or containing aluminum embedments or dissimilar metals or with stay-in-place galvanized metal forms	1000[C]	
Sulfate as SO_4, ppm	3000	D 516
Alkalies as (Na_2O + 0.658 K_2O), ppm	600	
Total solids, ppm	50 000	AASHTO T2

[A] Other test methods that have been demonstrated to yield comparable res may be used.

[B] Wash water reused as mixing water in concrete may exceed the lis concentrations of chloride and sulfate if it can be shown that the concentra calculated in the total mixing water, including mixing water on the aggregates a other sources does not exceed the stated limits.

[C] For conditions allowing use of $CaCl_2$ accelerator as an admixture, chloride limitation may be waived by the purchaser.

9. Batching Plant

9.1 Batching plant used for the preparation of batc mixed fiber-reinforced concrete shall comply with the app cable requirements of Specification C 94.

NOTE 14—A vibrating screen or other device for separating fib may be required to avoid clumping of some types of fibers prior mixing with concrete.

10. Mixing Equipment

10.1 Mixers or agitators for batch-mixed fiber-reinforc concrete shall comply with the applicable requirements Specification C 94.

10.2 Mixers for continuously mixed fiber-reinforced cc crete shall comply with the applicable provisions of Spec cation C 685.

11. Mixing and Delivery

11.1 Batch-mixed fiber-reinforced concrete, whether p pared on site or at a location remote from the site, shall mixed and delivered to the point designated by the purcha in accordance with the applicable requirements of Specif tion C 94.

11.2 Continuously mixed fiber-reinforced concr whether prepared on site or at a location remote from site, shall be mixed and delivered to the point designated the purchaser in accordance with the applicable requ ments of Specification C 685.

11.3 Fiber-reinforced concrete shall be free of fiber b when delivered.

12. Batch Ticket Information

12.1 The manufacturer of the fiber-reinforced conc shall furnish to the purchaser a delivery ticket or statemen particulars on which is printed, stamped, or written, in mation in one of the following two alternative formats:

12.1.1 *Batch-Mixing Format*—The details identified the applicable requirements of Specification C 94, and tails of the type, brand, and amount of fibers used.

12.1.2 *Continuous Mixing Format*—The details identi in the applicable requirements of Specification C 685, details of the type, brand, and amount of fibers used.

13. Inspection of Materials, Production, and Delivery

13.1 The manufacturer shall afford the inspector all reasonable access, without charge, for making necessary checks of the production facilities and for securing necessary samples to determine if the materials used in the fiber-reinforced concrete or shotcrete comply with the requirements of this specification. Inspection, sampling, and testing shall not interfere unnecessarily with the manufacturing and delivery operations.

14. Sampling

14.1 The contractor shall afford the inspector all reasonable access, without charge, for the procurement of samples of freshly mixed fiber-reinforced concrete or shotcrete at the time of placement to determine compliance with the requirements of this specification.

14.2 Samples of batch-mixed fiber-reinforced concrete shall be obtained in accordance with Method C 172, except that wet-sieving shall not be permitted. Sampling for uniformity tests shall be in accordance with Specification C 94.

14.3 Samples of continuously mixed fiber-reinforced concrete shall be obtained in accordance with the applicable requirements of Specification C 685, except that wet-sieving shall not be permitted. Sampling for uniformity tests shall be in accordance with Specification C 685.

15. Workability and Air Content Tests

15.1 Make tests for workability and air content at the time of placement at the option of the inspector as often as necessary for control checks and acceptance purposes, and always when specimens for tests on hardened concrete are made. When water is added in accordance with the requirements of this specification (see Tolerances in Workability Section), repeat all tests, and use the results of the second set of tests to establish whether or not the requirements of this specification are met.

15.2 If the measured slump, time of flow, or air content fall outside the limits permitted by this specification, make a check test immediately on another portion of the same sample. If the results again fall outside the permitted limits, the material represented by the sample fails to meet the requirements of this specification.

16. Tolerances in Workability

16.1 Unless other tolerances are included in the project specifications, the following shall apply to all forms of fiber-reinforced concrete except dry-mix shotcrete.

16.1.1 When the project specifications for slump are written as a "maximum" or "not to exceed" requirement:

	Specified Slump	
	If 3 in. (75 mm) or less	If more than 3 in. (75 mm)
Plus Tolerance	0	0
Minus Tolerance	1½ in. (40 mm)	2½ in. (65 mm)

When the project specifications for time of flow are written as a "minimum" or "not less than" requirement:

	Specified Time of Flow	
	If 15 s or less	If more than 15 s
Plus Tolerance	5 s	10 s
Minus Tolerance	0 s	0 s

These tolerances apply only if one addition of water is permitted on the job provided such addition does not increase the water-cement ratio above the maximum permitted by the project specifications.

NOTE 15—The slump of a fiber-reinforced concrete is less than the slump of an otherwise identical concrete without fibers. The magnitude of the difference depends strongly on the amount and type of fibers, so it is recommended that trial mixtures representing the amount and type of fibers to be used in the work be prepared and tested to ensure that the specified slump requirements are met. This recommendation is also appropriate when workability is specified in terms of time of flow.

16.1.2 When the project specifications for slump are not written as a "maximum" or "not to exceed" requirement:

Tolerances for Nominal Slumps

For Specified Slump of	Tolerance
2 in. (50 mm) and less	±½ in. (15 mm)
2 to 4 in. (50 to 100 mm)	±1 in. (25 mm)
more than 4 in. (100 mm)	±1½ in. (40 mm)

When the project specifications for time of flow are not written as a "minimum" or "not less than" requirement:

Tolerances for Time of Flow

For Specified Time of Flow of	Tolerance
8 to 15 s	±3 s
more than 15 s	±5 s

16.2 Fiber-reinforced concrete shall be available within the permissible range of slump or time of flow for a period of 30 min starting either on arrival at the job site or after the permitted slump adjustment, whichever is later. The first and last ¼ yd^3 or ¼ m^3 discharged are exempt from this requirement. If the user is unprepared for discharge of the material at the job site, the manufacturer shall not be responsible for failure to meet slump or time of flow requirements after 30 min have elapsed beyond either the actual arrival time at the job site or the requested delivery time, whichever is later.

17. Tolerance in Air Content

17.1 When air-entrainment is specified, the total air content measured using Method C 173 or Method C 231 shall be within a tolerance of ±1.5 of the specified value in percent.

18. Acceptance Testing of Hardened Fiber-Reinforced Concrete or Shotcrete

18.1 Obtain material for the preparation of test specimens in accordance with the sampling section of this specification.

18.2 When flexural toughness parameters, or first-crack strength, or both, are used as the basis for acceptance of fiber-reinforced concrete or shotcrete, make, condition, and test sets of test specimens in accordance with Method C 1018.

18.3 When flexural strength is used as the basis for acceptance, make sets of at least three test specimens in accordance with the requirements for sampling and conditioning given in Method C 1018, and test in accordance with the applicable requirements of Methods C 42 or C 78. Test specimens representing thin sections, as defined in Method C 1018, or specimens representing fiber-reinforced shotcrete of any thickness, shall be tested as cast or placed without being turned on their sides before placement on the support system. Acceptance shall not be based on flexural strength alone when toughness is important.

NOTE 16—Method C 1018 provides for the determination of flexural strength when required by the purchaser. For many type-amount fiber combinations, the flexural strength is not significantly greater than the first-crack strength.

18.4 When compressive strength is used as part of the basis for acceptance of fiber-reinforced concrete, make sets of at least two test specimens in accordance with the applicable requirements of Methods C 31 and C 192 and condition and test in accordance with Methods C 39 or C 42. Acceptance shall not be based on compressive strength alone.

18.5 The testing laboratory performing acceptance tests shall comply with the requirements of Practice C 1077.

19. Frequency of Tests

19.1 The frequency of tests on hardened fiber-reinforced concrete or shotcrete shall be in accordance with the following requirements:

19.1.1 *Batch-Mixing*—Tests shall be made with a frequency of not less than one test for each 150 yd^3 (115 m^3). Each test shall be made from a separate batch. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

19.1.1 *Continuous Mixing*—Tests shall be made for each 25 yd^3 (19 m^3) or fraction thereof, or whenever significant changes have been made in the proportioning controls. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

19.1.3 *Shotcrete*—Tests shall be made for each 50 yd^3 (38 m^3) placed using specimens sawed or cored from the structure or from corresponding test panels. On each day fiber-reinforced shotcrete is prepared, at least one test shall be made for each class of material.

19.2 The representative of the purchaser shall ascertain and record the delivery-ticket number or equivalent information and the exact location in the work at which the material represented by each test is deposited.

20. Calculation of Test Results

20.1 A test result shall be based on the mean of the property values for a set of hardened concrete test specimens constituting a test unit as defined herein or in the applicable test method.

20.2 Any individual test specimen in a set constituting a test unit, as defined herein or in the applicable test method, shall be deemed defective and discarded if it shows definite evidence of improper sampling, molding, handling, curing, or testing, and the mean of the property values for the remaining test specimens shall be considered the test result. If more than one specimen in the set is deemed defective on this basis, the test result shall be rejected.

21. Performance Requirements

21.1 Unless specifically excluded by the purchaser when ordering material in accordance with Alternatives Number 2 or 3, fiber-reinforced concrete or shotcrete prepared in accordance with this specification shall meet the following requirements:

21.2 For flexural toughness parameters defined in accordance with Method C 1018, the test results shall equal or exceed the specified values at the applicable test age.

NOTE 17—For the purchaser unfamiliar with the levels of perfo ance associated with various types and amounts of fibers, the follov is a guide on how and at what level performance should be specified various types of fiber:

Performance Level	Toughness Index, I_5 Specified Value	Toughness Index, I_5 Test Result	Toughness Index, I_{10} Specified Value	Toughness Index, I_{10} Test Result
I	2.7	3.0	5.4	6.0
II	3.6	4.0	7.2	8.0
III	4.5	5.0	9.0	10.0
IV	5.4	6.0	10.8	12.0

Due to variation in materials, mixing operations, fiber distribut and testing procedures, the average values of the toughness indice and I_{10}, represented by each test result must be greater than the spec values if a high proportion of the test results are to equal or exceed specified values. The relationship between the specified value and test result given above is based on the rationale described in Recommended Practice 214, specifically the condition that no n than 10 % of test results fail below the specified value, and on coefficients of variation of 12 % and 14 % for I_5 and I_{10} respecti given in the Precision and Bias section of Method C 1018.

Performance Level 4 is achievable only with high concentratior steel fibers having deformed surfaces or end anchorages offering supe resistance to pullout from the cementitious matrix. Such concentrat may be difficult to disperse uniformly in concrete using conventi mixing procedures unless a high-range water-reducing admixtur employed. Performance Levels 2 and 3 can be achieved by a variet steel fibers in moderate concentrations readily amenable to conventi mixing. These performance levels may also be achieved using glass fi which are more amenable to shotcreting than conventional mi because of damage to the fibers by most conventional mixing proce Performance Levels 3 and 4 are not normally attainable using maximum amounts of polypropylene fibers which can be unifo dispersed in concrete using conventional mixing procedures.

NOTE 18—A toughness requirement should not be specified w fibers are used only to control plastic shrinkage cracking.

21.3 When first-crack strength, flexural strength, or c pressive strength are performance requirements, the results shall equal or exceed the specified values at applicable test age.

21.4 When the fiber-reinforced concrete is to be exp to cycles of freezing and thawing, and the purchaser req evidence of satisfactory durability, such evidence sha provided by the manufacturer. A proven record of sati tory freeze-thaw durability for concrete with or with fibers, made using the same air content, aggregates, mixture proportions as the fiber-reinforced concrete sp fied for the work, shall be considered acceptable evide when the concrete has been in place for at least two win In the absence of such a record, satisfactory durability s be demonstrated for the fiber-reinforced concrete prop for the work by the attainment of an average durability fa of at least 80 % for a set of three specimens tested accor to Procedure A of Method C 666.

22. Failure to Meet Requirements

22.1 When fiber-reinforced concrete or shotcrete fai meet the requirements of this specification, the manufact and the purchaser shall confer to determine whether ag ment can be reached as to what adjustment, if any sha made. If agreement on a mutually satisfactory adjustr cannot be reached by the manufacturer and the purchas decision shall be made by a panel of three qualified e neers, one of whom shall be designated by the purchaser, by the manufacturer, and the third chosen by these

Report No. ACI 506.1R-84

State-of-the-Art Report on Fiber Reinforced Shotcrete

Reported by ACI Committee 506

This report describes the technology and uses of fiber reinforced shotcretes using steel fibers, glass fibers, and polypropylene fibers. Mechanical properties, particularly ductility, toughness, impact strength, and flexural strength are improved by the fiber addition, and these improvements are described along with other typical properties and proportions of typical mixtures. Batching, mixing, and application procedures are described, including methods of reducing rebound and equipment used to apply fiber reinforced shotcrete. Applications of fiber reinforced shotcrete in North America, Europe, and Scandinavian countries are described. These include rock slope stabilization work, construction and repair of mine and tunnel linings, bridge arch strengthening, and dome-shaped structures. Available design information is briefly discussed and design references are listed.

Keywords: fiber reinforced concretes; fibers; linings; metal fibers; glass fibers; polypropylene fibers; synthetic fibers; mines (excavations); mix proportioning; placing; reviews; shotcrete; slope protection; stabilization; strength; subsurface structures; tunnel linings.

CONTENTS

Pertinent discussion will be published in the June 1985 issue if received by March 1, 1985.

CHAPTER 1 — INTRODUCTION

1.1 — Definition of fiber reinforced shotcrete

Fiber reinforced shotcrete is mortar or concrete containing discontinuous discrete fibers that is pneumatically projected at high velocity onto a surface. Continuous meshes, woven fabrics, and long rods are not considered to be discrete fiber-type reinforcing elements in this report.

1.2 — Fiber types

Fibers made of steel, glass, synthetic, and natural materials are avalable in various shapes and sizes.

One parameter used to characterize a fiber is the aspect ratio, defined as the fiber length divided by its diameter or an equivalent fiber diameter.* Typical aspect ratios range from about 30 to 150 for length dimensions of 0.25 to 3 in. (6.4 to 76 mm).

Typical fiber diameters are

Steel — 0.010 to 0.030 in. (0.25 to 0.76 mm)

Glass — 0.0002 to 0.0006 in. (0.005 to 0.015 mm) These may be bonded together to form elements with diameters of 0.0005 to 0.050 in. (0.13 to 1.3 mm)

Synthetic — 0.0008 to 0.015 in. (0.02 to 0.38 mm)

Additional information on fibers may be found in the ACI "State-of-the-Art Report on Fiber Reinforced Concrete," ACI 544.1R.

1.3 — General

Fiber reinforced shotcrete is available using steel, glass, and polypropylene fibers. The inclusion of fibers in concrete and shotcrete generally improves material properties including ductility, toughness, flexural strength, impact resistance, fatigue resistance, and compressive strength. The type and amount of improvement is dependent upon the fiber type, size, strength and configuration, and the amount of fiber. Of the three types, steel fiber reinforced shotcrete accounts for the largest usage, having applications in mine and tunnel linings, rock slope stabilization, thin shell dome construction, refractory linings, dam construction, repair of surfaces, and fire protection coatings. Glass fiber shotcrete has been used very little; one reported use is in a coal mine. However, by using the spray-up process, glass fiber reinforced concrete (GFRC) is applied in a manner similar to shotcreting. Glass fiber spray up, described in Appendix A, is not a true shotcrete process because 1) the velocity is low, 2) it is hand compacted after application, and 3) it uses a slurry applied by a mortar gun. The glass fiber spray-up technique is used primarily as a plant process to manufacture lightweight building cladding panels. Polypropylene fiber shotcrete has just begun to be used and its present applications are primarily experimental in nature, although its use has been reported in thin shell domes, repair of surfaces, and as a component in stucco-type overlayment systems.

1.4 — Historical background

Fiber reinforced shotcrete using steel fibers was first placed in North America early in 1971 in experimental work under the direction of D. R. Lankard of Battelle Memorial Institute's Columbus Laboratories.[1] Additional trials were made under the direction of M. E. Poad for the U.S. Bureau of Mines in an investigation of new and improved methods of using shotcrete for underground support.[2] Subsequently, R. A. Kaden of the U.S. Corps of Engineers supervised the first practical application of steel fiber shotcrete in a tunnel adit at Ririe Dam, Idaho, in 1973.[3] Since that time, steel fiber reinforced shotcrete has been placed in Germany (Stahlfaserspritzbeton), Sweden (Stalfiberarmerad Sprubeton), England, Norway, Finland, Switzerland, Poland, South Africa, Australia, Canada, and Japan. Fiber shotcrete using polypropylene fibers was first placed in Europe in 1968.[4]

1.5 — Tests for fiber reinforced concrete

Properties of fiber reinforced concrete and shotcrete are generally measured by tests advocated in ACI Committee Report ACI 544.2R. Many current ASTM tests are directly applicable to fiber concrete and shotcrete and are mentioned in ACI 544.2R. Some specialized tests for fiber concrete listed in ACI 544.2R are being developed into ASTM Test Methods by ASTM Subcommittee C.09.03.04, Fiber Reinforced Concrete.

CHAPTER 2 — STEEL FIBER REINFORCED SHOTCRETE

2.1 — General

Steel fiber reinforced shotcrete is essentially a conventional shotcrete to which steel fibers have been added. It is placed using the same mixing and placing equipment used for conventional shotcrete. Some specialized equipment and nozzles have been developed to aid in metering and adding individual fibers, but spe-

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*The equivalent diameter is the diameter of a circle having an area equal to the cross-sectional area of the fiber.

cial equipment is generally not required for mixing and placing it. It can be placed by either the wet-mix or dry-mix process.

Steel fiber reinforced shotcrete incorporates steel fibers up to 2 percent by volume of the total mixture. Improvements in flexural strength, ductility and toughness are sufficient to enable it to be used as a replacement for steel mesh-reinforced shotcrete in certain instances such as rock slope stabilization, mine and tunnel linings, and thin shell structures. The improvements in toughness and flexural strength are evident in the mode of failure; large deformations are required to cause complete separation of steel fiber reinforced shotcrete, and it continues to carry a significant load after cracking. This post-crack resistance has been cited as providing ductility to the shotcrete[2,5,6] and works to an advantage in applications where there may be relatively large deformations such as in mine and tunnel linings.

2.2 — Fiber types

Steel fibers are manufactured by at least three processes 1) by cutting cold drawn wire, 2) by slitting steel sheet, and 3) by extracting them from a pool of molten steel (melt-extraction). Wire fibers with bent or deformed ends have a high pullout resistance and may be used in smaller quantities than straight fibers to achieve the same properties. The ultimate tensile strength of fibers varies from 50,000 to over 300,000 psi (345 to 2070 MPa). Fiber sizes range from ½ x 0.010 in. to 2½ x 0.030 in. (13 x 0.25 mm to 64 x 0.76 mm). A popular fiber size range for shotcrete is 1 to 1³⁄₁₆ in. x about 0.016 in. (25 to 30 x 0.40 mm). This size range is easily handled and is normally shot through a 2 in. (50 mm) diameter hose.

Carbon steel fibers are used in applications at ambient temperatures and in some high temperature applications, up to 1500 F (815 C) for elements heated from one side only. Stainless steel fibers are used in refractory concrete, both cast and shotcreted, for high temperature applications, up to 3000 F (1650 C) for elements heated from one side only.[7] See ACI 547R and References 7 and 8 for additional data on refractory shotcrete with fibers.

Corrosion of carbon steel fibers has been found to be minimal with no adverse effect on flexural strength after 7 years exposure of steel fiber concrete to deicing salts. Tests of the effects of outdoor weathering in an industrial atmosphere for 10 years have shown no adverse effects on strength properties of steel fiber reinforced mortar. Fiber corrosion was confined to fibers actually exposed on a surface. Internal fibers showed no corrosion. For references and additional data see report ACI 544.1R.

2.3 — Typical material properties

2.3.1 *Flexural and compressive strengths* — Typical 28-day flexural strengths as determined from beam specimens vary from about 800 psi (5.5 MPa) to about 1500 psi (10.3 MPa) with the average near 1000 to 1100 psi (6.9 to 7.6 MPa).[9] These flexural strengths were determined using 4 x 4 x 14 in. (100 x 100 x 350 mm) beams sawed from test panels and tested on a 12-in. (305 mm) span in accordance with ASTM C 78. In one investigation the U.S. Bureau of Mines reported flexural strengths of 4617 psi (31.9 MPa) for fibrous shotcrete and 2244 psi (15.5 MPa) for the plain, control shotcrete using regulated-set cement and 2 percent by volume of fibers.[10] These were 360-day strengths determined by ASTM C 78 as described above. BESAB, a shotcrete equipment manufacturer and applicator in Sweden, reported flexural strengths of about 2900 psi (20 MPa) on material placed with a special wet process nozzle using fibers with an aspect ratio *ℓ/d* of 100 at 1 to 2 percent by volume.

Compressive strengths at 28 days from mixtures such as in Table 2.4 have varied from about 4200 psi to 7500 psi (29 MPa to 51.7 MPa).[9] In some instances the compressive strength of the fibrous shotcrete has been lower (10 to 20 percent) than the control mixture. This is believed due to less compaction in the shotcrete caused by the presence of the fibers. However, in some instances, the compressive strength of the fibrous shotcrete has been up to 50 percent stronger than the plain control mixture.[9]

Placement of the shotcrete tends to orient the fibers in a plane parallel to the surface being shot.[4] This orientation is of benefit to the flexural properties of the shotcrete layer.

2.3.2 *Impact resistance* — Impact resistance of steel fiber reinforced shotcrete is measured by a test which uses a 10 lb (4.5 kg) hammer falling onto a steel ball centered on a 1½ to 2½ in. thick by 6 in. diameter specimen (38 to 63 mm thick x 150 mm diameter). (See ACI 544.2R.) The number of blows required to crack and separate fibrous specimens at 28 days ranges from about 100 to 500 or more depending upon the fiber amount, length, and configuration. Plain shotcrete specimens normally fail at from 10 to 40 blows.[11,12]

2.3.3 *Toughness* — The amount of energy* required to cause failure of fiber reinforced concrete by complete separation varies with the type and amount of fiber. Typical values of flexural toughness for small beams 4 x 4 x 14 in. (100 x 100 x 355 mm) are in the range of 10 to 50 times that required for plain concrete. This is reported as toughness* or as a toughness index.

2.3.4 *Pullout strength* — Tests have been made using pullout anchors which are embedded in the shotcrete as it is gunned. The pullout anchors, similar to those described in ASTM C 900, were discs about 1 in. (25 mm) in diameter, embedded about 1¼ in. (30 mm) deep. In plain shotcrete, pullout test results show

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*The energy to failure in flexure, or the flexural toughness, may be found by calculating the area under the load-deflection curve of a flexural specimen tested to complete separation following a modulus of rupture test (ASTM C 78) using a displacement-controlled testing machine.

TABLE 2.3.4—Fourteen day pull-out strengths[9]

Mixture	Pull-out strength psi (MPa)
Plain shotcrete*	1000 (6.9)
Fibrous shotcrete†	1800 (12.4)

*750 lb (341 kg) cement, 1825 lb (830 kg) ⅜ in. (9.5 mm) stone, 1175 lb (534 kg) sand, 5 lb (2.3 kg) Barra Gunit 2 accelerator.

†750 lb (341 kg) cement, 1475 lb (670 kg) ⅜ in. (9.5 mm) stone, 1300 lb (591 kg) sand, 250 lb (114 kg) fibers 0.010 × ½ in. (0.25 × 13 mm), 5 lb (2.3 kg) Barra Gunit 2 accelerator.

TABLE 2.4—Typical steel fiber reinforced shotcrete mixtures. (Reference 15, p. 52)

Material	Fine aggregate mixture lb/yd³ (kg/m³)	⅜ in. (9 mm) aggregate mixture lb/yd³ (kg/m³)
Cement	753-940 (446-558)	750 (445)
Blended sand ¼ in. maximum (6.35 mm)	2830-2500 (1679-1483)	1485-1175 (880-697)
⅜ in. aggregate (9 mm)		1180-1475 (700-875)
Steel fiber	66-265 (39-157)	66-250 (39-150)
Accelerator	varies	varies
Water-cement (by weight)	0.40-0.45	0.40-0.45

a linear relationship to compressive strength. For steel fiber reinforced shotcrete, a similarity in the magnitude and shape of strength-time curves for pullout and flexural strength (ASTM C 78) has been reported.[6] Tests on fibrous concrete placed on an open pit mine slope in Canada gave results shown in Table 2.3.4.

2.3.5 *Tensile strain at 90 percent ultimate load (strain-to-failure)* — Kaden[3] made rapid load flexural tests of shotcrete specimens (4 x 4 x 12 in.; 100 x 100 x 305 mm) and found significantly increased strain-to-failure in the steel fibrous material. Tensile strain in the outer fibers at 90 percent of ultimate load ranged from 320 microstrain to 440 microstrain for steel fibrous shotcrete at 28 days versus 192 microstrain for plain shotcrete.

2.3.6 *Bond strength* — BESAB reports bond strengths of about 145 psi (1 MPa) to granite for steel fiber reinforced shotcrete placed by the wet process.[11] A bond strength of about 0.4f'_c (540 psi, 3.7 MPa) was reported for in situ tests at the Peachtree Center Station, Atlanta, subway on a rough-surfaced granitic gneiss. These values were obtained by pulling off a 2 x 2 ft (610 x 610 mm) steel plate embedded in a flat (not arched) shotcrete layer and calculating the bond strength.[14] This is compared to 0.1 f'_c (135 psi, 0.9 MPa) for similar laboratory tests.[14] In other tests, a core drill was used to isolate a cylindrical specimen which was then pulled from the rock. Here bond strengths of 0.02 f'_c (130 psi, 0.9 MPa) were obtained for fiber reinforced shotcrete compared to 0.03f'_c to 0.05f'_c (220 to 375 psi, 1.5 to 2.6 MPa) for plain shotcrete.[14]

2.4 — Mixture compositions

2.4.1 *General* — Most steel fiber reinforced shotcrete placed to date has used the dry process. Early applications used a fine aggregate mixture having a sand: cement ratio of 2.4:1 by weight or about 940 lb of cement per yd³ (557 kg/m³). Mixtures containing ⅜ in. (9 mm) and ¾ in. (19 mm) aggregate and less cement have been used more recently, and this has helped to reduce shrinkage. The fiber sizes have varied from ½ to 1½ in. (13 to 38 mm) long and from 0.010 to 0.020 in. (0.25 to 0.51 mm) in diameter. The amount of fiber has varied from about 0.5 percent by volume to about 2 percent by volume (66 to 265 lb/yd³; 39 to 157 kg/m³). The proportions of typical mixtures are shown in Table 2.4. The fiber amounts shown in Table 2.4 are before gunning. Since the fiber rebound is generally greater than the aggregate rebound, there is usually a smaller pecentage of fiber in the material on the wall.[5] The fine aggregate weight shown includes about 5 percent moisture.

2.4.2 *Fiber size considerations* — Most fibers used in shotcrete mixtures are about ¾ to 1¼ in. long (19 to 32 mm). While both shorter, ½ in. (13 mm), and longer fibers, up to 1½ to 2 in. (38 to 50 mm), have been used, the midrange of about 1 in. (25 mm) has become the preferred length from the standpoint of in-place shotcrete strength and ease of mixing and placing. Shorter fibers are easier to mix and shoot and rebound less, but the shotcrete properties, particularly toughness and post-crack resistance, are lower. Longer fibers, although superior in producing high strength and toughness properties, usually result in more plugging and have a higher fiber rebound rate. Some of these problems with shorter fibers have been overcome with the introduction of fibers having deformations or end anchorage provisions.

2.5 — Batching and mixing

2.5.1 *General* — Batching and mixing for the dry process is often done by mixing the dry ingredients, complete with fibers, in a transit mixer. This is then delivered to the hopper of the shotcrete machine. The material has also been mixed the same as normal shotcrete with the fibers being added to a mixing hopper or screw auger or in a separate air stream. Fiber feeders, nozzles with provision for fiber addition, and special mixers are also available (see Equipment). Prebagging has been found to be very useful in mines where a mixer and bulk materials would aggravate space problems. Batching and mixing of steel fibrous mixtures with loose, bulk fibers needs some care to avoid the formation of fiber balls.

2.5.2 *Dry process* — Good results were obtained in a turbine mixer (a stationary, cylindrical, flat-bottomed pan with revolving mixing arms) for Bureau of Mines tests. The sand was placed in the mixer first, and the fibers were added through a 2½ in. (63 mm) mesh screen to break up any fiber clumps. After transfer to a transit mixer and transport to a remote job site, the cement was added from sacks. A screen over the machine hopper, already a part of the equipment, was used to intercept any fiber balls that were formed.

For a larger job, the Snake River rock slope stabilization, the contractor charged the materials in 5 yd^3 (3.8 m^3) batches into a large hopper using a front-end loader and from there into transit mixers via a conveyor. The ingredients were added in the following order: all the sand; one-half the fibers; all the cement plus accelerator; and one-half the fibers.[*] Fibers were added through a 4 x 4 in. (100 x 100 mm) crusher screen.

The important parts of the batching and mixing procedure that differ from mixing of plain shotcrete are

1. Fibers that show a tendency to clump should be added through a screen or by a shaker or apparatus that separates them and adds them so that they do not reclump. This means adding them to a rotating mixer, a conveyor belt, or a screw conveyor that is carrying the fibers away fast enough so that the fibers do not stack up on each other.

2. Mixing should avoid bending the fibers. Badly bent fibers cause poor compaction and reduced strengths. A paddle (pugmill) mixer with small counter-rotating paddle wheels has caused severe bending and subsequent formation of fiber balls.[6]

3. A screen should be put over the shotcrete hopper to divert any fiber clumps.

Williamson[16] reported that a screw-type mixer-conveyor was used along with a metering fiber feeder to mix shotcrete for spraying experimental domes at Champaign, Ill., by the U.S. Corps of Engineers. The fibers were mixed in the screw conveyor and the mixture discharged directly into the gun hopper. The U.S. Bureau of Mines has also added the fibers to a screw conveyor prior to discharging into the gun hopper on a rotating barrel-type shotcrete machine.

It has been found that a good electrical ground to the gun and nozzle dramatically reduces the fiber clumping and plugging that might otherwise occur.

Collated fibers, bundled together with a quick-dissolving glue, are available for the dry-mix process. They are added directly to the mixer after the aggregate has been added. They come apart after addition of the water at or near the nozzle.

2.5.3 *Wet process* — Wet process shotcrete uses a wet mixture similar to that used for cast-in-place concrete applications. The experience gained from mixing steel fiber reinforced concrete for cast-in-place applications may be used to help batch and mix fiber reinforced mixtures for wet shotcreting. (See ACI 544.1R — Chapter 3, Preparation of Fiber Reinforced Concrete).

There are some precautions that should be taken to prevent the formation of fiber balls during the wet mixing operation when adding loose bulk fibers. The fibers should not be added too quickly. They should be added clump-free and should be carried away before they pile up on one another. It may be necessary to pass them through a screen or shaker screen. They should not be allowed to hang up or pile up on their way to or inside the mixer. A good method is to introduce the fibers to the fine aggregate on a conveyor belt during aggregate addition.

Where fibers are added directly to a transit mixer, the fibers should land on the mixture, not on the mixing vanes where they can form clumps. The drum must rotate fast enough to carry away the fibers as they enter the mixture so they do not pile up on each other.

Collated fibers, fibers with a very low aspect ratio, usually less than about 40, and some large diameter fibers may be added directly into a completed mixture without causing a balling problem. Over-mixing should be avoided, in any event, as too much mixing of these or of any fiber may result in fiber ball formation. Worn mixing blades or harsh mixtures may also result in fiber balls. Therefore, a screen should be put over the pump hopper to intercept fiber balls.

2.6—Installation

2.6.1 *General* — Applying steel fiber reinforced shotcrete is basically the same as applying plain shotcrete. Information on good application techniques is included in ACI 506.X, "Guide for Shotcreting" (to be published). Specification-type requirements suitable for use in contracts are included in ACI 506.2.

2.6.2 *Equipment* — Existing shotcrete equipment has been used to apply steel fiber reinforced shotcrete with little or no modifications. The modifications, when made, are generally to reduce plugging by eliminating restrictions such as 90 deg elbows or abrupt changes in hose size. If line size is reduced, a long, tapered reducer should be used. When plugging occurs, it is usually at the outlet from the gun where a sudden size reduction or change in direction is a common feature. Larger hose sizes, 2 in. (50 mm) diameter and up, work better. Generally, the hose diameter should be two times the fiber length. However, 1 in. (25 mm) fiber has been gunned through 1 in. hose, and fibrous refractories using 1 in. (25 mm) fiber are shot regularly through 1½ in. (38 mm) hose.

Other modifications have included removing elastomeric wear linings at elbows, adding vibrators or revolving wiper arms to the hopper screen, and adding vanes in the hopper or changing wheel size on segmented rotor types to speed up material delivery. Sometimes a stronger rotor motor is needed. If no hopper screen is present, one should be added to divert fiber clumps which would otherwise plug the gun. Fig. 2.6.2.1 shows modifications made to a gun hopper for the Snake River rock slope stabilization project.[9,17]

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[*] This technique, where 500 lb (225 kg) of loose bulk fibers were added at one time, would normally work only for short fibers with a low aspect ratio such as those used — ½ in. × 0.010 in. (13 mm × 0.25 mm) fibers with $l/d = 50$.

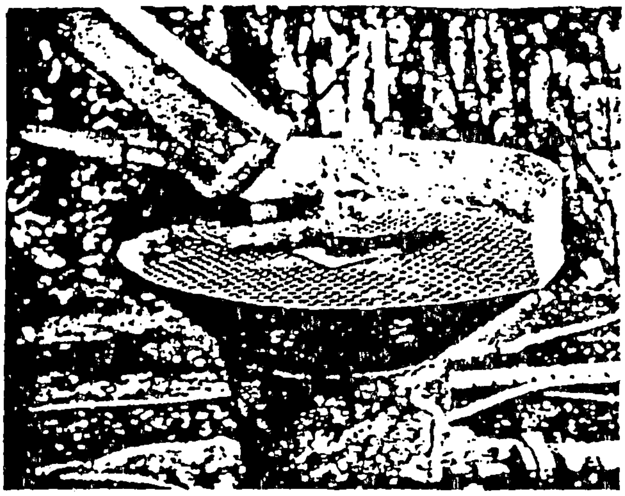

Fig. 2.6.2.1—Modified gun hopper with screen, revolving arms, and pneumatic vibrator.

Steel fiber reinforced shotcrete has been successfully applied with every kind of equipment, from the original single or dual chamber feed wheel type to the more recent revolving barrel and segmented rotor types. It has been placed by the wet process using a pressurized chamber-type machine, squeeze-pump-type pumps, and positive displacement pumps.

Some special equipment has been devised to separate and meter the fibers in a separate air stream and add them at the nozzle for both wet and dry process. This equipment enables the use of high aspect ratio fibers, up to an ℓ/d of about 125, avoids putting the fibers through the gun, and eliminates the fiber balling problem.

The specialized equipment for feeding fibers separately and adding them at the nozzle is shown in Fig. 2.6.2.2 and 2.6.2.3. This feeder equipment has been modified and adopted into an integrated mixing and placing system using a conventional gun and nozzle (Fig. 2.6.2.4). Fig. 2.6.2.5 shows a fiber mixer-feeder and predampener for refractory shotcrete.

Fiber metering equipment and machines for placing steel fiber reinforced shotcrete are widely available. Nearly all machines are available with air, electric, or fueled engine drive.

2.6.3 *Rebound considerations*

2.6.3.1 *General* — The factors affecting rebound encompass a wide range of items and conditions. Generally, it has been noted that a greater percentage of fibers than aggregate rebound from the wall. Ryan[11] reports fiber retention of 40 percent overhead and 65 percent on vertical surfaces. Parker[6] reported fiber retention of 44 percent to 88 percent (average 62 percent) for coarse aggregate mixtures, gunned onto vertical panels. In the Atlanta Research Chamber tests, the average rebound in a ten minute test where 2500 lb (1130

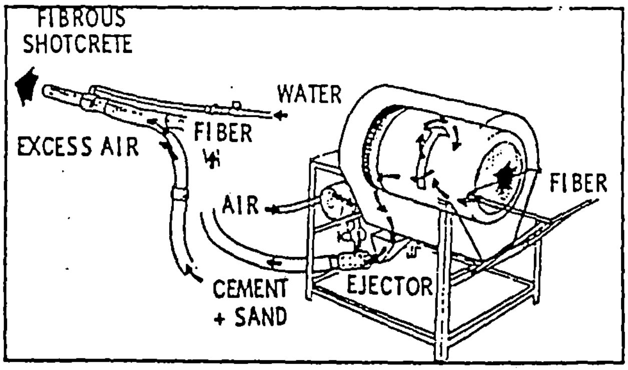

Fig. 2.6.2.2—Original BESAB fiber feeder. (Reference 13, p. 53)

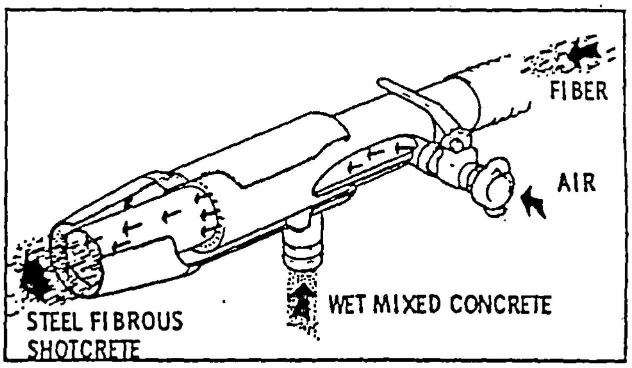

Fig. 2.6.2.3—BESAB nozzle for wet process fibrous shotcrete.

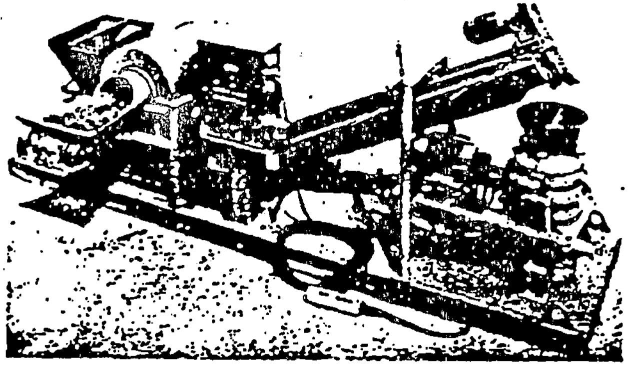

Fig. 2.6.2.4—Integrated fiber feeder, mixer, and gun for steel fiber reinforced shotcrete.

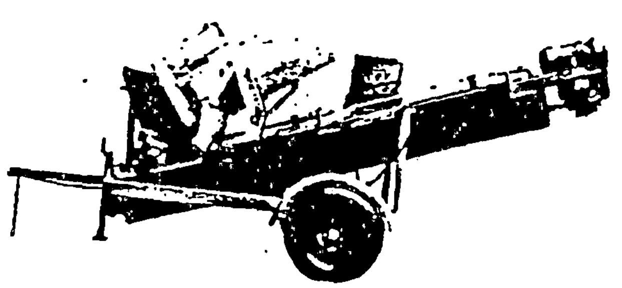

Fig. 2.6.2.5—Predampening and mixing unit with fiber feeder for refractory shotcrete.

kg) of mixture were shot was 22 percent for a three-inch-thick placement. Fiber content before gunning was 3.3 percent by weight of the dry material while fiber content in the rebound material was 4.6 percent.[14]

Some investigators and applicators have reported that steel fiber reinforced shotcrete showed less total rebound than plain shotcrete. Others have reported no difference from the fiber mixtures.

An example of less rebound was reported for a trial in Nevada conducted by Fenix and Scisson, Inc. In that work, 4 yd^3 (3 m^3) of a steel fiber mixture consisting of 700 lb (317 kg) cement, 2700 lb (1225 kg) sand, 150 lb (68 kg) ½ x 0.010 in. (13 x 0.25 mm) fiber per yd^3 placed 6 in. (150 mm) thick had a total estimated rebound of 10 percent. A control batch applied under identical conditions by the same personnel had an estimated rebound of 31 percent. The work was done in a tunnel and included vertical and overhead surfaces.[9]

On the other hand, Parker[6] reported average rebound of 18.3 percent and 17.7 percent for a nonfiber mixture and a fiber mixture, respectively, and concluded from that and other data that the mere presence of fibers in a mixture does not affect rebound appreciably. Instead, other factors appear to be more important than fiber.

2.6.3.2 *Factors affecting rebound of fibers* — Quantitative data on rebound of steel fiber reinforced shotcrete with the dry mixture process were obtained in a study which systematically investigated variables one at a time and used high-speed photography to observe the shotcrete airstream.[6]

The photography showed that many of the steel fibers were in the outer portion of the airstream and that many of them were blown away radially from near the point of intended impact shortly before or after they hit. Some fibers were blown up into the air and floated down. It was obvious that the fibers were mostly blown away by the remnant air currents and that the effect was not one of the fibers simply bouncing off the surface. If lower air pressure or less air is used, the amount and velocity of the remnant air currents is less and the rebound of fiber is less.

2.6.3.3 *Conditions that reduce rebound* — Parker's study[6] concluded that the rebound process differed during establishment of an initial critical thickness (Phase 1) and subsequent gunning into fresh shotcrete (Phase 2).

During Phase 1, anything that promotes adherence of material on the wall should reduce rebound. This includes the following mixture conditions: a higher cement content, more fines in the mixture (fly ash or very fine sand), smaller maximum size aggregate, proper wetness of aggregates so that particles are well coated with cement, and a finer gradation.

After the initial critical thickness is established, Phase 2 rebound is reduced by any condition or set of conditions that makes the shotcrete on the wall softer or more plastic, at least until it tends to drop off. Thus, for maximum reduction of Phase 2 rebound, shotcreting as wet as possible, that is, the wettest stable consistency, is one of the most beneficial and easiest conditions to control.

A large number of measures can be used to reduce rebound of steel fiber reinforced shotcrete in the dry mixture process. The most effective of these measures (which also applies to plain shotcrete) seem to be reduction of the air pressure, air velocity, or amount of [illegible] at the nozzle; use of more fines and smaller aggregate; use of shorter, thicker fibers; predampening to get the right moisture content; and shotcreting at the wettest stable consistency.[6,9]

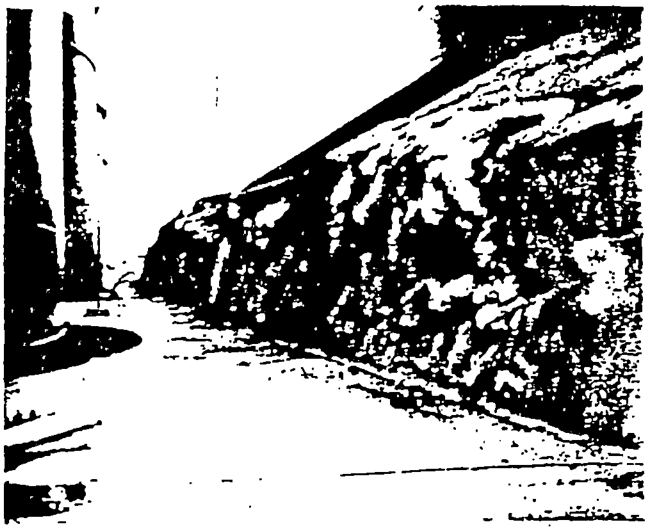

Fig. 2.7.1.2—Portion of rock surface stabilized at Brofjorden Refinery, Sweden.

2.7 — Applications

Applications of steel fiber reinforced shotcrete have been made to rock slopes, mines, tunnels, dams, powerhouses, bridge arches, thin shell dome structures, rock caverns for oil storage, houses, boat hulls, landslides for stabilization as well as to deteriorated concrete surfaces for repair.

2.7.1 — *Slope stabilization*

2.7.1.1 *Corps of Engineers — Snake River rock slope stabilization*[3,17] — A large application of steel fiber reinforced shotcrete was completed in January 1974, near Little Goose Dam along the Snake River in the State of Washington. The shotcrete was used to stabilize a deteriorating section of rock slope above the Camas Prairie Railroad. The work included scaling, installing rock bolts, and applying shotcrete a minimum of 2½ in. thick (63 mm). The area involved was about 1550 ft (460 m) long and varied from 15 to 45 ft (5 to 14 m) high for a total of 6900 yd^2 (5800 m^2).

2.7.1.2 *Joint Nordic Program (Nordforsk) — oil refinery — Brofjorden, Sweden*[19] — A large application was also made at an oil refinery at Brofjorden, on the

TABLE 2.7.2.2—Shotcrete mixture composition[20]

Component	lb/yd^3	kg/m^3
Type 10 cement	740	439
10 mm aggregate	610	362
Concrete sand	1,927	1,143
Fine blend sand	376	223
	3,653	2,167
Steel fibers	100	59
	3,753	2,226

west coast of Sweden (Fig. 2.7.1.2). About 4500 m^2 (5380 yd^2) of rock surface was stabilized. A layered construction was used: 5 to 10 mm (0.2 to 0.4 in.) of plain shotcrete followed by 30 mm (1 3/16 in.) of steel fiber reinforced shotcrete covered with a top layer of 5 to 10 mm of plain shotcrete.

2.7.2 — *Selected underground applications*

2.7.2.1 *Corps of Engineers, Ririe Dam, tunnel adit, Idaho*[3] — In December 1972, steel fiber reinforced shotcrete was used to line a 40 ft (12 m) length of an exploratory tunnel adit on the right abutment of Ririe Dam, Idaho. Thickness was 3 in. (75 mm) and the 34 day flexural strength of cast beams was 910 psi (6.3 MPa). The lining survived a blasting operation with minor cracking.

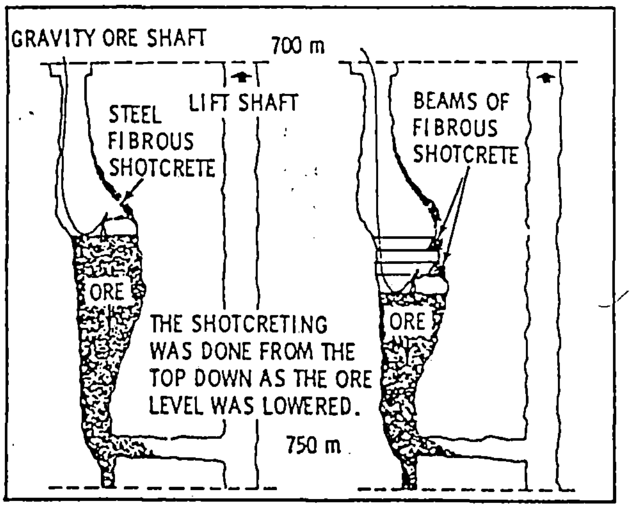

Fig. 2.7.2.5—Technique for lining of ore shaft at Bolidens Mine, Sweden.

2.7.2.2 *B.C. Hydro-Peace River Site C tunnels*[20] — At the Site C project, a proposed earthfill dam and powerhouse on the Peace River near Fort St. John in northeastern British Columbia, steel fiber reinforced shotcrete was used to line several hundred feet of exploratory tunnels and a test chamber. The work was done in 1981 to 1982.

A thickness of 2 in. (50 mm) was specified. The shotcrete used was a premixed type supplied in bags. The average composition of this mixture is given in Table 2.7.2.2.

2.7.2.3 *Atlanta subway tunnel lining*[14] — Another tunnel application, of limited size, was made in the Metropolitan Atlanta Rapid Transit Authority (MARTA) subway. Here a 200 ft (61 m) length of the subway tunnel was lined with 4 to 6 in. (100 to 150 mm) of steel fiber reinforced shotcrete by the dry-mix process. Examination after 18 months of use showed the lining to be in satisfactory condition.

2.7.2.4 *U.S. Bureau of Mines — coal mine applications* — Underground rooms at the U.S. Bureau of Mines' experimental mine at Bruceton, Pa., were enlarged, rock bolted and lined with steel fiber reinforced shotcrete.[21] Fiber shotcrete was also used to coat bulkheads, seals, and stoppings formed by Bernold steel.[22] It has been shown by testing to provide good fireproofing protection for urethane foam.[23]

2.7.2.5 *Bolidens Gruv AB — mines and ore shaft, Sweden*[11] — Steel fiber reinforced shotcrete has been used in a number of mines in Sweden. At the Bolidens Gruv AB mine near Kristineberg, the material was used to line and stabilize a gravity ore transfer shaft which was deteriorating from the impact of the ore. The shaft was filled with ore so that the top surface of the ore

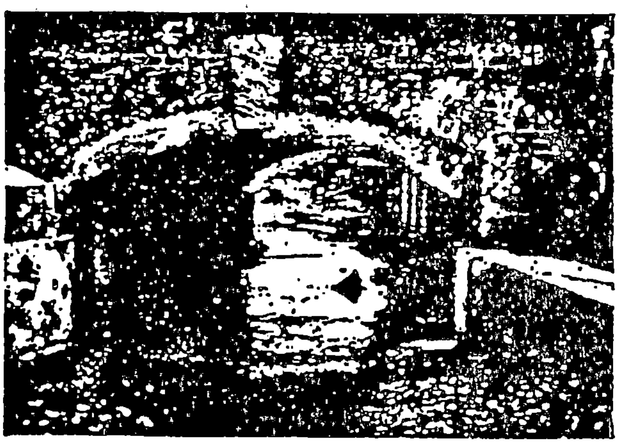

Fig. 2.7.2.6—Brick railway bridge near Birmingham, England; reinforced with about 6 in. (150 mm) of steel fiber reinforced shotcrete.

Fig. 2.7.2.7—Emergency cold water tunnel lining at Ringhals Nuclear Power Station, Sweden.

became the working platform for the shotcreting operation (Fig. 2.7.2.5). The thickness varied from 4.0 to 20 in. (100 to 500 mm).

2.7.2.6 *British Rail — arch and tunnel relining, England* — Steel fiber reinforced shotcrete is being used for strengthening tunnels and brick arches under bridges for British Rail in England. It is applied up to 6 in. (150 mm) thick. A ½ in. (13 mm) flash coat is used to cover exposed fibers (Fig. 2.7.2.6). One advantage found in rail tunnel work is that the scaffolding required for mesh installation can be eliminated and traffic interruption is minimized.

2.7.2.7 *Swedish State Power Board — Ringhals Nuclear Power Station* — An emergency cold water tunnel at the Ringhals Nuclear Power Station in Sweden was lined with steel fiber reinforced shotcrete using the wet process equipment. It was used in conjunction with rock bolts (Fig. 2.7.2.7).

2.7.2.8 *Roadway tunnels — Japan* — The Japanese have used steel fiber reinforced shotcrete in at least three vehicular tunnels. In the Miyanoshita tunnel it was used to repair concrete lining damaged by rock pressure. In the Itaya tunnel it was placed 4 in. (100 mm) thick to repair the original, 50-year-old lining which had deteriorated from icing conditions. In a tunnel near Hakodate, Hokkaido, it was placed as a trial lining. All of these applications used the wet process and a squeeze-type pump.

2.7.3 *Dome structures* — Two construction methods have been used to build dome-shaped structures using steel fiber reinforced shotcrete. In the first method, polyurethane foam is sprayed on the underside of an inflatable membrane of the desired shape (from inside the inflated shape) to a thickness of about 4 in. (100 mm).[24,25] After the foam hardens, the shotcrete is applied to the underside of the foam 1½ to 3 in. thick or more (38 to 76 mm). The resulting structure is very efficient thermally and can support heavy roof loads compared to conventional structures.[26] Uses are for homes, offices, warehouses and storage of grain, potatoes, and other agricultural products.

The second construction method reverses the foam and shotcrete so that the shotcrete is on the outside. Small domes of this type were made as experimental shelters for protection against small arms fire and grenades.[16]

2.7.4 *Other applications* — Other steel fiber reinforced shotcrete applications have included lining of an oil storage cavern at Skarvik, Sweden, using the wet process; residences of sandwich wall construction at Rainworth, England; lighthouse and chimney repairs in Sweden; resurfacing of a rocket flame deflector at Cape Canaveral, Fla.; coal mine strengthening and sealing of stoppings by National Coal Board, England; stabilization of the Tuve landslide in Sweden; and forming boat hulls similar to ferrocement, using fibers alone and fibers plus mesh.

2.8 — *Available design information*

2.8.1 *General* — Design of steel fiber reinforced shotcrete for structural uses is similar to design of plain shotcrete. Although design with fiber reinforced shotcrete and conventional shotcrete is basically the same, the material properties can be significantly different, thereby allowing considerable difference in shotcrete thickness and amount of reinforcement. At present, little data are available for the design of fiber reinforced shotcrete structures. Most design data that are available are for ground support such as tunnel linings.

Shotcrete in ground support has been most successful in treating problems associated with loosening ground and air slaking.

At present, the design of thin shotcrete linings is based on empirical rules and/or a analytical models of shotcrete-rock behavior. Empirical design is based on actual tunnel experience. The analytical models have been developed from observation of shotcrete performance under service conditions and from large scale testing in the laboratory and in the field.

2.8.2 *Precautions* — The scope of this report prevents a detailed treatment of the design of shotcrete for ground support. However, it is appropriate to list some available references relating to design and engineering properties of shotcrete and to list some general precautions. Some of the precautions are

Shotcrete may be used as sole support of underground excavations but only in cases where a good shotcrete-rock bond can be obtained, when the shotcrete is thick enough to act as a structurally continuous lining, or when air slaking is the only ground problem. In any other cases, shotcrete should be employed together with some other support elements (e.g., rock bolts, steel ribs, etc.).

The prevention or reduction of water flow from the ground because of the sealing action of the shotcrete may lead to a buildup of hydraulic forces and possibly to stability problems in the ground. Therefore, it is advisable to provide for drainage of such water.

A thin shotcrete lining applied over irregular rock surfaces has been found to be inadequate as the sole support of underground excavations in the following cases:[5]

a. Drill and blast openings 20 ft (6.1 m) or more in diameter.

b. Zones where blocks are bounded by smooth to slick joint surfaces, the overbreak is prominent and block sizes are typically 4 ft (1.2 m) or more in width.

c. Vertical side walls more than 10 ft (3 m) in height.

2.8.3 *Empirical design — plain shotcrete* — Several different empirical rules for estimating shotcrete thicknesses for tunnel support are presented in a publication by Mahar.[5] These rules include tables of thicknesses based on case histories in which shotcrete did or did not fail. Various thicknesses, depending upon conditions, were formulated by Alberts,[27] Kobler,[28] Cecil,[29] and Heuer.[30] Other researchers who used rock quality designation (RQD) and rock structure rating (RSR) to refine empirical rules include Deere[31] and Wickham.[32]

2.8.4 *Design based on analytical models — plain shotcrete* — A second method of estimating shotcrete thickness for initial support involves use of analytical models of shotcrete behavior.

A suggested method (Cecil) of determination of shotcrete thickness for a flat-roof tunnel by using models and analyses is shown in Mahar[5] and Cecil.[29] A thickness of not less than 2 in. (50 mm) is used because of possible deterioration of thinner layers from shrinkage, cracking, construction activity, or water seepage.

Design of shotcrete as a circular ring following the ultimate strength concepts of reinforced concrete design is illustrated by Peng.[33] Rabcewitz's methods, widely used in the new Austrian tunneling method, are illustrated in a series of articles.[34,35]

2.8.5 *Analytical models based on laboratory and field tests — fiber shotcrete* — Analytical models for steel fiber reinforced shotcrete based on large scale laboratory tests were formulated by Fernandez-Delgado, Mahar, and Parker of the University of Illinois and published in ACI SP-54.[36] Additional data on the same general subject, i.e., adhesion, flexure, and punch loads in arched and flat configurations for steel fiber reinforced shotcrete, also appear in ACI SP-54.[37]

The work was continued in large scale field tests in the Atlanta Research Chamber, and the results were applied to the design of liners for underground openings.[38] The models include analysis for wedges displacing through the liner and thrust coefficients for analysis of thicker, continuous arch configurations.

2.8.6 *Additional data — fiber shotcrete* — Data on the performance and design of steel fiber reinforced shotcrete compared to mesh reinforced shotcrete anchored on 4 ft (1.2 m) centers is given in a report by Morgan.[39] The report indicates that the two cases are equivalent and that fiber reinforced shotcrete provided good residual load capacity with large deformations, e.g., 50 mm (2 in.). Additionally, tests made by B.C. Hydro on the proposed Site C project on the Peace River confirm that in similar tests on mesh and fiber reinforced panels, first and second cracks generally occur at higher loads in the steel fiber reinforced shotcrete than in the mesh reinforced shotcrete. After cracking, both types exhibited similar load-carrying capabilities.[20] Additional data on engineering properties were generated by Poad, Serbousek, and Goris.[2]

CHAPTER 3 — GLASS FIBER REINFORCED SHOTCRETE

3.1 — General

Glass fiber reinforced shotcrete placed by conventional shotcrete methods, that is, shotcrete meeting the ACI-506.2 definition of "mortar or concrete pneumatically projected at high velocity onto a surface," has had little application to date and information on the material is sparse. Glass fiber reinforced concrete (GFRC), however, may be applied by a spray-up process which is described in Appendix A.

3.2 — Fiber types

See Appendix A for a description of glass fibers used in GFRC.

3.3 — Applications

It is reported that Cementation Mining Co. used glass fiber reinforced shotcrete as support for the drift entry for a coal mine in Selby, England.

3.4 — Available design information

No published design data exist for glass fiber shotcrete. See Appendix A for available design information on glass fiber spray-up.

CHAPTER 4 — SYNTHETIC FIBER REINFORCED SHOTCRETE

4.1 — Polypropylene fiber reinforced shotcrete

4.1.1 *General* — Limited data are available for a polypropylene fiber reinforced shotcrete which is termed "collated fibrillated polypropylene fiber shotcrete" (CFP fiber shotcrete) because of the form in which the fiber is manufactured.

CFP fiber shotcrete is a conventional shotcrete mixture with as low as 0.1 percent by volume (1.6 lb/yd^3; 0.95 kg/m^3) of CFP fiber added. The fiber is added to the mixture prior to putting it through the shotcreting system. No special equipment is needed to add the fiber and standard nozzles are used to spray the mixture. Limited testing indicates that rebound is less than normally experienced.

There are no data presently available on the properties of CFP fiber shotcrete or polypropylene monofilament fiber shotcrete. There are some data on polypropylene fiber reinforced concrete. See References 4 and 42.

4.2 — Shotcrete using other synthetic fibers

There are presently no data available on the use of other synthetic fibers in shotcrete.

CHAPTER 5 — REFERENCES

5.1 — Specified and/or recommended references

The standards of the American Society for Testing and Materials and the standards and reports of the American Concrete Institute referred to in this report are listed below with their serial designation, including the year of adoption or revision. The standards and reports listed were the latest editions at the time this report was prepared. Since some of these publications are revised frequently, generally in minor details only, the user of this report should check directly with the sponsoring group if it is desired to refer to the latest edition.

American Concrete Institute

ACI 544.1R-82	State-of-the-Art Report on Fiber Reinforced Concrete
ACI 544.2R-78	Measurement of Properties of Fiber Reinforced Concrete
ACI 506.X-XX	Guide for Shotcreting (to be published)
ACI 506.2-77	Specification for Materials, Proportioning, and Application of Shotcrete
ACI 547R-79	State-of-the-Art Report on Refractory Concrete

American Society for Testing and Materials

ASTM C78-75 (Reapproved 1982)	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading.

The above publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

5.2 — Cited references

Steel fiber shotcrete

1. Lankard, D. R., "Field Experiences with Steel Fibrous Concrete," presented at American Ceramic Society Meeting, Chicago, Apr. 26, 1971.

2. Poad, M. E.; Serbousek, M. O.; and Goris, J., "Engineering Properties of Fiber-Reinforced and Polymer-Impregnated Shotcrete," *Report of Investigations* No. 8001, U.S. Bureau of Mines, Washington, D.C., 1975, 25 pp.

3. Kaden, Richard A., "Fiber-Reinforced Shotcrete. Ririe Dam and Little Goose (CPRR) Relocation," *Shotcrete for Ground Support*, SP-54, American Concrete Institute/American Society of Civil Engineers, Detroit, 1977, pp. 66-88.

4. Hannant, D. J., *Fibre Cements and Fibre Concretes*, John Wiley & Sons, Chichester, 1978, 219 pp.

5. Mahar, J. W.; Parker, H. W.; and Wuellner, W. W., "Shotcrete Practice in Underground Construction," *Report* No. FRA-OR&D 75-90, Federal Railroad Administration, Washington, D.C., Aug. 1975, 482 pp.

6. Parker, H. W.; Fernandez, G.; and Lorig, L. J., "Field-Oriented Investigation of Conventional and Experimental Shotcrete for Tunnels," *Report* No. FRA-OR&D 76-06, Federal Railroad Administration, Washington, D.C., Aug. 1975, 628 pp.

7. Lankard, D. R., "Steel Fiber Reinforced Refractory Concrete," *Refractory Concrete*, SP-57, American Concrete Institute, Detroit, 1978, pp. 241-263.

8. Glassgold, I. Leon, "Refractory Shotcrete—Current State-of-the-Art," *Concrete International: Design & Construction*, V. 3, No. 1, Jan. 1981, pp. 41-49.

9. Henager, C. H., "The Technology and Uses of Steel Fibrous Shotcrete: A State-of-the-Art Report," Battelle-Northwest, Richland, Sept. 1977, 60 pp.

10. Henager, C. H., "A New Wrinkle—Shotcrete Containing Steel Fibers," *Concrete Construction*, V. 20, No. 8, Aug. 1975, pp. 345-347.

11. Morgan, Dudley R., "Steel Fiber Shotcrete—A Laboratory Study," *Concrete International: Design & Construction*, V. 3, No. 1, Jan. 1981, pp. 70-74.

12. Ramakrishnan, V.; Coyle, W. V.; Dahl, Linda Fowler; and Schrader, Ernest K., "A Comparative Evaluation of Fiber Shotcretes," *Concrete International: Design & Construction*, V. 3, No. 1, Jan. 1981, pp. 59-69.

13. Sandell, Bertil, "Steel Fiber Reinforced Shotcrete (Stalfiberarmerad Sprutbeton)," *Proceedings*, Informations-Dagen 1977, Cement-Och Betonginstitutet, Stockholm, 1977, pp. 50-75.

14. Rose, D. C., et al., "The Atlanta Research Chamber, Applied Research for Tunnels," *Report* No. UMTA-GA-06-0007-81-1, U.S. Department of Transportation, Washington, D.C., Mar. 1981.

15. Henager, Charles H., "Steel Fibrous Shotcrete: A Summary of the State-of-the-Art," *Concrete International: Design & Construction*, V. 3, No. 1, Jan. 1981, pp. 50-58.

16. Williamson, G. R., et. al., "Inflation/Foam/Shotcrete System for Rapid Shelter Construction," *CERL Technical Report* No. M-215, U. S. Army Construction Engineering Research Laboratory, Champaign, May 1977.

17. Kaden, R. A., "Slope Stabilized with Steel Fibrous Shotcrete," *Western Construction*, Apr. 1974, pp. 30-33.

18. Ryan, T. F., "Steel Fibers in Gunite, An Appraisal," *Tunnels and Tunneling* (London), July 1975, pp. 74-75.

19. Malmberg, B., and Ostfjord, S., "Field Test of Steel Fibre Reinforced Shotcrete at Scan-Raff, Brofjorden," *Fiberbetong*, Norforsks Projekt Committee for FRC-Material Delvapporter, Cement-Och Betonginstitutet, Stockholm, 1977, pp. Y1-Y16.

20. "Peace River Development Site C Project, Shotcrete Testing," Hydroelectric Generation Projects Division, Geotechnical Department, British Columbia Hydro, Jan. 1983.

21. Chronis, N. P., "Three Innovations in Mine Expansion Tested at Bruceton Experimental Mine," *Coal Age*, V. 80, No. 4, Apr. 1975.

22. Murphy, E. M., "Steel Fiber Shotcrete in Mines," *Concrete Construction*, V. 20, No. 10, Oct. 1975, pp. 443-445.

23. Warner, B. L., "Evaluation of Materials for Protecting Existing Urethane Foam in Mines," *Report* No. ORF 75-76 (NTIS PB 254 682). U.S. Bureau of Mines, Washington, D.C., Sept. 1974.

24. Wilkinson, Bruce M., "Foam Domes, High Performance Environmental Enclosures," *Concrete Construction*, V. 23, No. 7, July 1978, pp. 405-406.

25. "Shotcrete and Foam Insulation Shaped Over Inflated Balloon Form," *Concrete Construction*, V. 27, No. 6, June 1982, pp. 511-513.

26. Nelson, K. O., and Henager, C. H., "Analysis of Shotcrete Domes Loaded by Deadweight," *Preprint* No. 81-512, ASCE Convention (St. Louis, Oct. 1981), American Society of Civil Engineers, New York, 1981.

27. Alberts, C., "Bergforstarkning genom Beton sprutning och Injectering," *Proceedings*, 1965 Rock Mechanics Symposium, *Publication* No. 142, Swedish Academy of Sciences, Stockholm, 1965.

28. Kobler, Helmut G., "Dry-Mix Coarse-Aggregate Shotcrete as Underground Support," *Shotcreting*, SP-14, American Concrete Institute, Detroit, 1966, pp. 33-58.

29. Cecil, O. S., "Correlations of Rock Bolt-Shotcrete Support and Rock Quality Parameters in Scandinavian Tunnels," PhD thesis, University of Illinois, Urbana, 1970.

30. Heuer, Ronald E., "Selection/Design of Shotcrete for Temporary Support," *Use of Shotcrete for Underground Structural Support*, SP-45, American Concrete Institute/American Society of Civil Engineers, Detroit, 1974, pp. 160-174.

31. Deere, E. U.; Peck, R. B.; Monsees, N. E.; and Schmidt, B., "Design of Tunnel Liners and Support Systems," Contract No. 3-0152 (NTIS PB 183 799), Office of High Speed Ground Transportation, U. S. Department of Transportation, Washington, D. C., 1969, pp. 387-391.

32. Wickham, G. E.; Tiedemann, H. R.; and Skinner, E. H., "Ground Support Prediction Model RSR Concept," *Proceedings*, North American Rapid Excavation and Tunneling Conference, American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1974, V. 1, pp. 691-707.

33. Peng. S. S., *Coal Mine Ground Control*, John Wiley & Sons, New York, 1978, pp. 415-416.

34. Rabcewicz, L., "The New Austrian Tunneling Method, Parts I, II, III," *Water Power* (London), Nov., Dec. 1964, and Jan. 1965.

35. Rabcewicz, L., "Stability of Tunnels Under Rock Loads, Parts I, II, III," *Water Power* (London), June 1969, pp. 225-234, July 1969, pp. 266-273, and Aug. 1969, pp. 297-302.

36. Fernandez-Delgado, Gabriel; Mahar, James W.; and Parker, Harvey W., "Structural Behavior of Thin Shotcrete Liners Obtained from Large Scale Tests," *Shotcrete for Ground Support*, SP-54, American Concrete Institute/American Society of Civil Engineers, Detroit, 1977, pp. 399-442.

37. Holmgren, Jonas, "Thin Shotcrete Layers Subjected to Punch Loads," *Shotcrete for Ground Support*, SP-54, American Concrete Institute/American Society of Civil Engineers, Detroit, 1977, pp. 443-459.

38. Fernandez-Delgado, G., et al., "Thin Shotcrete Linings in Loosening Rock," *The Atlanta Research Chamber*, Report No. UMTA-GA-06-0007-81-1, U.S. Department of Transportation, Washington, D.C., Mar. 1981.

39. Morgan, D. R., "Report on Steel Fibre Shotcrete for Tunnel Support Lining," Hardy Associates Ltd., Vancouver, Mar. 1981.

Glass fiber reinforced concrete

40. "Recommended Practice for Glass Fiber Reinforced Concrete Panels," *Journal*, Prestressed Concrete Institute, V. 26, No. 1, Jan.-Feb. 1981, pp. 25-93.

41. Schrader, Ernest; Dikeou, James: and Gill, Dwight, "Deterioration and Repairs of Navigation Lock Concrete," *Performance of Concrete in Marine Environment*, SP-65, American Concrete Institute, Detroit, 1980, pp. 557-576.

Polypropylene fiber reinforced concrete

42. Zollo, R. F., "Collated Fibrillated Polypropylene Fibers in FRC," *Fiber Reinforced Concrete—International Symposium*, SP-81, American Concrete Institute, Detroit, 1984, pp. 397-409.

Table A.3—Typical 28-day properties of spray-up GFRC. (Reference 40, page 56)

Property	Typical range[*]
Density (dry)	105 to 140 (pcf)
Impact strength (Charpy)	60 to 140 (in. lb/in.²)
Compressive strength (edgewise)	7000 to 12,000 (psi)
Flexural: Yield	1000 to 1800 (psi)
Ultimate strength	3000 to 4500 (psi)
Modulus of elasticity	1.5 × 10^6 to 3.2 × 10^6 (psi)
Direct tension: Yield	400 to 1000 (psi)
Ultimate strength	1000 to 1600 (psi)
Strain to failure	0.6 to 1.2 (percent)
Shear: Interlaminar In-plane	 500 to 800 (psi) 1000 to 1600 (psi)
Coefficient of thermal expansion (77 to 115 F)	4 to 7 × 10^6 (in./in./F)
Thermal conductivity	3.5 to 7.0 (Btu/in./hr/ft²/F)

Note: 1 pcf = 16.02 kg/m³; 1 psi = 0.006895 MPa
1 in.-lb/in.² = 0.175 N·mm/mm²

[*] These are typical values and are not to be used for design or control purposes. Each manufacturer must test production composites to establish physical properties for design. The values achieved in practice will be dependent on quality control of materials, fabrication process, and curing.

APPENDIX A — GLASS FIBER SPRAY-UP

A.1 — General

Glass fiber reinforced concrete (GFRC) may be applied by a spray-up process which is used to produce items such as thin, lightweight panels for building cladding. In this method, chopped glass fiber and a sand-cement slurry are simultaneously deposited onto a form using a glass fiber chopping gun and a mortar spray gun. The fibers and mortar are, in effect, mixed at the point of placement. After being deposited, the wet composite is compacted by serrated hand rollers or a vibrating trowel. This wets all the fibers with paste, removes entrapped air, and compacts the composite.

Such a process has been used to repair deteriorating concrete where a very thin restorative layer was desired (see Applications).

A.2 — Fiber types

Typical glass fibers (chopped strand) have diameters of 0.0002 to 0.0006 in. (0.0005 to 0.015 mm), but these fibers may be bonded together to produce glass fiber elements with diameters of 0.0005 to 0.050 in. (0.013 to 1.3 mm). Typical fiber tensile strength is 150,000 to 550,000 psi (1035 to 4000 MPa), Young's modulus is 10 × 10^6 psi (69,000 MPa), ultimate elongation is 1.5 to 3.5 percent, and specific gravity is 2.5. Precut fibers are commonly 1 in. long (25 mm). When a chopping gun is used in placement, the strand is normally cut to 1½ to 2 in. (38 to 51 mm). Fibers are made from a special high zirconia alkali-resistant glass in order to resist attack in the highly alkaline portland cement environment. Unprotected E glass fibers, the type designed for use in the reinforcement of plastics, should not be used.[40]

A.3 — Typical material properties

As with other fiber concretes, the addition of glass fibers improves flexural strength, toughness, impact resistance, shear strength, and other properties.

Typical flexural strengths (modulus of rupture) of ⅜ in. thick (9.5 mm) specimens made by the spray-up process and having 4 to 5 volume percent of glass fiber are in the range of 3000 to 4500 psi (20 to 31 MPa) at 28 days. Other typical 28-day properties of spray-up GFRC are shown in Table A.3.

Certain GFRC properties tend to decrease over time, particularly under moist conditions. ACI 544.1R describes this phenomenon and indicates that improvements have been made and research efforts are underway to alleviate the effects of alkali attack and fiber damage from crystal growth in the matrix. For further information see ACI 544.1R, Chapter 4, Typical Material Properties.

A.4 — Mixture compositions

Slurry mixtures, which must be sprayed through a relatively fine nozzle, ¼ in. (6 mm), have high cement factors (2000 to 2200 lb/yd³; 1187 to 1305 kg/m³) and low water-cement ratios (0.3 to 0.35 maximum). Type I cement is usually used and a water reducer is recommended. Aggregate is usually a fine, graded, washed and dried silica sand which passes a No. 2 sieve (nominal sieve opening 0.85 mm; 0.0331 in.). Sand-cement ratios of 0.33 to 0.50 are commonly used. Fiber is added at the rate of 4 to 5 percent by volume.

A.5 — Batching and mixing

For the spray-up process, the slurry of sand, cement, and water is preferably prepared in mixers of the high speed shaft type with sawtooth disc blades which can break up lumps and give the mixture a smooth, flowing consistency. Additional details are given in ACI 544.1R, Section 3.3.1, Glass Fiber Spray-Up.

A.6 — Installation

Application of glass fiber spray-up is done as described in ACI Report 544.1R or Reference 40.

A.7 — Applications

The principal use of the glass fiber spray-up technique has been to manufacture nonstructural exterior wall cladding panels and similar cladding shapes such as column covers.[40] It has also been used to build a 1 in. (25 mm) thick hypar shell roof in Germany. In 1980, it was used to repair 150,000 sq ft^2 (1394 m^2) of abraded and freeze/thaw-spalled wall surface of a navigation lock at Lower Monumental Lock and Dam on the Snake River, Wash., using glass fiber-latex modified mortar.[41] (See Fig. A.7.)

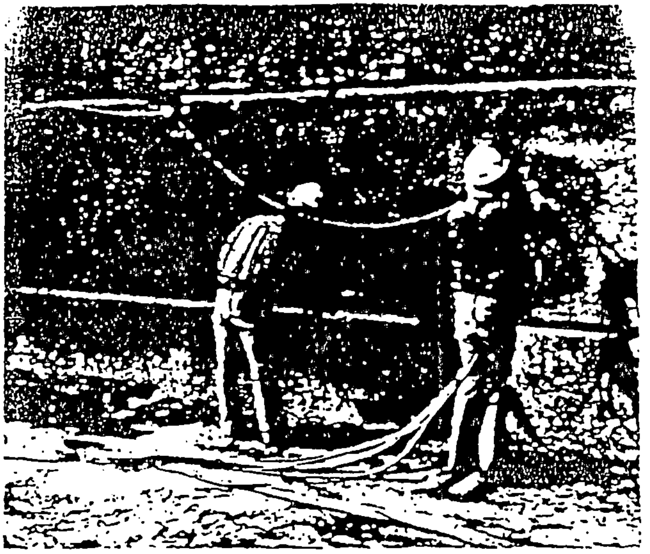

Fig. A.7—Applying fiber reinforced latex modified mortar at Lower Monumental Navigation Lock by the spray-up process.

A.8 — Available design information

A design document[42] has been developed by the Prestressed Concrete Institute (PCI) covering GFRC panels as made by the spray-up process.

This report was submitted to letter ballot of the committee which consists of 20 members; 16 were affirmative and 4 were not returned. It has been processed in accordance with Institute procedure and is approved for publication and discussion

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