UNIVERSIDAD NACIONAL DE INGENIERIA

FACULTAD DE INGENIERIA QUIMICA Y TEXTIL

"PROTECCION CONTRA LA CORROSIÓN DE INTERIOR DE TANQUES DE ACERO POR MEDIO DE RECUBRIMIENTOS LIBRE DE SOLVENTES"

INFORME DE COMPETENCIA PROFESIONAL

PARA OPTAR EL TITULO PROFESIONAL DE:

INGENIERO QUIMICO

POR LA MODALIDAD DE EXPERIENCIA PROFESIONAL

PRESENTADO POR:

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LIMA – PERU

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RESUMEN

El objetivo del informe, es dar a conocer cómo realizar el trabajo de protección del fondo de los tanques de almacenamiento de petróleo, siguiendo las siguientes reglas: pre inspección y evaluación de la condición del tanque, recomendación del sistema de pintura, pre-limpieza y preparación de la superficie, aplicación y pruebas posteriores de la pintura y los cuidados durante el trabajo de aplicación; diferenciando éstas de las que se realiza comúnmente con los sistemas de pinturas epóxicas convencionales.

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Capítulo I. INTRODUCCION

El presente informe, se basa en la experiencia profesional del trabajo realizado en el rubro de pinturas para mantenimiento industrial y marino, mostrando las nuevas tendencias de protección del fondo interior de un tanque de almacenamiento de petróleo con el fin de prevenir la corrosión.

La corrosión en el fondo del tanque, causa debilidad intensiva en la estructura, conduciendo a fallas estructurales repentinas y a la posibilidad de un desastre ambiental, por lo que es importante tratar la superficie.

En la actualidad, las empresas nacionales están utilizando, con mucho éxito en el mantenimiento de los tanques de acero, las pinturas 100% sólidas que son ventajosas en comparación con las pinturas a base de solventes, por dar un espesor de película compacta a las planchas de acero para contrarrestar la corrosión, lo que contribuye en la vida útil y costo de mantenimiento de los mismos.

Capítulo II. ORGANO EMPRESARIAL

1.- Empresa: **CORPORACION MARA S. A.**

Actividad: Se dedica a la fabricación de pinturas, siendo sus principales productos:

- Pinturas para mantenimiento industrial: interiores y exteriores de tanques de almacenamiento, estructuras en general, pisos y tuberías para diferentes tipos de sustratos.
- Pinturas para señalización: pintura para Tráfico.
- Pinturas marinas: Embarcaciones de madera y acero, buques de guerra, buques de carga, buques tanques, offshores, plantas de harina y aceite de pescado.
- Pulidores para autos.
- Pinturas para piscinas.
- Pinturas Arquitectónicas.

La empresa tiene ocho años de creada, teniendo como marcas:

- PINTURAS AURORA, de fabricación local, se creó en el año 1943 y es de reconocido prestigio por su calidad (tecnología e insumos alemanes).
- SIGMA COATINGS N.V., tiene la representación y fabricación (de algunos productos). Esta marca es la número dos en ventas a nivel de Europa y número cuatro a nivel mundial, líder en recubrimientos de última generación (amigables con el medio ambiente y no dañinos a la salud), con más de 270 años de experiencia.

Corporación Mara S.A. es el mayor exportador de pinturas en el Perú siendo sus destinos: Panamá, Colombia, Ecuador, Bolivia y Chile.

2.- Empresa: **ITICSA – CHEMS MASTERS DEL PERU S. A.**

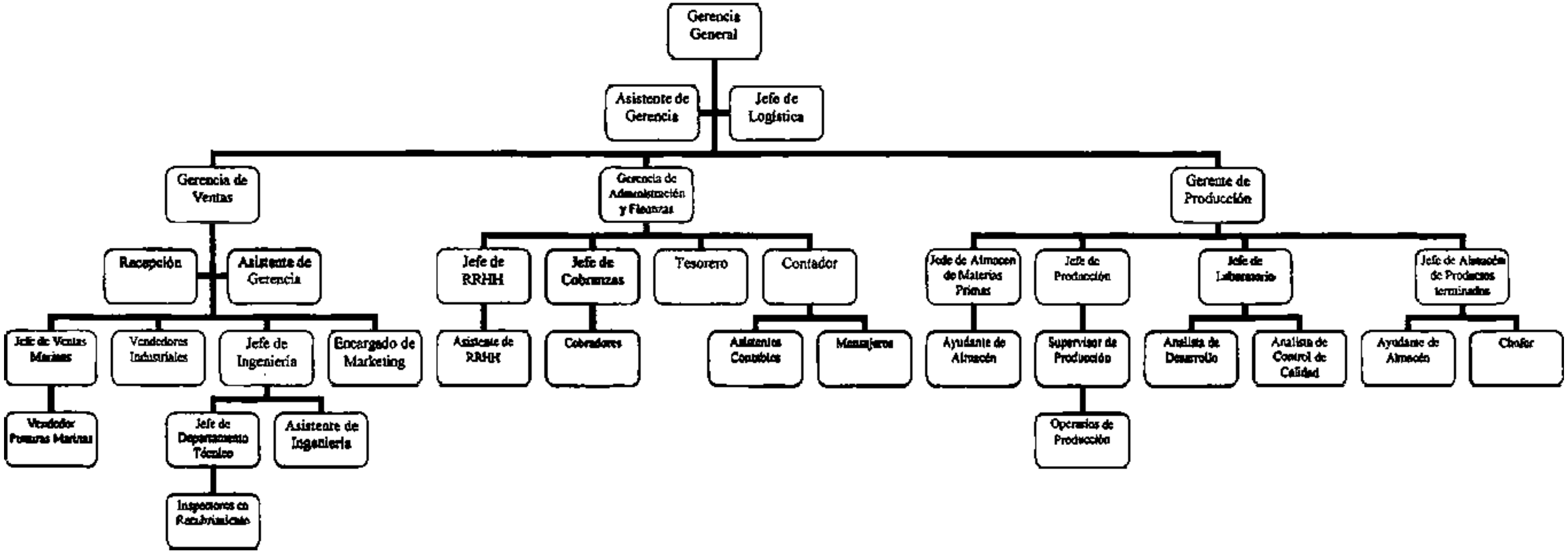
Actividad: Se dedica a la fabricación de aditivos para el concreto (marca CHEMA).

Sus principales productos son:

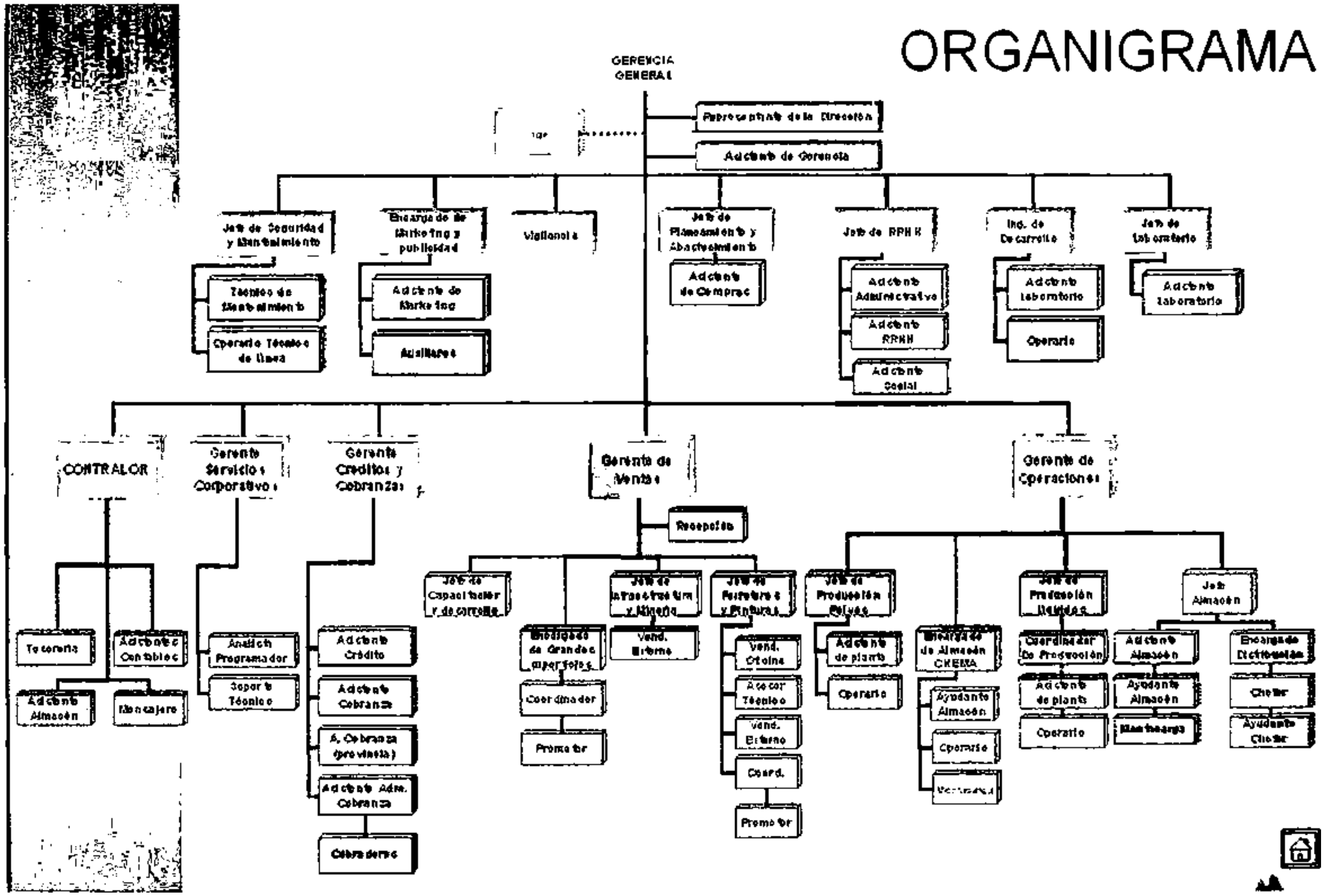
- Aditivos para el concreto: impermeabilizantes, acelerantes, plastificantes, retardadores, expansivos, reductores de rajaduras, etc.
- Desmoldantes de encofrados.
- Curadores.
- Selladores de superficies.
- Pegamentos cementicios y fraguas. (líder en el mercado).
- Antisalitres.
- Pegamentos epóxicos.
- Limpiadores.
- Pinturas arquitectónicas CHEMS.

Tiene más de 100 productos en el mercado y 40 años de experiencia en el área de la construcción. También tiene ISO 9001.

CUADRO 1-1: ORGANIGRAMA CORPORACION MARA S.A.



CUADRO: 1-2 ORGANIGRAMA ITICSA



Capítulo III. RELACIÓN PROFESIONAL – EMPLEADOR

1.- Empresa: **CORPORACION MARA S. A.**

Teléfono: 467-6777

Dirección: Jr. Perseo 251 La Campiña, Chorrillos.

a) Cargo: Analista de Laboratorio.

Responsabilidades:

- Responsable del Control de Calidad de las materias primas.
- Responsable del control de productos en proceso.
- Responsable del Control de Calidad de los productos terminados.
- Preparación de muestras y aplicaciones para los clientes.
- Responsable del manejo de equipos de corrosión acelerada.
- Responsable de la evaluación de muestras de las materias primas.
- Responsable de recepcionar, evaluar y solucionar los reclamos de los clientes.

Período: Del 01 de Marzo del 2002 al 28 de Febrero del 2005

Referencias Laborales: Ing. Frida Remuzgo – Jefa de Laboratorio.

b) Cargo: Inspector en Recubrimientos.

Responsabilidades:

- Resolver cualquier duda o consulta que tengan los clientes o el departamento de ventas sobre especificaciones de los sistemas de pintura.
- Ser la autoridad delegada por la empresa, para especificar un sistema de pintura en un determinado proyecto.
- Determinar por medio de medición y observación si la especificación recomendada está siendo cumplida por el aplicador.

- Asegurar que las pinturas sean almacenadas correctamente y que los lotes de pintura sean usados dentro del tiempo recomendado.
- Registrar todos los trabajos de inspección realizados, indicando las condiciones a las cuales fue aplicado el sistema de pintura.
- Informar al contratista cuando se están desviando de la especificación.
- Determinar que cada capa de pintura programada en el día, sea aplicada.
- Asegurar que todas las normas requeridas y los instrumentos de medición estén disponibles en cualquier momento y asegurar que cada instrumento esté en funcionamiento y correctamente calibrado.
- Dictar charlas a los clientes y al departamento de ventas.

Período: Del 01 de Marzo del 2005 al 28 de Febrero del 2007.

Referencias Laborales: Hernán Salazar – Jefe del Departamento Técnico.

2.- Empresa: **ITICSA – CHEMS MASTER DEL PERU S. A.**

Teléfono: 336-8407

Dirección: Av. Industrial 765, LIMA.

Cargo: Asesor técnico.

Responsabilidades:

Resolver cualquier duda o consulta que tengan los clientes o el departamento de ventas sobre aditivos para el concreto y los sistemas de pintura.

Ser la autoridad delegada por la empresa para especificar un sistema de pintura en un determinado proyecto.

Determinar por medio de medición y observación si la especificación recomendada está siendo cumplida por el aplicador.

- Informar a los clientes cuando se están desviando de la especificación.
- Asegurar que todas las normas requeridas y los instrumentos de medición estén disponibles en cualquier momento y asegurar que cada instrumento esté en funcionamiento y correctamente calibrado.
- Dictar charlas a los clientes y departamento de ventas (ferreteros y constructoras)

Período: Del 01 de Marzo del 2007 hasta la fecha.

Referencias Laborales: Arq. Rosario Maggi – Gerente de Ventas.

Capítulo IV. TRABAJO PROFESIONAL DESARROLLADO

4.1 Corrosión por influencia microbacteriana

El ataque por corrosión microbacteriana es, en la mayoría de los casos, iniciada en el fondo del tanque de almacenamiento de petróleo, donde está la capa de agua (haciendo una interfase con el acero).

Los microorganismos que habitan en el agua generan un pH bajo, produciendo un ataque directo por reacción química sobre el acero. Los mecanismos de ataque son complejos e interactivos y es importante reconocer que son el resultado de las actividades de comunidades de microorganismos de diferentes tipos.

El término "Corrosión por Influencia Microbacteriana" (Microbial Influenced Corrosion: MIC) es generalmente usado, ya que la actividad de crecimiento interactivo de la bacteria, es estimulado por el proceso de corrosión electroquímica.

Dentro de la compleja población de bacterias, se tienen dos grandes grupos: Las bacterias productoras de ácidos (Acid Producing Bacteria: APB) y las bacterias sulfato reductoras (Sulphate Reducing Bacteria: SRB), que juegan un rol muy importante durante el proceso de corrosión en el interior (fondo) de un tanque de almacenamiento de petróleo. De estos dos grupos, las SRB son las más agresivas y corrosivas, ya que en un ambiente propicio de temperatura y pH puede convertir los sulfatos en sulfuros.

Los microorganismos no son físicamente activos e intentarán asentarse en una superficie adecuada, formando una película de bacterias (que llamamos bio-película).

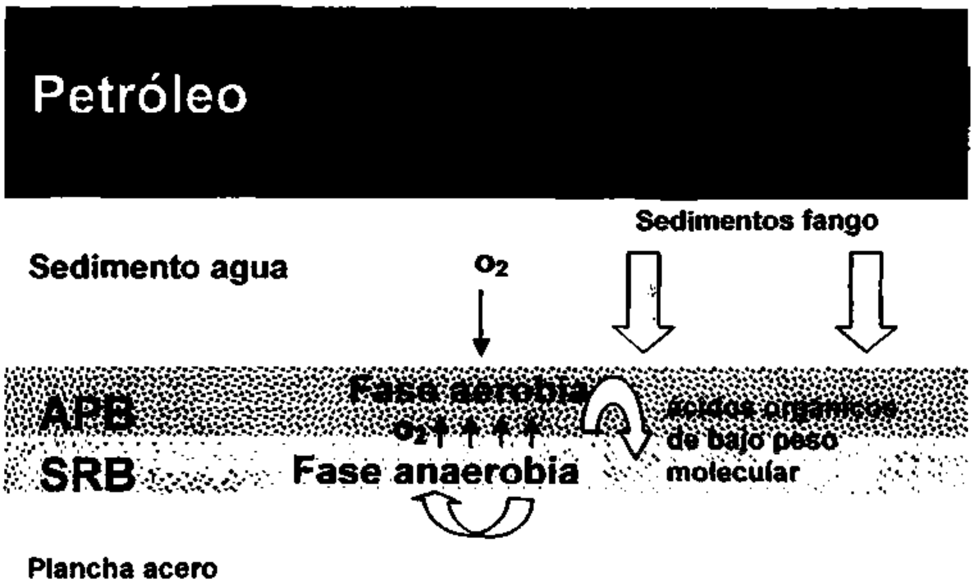
En el caso de las SRB una vez que se sedimentan se reproducirán y concentrarán de manera exponencial. (la concentración de las SRB llega hasta 10'000,000 por mililitro de agua sedimentada)

A continuación se explican las formas en que intervienen estos grupos de bacterias:

ACCIÓN DE LAS APB

Las APB están presentes tanto en el petróleo como en el agua sedimentada, y son estas bacterias (del tipo aerobias) las principales iniciadoras de la Corrosión por Influencia Microbacteriana (Microbial Influenced Corrosion: MIC). Su nutriente es el oxígeno y sus desechos son ácidos orgánicos de bajo peso molecular, como por ejemplo: alcoholes, ácidos orgánicos (propiónico, acético, fórmico) y aldehídos. Estos ácidos de bajo peso molecular no son corrosivos por ellos mismos, pero son importantes pues son la primera fuente de alimentación para las SRB que son más dañinos. Representación gráfica de este proceso en Figura 4.1.

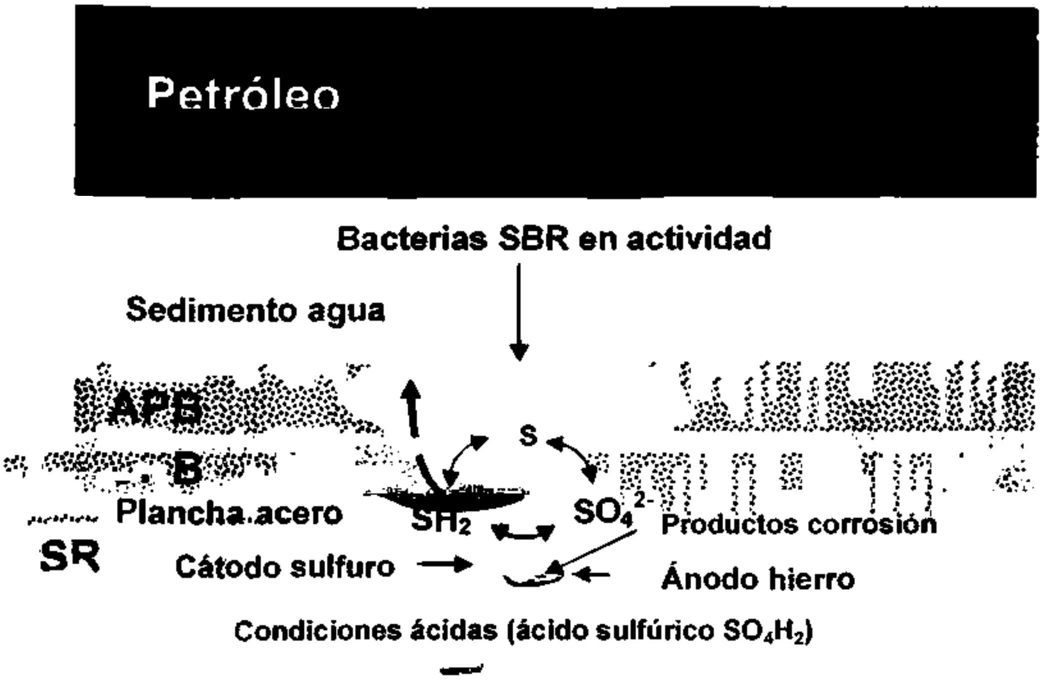
Figura 4.1: MECANISMO DE ACCION, DISPOSICION DEL BIOFILM EN TANQUES



ACCIÓN DE LAS SRB

El aumento de la acidez por acción de las APB, crea condiciones para que las SRB puedan comenzar a crecer. Una vez que las SRB comienzan a crecer y proliferar, metabolizan azufre o sulfatos produciendo ácido sulfhídrico (H_2S) generando un ambiente tóxico para los microorganismos aeróbicos y eventualmente pueden eliminar a la mayoría de los demás microorganismos (tal como se observa en Figura 4.2). Entonces el índice entre aerobios y anaerobios, así como el índice entre APB y SRB no es constante. En algunos tanques de almacenamiento de petróleo, la carga de petróleo tiene un alto índice de APB sobre SRB y en otros tanques la mayor proporción la tiene las SRB.

Figura 4.2: BIOCORROSION DEL ACERO



La corrosión por picadura en el fondo del tanque se inicia por la ruptura de la biopelícula por las SRB. Los sulfuros son catódicos al acero y atacan a la superficie por consumo del hierro:

En el ánodo (interior del agujero o grieta)

$Fe \text{ ---> } Fe^{n+} + n\,e^-$

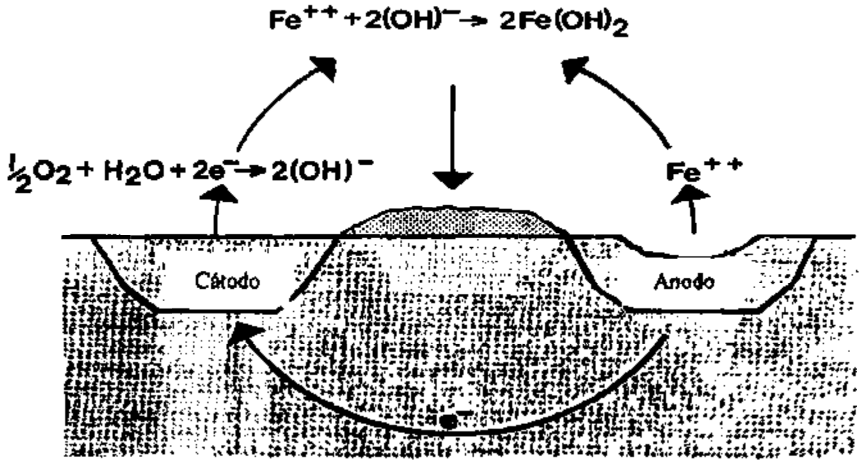
En el cátodo, (superficie del metal que rodea al óxido) en regiones oxigenadas ocurrirá

$O_2 + 2H_2O + 4\,e^- \text{ ---> } 4\,OH^-$

Las SRB generan ataque de sulfuros y reduce al acero en componentes ferrosos, que se expanden y forman crestas en el tope de la bio-película tal como se observa en la Figura 4.3 (usualmente se encuentran capas de las picaduras).

$Fe^{n+} + n\ H_2O$ -----> $Fe(OH)_n + n\ H^+$

Figura 4.3: Reacciones de corrosión en la superficie del Acero (fondo del tanque)



Este tipo de corrosión dentro del tanque, solo se observa en superficies horizontales, no hay evidencia de este tipo de corrosión en superficies verticales, por lo que no se pinta todas las paredes del tanque, sólo hasta los primeros 0.3 a 1.5 m desde la base, el resto se deja sin recubrir.

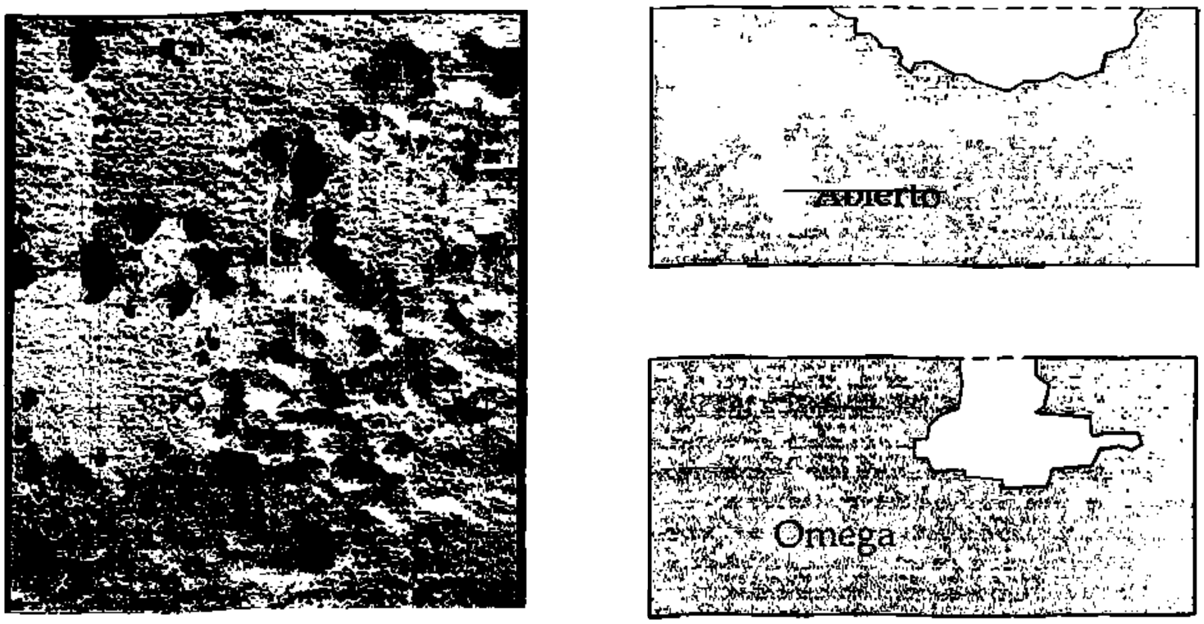
4.2 Tipos de picaduras observados en los tanques

PICADURA DE CRATER ABIERTO: Como su mismo nombre lo dice, son depresiones de abertura angosta o ancha y profundas (Figura 4.4).

PICADURA POR RANURAS: Son las menos comunes y sólo se han observado en los tanques de almacenamiento en embarcaciones.

PICADURAS DEL TIPO OMEGA: Este tipo de picadura se llama así por su forma similar a la letra griega. Es la picadura más peligrosa y difícil de tratar. Su identificación también es difícil, ya que tiene una entrada muy angosta, mientras el fondo es como una caverna. Esto último dificulta su limpieza y llenado (Figura 4.4).

Figura 4.4: Plancha después de su preparación de superficie y los tipos de picaduras que se observan



4.3. Solución planteada: pinturas libres de solventes

Identificado el problema en el fondo del tanque, se plantea la solución. Normalmente se recomienda proteger el fondo del tanque por barrera con recubrimientos epóxicos. Los sistemas de pinturas recomendados son pinturas epóxicas convencionales a base de solventes, pero actualmente se recomienda para este tipo de situación, las pinturas epóxicas 100% sólidas. A continuación se hace una comparación de éstas con las pinturas epóxicas convencionales.

4.3.1. Pinturas epóxicas convencionales

Por razones económicas, las pinturas epóxicas del tipo Coaltar en sistemas de multicapas son las más usadas en el mantenimiento de los fondos de tanques de almacenamiento de petróleo.

Tiene como ventajas:

- Son económicas
- Tienen razonable resistencia al crudo y los ácidos.

Tiene como desventajas:

- Espesores bajos (8mils de espesor de película seca por capa de pintura).
- En áreas con dificultades de accesibilidad producen retención de solvente (por consiguiente habrá ampollamiento por osmosis).
- Encogimiento de la película (Figura 4.5).
- Pobre adherencia en picaduras.
- No rellena las picaduras.
- La película sufre tensiones cuando hay carga de crudo.
- El Coaltar en picaduras no elimina o bordea filos, donde se tendrá bajos

espesores de película seca y proceso de corrosión.

El sistema tiene un periodo de vida no más de 5 años.

Figura 4.5: Película de pintura Epoxi Coaltar después de algunos años de servicio

4.3.2. Pintura epóxica libre de solventes

Cuando hablamos de pinturas libres de solventes, estamos refiriéndonos a recubrimientos 100% sólidos, que en algunos sistemas se le agrega diluyentes reactivos con el fin de evitar emitir VOC (componentes orgánicos volátiles) al medio ambiente, así como evitar intoxicación a los pintores durante la aplicación de estos recubrimientos.

Esencialmente los recubrimientos epóxicos libres de solventes, es algo novedoso en el mercado peruano que tiene excelentes características como:

No se encoge, no se quiebra y no se desprende, a diferencia de las pinturas alquitranadas. Esto se debe a la naturaleza de la resina.

Buena adherencia en toda la superficie de la picadura.

Se aplica fácilmente y con un espesor de película (16 mils de espesor de película seca por capa de pintura) mucho mayor que las epóxicas convencionales, manteniendo ese espesor inclusive en superficies con ángulos de 90° (a menudo es el punto donde fallan las pinturas y donde comienzan los puntos de corrosión, como en la Figura 4.6).

Figura 4.6: Diagrama de un filo, Pintura libre de solventes (izquierda) vs. Pintura en base solvente (derecha)

Excelente propiedad de nivelación, esto hace que pueda llenar todos los tipos de cavidades y fisuras. Esto sucede, debido a que no lleva solventes, que durante su proceso de curado no se evaporan y no generan tensiones internas a la película de pintura. Esto es muy importante, sobre todo para rellenar las picaduras del tipo OMEGA, que no se puede rellenar con pinturas convencionales, ya que se encogen y no cubren adecuadamente perfiles agudos (figuras 4.7 y 4.8).

Figura 4.7: Pintura libre de solvente aplicada en una plancha con fuerte corrosión por picadura

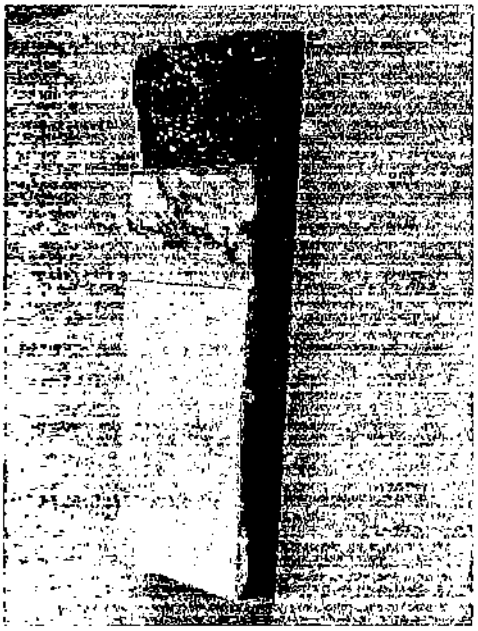
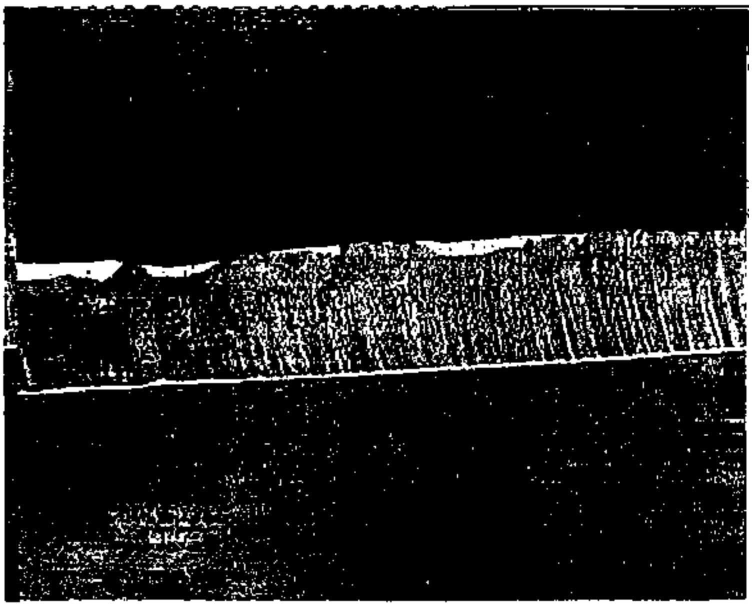


Figura 4.8: Corte transversal de una plancha con picaduras y como han sido rellenadas con la pintura libre de solventes



Gran resistencia al "chorreamiento" (Sagging). Se puede aplicar hasta 1 mm. de espesor de película seca en una sola capa en superficies verticales. Esto en gran parte ayuda a evitar sistemas de varias capas de pinturas. Durante la aplicación de estos recubrimientos, la pintura aplicada con pistola de aire no llega a la superficie seca (Overspray).

Estos recubrimientos no emiten solventes, esto es muy importante ya que hace más segura las condiciones de trabajo en el interior de los tanques (sin riesgos de explosión, intoxicación por parte de los pintores y mínimos problemas de ventilación) y significa a largo plazo, la reducción de la contaminación al medio ambiente.

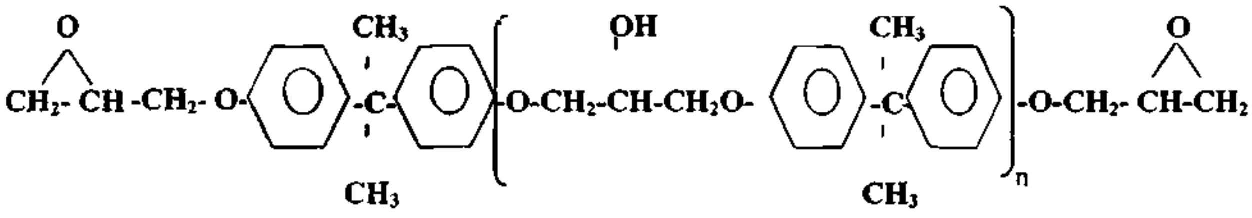
Por su naturaleza química, las pinturas 100% sólidos tienen muy buenas propiedades de resistencia química al petróleo crudo, los derivados del petróleo, aceites vegetales, agua potable y agua salada.

Se reduce el tiempo de mantenimiento de los tanques de almacenamiento de petróleo, estos trabajos pueden darse como máximo en 5 días, mientras que con pinturas convencionales puede doblarse el tiempo.

El sistema tiene un periodo de vida no menor a 25 años.

Los revestimientos mencionados, son resinas del tipo epóxico de peso molecular medio (<700), cuyo principal componente es el Bisfenol A (figura 4.9) que es curado por reacción química con otro componente, en este caso con una amina o un aducto amina (amina pre-reaccionada con una cantidad mínima de epóxico). Esto le confiere mejores propiedades de flexibilidad y no se encoge al tener elevada carga de petróleo. La reacción entre la amina y el epóxico, se rompe los anillos de oxirano por la activación de los hidrógenos de las aminas, haciendo que se produzca los enlaces cruzados y permitiendo que le de excelentes propiedades de resistencia química, dureza, grado de flexibilidad y adhesión.

Figura 4.9: Resina Epóxica



Diglicil éter de Bisfenol A

Para incrementar el porcentaje de sólidos en el recubrimiento hasta llegar al punto de dejarlo libre de solventes, se utiliza diluyentes reactivos, que son epóxicos de bajo peso molecular mono y di funcionales. Como ejemplo los alifáticos (butil glicidil éter y el diglicil éter de neopentil glicol) y los aromáticos (cresol diglicil éter). Estos diluyentes tienen muy baja viscosidad (1- 70 cps) comparado con la resina epóxica (11000 a 16000 cps). Teniendo sólo entre el 7 a 20% en peso de la resina epóxica tendrá un efecto de reducción de la viscosidad alrededor de 1000 cps.

Como ventaja se tiene que la modificación de la viscosidad del recubrimiento hace que se reduzca la tensión superficial que incrementa la humectación (durante la aplicación) y la adhesión. Como desventaja, en algunos casos, es la disminución de la dureza de la película de pintura y de la resistencia química.

Otro diluyente utilizado en este tipo de recubrimientos y que no es reactivo, es el alcohol bencílico, dosificándose en la fórmula en menos del 10% en peso de la resina epóxica, siendo casi imperceptible la modificación de las propiedades de la pintura.

4.3.3 Ensayos de corrosión acelerada

De las pruebas de corrosión acelerada en cámara de niebla salina según norma ASTM B-117 (ver anexo 1), se puede determinar la resistencia comparativa entre las pinturas epóxicas convencionales y las pinturas 100% sólidas. En unas pruebas para un tiempo de 3000 horas para los siguientes sistemas:

Preparación de superficie	**Sistema de Pintura**	**Espesores en promedio (micrones)**
Arenado SSPC- SP 6	Epoxi Coaltar multicapas base solvente	300
Arenado SSPC- SP 6	Epoxi puro libre de solventes curado con amina	300

Se realizaron además los ensayos de:

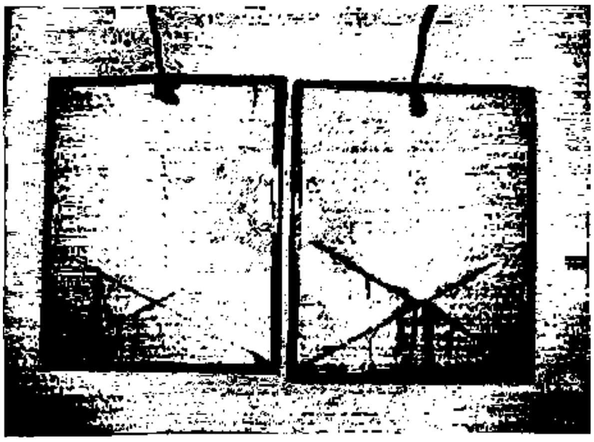
- Oxidación (norma ASTM D 610-5, ver anexo 1).
- Ampollamiento (norma ASTM D 714-05, ver anexo 1).
- Grado de Deterioro en la incisión (norma ASTM D 1654-05, ver anexo 1).

Obteniéndose los siguientes resultados de acuerdo a las Normas mencionadas:

Preparación de superficie	Sistema de Pintura	Grado de Oxidación	Grado de Ampollamiento	Deterioro en la incisión
Arenado SSPC- SP 6	Epoxi Coaltar multicapas base solvente	10	10	6
Arenado SSPC- SP 6	Epoxi puro libre de solventes curado con amina	10	10	10

De estos datos, se observa que el Sistema de Pinturas Libre de Solventes es el que no sufre ningún deterioro, que confirma la mayor resistencia con respecto a las pinturas epóxicas convencionales. (Figura 4.10)

Figura 4.10: Probetas luego de 3000 horas de exposición (Arriba: Sistema Epoxico libre de solventes, Abajo: Sistema epoxi Coaltar multicapas)



4.4 Procedimiento de trabajo

4.4.1 Evaluación de los tanques

Para hacer frente a los daños que se observan en el fondo de los tanques, se realizan en forma apropiada las tareas de mantenimiento. Los procedimientos de mantenimiento a veces, incluyen renovación de planchas de acero, rellenado de puntos de picadura profundos mediante soldadura, sistemas de pinturas adecuados que permitan proteger, para ampliar el período de servicio de las instalaciones. Un buen mantenimiento disminuye al máximo los riesgos de deterioro en el fondo de los tanques.

Cuando se trata de tanques nuevos, aplicar revestimientos de alta calidad es una decisión que permitirá en el futuro reducir los costos de mantenimiento y evitar actividades como: renovación de planchas de acero, procesos de soldadura para reparar puntos de picadura, preparaciones de superficie por chorro abrasivo y procesos de pintado, interrumpiendo, de esta forma, el proceso de servicio del tanque. Se trata de reducir al máximo los tiempos de parada del tanque, obteniendo una mayor flexibilidad en su servicio.

Cuando se trata del mantenimiento del fondo de un tanque fuertemente corroído, se debe tomar en cuenta un aspecto importante, como la adecuada limpieza del tanque, requisito básico para hacer un tratamiento superficial por chorro abrasivo, según Norma ISO 8501-1 Sa 2 (ver anexo 1).

Los sistemas de pintura, no deberán ser usados para camuflar los daños o para reforzar un inaceptable estado estructural del tanque. Por eso es importante la correcta elección de un sistema de protección anticorrosivo duradero, para la protección del tanque.

Para elegir un sistema de pintura, tener en cuenta los siguientes criterios:

a. Productos Químicos a ser almacenados en el tanque.
b. Flexibilidad: cambios futuros en el servicio del tanque
c. Condiciones de aplicación a mantener durante la ejecución de los trabajos. (ventilación, temperatura del sustrato, etc.)
d. Equipos disponibles de aplicación y experiencia del aplicador.
e. Tiempo disponible para la realización de los trabajos en el tanque (número de capas y tiempo de curado antes de la puesta en servicio del tanque)
f. Riesgos potenciales de migración del revestimiento a la carga del tanque.
g. Preferencia por colores claros para una más fácil inspección y aplicación.
h. Características de flexibilidad del revestimiento en caso de posibles deformaciones en el fondo del tanque.
i. Conocimiento de la legislación en la emisión de volátiles orgánicos. Productos con bajo nivel de volátiles serán preferidos.
j. Los certificados de calidad que se vayan a requerir.
k. Condiciones del acero (para aceros fuertemente atacados, sistemas de pinturas sin disolvente, son los más adecuados).
l. Bajo costo, por el tiempo de vida útil.
m. Facilidad de limpieza de la capa de acabado aplicada.

4.4.2 Mantenimiento de un tanque de almacenamiento.

Antes de empezar el mantenimiento de un tanque de almacenamiento, se realiza un plan donde todos los trabajos necesarios deberán de ser cuidadosamente planificados. Si se hace adecuadamente, la calidad del trabajo será óptima y se podrá solucionar o preveer circunstancias inesperadas, en alguna de las partes del plan. Para realizar cualquier trabajo de mantenimiento en el interior del fondo del tanque de almacenamiento de petróleo, se debe seguir el siguiente procedimiento de trabajo:

Limpieza del tanque.

Antes de empezar con la extracción de residuos, el tanque deberá ventilarse hasta obtener una total desgasificación del mismo.

La eliminación de residuos y contaminantes (lodo, agua, grasa, crudo) se realiza normalmente por lavado con agua a alta presión, en combinación con el uso de detergentes adecuados, vapor, etc. Despúes de la limpieza, se requerirá un enjuague de la superficie con agua dulce, para asegurar que todos los residuos solubles en agua se han eliminado totalmente. La presencia de sales solubles irá en perjuicio de cualquier tipo de sistema de revestimiento, que estará expuesto a una inmersión permanente.

Para mantener la superficie limpia y evitar que se contamine con la parte interna del tanque, se recomienda sellar la parte superior utilizando el techo flotante y, sellar la abertura que exista entre el tanque y el techo flotante, para protegerlo de la lluvia.

Condiciones de la superficie

Antes de realizar la preparación de la superficie, debe realizarse una previa inspección, revisando los contaminantes que puedan existir. El resultado de esta inspección determinará el procedimiento del pre tratamiento.

- Las superficies con escamas de laminación, deben de ser eliminadas mediante herramientas neumáticas o martillo, previo al chorreado.
- Las superficies con ángulos deben ser redondeadas aproximadamente a 3mm de radio como mínimo.
- Todo punto de salpicadura debe ser removida mediante medios mecánicos.
- El corte o soldadura, debe ser nivelada, eliminando los residuos y las quemaduras que suelen presentarse cuando se realiza este tipo de trabajo.
- La soldadura mal rellenada, debe ser nuevamente soldada antes de cualquier trabajo de mantenimiento.
- Laminación existente en la superficie, debe ser eliminada mediante medios mecánicos.
- El trabajo de soldadura o corte adyacente al área, debe ser terminado antes de realizar la preparación de superficie.
- Si después de haber reparado mediante soldadura, quedara la superficie con filos, éstos deben ser removidos hasta obtener una superficie completamente lisa.

Requerimiento adicional

Debe existir el suficiente espacio para poder trabajar, sin ningún inconveniente, dentro de los tanques y para instalar el sistema de ventilación requerido.

Aceptación de las condiciones iniciales de la superficie

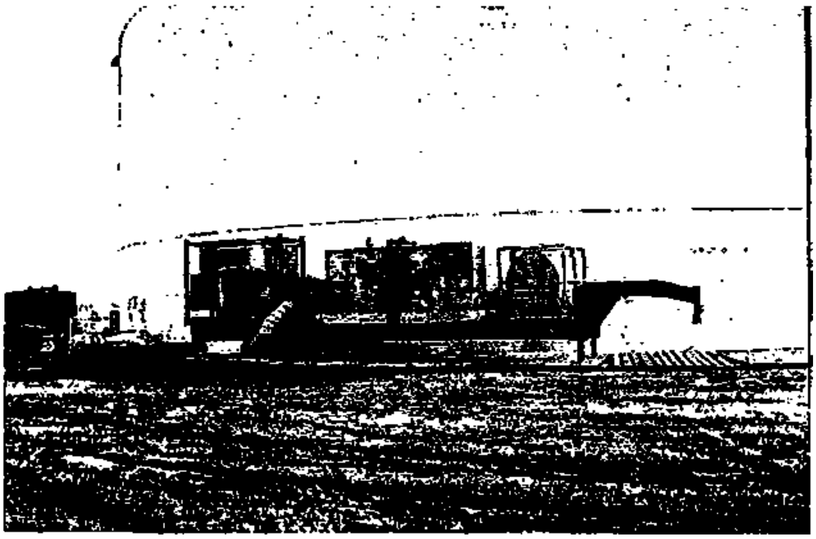
Una vez realizada la inspección previa, y dadas las condiciones, el ingeniero encargado de la inspección da el visto bueno en coordinación con la empresa contratista que realiza la aplicación del revestimiento, así como con el cliente responsable del tanque y de la empresa contratista que realiza los trabajos previos de preparación de superficie.

Preparación de la Superficie y especificación del sistema de Pinturas

- Visibilidad: Se debe proporcionar la luz necesaria, para que los trabajos se realicen con la suficiente visibilidad, para lo cual se utilizan reflectores.
- Ventilación: Una ventilación adecuada debe mantenerse durante todo el tiempo de la preparación de superficie (chorreado con abrasivo), la aplicación del sistema de pinturas y durante su proceso de curado, de acuerdo a las instrucciones del fabricante de pinturas.

  La ventilación debe ser lo suficiente capaz para prevenir la condensación del agua en la superficie a tratar, si fuera necesario debe utilizarse deshumidificadores (Figura 4.11).

Figura 4.11: Deshumidificador

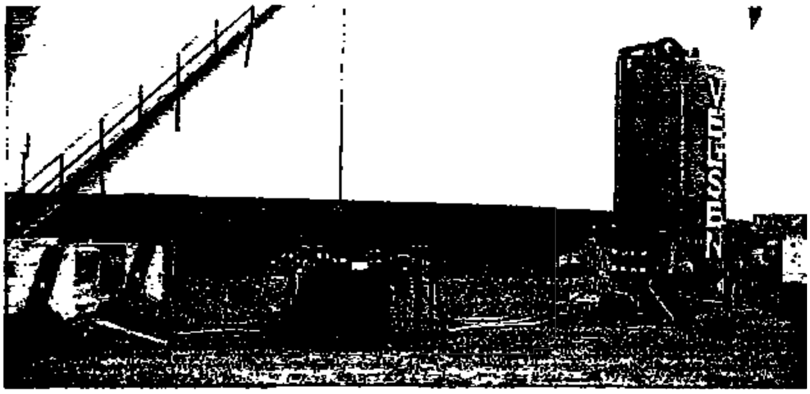


Aire comprimido para el trabajo de arenado: Todo equipo que proporciona aire comprimido, debe tener filtros de humedad y de aceite, para conseguir que el aire de la boquilla del equipo de arenado este libre de grasa y humedad. Además debe proporcionar suficiente presión para que el trabajo se realice de manera eficiente y efectiva.

La compresora de aire (Figura 4.12) para el trabajo de chorreo mediante abrasivo, debe suministrar como mínimo 9m^3/min. por boquilla y 7 atm. (100 psi) de presión. El filtro de aceite debe estar a 7.5 m de la salida del aire.

Para evitar contaminación por aceite y humedad en la superficie del tanque, se debe realizar una prueba de acuerdo a la Norma ASTM D-4285 (ver anexo 1). Ésta debe realizarse antes de comenzar la preparación de superficie y cada 4 horas de trabajo de la compresora; si se produce fallas, se cambian los filtros de humedad y aceite.

Figura 4.12: Compresora de Aire



Preparación de la Superficie

Antes de realizar la preparación de superficie, se debe realizar una limpieza, eliminando los residuos remanentes de petróleo, grasa u otros contaminantes sobre la superficie del fondo del tanque.

Según *Norma ISO 8504-1 "Preparación de superficie de acero antes de la aplicación de pinturas y productos relacionados. Métodos de preparación de superficie. Generalidades"* se puede utilizar vapor de agua, así como agua a alta presión (con detergentes) para remover petróleo, grasa y otros contaminantes. En el caso de utilizar agua a presión con detergentes, se debe realizar un enjuague después de la limpieza para remover los remanentes de detergente, así como material soluble al agua.

Control de Humedad y ventilación (durante el chorreado y el pintado)

El contratista debe proporcionar suficientes equipos de ventilación, calor, enfriamiento o deshumidificadores, en todas las etapas que implica el pintado del interior del tanque, como por ejemplo: preparación de superficie, pintado y curado de la pintura. Las condiciones en el interior del tanque deben mantenerse de acuerdo a lo siguiente (Se observa adicionalmente en la Figura 4.13):

El tanque debe estar libre de condensación.

La temperatura de la superficie a recubrir debe ser mayor en 3°C a la temperatura de rocío, recomendado por todos los fabricantes de pinturas y recubrimientos.

Durante la preparación de la superficie mediante el chorro abrasivo, la humedad relativa del medio debe ser inferior al 80% (la calidad de la superficie después de haberse tratado por chorro abrasivo se mantendrá por mucho más horas si la humedad es menor al 50%).

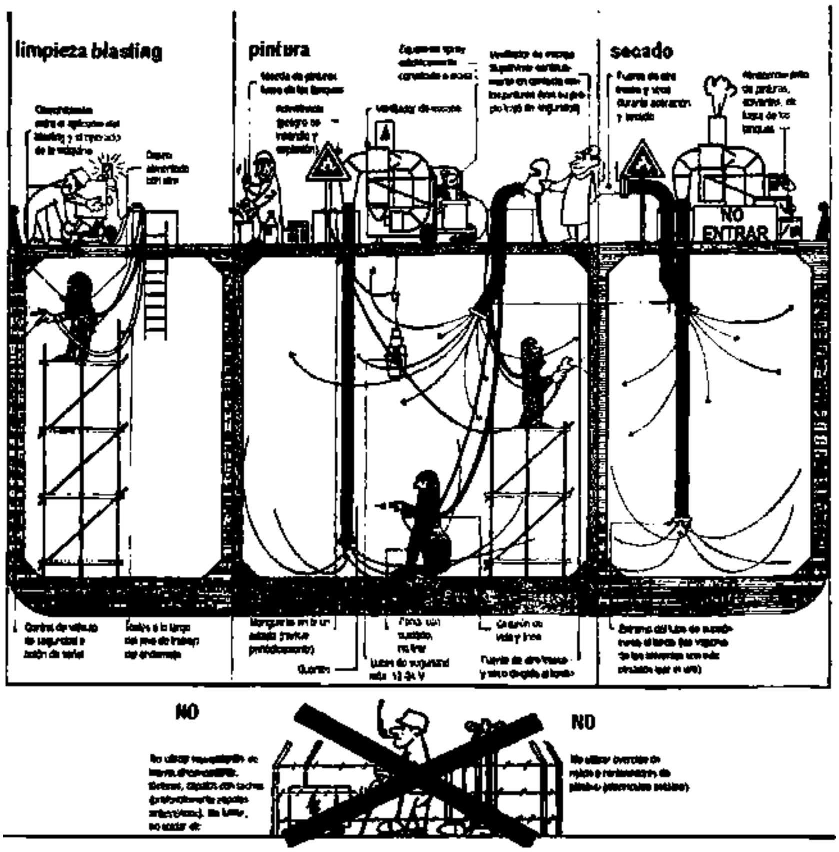
Durante la aplicación de la pintura y el proceso de curado (secado), el tanque debe mantenerse bien ventilado, así como libre de condensación.

Los ductos de ventilación deben ser acomodados de tal forma que la circulación del aire sea la óptima.

Si hay lluvia, tener en consideración la adecuada protección para evitar el ingreso del agua de lluvia al tanque.

En condiciones de bajas de temperaturas, aislar el tanque de manera que éste pueda mantener su temperatura de aplicación y evitar así la demora en el secado de la pintura.

Figura 4.13: Esquema de Trabajos en espacios confinados



Colocación de andamios

Si es necesario colocar andamios, éstos deben ser colocados de manera que sea accesible a todo el ambiente en forma segura, teniendo especial cuidado en las zonas donde no se realizará algún trabajo. La distancia entre la superficie y el andamio debe ser mínimo 30 cm y máximo 60 cm. Si hubiera algún contacto entre los andamios y la superficie, debe ser resanado de manera inmediata.

Todo andamio debe ser de fácil limpieza.

Todos los andamios deben de ser armados antes de hacer el tratamiento mediante chorro abrasivo, y deben ser removidos cuando el sistema de pintura aplicado haya sido aceptado.

Limpieza mediante chorro abrasivo

El grado de limpieza mediante chorro abrasivo, debe estar de acuerdo a la especificación de la pintura, de acuerdo a lo mencionado en la ISO 8501-2 (ver anexo 1).

Los tipos de abrasivos usados para el tratamiento de la superficie, deben encontrarse de acuerdo a las especificaciones descritas en las normas *ISO 11124 "Preparación de superficie de acero antes de la aplicación de pinturas. Especificación de abrasivos metálicos destinados a la preparación de superficie por chorreado"* e *ISO 11126 "Preparación de superficie de acero antes de la aplicación de pinturas. Especificación de abrasivos no metálicos destinados a la preparación de superficie por chorreado"*:

Abrasivos de preferencia nuevos y de origen mineral (Figura 4.14).

Los abrasivos minerales tales como el corindón, silicato de aluminio, son adecuados para remover óxidos, escama de laminación, pintura antigua, imprimaciones de taller del acero mediante el chorro a presión y dando excelentes perfiles de anclaje. Si se va a utilizar abrasivo reciclado, debemos estar seguros que estará libre de grasa, petróleo, sales solubles, estando dentro de las especificaciones.

Cualquier material se considera abrasivo para ser usado siempre y cuando esté libre de contaminantes como suciedad, petróleo, grasa, sales solubles, sustancias tóxicas, materia orgánica. El proveedor del abrasivo debe certificar que éste cumple con lo mencionado.

El pH se determina utilizando 100 g de una muestra representativa del abrasivo, previamente molida en un mortero. Aproximadamente 50 g de este material se le añade 200 ml de agua desionizada. El pH de este lodo se puede medir mediante un pH-metro con una precisión de +/- 0,01 unidad de pH. El pH obtenido no debe ser menor a 6,2.

La cantidad de sales solubles en agua del abrasivo puede determinarse según norma *ISO 11127-6 ("Preparación de superficie de acero antes de la aplicación de pinturas y productos relacionados. Métodos de ensayo para abrasivos no metálicos destinados a la preparación de superficie por chorreado. Parte 6: Determinación de los contaminantes solubles en agua mediante medidas de conductividad")*, mezclándose con agua desionizada en proporción de 1:2 (en volumen, ejemplo 50 cm^3 de abrasivo con 100 cm^3 de agua desionizada con un máximo de conductividad de 1 μS/cm). La mezcla es batida durante 5 min. Se decanta el agua y se mide la conductividad (Con los equipos mostrados en Figura 4.15). Si la conductividad excede los 300 μS/cm, el abrasivo se rechaza.

El contenido de humedad del abrasivo se determina de acuerdo a la norma ISO 11125-7 *("Preparación de superficie de acero antes de la aplicación de pinturas y productos relacionados. Métodos de ensayo para abrasivos metálicos destinados a la preparación de superficie por chorreado. Parte 7: Determinación de la humedad")*, la cual indica que debe pesar aproximadamente 200 g (en una balanza con precisión de 0,1 g), en un envase y se seca a temperatura entre 105 - 110° C durante 3 horas, pudiéndose extender a mas dependiendo del cambio de porcentaje de humedad no sea mas del 0,1%.

El cálculo de la humedad se da por la siguiente fórmula:

$$\% \text{ de Humedad} = \frac{\text{Peso inicial} - \text{Peso final}}{\text{Peso inicial}} \text{ X } 100$$

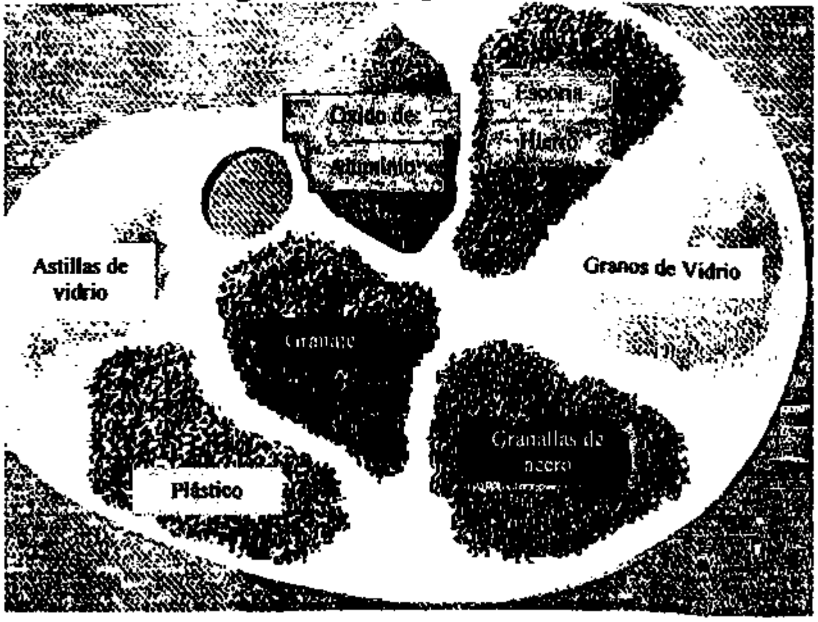
El contenido de humedad del abrasivo no debe exceder el 0,5% en peso.

El abrasivo no debe estar contaminado de aceite y grasas; para verificar se mezcla 10 cm^3 de abrasivo con 10 cm^3 cloruro de metileno o aguarrás durante 5 min. luego se coloca sobre un vidrio 5 gotas de este solvente. Después de evaporarse el solvente, este vidrio se lleva a luz ultravioleta en total oscuridad, si se observa luz color azul, el abrasivo es rechazado.

Los granos de abrasivo deben de ser de forma angular (para obtener mayor perfil de anclaje).

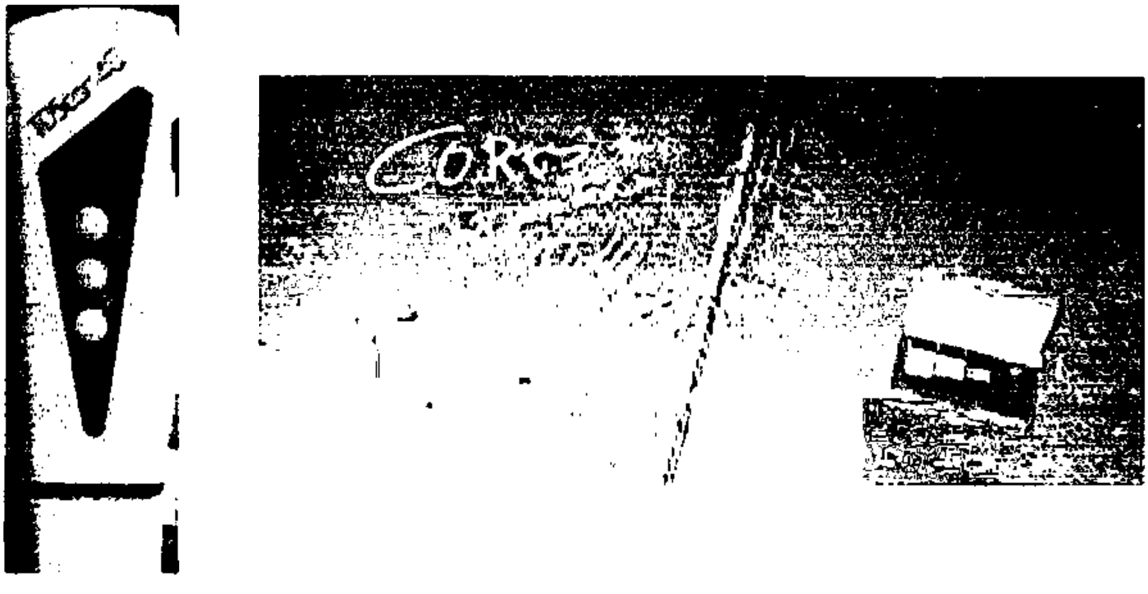
El material abrasivo debe dar como perfil de anclaje entre 50 a 100 μm (2 a 4 mils).

Figura 4.14: Tipos de abrasivos



Antes de comenzar a realizar el trabajo de limpieza mediante chorro abrasivo deben realizarse pruebas previas, para determinar las sales solubles que existan en la superficie. Adicionalmente se debe inspeccionar el perfil de anclaje y la rapidez de remoción del abrasivo pulverizado. El máximo nivel de sales solubles permisible en niveles de cloruros es de 60 mg/m^2, que corresponde a una conductividad de 12 µS/cm (se realiza esta prueba de acuerdo a la norma ISO 8502 o llamada Prueba del parche Bresle del anexo 1). Si la prueba indica niveles más altos de cloruros, será necesario hacer una limpieza adicional.

Figura 4.15: Conductivímetro y aplicación del parche Bresle

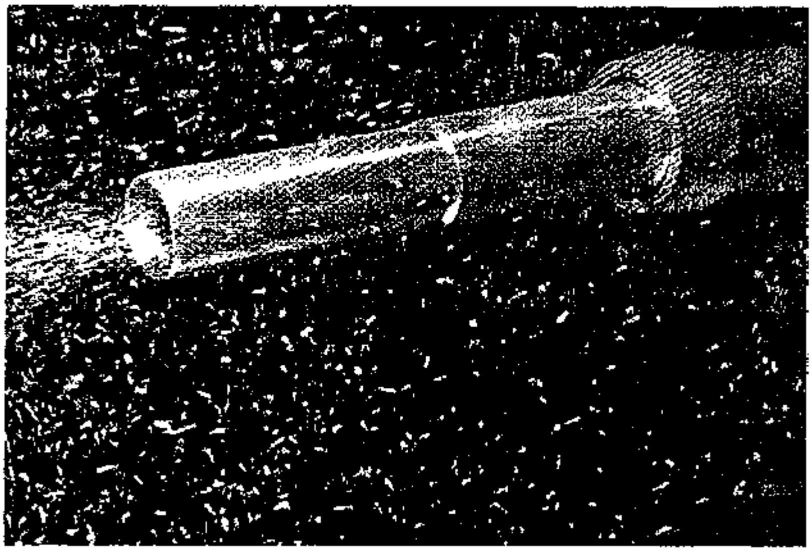


Para realizar el proceso de chorro abrasivo se utilizan las Boquillas de arenado (Figura 4.16), que son de dos tipos:

Perfil recto: velocidad de salida 300 km/h (para eliminar pintura y óxidos).

Venturi: velocidad de salida 700 km/h (para eliminar escama de laminación).

Figura 4.16: Boquilla de arenado



Avance del arenado (ver cuadro 4.17)

Cuadro 4.17 RELACION DE BOQUILLA DE ACUERDO CON EL RENDIMIENTO Y CONSUMO DE ARENA O ABRASIVO

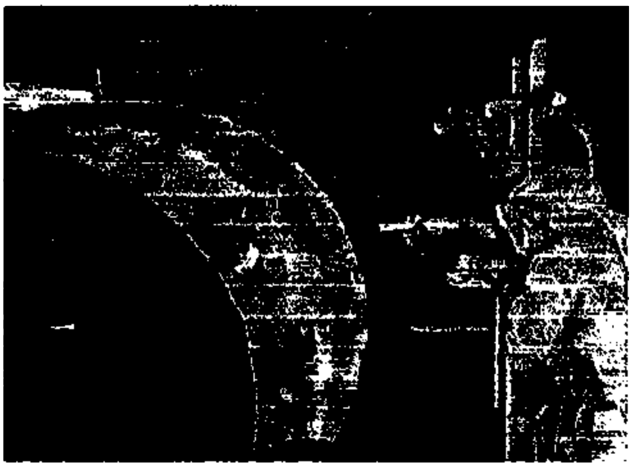
Diámetro interno boquilla		Rendimiento	Consumo	Consumo	Potencia de
Pulgadas	mm	(m^2/h)	de aire (pcm*)	de arena (kg/m^2)	motor (hp)
¼	6,4	10	81	224	17
5/16	8,0	15	137	368	29
3/8	9,6	20	196	524	41
7/16	11,2	30	254	720	53
1/2	12,7	40	338	920	70

pcm= pie cúbico por minuto.

Después de realizar la limpieza mediante chorro abrasivo (Figura 4.18), la superficie debe estar libre de escamas de laminación, óxido, grasa, restos de pinturas y otros materiales extraños, de acuerdo a la especificación.

Si se utiliza andamios, tomar en cuenta la limpieza de las zonas de apoyo del andamio, en el fondo del tanque.

Figura 4.18: Chorreado con abrasivo

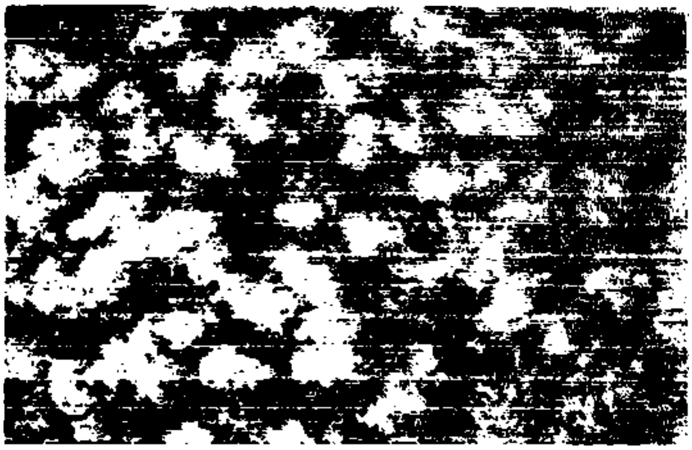


Arenado.

Los sistemas de revestimiento de tanques, alcanzan su máxima performance cuando se aplican sobre sustratos de acero arenados con un alto grado de limpieza y perfil de anclaje (rugosidad). Por tanto se recomienda que la rugosidad media (Rz) sea entre 50-100 µm (2-4 mils) y que el grado de limpieza sea según la Norma ISO 8501-1 Sa 2 1/2 (ver anexo 1)

Ver en la Figura 4.19 el grado de corrosión severa del fondo del tanque.

Figura 4.19: Corrosión severa



El grado de corrosión observado en la Figura 4.19, corresponde a un grado D como se describe en la norma SSPC-VIS 1 (ver anexo 1). Las fotos de este Standard de referencia, ilustran las condiciones iniciales de corrosión antes de la preparación superficial, cubriendo el rango desde la cascarilla de laminación hasta el acero picado. Durante el mantenimiento del fondo de un tanque, grados de corrosión mayor que B se verán en forma frecuente y éstos deberán de ser pre-tratados, tal como indica la norma SSPC-VIS-1.

Limpieza de la Superficie: después del tratamiento de la superficie

Inmediatamente después de haber tratado la superficie con el chorro abrasivo, se realiza una limpieza removiendo todo el polvo y suciedad antes de efectuar el trabajo de pintado.

Los andamios deben estar libres de polvo y suciedad.

La limpieza final deberá realizarse con aspiradoras industriales (Figura 4.20) para que la superficie esté completamente libre de polvo. Se debe tener especial cuidado en la limpieza de las zonas que presenten picaduras y zonas soldadas.

Después de haberse limpiado por completo, es necesario realizar la inspección de la superficie: el perfil de anclaje recomendado, y la remoción total del abrasivo de la superficie. Se debe realizar también el test de la conductividad para determinar el contenido de sales solubles (como indicamos líneas arriba no debe exceder los 60 mg/m^2 o el equivalente 12 μS/cm según el método del parche Bresle de la norma ISO 8502 (ver anexo 1).

La preparación de la superficie debe estar de acuerdo a la norma ISO 8501-1 Sa 2 ½.

El perfil de anclaje puede ser medido de manera visual o mediante equipos descritos en la norma ASTM D 4417-93 método C (ver anexo 1).

Figura 4.20: Limpieza del abrasivo con aspiradora industrial

Sistema de pintura

Todas las pinturas, en las hojas técnicas indican sus propiedades, modo de preparación y los equipos que se utilizan para su aplicación.

Para el tipo de pintura libre de solventes se tiene las siguientes especificaciones:

Nº Capa	Función	Pintura	Espesor de película seca (eps) - micrones
1	Imprimante	Epoxi curado con aducto de poliamida	50,0
2	Relleno de picaduras	Epoxi libre de solventes	Dependiendo de la profundidad
3	Nivelación de uniones y ángulos	Mortero epóxico (epóxico + sílice)	-
4	Revestimiento + fibra de vidrio	Epóxico libre de solventes + fibra proyectada	1200
5	Pintura de acabado	Epoxi libre de solventes	300

Tanques de almacenamiento antiguos

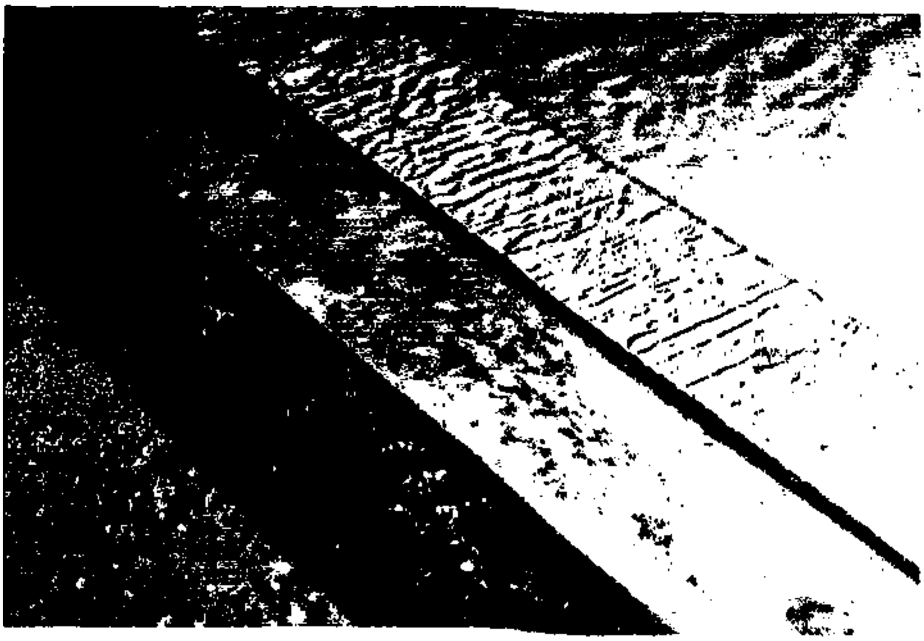
Antes de la aplicación del sistema de pinturas en tanques de almacenamiento antiguos, debe evaluarse y hacer un tratamiento previo como rellenar picaduras, usar imprimantes promotores de adherencia, tanto en el fondo del tanque así como en los techos. En algunos casos, será necesario reforzar los fondos de tanques con fibra de vidrio, ya sea como mantos o fibras cortadas (Figura 4.21). Se puede utilizar mantos con la especificación de 450 g/m^2.

Figura 4.21 Aplicación de fibra de Vidrio: Mantos (izquierda) y en fibras (derecha)

Imprimación de taller

Este tipo de imprimación o base, se utiliza en algunos casos después de la limpieza por arenado donde las condiciones de humedad no puedan ser controlados del todo, siendo su uso temporal. Adicionalmente facilita la detección de imperfecciones como picaduras, salpicaduras de soldadura, quemaduras, etc. Un buen imprimante es aquella pintura epóxica, que es curado con un aducto de poliamida a 50 micrones de espesor de película seca (capa color roja, ver figura 4.22) y que tiene una excelente adhesión al sistema de pinturas recomendado, aumentando así su durabilidad.

Figura 4.22: Sistema de pintura completo: Imprimante (película roja), Relleno de picaduras (película celeste trasparente), Manto de fibra de vidrio (plateado) y pintura libre de solventes (celeste)

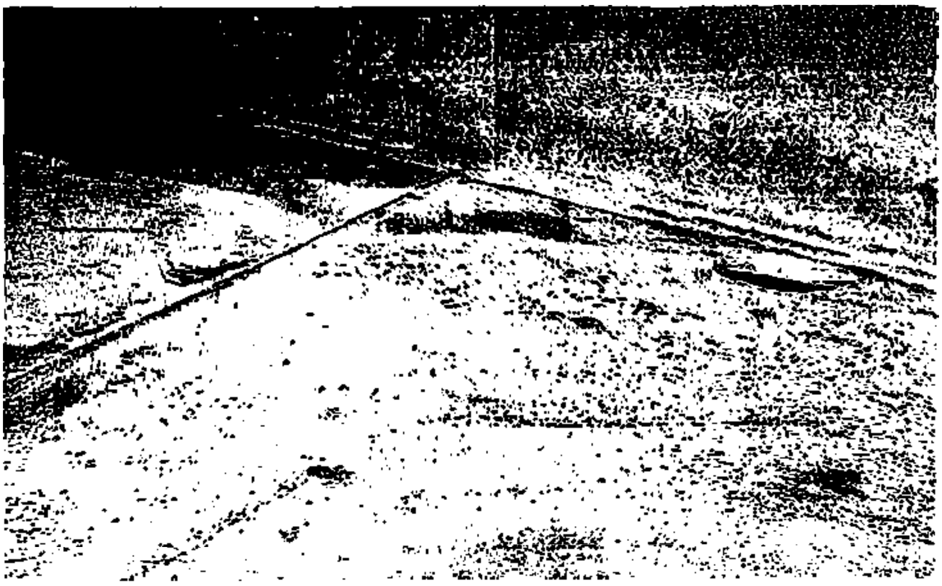


Reparación de picaduras

Tal como se ha descrito anteriormente, la corrosión por picadura se encuentra en el fondo de los tanques, por lo que generalmente las paredes verticales solo se pintan o recubren los primeros 0,3 a 1,5 m, y lo demás se deja sin recubrir, pues no tienen contacto con el agua que se deposita en el fondo.

Las picaduras observadas en el fondo del tanque tienen una profundidad de 8 mm tal como se indica en la figura 4.23.

Figura 4.23: Interior del fondo de un Tanque con Picaduras



Si la corrosión por picadura ataca de manera profunda al fondo del tanque, es necesario repararlo para evitar que, en un futuro, la corrosión perfore todo el espesor del tanque y no ocurra un derrame del petróleo, por lo que se procede de la siguiente manera:

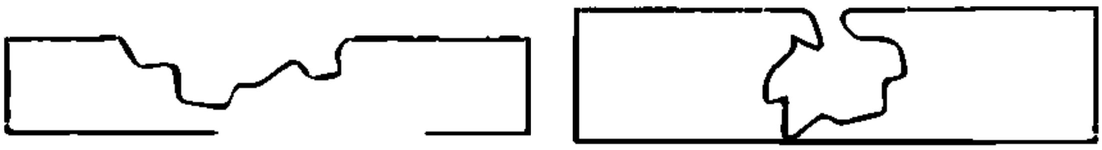
Cuando la plancha de metal ha perdido más del 50% de espesor por las picaduras es necesario cambiar esa plancha.

Cuando la plancha de metal ha perdido menos del 50% de espesor por las picaduras, podrá ser rellenada con pinturas libre de solventes.

Generalmente, alrededor de las picaduras el acero sufre fuertes ataques de corrosión, será necesario dar capas gruesas de pintura, para nivelar la superficie y proporcionar la protección adecuada contra la corrosión.

Los dibujos en la Figura 4.24 representan las picaduras en el fondo del tanque rellenadas con pintura 100% sólida.

Figura 4.24: Tipos de picaduras.



Cráter abierto

Picadura Tipo "Omega"

▭ Revestimiento.

Techo Flotante

Los techos flotantes en los tanques de almacenamiento de petróleo, también deben ser recubiertos, siendo el procedimiento de protección el siguiente:

Realización de la limpieza con chorro abrasivo según norma ISO Sa 2,5 (ver anexo 1).

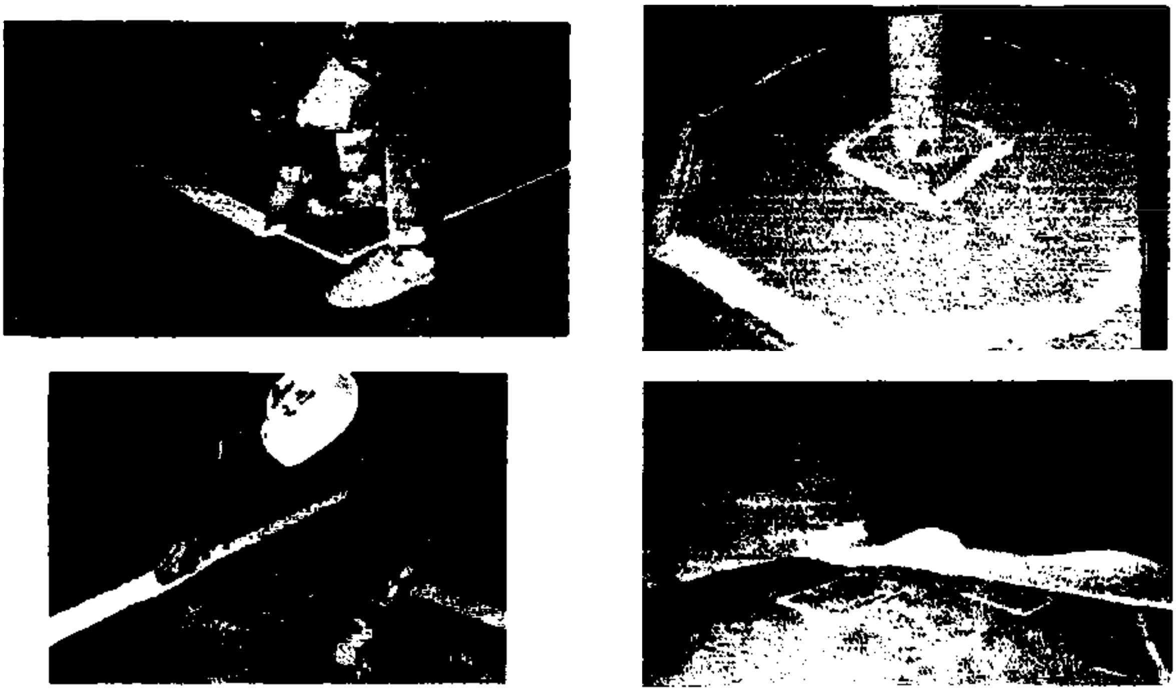
Aplicación de la pintura libre de solventes, a espesores de película seca 2000 a 3000 micrones.

Zonas inaccesibles en el fondo del tanque

En zonas que son difíciles de aplicar la pintura, es necesario que se recubra con un material de relleno (mortero epóxico= pintura libre de solventes mezclado con sílice). Este material se utiliza en placas soldadas, juntas traslapadas y juntas del tanque, tal como se observa en la figura 4.25.

Para reforzar este sistema de pintura, se usa fibra de vidrio, ya sea como manto o como fibra cortada. Sin el material de relleno se dificultaría la instalación de este refuerzo.

Figuras 4.25: Aplicación del material de relleno



4.4.3 Preparación de la aplicación de la pintura

Toda pintura aplicada en la superficie, debe mantenerse seca y limpia, hasta la culminación de los trabajos.

Para prevenir la condensación durante la aplicación y el curado de la pintura, la temperatura de la superficie debe mantenerse 3° C, por encima de la temperatura del punto de rocío.

Durante la aplicación, cada pintura del sistema recomendado debe ser medido el espesor de película húmeda, mediante un medidor de película húmeda según norma ASTM D4414 (ver anexo 1).

Aplicación de la pintura 100% sólidas

Aplicada la pintura de imprimación y después de haber rellenado todas las picaduras, se procede a realizar el pintado de la superficie en referencia, teniendo las siguientes recomendaciones:

La pintura libre de solventes debe ser aplicada directamente sobre la superficie tratada, tal como se aprecia en la figura 4.26.

La aplicación de este revestimiento se debe realizar con equipo airless (equipo 60:1).

Los espesores recomendados por capa debe ser de 300 micrones.

En zonas donde existe ángulos, uniones, soldaduras, etc. Debe aplicarse previamente una capa de pintura llamada "stripecoat" (capa delgada que se aplica antes de una capa de pintura para alcanzar el espesor recomendado en zonas de difícil acceso), después de su secado se procede a aplicar el espesor recomendado.

Se deben evitar durante la aplicación defectos tales como, exceso de espesor, inadecuada mezcla, o espesores bajos. Cada pintura del sistema especificado, debe ser inspeccionado incluido el stripecoat.

La película de pintura debe ser uniforme, libre de pulverizado seco ("overspray"), chorreo, cortinas, agujeros, suciedad y restos de abrasivos (figura 4.27). Todos estos defectos deben ser resanados antes de aplicar la siguiente capa de pintura y debe estar dentro de los limites de repintados. El polvo remanente debe ser eliminado mediante aspiradoras industriales.

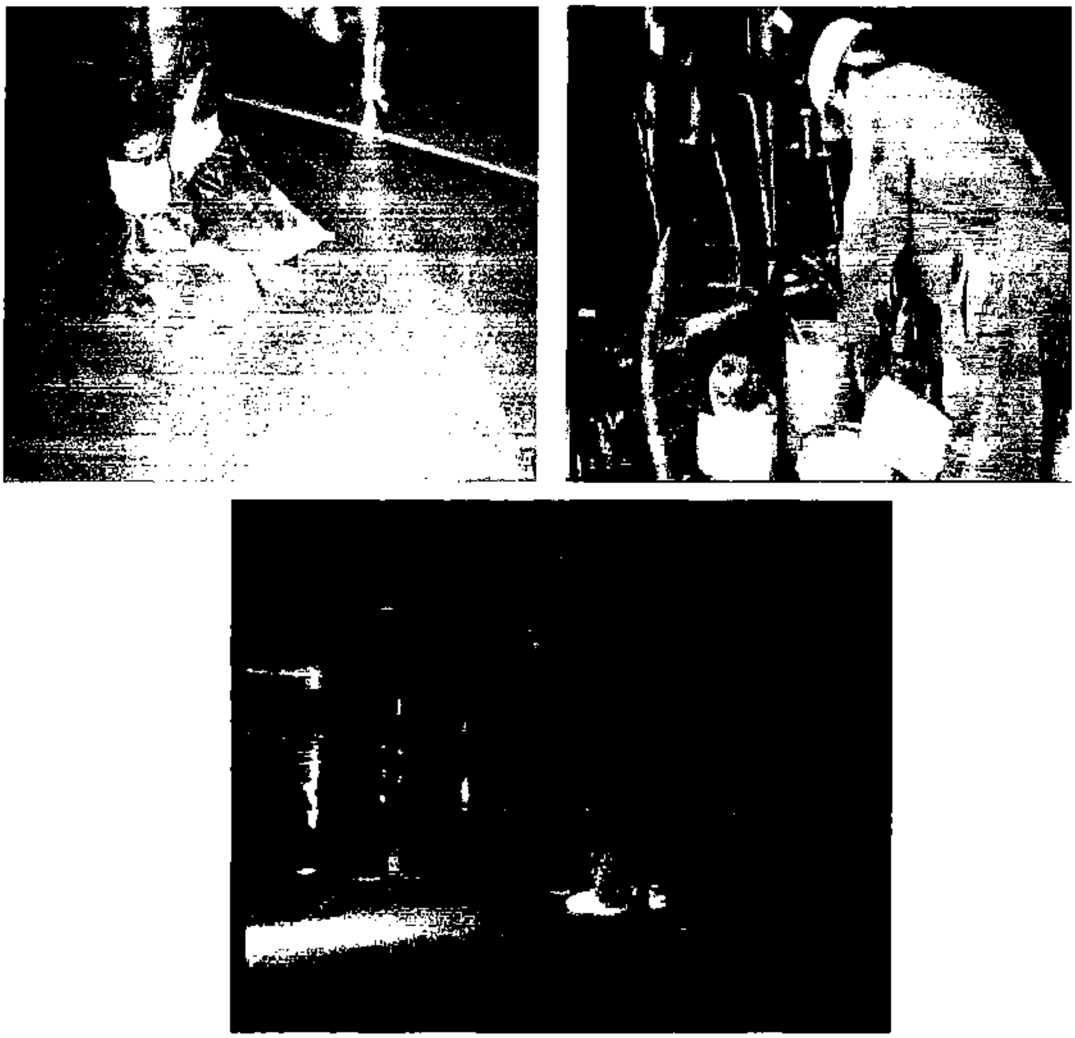
El overspray, debe ser evitado en todo momento durante la aplicación, si fuera posible hacer pruebas previas antes de aplicar directamente sobre la superficie. Si hubiera el overspray en la superficie, debe ser reparado.

La medición del espesor de película seca se realizará con un medidor no destructivo. En el caso de esta pintura libre de solventes, tiene una baja dureza inicial por lo que se sugiere esperar unos días para hacer la respectiva medición. La medición de los espesores de películas secas debe realizarse de acuerdo a la norma SSPC PA 2 *("Método de Medición de espesores de película seca de un recubrimiento no magnético sobre una superficie magnética con instrumentos")*.

El pintado de cada capa de pintura, debe realizarse dentro de los intervalos de repintados especificados en las hojas técnicas proporcionado por el fabricante.

Todas las pinturas deben ser almacenadas en lugares donde la temperatura oscile entre 10 - 30° C. Para las pinturas libres de solventes, debe almacenarse por lo menos un día antes en un lugar donde la temperatura oscile entre 20 - 25° C.

Figuras 4.26: Pintado del fondo de un Tanque



Figuras 4.27: Acabado final: Pintura epoxi coaltar (lado izquierdo) vs. Pintura libre de solventes (lado derecho)

4.4.4 Pruebas a realizar después de la aplicación y curado de la pintura

Adhesión

La adherencia se debe medir de acuerdo a las Normas ASTM D 3359 (ver anexo 1) y ASTM D 4541 (ver anexo 1)

Para la aceptación del Sistema de Pinturas, se requiere como mínimo los siguientes resultados :

- ASTM D 3359: 5 A
- ASTM D 4541: mínimo 500 psi

Para la inspección se utilizan los equipos de la figura 4.28.

Figura 4.28: Equipos utilizados en la inspección (de izquierda a derecha): Cuchilla, medidor de humedad, medidor de espesor de película seca digital

Detección de agujeros

Los pinholes o agujeros, suelen presentarse cuando se realiza aplicación a altos espesores. Se recomienda hacer una inspección mediante la norma ASTM G 62 (ver anexo 1) usando un equipo que suministra voltaje, sobretodo a espesores mayores a 500 micrones. Cualquier agujero debe ser resanado inmediatamente.

Retiro de los andamios

Los andamios se retirarán siempre y cuando se hayan terminado por completo los trabajos en las zonas altas, haber sido aceptado y con el visto bueno del inspector en recubrimientos. Durante el retiro, se debe tener mucho cuidado de no deteriorar la pintura que recientemente ha sido aplicada. Si hubiera algún deterioro se hace el resane de manera inmediata, de acuerdo al sistema de pintura especificado.

4.4.5 Criterios de aceptación del trabajo realizado

La recepción de los trabajos de pintado se realizará conforme a los siguientes criterios:

El espesor de película seca debe estar de acuerdo al especificado en el sistema de pintado y se evaluará de acuerdo a SSPC PA 2.

No deben existir defectos de aplicación como “pinholes”, grumos y zonas descubiertas.

4.4.6 Responsabilidades

Es responsabilidad del Ingeniero Residente de la obra y el supervisor del Departamento Técnico del fabricante de las pinturas, el total cumplimiento del presente procedimiento en la obra.

Si las condiciones ambientales (temperatura, lluvia, etc.), así como el estado de los equipos de aplicación no son satisfactorios a criterio del Supervisor (del fabricante de pinturas), los trabajos se suspenderán, a fin de salvaguardar la correcta protección del fondo del tanque con el sistema de pintura recomendado.

4.5 Comparación de costos entre las pinturas epóxicas convencionales y las 100% sólidas.

Considerando la importancia de analizar costos entre pinturas, se ha realizado la comparación tomando como base un área de 1000 m^2, consiguiendo los siguientes costos de pintura epóxica convencional con solventes (Cuadro 4.29) y la pintura epóxica 100% sólida (Cuadro 4.30) y su aplicación:

Cuadro 4.29: Costos de Pintura Epóxica convencional con solventes

Descripción	Espesor Película Seca (mils)	% Sólidos en Volumen	Rendimiento Teórico (m2/mil)	Pérdidas (%)	Rendimiento Práctico (m2/mil)	Cantidad Galones	P. Unit. US$	P. Total US$
Costo de la pintura epóxica del tipo coaltar	6	76	19	30	13	75	30.0	2,255.6
Costo de la pintura epóxica del tipo coaltar	6	76	19	30	13	75	30.0	2,255.6
Costo del diluyente epóxico	-	-	-	-	-	15	12.5	188.0
costo de aplicación por 2 capas de pintura	-	-	-	-	-	-	2.0	2,000.0

TOTAL US$ 6,699.2

Cuadro 4.30: Costos de Pintura Epóxica 100% sólida

Descripción	Espesor Película Seca (mils)	% Sólidos en volumen	Rendimiento Teórico (m2/mil)	Pérdidas (%)	Rendimiento Práctico (m2/mil)	Cantidad Galones	P. Unit. US$	P. Total US$
Costo de la pintura 100% sólidos	12	100	12.5	30	9	114	80.0	9,142.8
Costo de aplicación por 1 capa de pintura	-	-	-	-	-	-	1.0	1000.0
						TOTAL US$		10,142.8

De acuerdo a los cuadros anteriores, se observa lo siguiente:

La pintura epóxica 100% sólida cuesta aproximadamente 3 veces más que la pintura epóxica base solvente.

El costo total de aplicación entre las pinturas difieren en US $ 3443.6, a favor del sistema de pintura epóxica base solvente.

La duración del sistema de pintura epóxica base solvente es de 8 años y la de la pintura epóxica 100% sólida es de 25 años.

Con la pintura epóxica convencional tendría que hacer 2 mantenimientos adicionales para poder alcanzar la durabilidad del sistema de pintura epóxica 100% sólida, lo que significaría gastar US$ 13398.4 (dos mantenimientos) adicionales, lo cual ahorraríamos este monto en el tiempo, si utilizáramos las pinturas 100% sólidas.

Capítulo V. CONCLUSIONES

Con el uso de pinturas libre de solventes, se dará un mayor tiempo de vida útil a los tanques de almacenamiento de petróleo, ahorrando costos por mantenimiento a futuro.

Con el uso de pinturas libre de solventes, se protege el medio ambiente y se cuida la salud de los pintores, pues no se expone solventes al aire durante la aplicación de la pintura.

Con el uso de pinturas libre de solventes, se consigue ahorro en el costo y tiempo de mantenimiento evitando pérdidas por costos indirectos (costo por dejar de almacenar crudo).

Para que el sistema de pintura libre de solventes tenga durabilidad en el tiempo, es necesario seguir el plan de trabajo proporcionado en este informe por el ingeniero inspector en recubrimientos.

A pesar de que la pintura 100% sólidos es más cara que la pintura epóxica convencional, con el tiempo es más económica, pues se elimina costos por mantenimiento.

Capítulo VI. BIBLIOGRAFIA

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Capítulo VII. ANEXO 1

Se adjuntan normas técnicas mencionadas en el presente informe:

1. ASTM B-117: Standard Practice for Operating Salt Spray (Fog) Apparatus.

2. ASTM D-610: Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces.

3. ASTM D-714: Standard Test Method for Evaluating Degree of Blistering of Paints.

4. ASTM D-1654: Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments.

5. ASTM D-4285: Standard Test Method for Indicating Oil or Water in Compressed Air.

6. ISO 8501-1: Preparación de superficies de acero antes de la aplicación de pinturas y productos relacionados. Evaluación visual de la preparación de superficie. Parte 1: Grados de oxidación y grados de preparación de sustratos de acero y sustratos de acero después de remover toda pintura antigua.

7. ISO 8502-9: Test de Cloruros mediante el uso de Conductímetro.

8. SSPC VIS 1: Norma visual de preparación de superficie.

9. ASTM D-4417: Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel.

10. ASTM D-4414: Standard Practice for Measurement of Wet Film Thickness by Notch Gages.

11. ASTM D-3359: Standard Test Method for Measuring Adhesion by Tape Test.

12. ASTM D-4541: Standard Test Method for Pull-off Strength of Coating Using Portable Adhesion Testers.

13. ASTM G-62: Standard Test Method for Holiday Detection in Pipeline Coatings.

Designation: B 117 – 97

Standard Practice for Operating Salt Spray (Fog) Apparatus[1]

This standard is issued under the fixed designation B 117; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice describes the apparatus, procedure, and conditions required to create and maintain the salt spray (fog) test environment. Suitable apparatus which may be used is described in Appendix X1.

1.2 This practice does not prescribe the type of test specimen or exposure periods to be used for a specific product, nor the interpretation to be given to the results.

1.3 The values stated in SI units are to be regarded as standard. The inch-pound units in parentheses are provided for information and may be approximate.

1.4 *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:*

B 368 Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (CASS Test)[2]

D 609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products[3]

D 1193 Specification for Reagent Water[4]

D 1654 Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments[3]

E 70 Test Method for pH of Aqueous Solutions with the Glass Electrode[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

G 85 Practice for Modified Salt Spray (Fog) Testing[7]

3. Significance and Use

3.1 This practice provides a controlled corrosive environment which has been utilized to produce relative corrosion resistance information for specimens of metals and coated metals exposed in a given test chamber.

3.2 Prediction of performance in natural environments has seldom been correlated with salt spray results when used as stand alone data.

3.2.1 Correlation and extrapolation of corrosion performance based on exposure to the test environment provided by this practice are not always predictable.

3.2.2 Correlation and extrapolation should be considered only in cases where appropriate corroborating long-term atmospheric exposures have been conducted.

3.3 The reproducibility of results in the salt spray exposure is highly dependent on the type of specimens tested and the evaluation criteria selected, as well as the control of the operating variables. In any testing program, sufficient replicates should be included to establish the variability of the results. Variability has been observed when similar specimens are tested in different fog chambers even though the testing conditions are nominally similar and within the ranges specified in this practice.

4. Apparatus

4.1 The apparatus required for salt spray (fog) exposure consists of a fog chamber, a salt solution reservoir, a supply of suitably conditioned compressed air, one or more atomizing nozzles, specimen supports, provision for heating the chamber, and necessary means of control. The size and detailed construction of the apparatus are optional, provided the conditions obtained meet the requirements of this practice.

4.2 Drops of solution which accumulate on the ceiling or cover of the chamber shall not be permitted to fall on the specimens being exposed.

4.3 Drops of solution which fall from the specimens shall not be returned to the solution reservoir for respraying.

4.4 Material of construction shall be such that it will not affect the corrosiveness of the fog.

4.5 All water used for this practice shall conform to Type IV water in Specification D 1193 (except that for this practice limits for chlorides and sodium may be ignored). This does not

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[1] This practice is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.05 on Laboratory Corrosion Tests.

Current edition approved Apr. 10, 1997. Published November 1997. Originally published as B 117 – 39 T. Last previous edition B 117 – 95.

[2] *Annual Book of ASTM Standards*, Vol 02.05.

[3] *Annual Book of ASTM Standards*, Vol 06.01.

[4] *Annual Book of ASTM Standards*, Vol 11.01.

[5] *Annual Book of ASTM Standards*, Vol 15.05.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

[7] *Annual Book of ASTM Standards*, Vol 03.02.

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apply to running tap water. All other water will be referred to as reagent grade.

5. Test Specimens

5.1 The type and number of test specimens to be used, as well as the criteria for the evaluation of the test results, shall be defined in the specifications covering the material or product being exposed or shall be mutually agreed upon between the purchaser and the seller.

6. Preparation of Test Specimens

6.1 Specimens shall be suitably cleaned. The cleaning method shall be optional depending on the nature of the surface and the contaminants. Care shall be taken that specimens are not recontaminated after cleaning by excessive or careless handling.

6.2 Specimens for evaluation of paints and other organic coatings shall be prepared in accordance with applicable specification(s) for the material(s) being exposed, or as agreed upon between the purchaser and the supplier. Otherwise, the test specimens shall consist of steel meeting the requirements of Practice D 609 and shall be cleaned and prepared for coating in accordance with the applicable procedure of Practice D 609.

6.3 Specimens coated with paints or nonmetallic coatings shall not be cleaned or handled excessively prior to test.

6.4 Whenever it is desired to determine the development of corrosion from an abraded area in the paint or organic coating, a scratch or scribed line shall be made through the coating with a sharp instrument so as to expose the underlying metal before testing. The conditions of making the scratch shall be as defined in Test Method D 1654, unless otherwise agreed upon between the purchaser and the seller.

6.5 Unless otherwise specified, the cut edges of plated, coated, or duplex materials and areas containing identification marks or in contact with the racks or supports shall be protected with a suitable coating stable under the conditions of the practice.

Note 1—Should it be desirable to cut test specimens from parts or from preplated, painted, or otherwise coated steel sheet, the cut edges shall be protected by coating them with paint, wax, tape, or other effective media so that the development of a galvanic effect between such edges and the adjacent plated or otherwise coated metal surfaces, is prevented.

7. Position of Specimens During Exposure

7.1 The position of the specimens in the salt spray chamber during the test shall be such that the following conditions are met:

7.1.1 Unless otherwise specified, the specimens shall be supported or suspended between 15 and 30° from the vertical and preferably parallel to the principal direction of flow of fog through the chamber, based upon the dominant surface being tested.

7.1.2 The specimens shall not contact each other or any metallic material or any material capable of acting as a wick.

7.1.3 Each specimen shall be so placed as to permit free settling of fog on all specimens.

7.1.4 Salt solution from one specimen shall not drip on any other specimen.

Note 2—Suitable materials for the construction or coating of racks and supports are glass, rubber, plastic, or suitably coated wood. Bare metal shall not be used. Specimens shall preferably be supported from the bottom or the side. Slotted wooden strips are suitable for the support of flat panels. Suspension from glass hooks or waxed string may be used as long as the specified position of the specimens is obtained, if necessary by means of secondary support at the bottom of the specimens.

8. Salt Solution

8.1 The salt solution shall be prepared by dissolving 5 ± parts by mass of sodium chloride in 95 parts of water conforming to Type IV water in Specification D 1193 (except that for this practice limits for chlorides and sodium may be ignored). The salt used shall be sodium chloride substantially free of nickel and copper and containing on the dry basis not more than 0.1 % of sodium iodide and not more than 0.3 % of total impurities. Some salts contain additives that may act as corrosion inhibitors; careful attention should be given to the chemical content of the salt. Upon agreement between the purchaser and the seller, analysis may be required and limits established for elements or compounds not specified in the chemical composition given above.

8.2 The pH of the salt solution shall be such that when atomized at 35°C (95°F) the collected solution will be in the pH range from 6.5 to 7.2 (Note 3). Before the solution is atomized it shall be free of suspended solids (Note 4). The pH measurement shall be made at 25°C (77°F) using a suitable glass pH-sensing electrode, reference electrode, and pH meter system in accordance with Test Method E 70.

Note 3—Temperature affects the pH of a salt solution prepared from water saturated with carbon dioxide at room temperature and pH adjustment may be made by the following three methods:

(*1*) When the pH of a salt solution is adjusted at room temperature, and atomized at 35°C (95°F), the pH of the collected solution will be higher than the original solution due to the loss of carbon dioxide at the higher temperature. When the pH of the salt solution is adjusted at room temperature, it is therefore necessary to adjust it below 6.5 so the collected solution after atomizing at 35°C (95°F) will meet the pH limits of 6.5 to 7.2. Take about a 50-mL sample of the salt solution as prepared at room temperature, boil gently for 30 s, cool, and determine the pH. When the pH of the salt solution is adjusted to 6.5 to 7.2 by this procedure, the pH of the atomized and collected solution at 35°C (95°F) will come within this range.

(*2*) Heating the salt solution to boiling and cooling to 35°C (95°F) and maintaining it at 35°C (95°F) for approximately 48 h before adjusting the pH produces a solution the pH of which does not materially change when atomized at 35°C (95°F).

(*3*) Heating the water from which the salt solution is prepared to 35°C (95°F) or above, to expel carbon dioxide, and adjusting the pH of the salt solution within the limits of 6.5 to 7.2 produces a solution the pH of which does not materially change when atomized at 35°C (95°F).

Note 4—The freshly prepared salt solution may be filtered or decanted before it is placed in the reservoir, or the end of the tube leading from the solution to the atomizer may be covered with a double layer of cheesecloth to prevent plugging of the nozzle.

Note 5—The pH can be adjusted by additions of dilute ACS reagent grade hydrochloric acid or sodium hydroxide solutions.

9. Air Supply

9.1 The compressed air supply to the nozzle or nozzles for atomizing the salt solution shall be free of oil and dirt (Note 6) and maintained between 69 and 172 kPa/m^2 (10 and 25 psi).

Note 6—The air supply may be freed from oil and dirt by passing it through a water scrubber or at least 610 mm (2 ft) of suitable cleaning material such as sheep's wool, excelsior, slag wool, or activated[8] alumina. Commercial cartridge filters which include an expiration indicator may also be used.

10. Conditions in the Salt Spray Chamber

10.1 *Temperature*—The exposure zone of the salt spray chamber shall be maintained at $35 + 1.1 - 1.7$°C ($95 + 2 - 3$°F). The temperature within the exposure zone of the closed cabinet shall be recorded at least twice a day at least 7 h apart (except on Saturdays, Sundays, and holidays when the salt spray test is not interrupted for exposing, rearranging, or removing test specimens or to check and replenish the solution in the reservoir).

NOTE 7—A suitable method to record the temperature is by a continuous recording device or by a thermometer which can be read from outside the closed cabinet. The recorded temperature must be obtained with the salt spray chamber closed to avoid a false low reading because of wet-bulb effect when the chamber is open.

10.2 *Atomization and Quantity of Fog*— At least two clean fog collectors shall be so placed within the exposure zone that no drops of solution from the test specimens or any other source shall be collected. The collectors shall be placed in the proximity of the test specimens, one nearest to any nozzle and the other farthest from all nozzles. The fog shall be such that for each 80 cm^2 (12.4 $in.^2$) of horizontal collecting area there will be collected in each collector from 1.0 to 2.0 mL of solution per hour based on an average run of at least 16 h (Note 8). The sodium chloride concentration of the collected solution shall be 5 ± 1 mass % (Note 9). The pH of the collected solution shall be 6.5 to 7.2. The pH measurement shall be made as described in 8.2 (Note 3).

NOTE 8—Suitable collecting devices are glass or plastic funnels with the stems inserted through stoppers into graduated cylinders, or crystallizing dishes. Funnels and dishes with a diameter of 10 cm (3.94 in.) have an area of about 80 cm^2 (12.4 $in.^2$).

NOTE 9—A solution having a specific gravity of 1.0255 to 1.0400 at 25°C (77°F) will meet the concentration requirement. The sodium chloride concentration may also be determined using a suitable salinity meter (for example, utilizing a sodium ion-selective glass electrode) or colorimetrically as follows. Dilute 5 mL of the collected solution to 100 mL with distilled water and mix thoroughly; pipet a 10-mL aliquot into an evaporating dish or casserole; add 40 mL of distilled water and 1 mL of 1 % potassium chromate solution (chloride-free) and titrate with 0.1 *N* silver nitrate solution to the first appearance of a permanent red coloration. A solution that requires between 3.4 and 5.1 mL of 0.1 *N* silver nitrate solution will meet the concentration requirements.

10.3 The nozzle or nozzles shall be so directed or baffled that none of the spray can impinge directly on the test specimens.

11. Continuity of Exposure

11.1 Unless otherwise specified in the specifications covering the material or product being tested, the test shall be continuous for the duration of the entire test period. Continuous operation implies that the chamber be closed and the spray operating continuously except for the short daily interruptions necessary to inspect, rearrange, or remove test specimens, to check and replenish the solution in the reservoir, and to make necessary recordings as described in Section 10. Operations shall be so scheduled that these interruptions are held to a minimum.

12. Period of Exposure

12.1 The period of exposure shall be as designated by the specifications covering the material or product being tested or as mutually agreed upon between the purchaser and the seller.

NOTE 10—Recommended exposure periods are to be as agreed upon between the purchaser and the seller, but exposure periods of multiples of 24 h are suggested.

13. Cleaning of Tested Specimens

13.1 Unless otherwise specified in the specifications covering the material or product being tested, specimens shall be treated as follows at the end of the test:

13.1.1 The specimens shall be carefully removed.

13.2 Specimens may be gently washed or dipped in clean running water not warmer than 38°C (100°F) to remove salt deposits from their surface, and then immediately dried.

14. Evaluation of Results

14.1 A careful and immediate examination shall be made as required by the specifications covering the material or product being tested or by agreement between the purchaser and the seller.

15. Records and Reports

15.1 The following information shall be recorded, unless otherwise prescribed in the specifications covering the material or product being tested:

15.1.1 Type of salt and water used in preparing the salt solution,

15.1.2 All readings of temperature within the exposure zone of the chamber,

15.1.3 Daily records of data obtained from each fog-collecting device including the following:

15.1.3.1 Volume of salt solution collected in millilitres per hour per 80 cm^2 (12.4 $in.^2$),

15.1.3.2 Concentration or specific gravity at 35°C (95°F) of solution collected, and

15.1.3.3 pH of collected solution.

15.2 Type of specimen and its dimensions, or number or description of part,

15.3 Method of cleaning specimens before and after testing,

15.4 Method of supporting or suspending article in the salt spray chamber,

15.5 Description of protection used as required in 6.5,

15.6 Exposure period,

15.7 Interruptions in exposure, cause, and length of time, and

15.8 Results of all inspections.

NOTE 11—If any of the atomized salt solution which has not contacted the test specimens is returned to the reservoir, it is advisable to record the concentration or specific gravity of this solution also.

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[8] A suitable device for maintaining the level of liquid in either the saturator tower or reservoir of test solution may be designed by a local engineering group, or may be purchased from manufacturers of test cabinets as an accessory.

Keywords

6.1 controlled corrosive environment; corrosive condis; determining mass loss; salt spray (fog) exposure

APPENDIXES

(Nonmandatory Information)

X1. CONSTRUCTION OF APPARATUS

1 Cabinets

1.1.1 Standard salt spray cabinets are available from ral suppliers, but certain pertinent accessories are required re they will function according to this practice and provide sistent control for duplication of results.

1.1.2 The salt spray cabinet consists of the basic chamber, air-saturator tower, a salt solution reservoir, atomizing zles, specimen supports, provisions for heating the cham-, and suitable controls for maintaining the desired tempera-e

X1.1.3 Accessories such as a suitable adjustable baffle or tral fog tower, automatic level control for the salt reservoir, automatic level control for the air-saturator tower are tinent parts of the apparatus.

X1.1.4 The size and shape of the cabinet shall be such that atomization and quantity of collected solution is within the its of this practice.

X1.1.5 The chamber shall be made of suitably inert mates such as plastic, glass, or stone, or constructed of metal and d with impervious plastics, rubber, or epoxy-type materials equivalent.

X1.1.6 All piping that contacts the salt solution or spray uld be of inert materials such as plastic. Vent piping should of sufficient size so that a minimum of back pressure exists should be installed so that no solution is trapped. The osed end of the vent pipe should be shielded from extreme currents that may cause fluctuation of pressure or vacuum in cabinet.

.2 Temperature Control

X1.2.1 The maintenance of temperature within the salt amber can be accomplished by several methods. It is nerally desirable to control the temperature of the surroundgs of the salt spray chamber and to maintain it as stable as ossible. This may be accomplished by placing the apparatus n a constant-temperature room, but may also be achieved by urrounding the basic chamber of a jacket containing water or ir at a controlled temperature.

X1.2.2 The use of immersion heaters in an internal salt olution reservoir or of heaters within the chamber is detrimenal where heat losses are appreciable, because of solution vaporation and radiant heat on the specimens.

X1.3 Spray Nozzles

X1.3.1 Satisfactory nozzles may be made of hard rubber, plastic, or other inert materials. The most commonly used type is made of plastic. Nozzles calibrated for air consumption and solution-atomized are available. The operating characteristics of a typical nozzle are given in Table X1.1.

TABLE X1.1 Operating Characteristics of Typical Spray Nozzle

Siphon Height cm	Air Flow, dm³/min				Solution Consumption, cm³/h			
	Air Pressure, kPa				Air Pressure, kPa			
	34	69	103	138	34	69	103	138
10	19	26.5	31.5	36	2100	3840	4584	5256
20	19	26.5	31.5	36	636	2760	3720	4320
30	19	26.5	31.5	36	0	1380	3000	3710
40	19	26.6	31.5	36	0	780	2124	2904

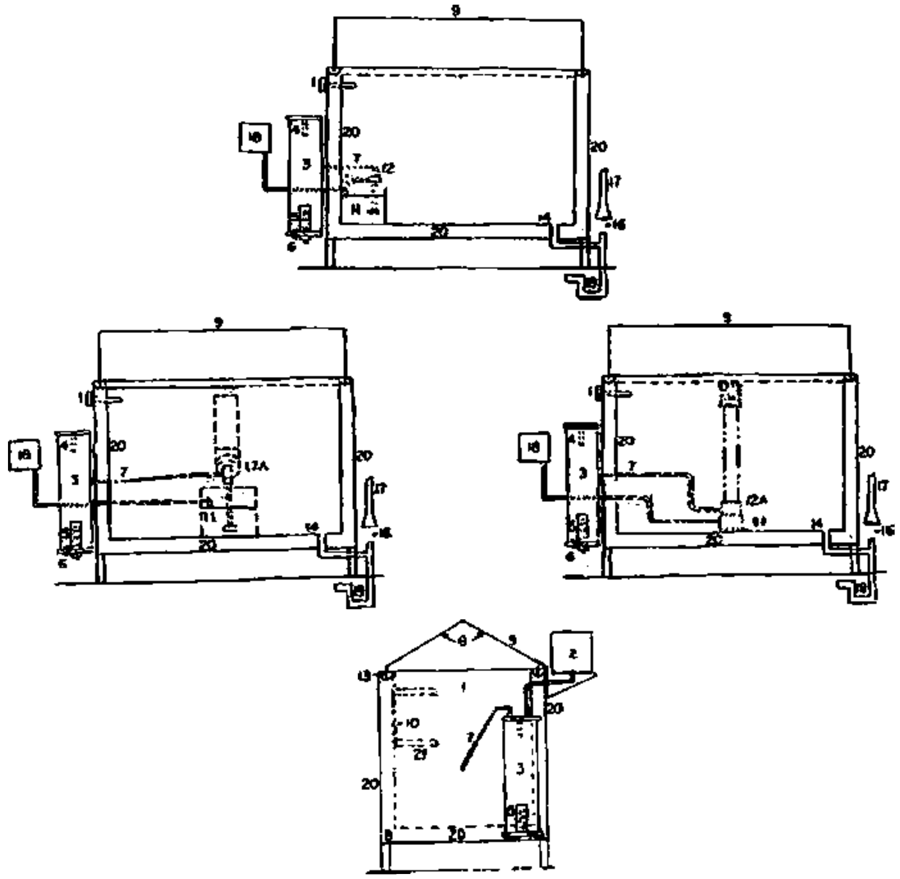
Siphon Height, in.	Air Flow, L/min				Solution Consumption, mL/h			
	Air Pressure, psi				Air Pressure, psi			
	5	10	15	20	5	10	15	20
4	19	26.5	31.5	36	2100	3840	4584	5256
8	19	26.5	31.5	36	636	2760	3720	4320
12	19	26.5	31.5	36	0	1380	3000	3710
16	19	26.6	31.5	36	0	780	2124	2904

X1.3.2 It can readily be seen that air consumption is relatively stable at the pressures normally used, but a marked reduction in solution sprayed occurs if the level of the solution is allowed to drop appreciably during the test. Thus, the level of the solution in the salt reservoir must be maintained automatically to ensure uniform fog delivery during the test.[8]

X1.3.3 If the nozzle selected does not atomize the salt solution into uniform droplets, it will be necessary to direct the spray at a baffle or wall to pick up the larger drops and prevent them from impinging on the test specimens. Pending a complete understanding of air-pressure effects, etc., it is important that the nozzle selected shall produce the desired condition when operated at the air pressure selected. Nozzles are not necessarily located at one end, but may be placed in the center and can also be directed vertically up through a suitable tower.

X1.4 Air for Atomization

X1.4.1 The air used for atomization must be free of grease, oil, and dirt before use by passing through well-maintained filters. Room air may be compressed, heated, humidified, and washed in a water-sealed rotary pump, if the temperature of the water is suitably controlled. Otherwise cleaned air may be introduced into the bottom of a tower filled with water, through a porous stone or multiple nozzles. The level of the water must be maintained automatically to ensure adequate humidification. A chamber operated in accordance with this method and Appendix X1 will have a relative humidity between 95 and 98 %. Since salt solutions from 2 to 6 % will give the same results (though for uniformity the limits are set at 4 to 6 %), it is preferable to saturate the air at temperatures well above the chamber temperature as insurance of a wet fog. Table X1.2 shows the temperatures, at different pressures, that are required

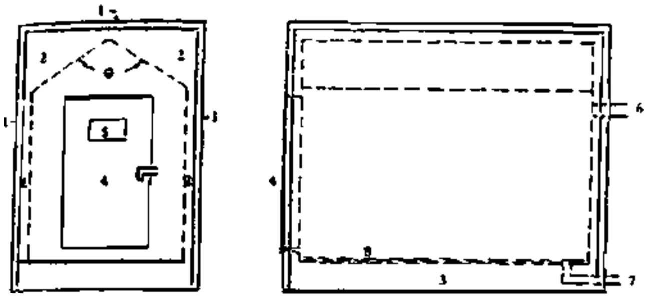


Note 1—θ—Angle of lid, 90 to 125°

1—Thermometer and thermostat for controlling heater (Item No. 8) in base
2—Automatic water leveling device
3—Humidifying tower
4—Automatic temperature regulator for controlling heater (Item No. 5)
5—Immersion heater, nonrusting
6—Air inlet, multiple openings
7—Air tube to spray nozzle
8—Heater in base
9—Hinged top, hydraulically operated, or counterbalanced
10—Brackets for rods supporting specimens, or test table
11—Internal reservoir
12—Spray nozzle above reservoir, suitably designed, located, and baffled
12A—Spray nozzle housed in dispersion tower located preferably in center of cabinet (typical examples)
13—Water seal
14—Combination drain and exhaust. Exhaust at opposite side of test space from spray nozzle (Item 12), but preferably in combination with drain, waste trap, and forced draft waste pipe (Items 16, 17, and 19).
16—Complete separation between forced draft waste pipe (Item 17) and combination drain and exhaust (Items 14 and 19) to avoid undesirable suction or back pressure.
17—Forced draft waste pipe
18—Automatic leveling device for reservoir
19—Waste trap
20—Air space or water jacket
21—Test table or rack, well below roof area

Note 2—This figure shows the various components including alternate arrangements of the spray nozzles and solution reservoir.

FIG. X1.1 Typical Salt Spray Cabinet



Note 1—The controls are the same, in general as for the smaller laboratory type cabinet (Fig. X1.1), but are sized to care for the larger cube. The chamber has the following features:

θ—Angle of ceiling, 90 to 125°
1—Heavy insulated outer panels
2—Air space
3—Low-watt density heaters, or steam coils
4—Single- or double-, full-opening door (refrigeration type), with inward sloping door sill
5—Viewing window/s
6—Inner chamber vent
7—Inner chamber drain
8—Duct boards on floor

FIG. X1.2 Walk-in Chamber, 1.5 by 2.4 m (5 by 8 ft) and Upward in Overall Size

TABLE X1.2 Temperature and Pressure Requirements for Operation of Test at 95°F

	Air Pressure, kPa			
	83	96	110	124
Temperature, °C	46	47	48	49
	Air Pressure, psi			
	12	14	16	18
Temperature, °F	114	117	119	121

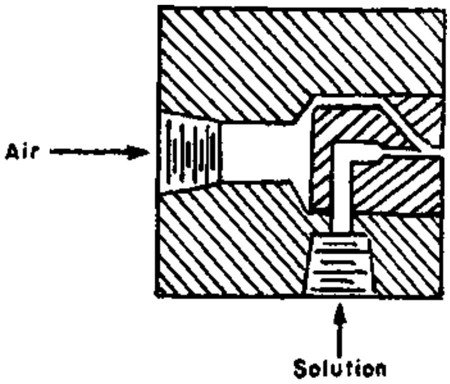


FIG. X1.3 Typical Spray Nozzle

to offset the cooling effect of expansion to atmospheric pressure.

X1.4.2 Experience has shown that most uniform spray chamber atmospheres are obtained by increasing the atomizing air temperature sufficiently to offset heat losses, except those that can be replaced otherwise at very low-temperature gradients.

X1.5 Types of Construction

X1.5.1 A modern laboratory cabinet is shown in Fig. X1.1. Walk-in chambers are usually constructed with a sloping ceiling. Suitably located and directed spray nozzles avoid ceiling accumulation and drip. Nozzles may be located at the ceiling, or 0.91 m (3 ft) from the floor directed upward at 30 to 60° over a passageway. The number of nozzles depends on type and capacity and is related to the area of the test space. An 11 to 19 L (3 to 5-gal) reservoir is required within the chamber, with the level controlled. The major features of a walk-in type cabinet, which differs significantly from the laboratory type, are illustrated in Fig. X1.2. Construction of a plastic nozzle, such as is furnished by several suppliers, is shown in Fig. X1.3.

X2. USE OF THE SALT SPRAY (FOG) TEST IN RESEARCH

X2.1 This practice is primarily used for process qualification and quality acceptance. Regarding any new applications it is essential to correlate the results of this practice with actual field exposure results.

X2.2 The salt spray has been used to a considerable extent for the purpose of comparing different materials or finishes. It should be noted there is usually not a direct relation between salt spray (fog) resistance and resistance to corrosion in other media, because the chemistry of the reactions, including the formation of films and their protective value, frequently varies greatly with the precise conditions encountered. Informed personnel are aware of the erratic composition of basic alloys, the possibility of wide variations in quality and thickness of plated items produced on the same racks at the same time, and the consequent need for a mathematical determination of the number of specimens required to constitute an adequate sample for test purposes. In this connection it is well to point out that Practice B 117 is not applicable to the study or testing of decorative chromium plate (nickel-chromium) on steel or on zinc-base die castings or of cadmium plate on steel. For this purpose Method B 368 and Practice G 85 are available, which are also considered by some to be superior for comparison of chemically treated aluminum (chromated, phosphated, or anodized), although final conclusions regarding the validity of test results related to service experience have not been reached. Practice B 117 and Practice G 85 are considered to be most useful in estimating the relative behavior of closely related materials in marine atmospheres, since it simulates the basic conditions with some acceleration due to either wetness or temperature, or both.

X3. EVALUATION OF CORROSIVE CONDITIONS

X3.1 *General*—This appendix covers test panels and procedures for evaluating the corrosive conditions within a salt spray cabinet. The procedure involves the exposure of steel test panels and the determination of their mass losses in a specified period of time. This may be done monthly or more frequently to ensure consistent operation over time. It is also useful for correlating the corrosive conditions among different cabinets.

X3.2 *Test Panels*—The required test panels, 76 by 127 by 0.8 mm (3.0 by 5.0 by .0315 in.), are made from SAE 1008 commercial-grade cold-rolled carbon steel (UNS G10080).

X3.3 *Preparation of Panels Before Testing*—Clean panels before testing by degreasing only, so that the surfaces are free of dirt, oil, or other foreign matter that could influence the test results. After cleaning, weigh each panel on an analytical balance to the nearest 1.0 mg and record the mass.

X3.4 *Positioning of Test Panels*—Place a minimum of two weighed panels in the cabinet, with the 127-mm (5.0 in.) length supported 30° from vertical. Place the panels in the proximity of the condensate collectors. (See Section 6.)

X3.5 *Duration of Test*—Expose panels to the salt fog for 48 to 168 h.

X3.6 *Cleaning of Test Panels After Exposure*—After removal of the panels from the cabinet, rinse each panel immediately with running tap water to remove salt, and rinse in reagent grade water (see Specification D 1193, Type IV). Chemically clean each panel for 10 min at 20 to 25°C in a fresh solution prepared as follows:

Mix 1000 mL of hydrochloric acid (sp gr 1.19) with 1000 mL reagent grade water (D 1193, Type IV) and add 10 g of hexamethylene tetramine. After cleaning, rinse each panel with reagent grade water (Type IV) and dry (see 13.2).

X3.7 *Determining Mass Loss*—Immediately after drying, determine the mass loss by reweighing and subtracting panel mass after exposure from its original mass.

X3.7.1 Data generated in the interlaboratory study using this method are available from ASTM as a Research Report.[9]

X3.8 *Precision and Bias—Steel Panel Test:*

X3.8.1 An interlaboratory test program using three different sets of UNS G10080 steel panels, 76 by 127 by 0.8 mm (3.0 by 5.0 by .0315 in.) has shown that the repeatability of the mass loss of the steel panels, that is, the consistency in mass loss results that may be expected when replicate panels are run simultaneously in a salt spray cabinet, is dependent upon exposure time and the panel lot or source. The interlaboratory program yielded repeatability standard deviations, S_r, from which 95 % repeatability limits, r, were calculated as follows (see Practice E 691):

$$r = 2.8\,S_r \qquad \text{(X3.1)}$$

The values of S_r and r are reported in Table X3.1. Note that the corrosion rate of steel in this environment is approximately constant over the exposure interval and that the ratio of the standard deviation to the average mass loss, the coefficient of variation, Cv, varies between 5 and 10 % with a weighted average of 7.4 % and an r of ±21 % of the average mass loss.

X3.8.2 This interlaboratory program also produced results on the reproducibility of results, that is, the consistency of mass loss results in tests in different laboratories or in different cabinets in the same facility. This program yielded reproducibility standard deviations S_R from which 95 % reproducibility limits, R were calculated as follows (See Practice E 691):

$$R = 2.8\,S_R \qquad \text{(X3.2)}$$

The values of S_R and R are reported in Table X3.2. Note that the ratio of standard deviation to the average mass loss, the coefficient of variation, Cv, varies between 8 to 18 % with a weighted average of 12.7 % and an R of ±36 % of the average mass loss.

X3.8.3 The mass loss of steel in this salt spray practice is dependent upon the area of steel exposed, the temperature, time of exposure, salt solution make up and purity, pH, spray conditions, and the metallurgy of the steel. The procedure in Appendix X3 for measuring the corrosivity of neutral salt spray cabinets with steel panels has no bias because the value of corrosivity of the salt spray is defined only in terms of this practice.

TABLE X3.1 Repeatability Statistics

NOTE 1—Based on two replicates in every test run. No. = number of different salt spray cabinets in test program; r = 95 % repeatability limits, g; Cv = S_r/avg, coefficient of variation, %; and S_r = repeatability standard deviations, g.

Materials	Test Duration, h	Average Mass Loss, g	S_r, g	Cv, %	r, g	No.
QP1	48	0.8170	0.0588	7.20	0.1646	12
QP1	96	1.5347	0.1048	7.28	0.2934	12
QP1	168	2.5996	0.2498	9.61	0.6994	12
AP	48	0.7787	0.0403	5.17	0.1128	10
AP	96	1.4094	0.0923	6.55	0.2584	10
AP	168	2.4309	0.1594	6.56	0.4463	10
QP2	48	0.8566	0.0686	8.01	0.1921	5
QP2	96	1.5720	0.0976	6.21	0.2733	5
QP2	168	2.7600	0.2588	9.38	0.7246	5

---

[9] Available from ASTM Headquarters. Request RR No. G1-1003.

TABLE X3.2 Reproducibility Statistics

Note 1—No. = number of different salt spray cabinets in test program; R = 95 % reproduciblity limits, g; Cv = S_R/avg, coefficient of variation, %; and S_R = reproducibility standard deviation, g.

Materials	Test Duration, h	Average Mass Loss, g	S_R, g	Cv, %	R, g	No.
QP1	48	0.8170	0.0947	11.58	0.2652	12
QP1	96	1.5347	0.2019	14.02	0.5653	12
QP1	168	2.5996	0.3255	12.52	0.9114	12
AP	48	0.7787	0.0805	10.33	0.2254	10
AP	96	1.4094	0.1626	11.54	0.4553	10
AP	168	2.4309	0.3402	14.00	0.9526	10
QP2	48	0.8566	0.1529	17.85	0.4281	5
QP2	96	1.5720	0.1319	8.39	0.3693	5
QP2	168	2.7600	0.3873	14.03	1.0844	5

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Designation: D 714 – 87 (Reapproved 2000)

Standard Test Method for Evaluating Degree of Blistering of Paints[1]

This standard is issued under the fixed designation D 714; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method employs photographic reference standards to evaluate the degree of blistering that may develop when paint systems are subjected to conditions which will cause blistering. While primarily intended for use on metal and other nonporous surfaces, this test method may be used to evaluate blisters on porous surfaces, such as wood, if the size of blisters falls within the scope of these reference standards. When the reference standards are used as a specification of performance, the permissible degree of blistering of the paint system shall be agreed upon by the purchaser and the seller.

1.2 *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. Significance and Use

2.1 A phenomenon peculiar to painted surfaces is the formation of blisters relative to some system weakness. This test method provides a standard procedure of describing the size and density of the blisters so that comparisons of severity can be made.

3. Reference Standards

3.1 The photographic reference standards are glossy prints.[2] Figs. 1-4 are reproductions of these standards and are included to illustrate two characteristics of blistering: size and frequency.

3.2 *Size*—Reference standards have been selected for four steps as to size on a numerical scale from 10 to 0, in which No. 10 represents no blistering. Blistering standard No. 8 represents the smallest size blister easily seen by the unaided eye. Blistering standards Nos. 6, 4, and 2 represent progressively larger sizes.

3.3 *Frequency*—Reference standards have been selected for four steps in frequency at each step in size, designated as follows:

Dense, *D*,
Medium dense, *MD*,
Medium, *M*, and
Few, *F*.

NOTE 1—A quantitative physical description of blistering would include the following characteristics determined by actual count:
Size distribution in terms of mensuration units,
Frequency of occurrence per unit area,
Pattern of distribution over the surface, and
Shape of blister
For the usual tests, an actual count is more elaborate than is necessary.

4. Procedure

4.1 Subject the paint film to the test conditions agreed upon by the purchaser and the seller. Then evaluate the paint film for the degree of blistering by comparison with the photographic reference standards in Figs. 1-4.

5. Report

5.1 Report blistering as a number (Note 2) designating the size of the blisters and a qualitative term or symbol indicating the frequency.

5.2 Intermediate steps in size or frequency of blisters may be judged by interpolation.

5.3 When the distribution of blisters over the area has a nonuniform pattern, use an additional phrase to describe the distribution, such as "small clusters," or "large patches."

NOTE 2—The number refers to the largest size blister that is numerous enough to be representative of the specimen. For example, photographic standard No. 4, "Dense," has blisters ranging in size from about No. 7 to No. 4, inclusive.

6. Keywords

6.1 blistering; corrosion; evaluations; reference standards

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[1] This test method is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.25 on Pictorial Standards of Coating Defects.

Current edition approved May 29, 1987. Published July 1987. Originally published as D 714 – 43 T. Last previous edition D 714 – 56 (1981).

[2] Glossy prints of the photographic reference standards showing types of blistering are available at a nominal charge from ASTM Headquarters. Order Adjunct ADJD0714.

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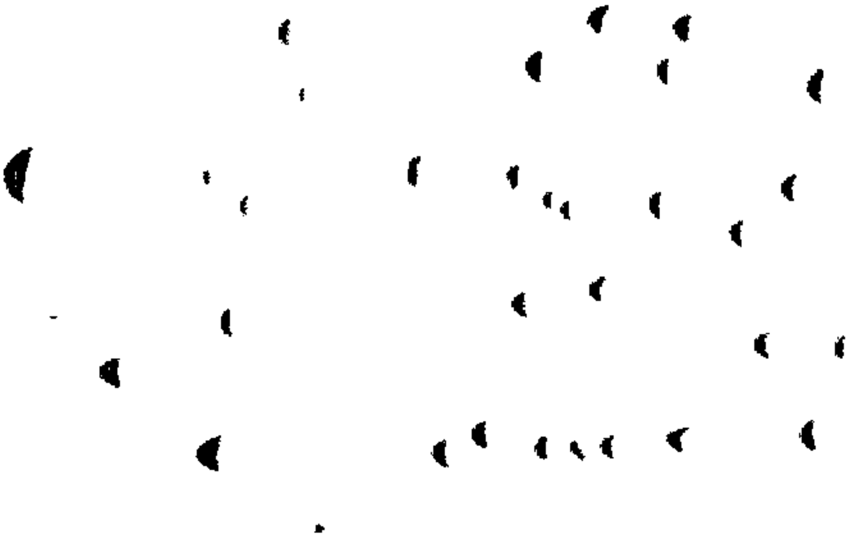
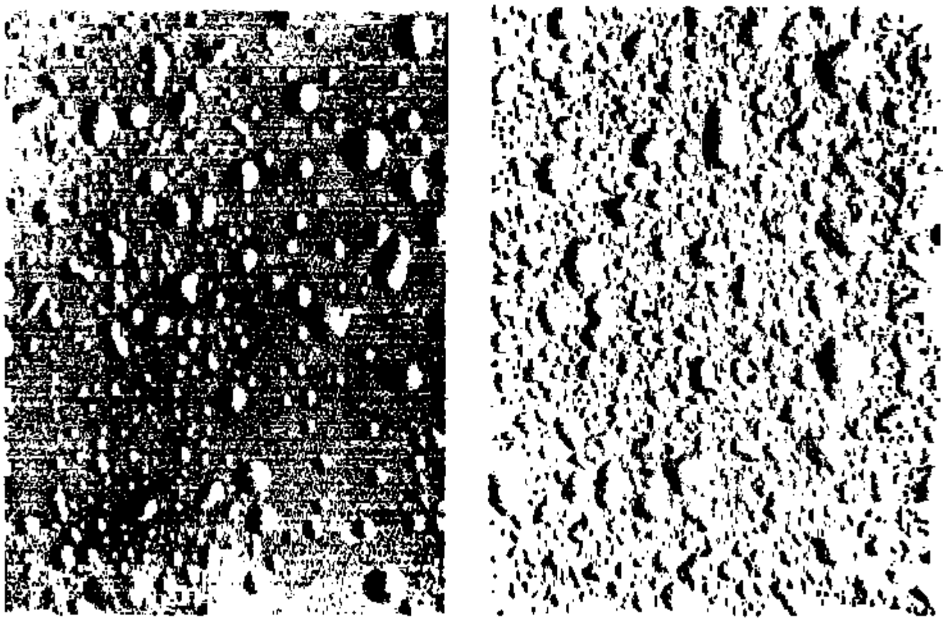


Few

Medium

FIG. 1 Blister Size No. 2



Medium Dense

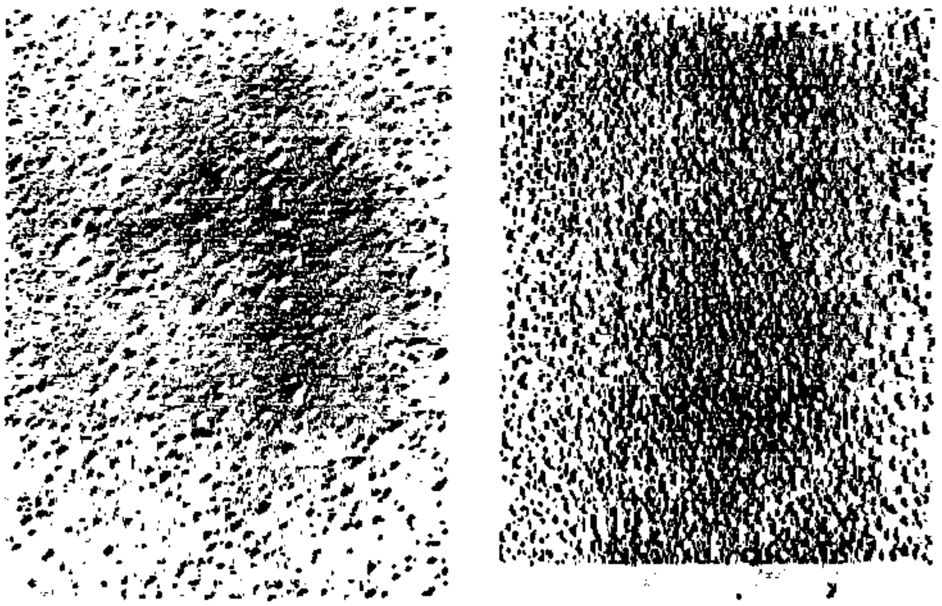
Dense

FIG. 1 *(continued)*

Few

Medium

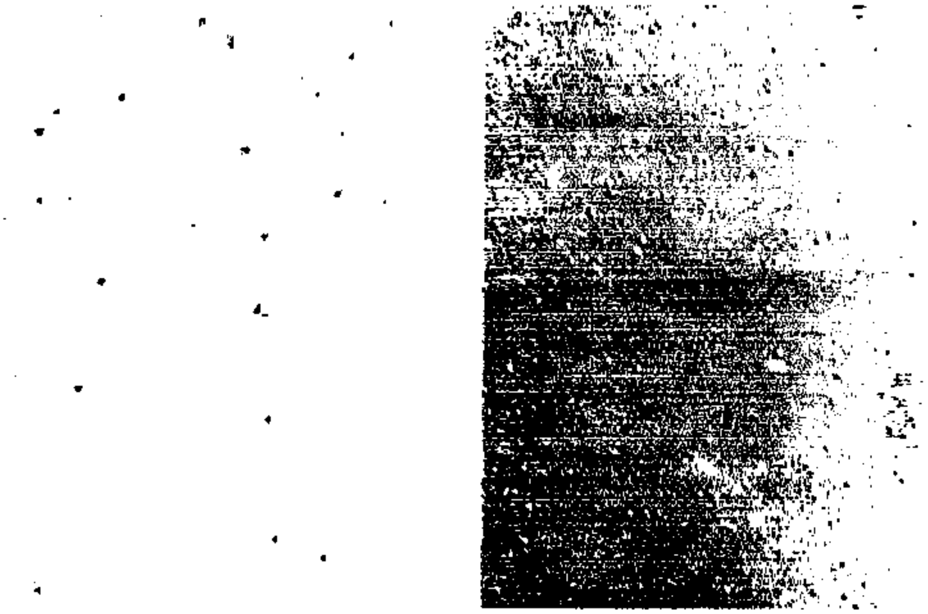
FIG. 2 Blister Size No. 4



Dense

Dense

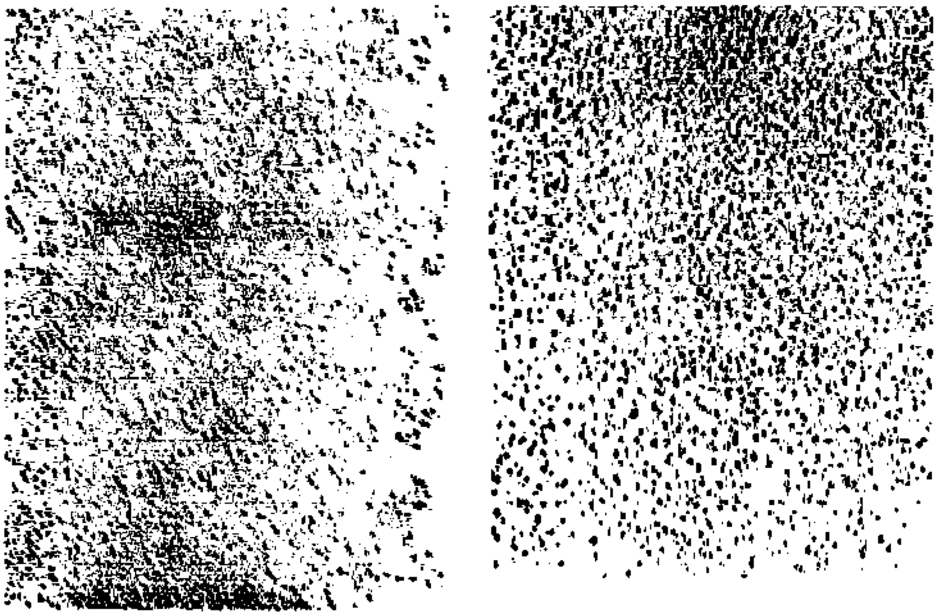
FIG. 2 *(continued)*



Few

Medium

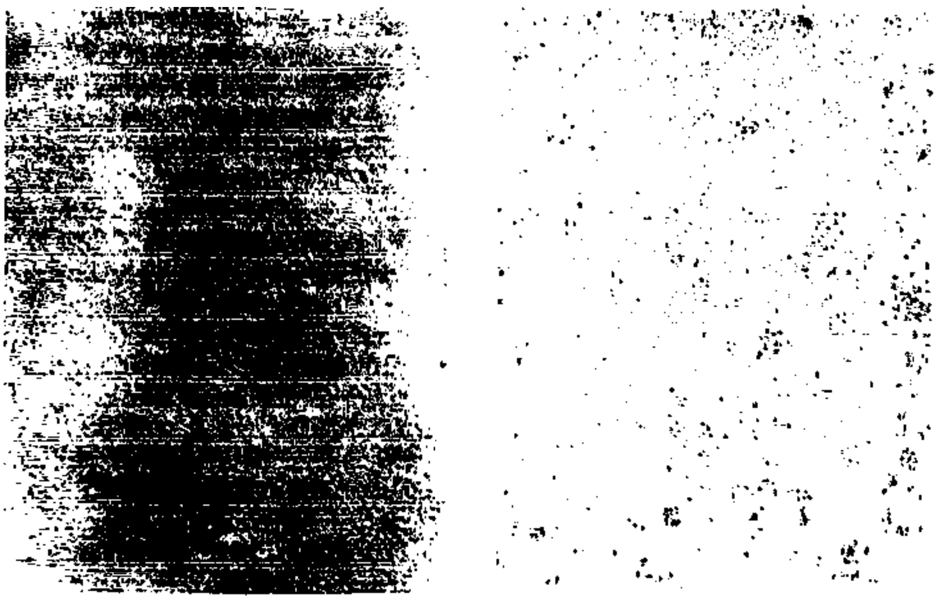
FIG. 3 Blister Size No. 6



Medium Dense

Dense

FIG. 3 *(continued)*



Medium Dense

Dense

FIG. 4 *(continued)*

Few

Medium

FIG. 4 Blister size No. 8

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Designation: D 1654 – 92 (Reapproved 2000)

Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments[1]

This standard is issued under the fixed designation D 1654; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the treatment of previously painted or coated specimens for accelerated and atmospheric exposure tests and their subsequent evaluation in respect to corrosion, blistering associated with corrosion, loss of adhesion at a scribe mark, or other film failure.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 117 Practice for Operating Salt Spray (Fog) Testing Apparatus[2]

D 610 Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces[3]

D 714 Test Method for Evaluating Degree of Blistering of Paints[4]

D 870 Practice for Testing Water Resistance of Coatings Using Water Immersion[4]

D 1014 Practice for Conducting Exterior Exposure Tests of Paints on Steel[4]

D 1735 Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus[4]

D 2247 Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity[4]

D 2803 Guide for Filiform Corrosion Resistance of Organic Coatings on Metal[4]

D 4141 Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings[4]

D 4585 Practice for Testing Water Resistance of Coatings Using Controlled Condensation[4]

D 4587 Practice for Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light- and Water-Exposure Apparatus[4]

G 23 Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[5]

G 26 Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[5]

G 85 Practice for Modified Salt Spray (Fog) Testing[6]

G 87 Practice for Conducting Moist SO_2 Tests[6]

2.2 *ANSI Standard:*

B94.50 Single-Point Cutting Tools, Basic Nomenclature and Definitions for[7]

3. Significance and Use

3.1 This method provides a means of evaluating and comparing basic corrosion performance of the substrate, pretreatment, or coating system, or combination thereof, after exposure to corrosive environments.

4. Apparatus

4.1 *Scribing Tool*—A straight-shank tungsten carbide tip, lathe cutting tool (ANSI B94.50, Style E) or carbide-tipped pencil-type tool is recommended. Any other type of scribing instrument such as a scalpel, razor blade, knife, or other sharp pointed tool is unacceptable unless agreed upon between the producer and the user.

4.2 *Straightedge*—Any straightedge of sufficient length and rigidity to guide the scribing tool in a straight line.

4.3 *Air Source*—A source of compressed air capable of delivering at least 10 ft^3/min (4.72 L/s) at 80 psi (552 kPa).

4.4 *Air Gun*—An air dusting gun and nozzle combination[8] to meet the following specification:

Air Consumption, ft^3/min (m^3/min)	Pressure, psi (kPa)	Nozzle Diameter, in. (mm)

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[1] This method is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.25 on Evaluation of Weathering Effects.

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[2] *Annual Book of ASTM Standards*, Vol 03.02.

[3] *Annual Book of ASTM Standards*, Vol 06.02.

[4] *Annual Book of ASTM Standards*, Vol 06.01.

[5] Discontinued; G 23 replaced by G 152 and G 153; G 26 replaced by G 155. See 2000 *Annual Book of ASTM Standards*, Vol 14.04.

[6] *Annual Book of ASTM Standards*, Vol 03.02.

[7] Available from American National Standards Institute, 13th Floor, 11 W. 42nd St., New York, NY 10036.

[8] Spray gun and nozzles, Model No. AA23LTP0020 have been found satisfactory and may be obtained from Spray Systems Co., North Avenue at Schmale Road, Wheaton, IL 60187. Equivalents may be used.

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8.4 (0.24)	80 (550)	0.12 (3.0)

4.4.1 A guard consisting of barriers, baffles, or screens is required to protect the operator and other individuals near the area where the air is being used. The guard must be placed between the air nozzle and the operator. A device such as a sand-blasting cabinet has been found to be acceptable.

NOTE 1—The use of an air gun without a guard is in violation of the U. S. Occupational Safety and Health Administration regulation.

4.5 *Scraping Tool*—A rigid spatula, knife, or similar instrument with no sharp edges or sharp corners.

4.6 *Scale*—Any rule with 1-mm divisions.

5. Preliminary Treatment of Test Specimens

5.1 *Scribed Specimens*:

5.1.1 Where specified or agreed upon, prepare each specimen for testing by scribing it in such a manner that the scribe can be exposed lengthwise when positioned in the test cabinet. This position will allow solution droplets to run lengthwise along the scribe.

5.1.2 Scribe the specimen by holding the tool at approximately a 45° angle to the surface. Position the tool so that only the carbide tip is in contact with the surface. Pull the scribing tool to obtain a uniform V-cut through the coating that is being tested. Inspect the tool frequently for dulling, chipping or wear and replace or repair as needed. The scribe should be of sufficient length to cover the significant test area, but should not contact the edge of the specimen. The scribe must penetrate all organic coating layers on the metal, leaving a uniformly bright line of burrs. The extent of scribe penetration through metallic coatings should be agreed upon between the producer and user. Quality of the scribe may be observed with the aid of low-power magnification. Note, mark, and describe defects, coding, and flaws that may affect results.

5.1.3 Scribe lines other than those of a single, straight nature may be used if agreed upon between the producer and the user.

5.1.4 Expose scribed specimens in accordance with 6.1 and rate in accordance with Section 7.

5.2 *Unscribed Specimens*—Specimens coated with paint undercoats, oils, or waxes may be evaluated without a scribe. Expose such specimens in accordance with Section 6 and rate for corrosion of the general surface in accordance with Section 8.

5.3 *Cut Edges*—Cut edges of panels may be exposed during testing, or protected by wax, tape, or other means as agreed upon between the producer and the user. If left unprotected, method of shearing panel edges should be agreed upon between the producer and user, noting whether edges are oriented in the "burr up" or "burr down" configuration.

5.4 *Deformation*—Deformation of test panels prior to exposure, if desired, should be agreed upon between the producer and user.

6. Exposure of Test Specimens

6.1 Expose test specimens in accordance with one or more of the following test methods or practices: B 117, D 610, D 714, D 870, D 1014, D 1735, D 2247, D 2803, D 4141, D 4585, D 4587, G 23, G 26, G 85, G 87, or any other applicable test method, as agreed upon between the producer and the user. The length of test and evaluation intervals should be agreed upon prior to exposure of specimens.

7. Procedure A—Evaluation of Scribed Specimens

7.1 *Method 1 (Air Blow-Off)*—Rinse each specimen after completion of the exposure period, using a gentle stream of water at a temperature up to 110°F (45°C). Holding the nozzle at approximately a 45° angle, blow along the entire scribe line, disturbing the surface adjacent to the scribe mechanically by the air nozzle to ensure an opening for the air blast. Complete the air blasting within 15 min of specimen removal from the exposure cabinet. If the air blasting cannot be completed within the prescribed time, immerse the specimens in water at room temperature or store in a plastic bag to avoid any drying effect.

7.2 *Method 2 (Scraping)*—Rinse the specimen after completion of the exposure period, using a gentle stream of water at a temperature up to 110°F (45°C). Scrape the specimen vigorously with an instrument described in 4.5 while under the gentle stream of the rinse water. Hold the scraper with its face perpendicular to the specimen surface and parallel to the scribe, moving it back and forth across the scribe to remove the coating that has been undercut and has suffered loss of adhesion only, not to remove the coating that still has adhesion. Complete the scraping within 15 min of specimen removal from the exposure cabinet. If scraping cannot be completed within the prescribed time, immerse the specimens in water at room temperature or store in a plastic bag to avoid any drying effect.

NOTE 2—Rinsing, scraping, or air blow off may not be appropriate in all cases, such as for interim ratings in continuing tests. Alternative methods may be used if agreed upon between the producer and the user.

7.3 *Rating*—Rate the corrosion or loss of paint extending from a scribe mark as prescribed in Table 1. Record the representative mean, maximum, and minimum creepage from the scribe, and note whether or not the maximum is an isolated spot. Record creep values in millimeters, inches, or rating numbers, as agreed upon between producer and user.

7.3.1 Unless otherwise agreed upon by the producer and user, scribe creepage is defined as "one sided", that is, from the original scribe line to the creepage front. Also, rate in accordance with Table 2 the prevalence of corrosion on areas removed from the scribe.

8. Procedure B—Evaluation of Unscribed Areas

8.1 Rinse the specimen after completion of the exposure

TABLE 1 Rating of Failure at Scribe (Procedure A)

Representative Mean Creepage From Scribe		
Millimetres	Inches (Approximate)	Rating Number
Zero	0	10
Over 0 to 0.5	0 to 1/64	9
Over 0.5 to 1.0	1/64 to 1/32	8
Over 1.0 to 2.0	1/32 to 1/16	7
Over 2.0 to 3.0	1/16 to 1/8	6
Over 3.0 to 5.0	1/8 to 3/16	5
Over 5.0 to 7.0	3/16 to 1/4	4
Over 7.0 to 10.0	1/4 to 3/8	3
Over 10.0 to 13.0	3/8 to 1/2	2
Over 13.0 to 16.0	1/2 to 5/8	1
Over 16.0 to more	5/8 to more	0

TABLE 2 Rating of Unscribed Areas (Procedure B)

Area Failed, %	Rating Number
No failure	10
0 to 1	9
2 to 3	8
4 to 6	7
7 to 10	6
11 to 20	5
21 to 30	4
31 to 40	3
41 to 55	2
56 to 75	1
Over 75	0

period (Section 6), using a gentle stream of water at a temperature up to 100°F (40°C). Dry the surface of the specimen with paper towels or compressed air. Drying should be done in such a manner that the corrosion on the specimen surface is not disturbed.

8.2 Evaluate unscribed specimens for corrosion spots, blisters, and any other types of failure that may occur. Where the character of the failure permits, the photographic blister standards given in Test Method D 714 may be used to describe the results of the exposure test, with respect to size of blisters or corroded areas, while Method D 610 may serve to describe the frequency and distribution of rusting. Record the size, frequency, or area affected. Discount corrosion within ½in. (12.7 mm) of edges.

8.3 *Rating*—Record percent failed area or convert percent failure to rating numbers in accordance with Table 2 as agreed upon between the producer and user.

NOTE 3—Formation of under-film corrosion may be evaluated and reported in accordance with Table 2 if the film is first carefully stripped with a neutral stripper. Exercise care to avoid alteration of the corrosion pattern or pretreatment.

NOTE 4—Where the character of the failure permits, the photographic blister standards given in Test Method D 714 may be used to describe the results of the exposure test, in respect to size of blisters or corroded areas, while Method D 610 may serve to describe the frequency and distribution, if desired.

9. Procedure C—Evaluation of Unprotected Edges

9.1 If paint creepage from cut edges is tested, rate the corrosion or loss of paint extending from a cut edge in the same manner described for scribes in Procedure A.

10. Procedure D—Evaluation of Formed Areas

10.1 If tested samples contain bends, dimples, or other formed areas of interest, rate the extent of failure at these areas separately in the same manner described in Procedure B, or as agreed upon between the producer and user.

11. Report

11.1 The report shall include the following information, unless otherwise agreed upon between the producer and user:

11.1.1 All pertinent information regarding the conduct of each corrosion test, as prescribed in the specifications for each test,

11.1.2 Methods of scribing, shearing, or forming, or combination thereof, or test specimens.

11.1.3 Ratings of test specimens, including procedure(s) employed.

12. Precision and Bias

12.1 *Precision*—Since this is a method of evaluation based on measurements after various tests, the statement of precision applicable to each specific method of exposure to corrosive environments applies.

13. Keywords

13.1 blistering; corrosion; paints/related coatings/materials; creepage; edge/scribe; rust

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Designation: D 4285 – 83 (Reapproved 1999)

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Indicating Oil or Water in Compressed Air[1]

This standard is issued under the fixed designation D 4285; 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 is used to determine the presence of oil or water in compressed air used for abrasive blast cleaning, air blast cleaning, and coating application operations.

1.2 *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.* For specific hazard statements, see Section 4.

2. Significance and Use

2.1 Clean compressed air is required to prevent contamination of coating materials and surfaces being prepared for coating. This test method is a visual examination technique for determining oil or water in compressed air. Other types of contamination may require additional analytical techniques for detection.

3. Apparatus and Materials

3.1 *Absorbent Collector*, such as white absorbent paper or cloth and rigid backing for mounting absorbent collector, or

3.2 *Nonabsorbent Collector*, such as rigid transparent plastic, approximately ¼ in. thick.

4. Cautions

4.1 To avoid false indications prior to testing:

4.1.1 Allow compressed air system to reach operating conditions, and

4.1.2 Allow air to discharge at operating conditions to remove accumulated condensation in the system.

4.2 Fasten the collector material to the rigid backing. **Precaution:** Avoid personal contact with the air stream.

5. Sampling

5.1 Conduct the test on discharging air as close to the use point as possible and after the inline oil and water separators.

6. Procedure

6.1 Use either the absorbent or nonabsorbent collector.

6.2 Position the collector within 24 in. of the air-discharge point, centered in the air stream.

6.3 Adjust air discharge so that the collector remains intact during the test. Allow air to discharge onto the collector for a minimum of 1 min.

6.4 Visually examine the collector for the presence or absence of oil or water, or both.

7. Interpretation of Results

7.1 Any indication of oil discoloration on the collector shall be cause for rejection of the compressed air for use in abrasive blast cleaning, air blast cleaning, and coating application operations.

7.2 Any indications of water contamination on the collector shall be cause for rejection of the compressed air for use in those applications where water is detrimental, such as abrasive blast cleaning, air blast cleaning, and coating application operations.

8. Precision and Bias

8.1 No precision or bias statement has been established for this test method.

9. Keywords

9.1 compressed air; oil and water in compressed air

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[1] This test method is under the jurisdiction of ASTM Committee D-33 on Protective Coating and Lining Work for Power Generating Facilities and is the direct responsibility of Subcommittee D33.05 on Surface Preparation.

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NORMA ISO 8501-1

Los grados de limpieza de superficies metálicas, están especificados por varias normas, siendo la más extendida la norma **SIS 055900 SWEDISH**, transformada posteriormente en **ISO 8501-1: 1988**, considerando los grados de preparación de la superficie en relación con el estado inicial del acero a pintar. Estas normas se refieren a acero envejecido, pero que nunca ha sido tratado con pintura.

Los **Estados Iniciales** definidos de acuerdo a estas normas son:

Superficies de acero completamente recubierta con cascarilla de laminación o calamina y con trazas de óxido. (El grado **A** es normalmente el que presenta el acero poco tiempo después de su laminación en caliente).

Superficies de acero que ha iniciado su corrosión y de la que ha empezado a desprenderse la cascarilla de laminación (El grado **B** es normalmente el estado de una superficie de acero laminado en caliente después de haber permanecido expuesta a la intemperie, sin protección, en una atmósfera medianamente corrosiva, durante 2 ó 3 meses).

Superficie de acero de la que la corrosión ha hecho saltar la totalidad de la cascarilla de laminación, pero que todavía no presenta picaduras detectables a simple vista. (El grado **C** es normalmente el estado de una superficie de acero que ha sido expuesta a la intemperie, sin protección, en una atmósfera medianamente corrosiva, durante 1 año, aproximadamente).

Superficiede acero de la que se ha desprendido la totalidad de la cascarilla de laminación y en la que se observan picaduras a simple vista. (El grado **D** corresponde al estado de una superficie de acero después de su exposición a la intemperie, sin protección, en una atmósfera medianamente corrosiva durante unos 3 años).

GRADOS DE PREPARACIÓN: A partir de cada uno de los estado iniciales se definen varios tipos de preparación, denominados con las siglas St, Sa o FI.

- **St:** Rascado, cepillado, picado, etcétera, por medios manuales o mecánicos.
- **Sa:** Chorreado abrasivo
- **FI:** Limpieza a la llama (flameado).

El estado inicial **A** sólo admite preparación por chorreado abrasivo (**Sa**), único método que permite eliminar la calamina.

En lo sucesivo sólo se considerarán los grados **St y Sa**, ya que el flameado se utiliza muy poco en la práctica.

Los diferentes grados utilizados:

ISO 8501-1
SIS 055900
Sa3

Eliminar la totalidad del óxido visible, cascarilla de laminación, pintura vieja y cualquier materia extraña. Limpieza por chorreado hasta **metal blanco**. El chorro se pasa sobre la superficie durante el tiempo necesario para eliminar la **totalidad** de la cascarilla de laminación, herrumbre y materias extrañas. Finalmente, la superficie se limpia con un aspirador, aire comprimido limpio y seco o con un cepillo limpio, para eliminar los residuos de polvo de abrasivo. Debe entonces quedar con un color metálico uniforme.

SSPC-SP-5
Chorreado a metal blanco.

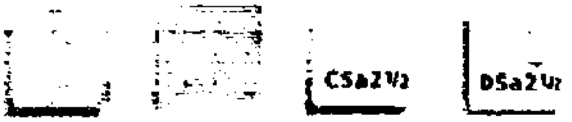
BS 4232: Primera calidad.

ISO 8501-1
SIS 055900
Sa2½

Chorreado abrasivo hasta **metal casi blanco**, a fin de conseguir que por lo menos el 95% de cada porción de la superficie total quede libre de cualquier residuo visible. Chorreado muy cuidadoso. El chorro se mantiene sobre la superficie el tiempo necesario para asegurar que la cascarilla de laminación, herrumbre y materias extrañas son eliminados de tal forma que cualquier residuo aparezca sólo como ligeras sombras o manchas en la superficie. Finalmente, se elimina el polvo de abrasivo con un aspirador, con aire comprimido limpio y seco o con cepillo limpio.

SSPC-SP-10
Chorreado a metal casi blanco.

BS 4232: Segunda calidad.



ISO 8501-1
SIS 055900
Sa2

Chorreado hasta que al menos los 2/3 de cualquier porción de la superficie total estén libres de todo residuo visible. Chorreado cuidadoso. El chorro se pasa sobre la superficie durante el tiempo suficiente para eliminar la casi totalidad de cascarilla de laminación, herrumbre y materias extrañas. Finalmente se elimina el polvo abrasivo con un aspirador, con aire comprimido limpio y seco o con un cepillo limpio.

SSPC-SP-6
Chorreado comercial.

BS 4232: Tercera calidad.

ISO 8501-1
SIS 055900
St3

Rascado con rasquetas de metal duro y cepillado con cepillo de alambre, muy cuidadoso. El rascado y cepillado deben realizarse en primer lugar en una dirección y después en sentido perpendicular. Una vez eliminado el polvo, la superficie debe mostrar un pronunciado aspecto metálico.

SSPC-SP-3
Limpieza mecánica.

BS 4232: No tiene equivalente.

ISO 8501-1
SIS 055900
St2

Rascado cuidadoso con rasquetas de metal duro y cepillado con cepillo de alambre. El rascado y cepillado deben realizarse en primer lugar en una dirección y después en sentido perpendicular. Una vez eliminado el polvo, la superficie debe mostrar aspecto metálico.

SSPC-SP-2
Limpieza manual.

BS 4232: No tiene equivalente.

NOTA: Existe también el grado **Sa1**, que corresponde a un chorreado ligero o soplado con abrasivo, pero en la práctica se usa muy poco.

SALES SOLUBLES EN AGUA SOBRE SUPERFICIES DE ACERO (ISO 8502-9 1998)

TEST DE CLORUROS MEDIANTE CONDUCTIVIMETRO (TDSCAN 40)

Procedimiento operativo para el muestreador estándar Bresle de 12,5 cm^2 (A-1250)

1. Buscar la superficie adecuada sobre la que se hará el test de cloruros. Esta puede ser horizontal, vertical ó inclinada. Lo más importante es que la superfice esté relativamente seca sin trazas de humedad. En muchos casos se recomienda hacer el test en más de un punto para ver la varicación de cloruros según las zonas.
2. Eliminar el film de protección (lleva el logo Bresle) y la superficie de 12,5 cm^2 almohadillada queda dispuesta.
3. Adherir la almohadilla adhesiva a la superficie seca y presionar firmemente. Es imprescindible crear una superficie sellada. La superficie puede ser vertical u horizontal.
4. Introducir la jeringuilla de 5 cc a través de la esponja que rodea el perímetro. No pinchar a través del film semitransparente. Sacar el aire aspirando con la jeringuilla. Eliminar y sacar la jeringuilla.
5. Lavar los electrodos del conductimetro con agua destilada o desionizada.
6. Tomar 15 ml de agua destilada o desionizada en el pequeño container y chequear la conductividad con el TDScan 40 y anotar la lectura. Este valor será el tomado como patrón.
7. Tomar 3 ml del líquido patrón e inyectarlos en el sello a través de la espuma. Hay que comprobar que no queda aire ni burbujas. Mantener presionado por los bordes el sello durante la inyección/extracción de la jeringuilla para evitar el desprendimiento del sello.
8. Sacar la jeringuilla y suavemente frotar la superficie semitransparente durante 10-15 segundos para garantizar la disolución de las sales en el agua.
9. Repetir la operación de reinyectar el agua al menos tres veces, frotando suavemente la superficie semitransparente 10-15 segundos cada vez.
10. En la última extracción, tratar de extraer el máximo de los 3 ml. con la jeringuilla.
11. Vaciar la jeringuilla dentro del pequeño container para tratar de alcanzar de nuevo los 15 ml originales
12. Medir el líquido en el container con el conductimetro, anotar la medida que se muestra en el display del aparato y restar el valor tomado al inicio (paso 6), el resultado será el valor final de la medida.
13. Es decir el resultado final será la diferencia entre el valor medido y el valor tomado como patrón.

La siguiente tabla muestra la relación entre la conductividad y su equivalente en cloruro sódico para un volumen de 15 ml.

Resultado de la conductividad	Equivalente en cloruro sódico
10,0	60
13,	80
16,	100
20,	120
23,	140

Granallado- NORMAS DE PREPARACION DE SUPERFICIES

Los trabajos de preparación de superficies están normalizados por varias asociaciones internacionales. Las normas definen la terminación deseada o sea el grado de granallado a alcanzar.

Algunas normas son de comparación visual utilizando probetas de acero, discos comparadores o fotografías y otras normas solo son escritas. Todas ellas están sujetas a un vasto grado de interpretación y aplicación de las especificaciones dadas por los usuarios, inspectores, aplicadores y otros.

Norma SIS - Sueca	Norma Americana	Norma SSPC	Norma Francesa	Norma Inglesa	Norma NACE
SA 3	Metal Blanco	SP 5	DS 3	1st Quality	Nace 1
SA 2 ½	Semi Blanco	SP 10	DS 2.5	2nd. Quality	Nace 2
SA 2	Comercial	SP6	DS 2	3rd Quality	Nace 3
SA 1	Cepillado granallado ligero	SP7	DS 1		Nace 4

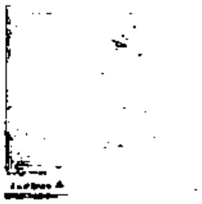
Las normas de mayor utilización en toda América Latina son las siguientes:

- **Normas SSPC**
  Steel Structures Painting Council
  Pittsburgh USA

- **Normas SIS**
  Swedish Standards Institution
  Stockholm Suecia

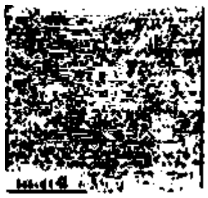
La metodología utilizada se basa en la comparación de la superficie tratada con el patrón de la norma, fotografías en el caso de la norma SSPC y transparencias en el caso de la norma SIS.

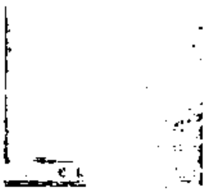
GRADOS DE HERRUMBRE UTILIZADOS EN AMBAS NORMAS



Grado A Superficie de acero con la capa de laminación intacta en toda la superficie y prácticamente sin corrosión.

Grado B Superficie de acero con principio de corrosión y en la cual la capa de laminación comienza a despegarse.





Grado C Superficie de acero en donde la capa de laminación ha sido eliminada por la corrosión o la capa de laminación puede ser eliminada por raspado, pero en la cual no se han formado en gran escala cavidades visibles.

Grado D Superficie de acero en donde la capa de laminación ha sido eliminada por la corrosión y se han formado en gran escala cavidades visibles.

NORMA EUROPEA SIS 05 5900

La norma define, para superficies de acero laminadas en caliente los cuatro grados diferentes de herrumbre, antes enunciados como A, B, C, D.

Partiendo de cada grado de herrumbre se definen grados de preparación de superficie, codificados como:

ST 2 y ST 3: para raspado y cepillado
Sa 1, Sa 2, Sa 2 1/2, Sa 3 mediante proyección de partículas abrasivas (arenado- granallado)

Así se combinan el punto de partida (superficie previa al granallado) y la terminación final (superficie ya granallada). Como ejemplo, si se parte de un grado de herrumbre "B" y se logra un grado de preparación Sa 2 1/2 el trabajo se define como B Sa 2 1/2.

También los grados de preparación superficial están descriptos con palabras pero las ilustraciones siempre proporcionan una información mas precisa.

Grados de preparación por raspado y cepillado manual con cepillo de acero

Las superficies de acero se limpiarán para quitar el aceite, grasa, etc., y las capas gruesas de óxido se sacarán con un cincel antes del tratamiento.

Grado St 2 Raspado, cepillado manual con cepillo de acero - cepillado a máquina- esmerilado a máquina- etc. de una manera minuciosa. Mediante el tratamiento se quitarán las capas sueltas de laminación, el óxido y las partículas extrañas. Luego se limpiará la superficie con un aspirador de polvo, aire comprimido limpio y seco o un cepillo limpio. Entonces deberá adquirir un suave brillo metálico.

El aspecto deberá coincidir con las figuras de la designación St 2.

Grado St 3 Raspado, cepillado manual con cepillo de acero, cepillado a máquina esmerilado a máquina, etc. de una manera muy minuciosa. La superficie se tratará como en el grado St 2 pero de una manera mucho más minuciosa. Después de quitar el polvo, la superficie deberá presentar un claro brillo metálico y su aspecto deberá coincidir con las figuras de la designación St 3

Grados de preparación por proyección de abrasivos

Las superficies de acero se limpiarán para quitar el aceite, grasa, etc. y las capas gruesas de óxido se sacarán con un cincel antes del tratamiento.

Grado Sa 1 Arenado-Granallado ligero: se quita la capa suelta de laminación, el óxido suelto y las partículas extrañas sueltas. El aspecto deberá coincidir con las figuras para Sa 1.

Grado Sa 2 Arenado-Granallado minucioso: se quita casi toda la capa de laminación y de óxido y casi todas las partículas extrañas. Deberá adquirir entonces un color grisáceo y su aspecto deberá coincidir con las figuras de la designación Sa 2.

Grado Sa 2 1/2 Arenado-Granallado muy minucioso: Las capas de laminación, óxido y partículas extrañas se quitan de una manera tan perfecta que los restos sólo aparezcan como ligeras manchas o rayas. Su aspecto deberá entonces coincidir con las figuras de la designación Sa 2 1/2.

Grado Sa 3 Arenado-Granallado a metal blanco: Toda la capa de laminación, todo el óxido y todas las partículas extrañas se quitan sin dejar ningun resto de contaminante. Deberá adquirir un color metálico uniforme y coincidir con las figuras de la designación Sa 3.

NORMA AMERICANA SSPC VIS 1- 89

Al igual que la norma Europea, la SSPC define cuatro grados de herrumbre (A, B, C, D) equivalentes y partiendo de éstos se definen distintos grados de preparación:

- **Grado SSPC SP7** Granallado / Arenado Rápido
- **Grado SSPC SP6** Granallado / Arenado Comercial
- **Grado SSPC SP10** Granallado / Arenado cercano a metal blanco
- **Grado SSPC SP5** Granallado / Arenado a metal blanco

Como ejemplo, si se parte de un grado de herrumbre "B" y se logra un grado de preparación SP 10 el trabajo se define como B SP 10

- ***Grado SSPC SP7 Arenado - Granallado Rápido:*** la superficie debe verse libre de aceite, grasa, polvo, capa suelta de laminación, óxido suelto y capas de pintura desprendidas. Conserva la capa de laminación donde está firmemente adherida. Estas partes no deben desprenderse mediante un objeto punzante. Es utilizado sólo en los casos de condiciones muy poco severas y presentará áreas de probables fallas.

  Grado SSPC SP6 Arenado Granallado Comercial: la superficie debe verse libre de aceite, grasa, polvo, óxido y los restos de capa de laminación no deben superar al 33% de la superficie en cada pulgada cuadrada de la misma. Los restos deben verse sólo como de distinta coloración. Generalmente se lo especifica en aquellas zonas muy poco solicitadas sin ambientes corrosivos.

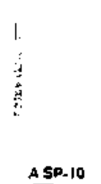
  Grado SSPC SP10 Arenado Granallado cercano a metal blanco: la superficie debe verse libre de aceite, grasa, polvo, óxido, capa de laminación, restos de pintura y otros materiales extraños. Se admite hasta un 5% de restos que pueden aparecer sólo como distinta coloración en cada pulgada cuadrada de la superficie.

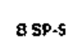
  Es la especificación más comúnmente utilizada. Reúne las características de buena preparación y rapidez en el trabajo. Se lo utiliza para condiciones regulares a severas.

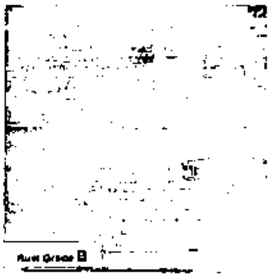
- ***Grado SSPC SP5 Arenado a metal blanco:*** la superficie debe verse libre de aceite, grasa, polvo, óxido, capa de laminación restos de pintura sin excepciones. Es utilizada donde las condiciones son extremadamente severas, con contaminantes ácidos, sales en solución, etc.

MUESTRAS DE DISTINTOS GRADOS DE PREPARACION DE SUPERFICIE


Rust Grade A


A SP-10

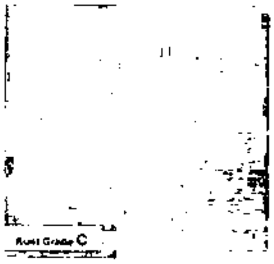

B SP-5


Rust Grade B


B SP-6


B SP-10

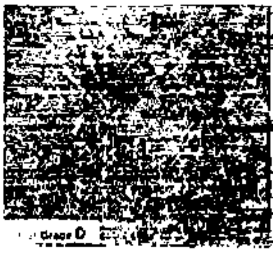

B SP-5


Rust Grade C


C SP-6


C SP-10


C SP-5


Grade D


D SP-6


D SP-10


D SP-5

NOTAS ACLARATORIAS

- En la práctica el grado de preparación más utilizado es el Sa 2 1/2 o SP10 debido a que provee un anclaje suficiente para la pintura (en las utilizaciones más generales), sin llegar a una terminación Sa 3 o SP5 que es la más completa, pero al mismo tiempo la más costosa.

- Es importante recalcar que cuando se utilizan los patrones de comparación visual se debe tener presente que el resultado no tiene porque ser exacto al de la ilustración que da la norma. Toda superficie una vez granallada puede diferir en su aspecto y color conforme el tipo de abrasivo utilizado (arena, granalla de acero, etc) además del metal base que se limpió. Es importante en estos casos remitirse al grado de remoción de óxidos que dice la norma.

  Una forma de controlar el trabajo es realizar probetas del mismo material a procesar con el abrasivo y en condiciones de trabajo similares a las de obra. Una vez medidas y aprobadas se efectúan durante el trabajo todas las comparaciones con dichas probetas.

- Es muy importante alcanzar el grado de terminación requerido, pues una especificación no alcanzada puede derivar en una falla prematura, en cambio superar la norma involucrará un mayor costo en el trabajo.

PROYECTOS ESPECIALES

Si lo que Ud. está necesitando no está enumerado en estas páginas no dude en consultarnos, nuestros departamentos de ingeniería y ventas lo asesorarán en todo lo relacionado con equipos, procesos, acabados, producciones y automatizaciones. Ponemos además a Vuestra disposición nuestras instalaciones y equipos de test para efectuar ensayos.

NORMA ISO 8501-1

Los grados de limpieza de superficies metálicas, están especificados por varias normas, siendo la más extendida la norma **SIS 055900 SWEDISH**, transformada posteriormente en **ISO 8501-1: 1988**, considerando los grados de preparación de la superficie en relación con el estado inicial del acero a pintar. Estas normas se refieren a acero envejecido, pero que nunca ha sido tratado con pintura.

Los **Estados Iniciales** definidos de acuerdo a estas normas son:

Superficies de acero completamente recubierta con cascarilla de laminación o calamina y con trazas de óxido. (El grado **A** es normalmente el que presenta el acero poco tiempo después de su laminación en caliente).

Superficies de acero que ha iniciado su corrosión y de la que ha empezado a desprenderse la cascarilla de laminación (El grado **B** es normalmente el estado de una superficie de acero laminado en caliente después de haber permanecido expuesta a la intemperie, sin protección, en una atmósfera medianamente corrosiva, durante 2 ó 3 meses).

Superficie de acero de la que la corrosión ha hecho saltar la totalidad de la cascarilla de laminación, pero que todavía no presenta picaduras detectables a simple vista. (El grado **C** es normalmente el estado de una superficie de acero que ha sido expuesta a la intemperie, sin protección, en una atmósfera medianamente corrosiva, durante 1 año, aproximadamente).

Superficiede acero de la que se ha desprendido la totalidad de la cascarilla de laminación y en la que se observan picaduras a simple vista. (El grado **D** corresponde al estado de una superficie de acero después de su exposición a la intemperie, sin protección, en una atmósfera medianamente corrosiva durante unos 3 años).

GRADOS DE PREPARACIÓN: A partir de cada uno de los estado iniciales se definen varios tipos de preparación, denominados con las siglas **St**, **Sa** o **FI**.

- **St:** Rascado, cepillado, picado, etcétera, por medios manuales o mecánicos.
- **Sa:** Chorreado abrasivo
- **FI:** Limpieza a la llama (flameado).

El estado inicial **A** sólo admite preparación por chorreado abrasivo (**Sa**), único método que permite eliminar la calamina.

En lo sucesivo sólo se considerarán los grados **St** y **Sa**, ya que el flameado se utiliza muy poco en la práctica.

Los diferentes grados utilizados:

ISO 8501-1
SIS 055900
Sa3

Eliminar la totalidad del óxido visible, cascarilla de laminación, pintura vieja y cualquier materia extraña. Limpieza por chorreado hasta **metal blanco**. El chorro se pasa sobre la superficie durante el tiempo necesario para eliminar la **totalidad** de la cascarilla de laminación, herrumbre y materias extrañas. Finalmente, la superficie se limpia con un aspirador, aire comprimido limpio y seco o con un cepillo limpio, para eliminar los residuos de polvo de abrasivo. Debe entonces quedar con un color metálico uniforme.

SSPC-SP-5
Chorreado a metal blanco.

BS 4232: Primera calidad.

ISO 8501-1
SIS 055900
Sa2½

Chorreado abrasivo hasta **metal casi blanco**, a fin de conseguir que por lo menos el 95% de cada porción de la superficie total quede libre de cualquier residuo visible. Chorreado muy cuidadoso. El chorro se mantiene sobre la superficie el tiempo necesario para asegurar que la cascarilla de laminación, herrumbre y materias extrañas son eliminados de tal forma que cualquier residuo aparezca sólo como ligeras sombras o manchas en la superficie. Finalmente, se elimina el polvo de abrasivo con un aspirador, con aire comprimido limpio y seco o con cepillo limpio.

SSPC-SP-10
Chorreado a metal casi blanco.

BS 4232: Segunda calidad.

ISO 8501-1
SIS 055900
Sa2

Chorreado hasta que al menos los 2/3 de cualquier porción de la superficie total estén libres de todo residuo visible. Chorreado cuidadoso. El chorro se pasa sobre la superficie durante el tiempo suficiente para eliminar la casi totalidad de cascarilla de laminación, herrumbre y materias extrañas. Finalmente se elimina el polvo abrasivo con un aspirador, con aire comprimido limpio y seco o con un cepillo limpio.

SSPC-SP-6
Chorreado comercial.

BS 4232: Tercera calidad.

ISO 8501-1
SIS 055900
St3

Rascado con rasquetas de metal duro y cepillado con cepillo de alambre, muy cuidadoso. El rascado y cepillado deben realizarse en primer lugar en una dirección y después en sentido perpendicular. Una vez eliminado el polvo, la superficie debe mostrar un pronunciado aspecto metálico.

SSPC-SP-3
Limpieza mecánica.

BS 4232: No tiene equivalente.

ISO 8501-1
SIS 055900
St2

Rascado cuidadoso con rasquetas de metal duro y cepillado con cepillo de alambre. El rascado y cepillado deben realizarse en primer lugar en una dirección y después en sentido perpendicular. Una vez eliminado el polvo, la superficie debe mostrar aspecto metálico.

SSPC-SP-2
Limpieza manual.

BS 4232: No tiene equivalente.

NOTA: Existe también el grado **Sa1**, que corresponde a un chorreado ligero o soplado con abrasivo, pero en la práctica se usa muy poco.

Designation: D 4417 – 93 (Reapproved 1999)

Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel[1]

This standard is issued under the fixed designation D 4417; 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 These test methods cover the description of techniques for measuring the profile of abrasive blast cleaned surfaces in the laboratory, field, or in the fabricating shop. There are additional techniques suitable for laboratory use not covered by these test methods.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Summary of Test Method

2.1 The methods are:

2.1.1 *Method A*—The blasted surface is visually compared to standards prepared with various surface profile depths and the range determined.

2.1.2 *Method B*—The depth of profile is measured using a fine pointed probe at a number of locations and the arithmetic mean determined.

2.1.3 *Method C*—A composite plastic tape is impressed into the blast cleaned surface forming a reverse image of the profile, and the maximum peak to valley distance measured with a micrometer.

3. Significance and Use

3.1 The height of surface profile has been shown to be a factor in the performance of various coatings applied to steel. For this reason, surface profile should be measured prior to coating application to ensure that it meets that specified. The instruments described are readily portable and sufficiently sturdy for use in the field.

NOTE 1—Optical microscope methods serve as a referee method for surface profile measurement. Profile depth designations are based on the concept of mean maximum profile ($\bar{h}$ max); this value is determined by averaging a given number (usually 20) of the highest peak to lowest valley measurements made in the field of view of a standard measuring microscope. This is done because of evidence that coatings performance in any one small area is primarily influenced by the highest surface features in that area and not by the average roughness.[2]

4. Apparatus

4.1 *Method A*—A profile comparator consisting of a number of areas (each approximately one square inch in size), usually side by side, with a different profile or anchor pattern depth. Each area is marked giving the nominal profile depth in mils or micrometres. Typical comparator surfaces are prepared with steel shot, steel grit, or sand or other nonmetallic abrasive, since the appearance of the profile created by these abrasives may differ. The comparator areas are used with or without magnification of 5 to 10 power.

4.2 *Method B*—A dial gage[3] depth micrometer fitted with a pointed probe. The probe is machined at a 60° angle with a nominal radius of 50 µm. The base of the instrument rests on the tops of the peaks of the surface profile while the spring loaded tip projects into the valleys.

4.3 *Method C*—A special tape[4] containing a compressible foam attached to a noncompressible uniform plastic film. A burnishing tool is used to impress the foam face of the tape into the surface to create a reverse replica of the profile that is measured using a spring-loaded micrometer.

5. Test Specimens

5.1 Use any metal surface that, after blast cleaning, is free of

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[1] These test methods are under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.46 on Industrial Protective Painting.

Current edition approved May 15, 1993. Published July 1993. Originally published as D 4417 – 84. Last previous edition D 4417 – 84.

[2] John D. Keane, Joseph A. Bruno, Jr., Raymond E. F. Weaver, "Surface Profile for Anti-Corrosion Paints," Oct. 25, 1976, Steel Structures Painting Council, 4400 Fifth Ave., Pittsburgh, PA 15213.

[3] The sole source of supply of suitable depth micrometers known to the committee at this time is the surface profile gage, Model 123, Elcometer Instruments, Ltd., Edge Lane, Droylston, Manchester M35 6UB, United Kingdom, England. If you are aware of alternative suppliers, please proved this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committtee,'which you may attend.

[4] The sole source of supply of suitable replica tape, Press-O-Film, known to the committee at this time is Testex, 8 Fox Lane, Newark, DE 19711. If you are aware of alternative suppliers, please proved this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committtee,'which you may attend

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loose surface interference material, dirt, dust, and abrasive residue.

6. Procedure

6.1 *Method A*:

6.1.1 Select the comparator standard appropriate for the abrasive used for blast cleaning.

6.1.2 Place the comparator standard directly on the surface to be measured and compare the roughness of the prepared surface with the roughness on the comparator segments. This can be done with the unaided eye, under 5 to 10 power magnification, or by touch. When using magnification, the magnifier should be brought into intimate contact with the standard, and the depth of focus must be sufficient for the standard and surface to be in focus simultaneously.

6.1.3 Select the comparator segment that most closely approximates the roughness of the surface being evaluated or, if necessary, the two segments to which it is intermediate.

6.1.4 Evaluate the roughness at a sufficient number of locations to characterize the surface as specified or agreed upon between the interested parties. Report the range of results from all locations as the surface profile.

6.2 *Method B*:

6.2.1 Prior to use set the gage to zero by placing it on a piece of plate float glass. Hold the gage by its base and press firmly against the glass. Adjust the instrument to zero.

6.2.2 To take readings, hold the gage firmly against the prepared substrate. Do not drag the instrument across the surface between readings, or the spring-loaded tip may become rounded leading to false readings.

6.2.3 Measure the profile at a sufficient number of locations to characterize the surface, as specified or agreed upon between the interested parties. At each location make ten readings and determine the mean. Then determine the mean for all the locations and report it as the profile of the surface.

6.3 *Method C*:

6.3.1 Select the correct tape range for the profile to be measured: coarse, 0 to 50 µm (0 to 2 mils) and extra coarse, 40 to 115 µm (1.5 to 4.5 mils).

6.3.2 Remove the wax paper backing and place the tape on the prepared surface with the foam side down, that is, put the dull side down.

6.3.3 Hold the tape firmly on the surface and rub the circular cut-out portion (approximately 6.5 mm (⅜ in.) diameter) with the burnishing tool until a uniform gray color appears.

6.3.4 Remove the tape and place it between the anvils of a spring-loaded micrometer. Measure the thickness of the tape (compressed foam and non-compressible plastic film combined). Subtract the thickness of the noncompressible plastic film to obtain the surface profile.

6.3.5 Measure the profile at a sufficient number of locations to characterize the surface, as specified or agreed upon between the interested parties. At each location make three readings and determine the mean. Then determine the mean for all the locations and report it as the profile of the surface.

7. Report

7.1 Report the range and the appropriate average (mean or mode) of the determinations, the number of locations measured, and the approximate total area covered.

8. Precision and Bias

8.1 *Test Method A*:

8.1.1 *Applicability*—Based on measurements of profiles on surfaces of 8 steel panels, each blast cleaned with 1 of 8 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 37 µm (1.5 mils) to 135 µm (5.4 mils), the correlation coefficient for Test Method A was found to be 0.75 and the coefficient of determination was found to be 0.54.

8.1.2 *Precision*—In an interlaboratory study of Test Method A in which 2 operators each running 2 tests on separate days in each of 6 laboratories tested 8 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 20 % with 141 df and the interlaboratory coefficient was found to be 19 % with 40 df, after rejecting 3 results for one time because the range between repeats differed significantly from all other ranges. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.1.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 56 %.

8.1.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 54 %.

8.2 *Test Method B*:

8.2.1 *Applicability*—Based on measurements of profiles on surfaces of 8 steel panels, each blast cleaned with 1 of 8 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 1.5 mils (37 µm) to 5.4 mils (135 µm), the correlation coefficient for Test Method B was found to be 0.99 and the coefficient of determination was found to be 0.93.

8.2.2 *Precision*—In an interlaboratory study of Test Method B in which 2 operators, each running 2 tests on separate days, in each of 5 laboratories tested 8 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 19 % with 113 df and the interlaboratory coefficient was found to be 28 % with 32 df, after rejecting 3 results for one time because the range between repeats differed significantly from all other ranges. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.2.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 54 %.

8.2.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 79 %.

8.3 *Method C (X-Coarse Tape)*:

8.3.1 *Applicability*—Based on measurements of profiles on surfaces of 8 steel panels, each blast cleaned with 1 of 8 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 37 µm (1.5 mils) to 135 µm (5.4 mils), the correlation coefficient for Test

Method C (X-Coarse Tape) was found to be 0.96 and the coefficient of determination was found to be 0.93.

8.3.2 *Precision*—In an interlaboratory study of Test Method C (X-Coarse Tape) in which 2 operators each running 2 tests on separate days in each of 6 laboratories tested 8 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 9 % with 120 df and the interlaboratory coefficient 13 % with 32 df. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.3.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 25 %.

8.3.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 37 %.

8.4 *Test Method C (Coarse Tape)*:

8.4.1 *Applicability*—Based on measurements of profiles on surfaces of 6 steel panels, each blast cleaned with 1 of 6 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 37 µm (1.5 mils) to 57 µm (2.3 mils), the correlation coefficient for Test Method C (Coarse Tape) was found to be 0.48 and the coefficient of determination was found to be 0.23.

8.4.2 *Precision*—In an interlaboratory study of Test Method C (Coarse Tape) in which 2 operators each running 2 tests on separate days in each of 5 laboratories tested 6 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 11 % with 90 df and the interlaboratory coefficient 11 % with 24 df. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.4.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 30 %.

8.4.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 28 %.

8.5 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in these test methods for measuring surface profile, bias cannot be determined.

NOTE 2—The test methods measure different values and the qualitative rating on which the applicability was determined also measures a different value. The mode is determined with the comparator of Test Method A. The height of a single valley below a plane at the level of the highest surrounding peaks is measured with the fine pointed probe of Test Method B. The distance from the bottoms of many of the deepest valleys to the tops of the highest peaks (maximum profiles) are measured with the composite plastic of Test Method C. The height of a single peak above an adjacent valley below is measured with a microscope for the qualitative rating that is compared with each of the methods in correlation calculations. Because the results for the microscope and for the fine pointed probe are measurements to an individual valley, the readings range over much broader limits than the results of the tape or the comparator.

9. Keywords

9.1 abrasive; abrasive blast cleaning; anchor pattern; surface profile; surface roughness

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Designation: D 4414 – 95 (Reapproved 2001)

Standard Practice for Measurement of Wet Film Thickness by Notch Gages[1]

This standard is issued under the fixed designation D 4414; 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 practice describes the use of thin rigid metal notched gages, also called step or comb gages, in the measurement of wet film thickness of organic coatings, such as paint, varnish, and lacquer.

1.2 Notched gage measurements are neither accurate nor sensitive, but they are useful in determining approximate wet film thickness of coatings on articles where size(s) and shape(s) prohibit the use of the more precise methods given in Methods D 1212.

1.3 This practice is divided into the following two procedures:

1.3.1 *Procedure A*—A square or rectangular rigid metal gage with notched sides is used to measure wet film thicknesses ranging from 3 to 2000 µm (0.5 to 80 mils 1). Such a gage is applicable to coatings on flat substrates and to coatings on articles of various sizes and complex shapes where it is possible to get the end tabs of the gage to rest in the same plane on the substrate.

1.3.2 *Procedure B*—A circular thin rigid metal notched gage is used to measure wet film thicknesses ranging from 25 to 2500 µm (1 to 100 mils). Such a gage is applicable to coatings on flat substrates and to coatings on objects of various sizes and complex shapes.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

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:*

D 1212 Test Methods for Measurement of Wet Film Thickness of Organic Coatings[2]

3. Summary of Practice

3.1 The material is applied to the articles to be coated and the wet film thickness measured with a notched gage.

3.2 *Procedure A*—A square or rectangular thin rigid metal gage with notched sides, having tabs of varying lengths, is pushed perpendicularly into the film. After removal from the film, the gage is examined and the film thickness is determined to lie between the clearance of the shortest tab wet by the film and the clearance of the next shorter tab not wetted by the film.

3.3 *Procedure B*—A circular thin rigid metal gage having spaced notches of varying depths around its periphery is rolled perpendicularly across the film. After removal from the film, the gage is examined and the film thickness is determined as being between the clearance of the deepest face wetted and the clearance of the next deepest notch face not wetted by the film.

4. Significance and Use

4.1 Wet film thickness measurements of coatings applied on articles can be very helpful in controlling the thickness of the final dry coating, although in some specifications the wet film thickness is specified. Most protective and high performance coatings are applied to meet a requirement or specification for dry film thickness for each coat or for the completed coating system, or for both.

4.2 There is a direct relationship between dry film thickness and wet film thickness. The wet film/dry film ratio is determined by the volume of volatiles in the coating as applied, including permitted thinning. With some flat coatings the dry film thickness is higher than that calculated from the wet film thickness. Consequently, the results from the notch gage are not to be used to verify the nonvolatile content of a coating.

4.3 Measurement of wet film thickness at the time of application is most appropriate as it permits correction and adjustment of the film by the applicator at the time of application. Correction of the film after it has dried or chemically cured requires costly extra labor time, may lead to contamination of the film, and may introduce problems of adhesion and integrity of the coating system.

4.4 The procedures using notched gages do not provide as accurate or sensitive measurements of wet film thickness as do the Interchemical and Pfund gages described in Methods D 1212. Notch gages may, however, be used on nonuniform surfaces, like concrete block, that are too rough to use the

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[1] This practice is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

Current edition approved Nov. 10, 1995. Published January 1996. Originally published as D 4414 – 84. Last previous edition D 4414 – 84 (1990)$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 06.01.

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Interchemical and Pfund gages. Also notched gages can be very useful in the shop and field for determining the approximate thickness of wet films over commercial articles where size(s) and shape(s) are not suitable for measurements by other types of gages. Examples of such items are ellipses, thin edges, and corners.

4.5 An operator experienced in the use of a notched gage can monitor the coating application well enough to ensure the minimum required film thickness will be obtained.

4.6 Application losses, such as overspray, loss on transfer, and coating residue in application equipment, are a significant unmeasurable part of the coating used on a job and are not accounted for by measurement of wet film thickness.

5. Report

5.1 Report the following information:

5.1.1 The mean and range of the readings taken and the number of readings.

5.1.2 The smallest graduation of the gage used.

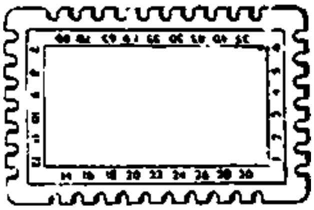

FIG. 1 Rectangular Notched Gage

6. Precision and Bias

6.1 The precision and bias of Procedure A or B for measuring wet film thickness with notch gages are very dependent on methods of film application, time that the measurement is taken after film application, mechanical condition of the notch gages, and the step range of the gages.

6.2 Generally, the agreement between notch gages is good because they are insensitive to small differences in film thickness, that is the step intervals of the gages are relatively large.

PROCEDURE A

7. Apparatus

7.1 *Notched Gage*, square or rectangular, thin rigid metal plate, with notched sides (see Fig. 1), made from steel or aluminum[3] (Note 1). Nonmetallic gages shall not be used.

NOTE 1—Aluminum or aluminum alloy gages are more easily distorted and may exhibit greater wear than steel gages. Gages made of plastic or deformable metal are not suitable.

7.1.1 Each notched side shall consist of a series of tabs (between notches) varying in length and located in a line between two end tabs equal in length and longest in the row.

7.1.2 As an example, the tabs on one row of a gage may differ in length as follows:

By 13 μm (0.5 mil) between 0 to 150 μm (0 and 6 mils),
By 25 μm (1 mil) between 150 to 250 μm (6 and 10 mils),
By 50 μm (2 mils) between 250 to 750 μm (10 and 30 mils), and
By 125 μm(5 mils) over 750 μm (30 mils).

8. Procedure

8.1 Apply the coating material to a rigid substrate and test with the gage immediately. The gage must be used immediately following application of the coating. Some coatings lose solvents quickly and spray application increases the speed. The resulting rapid reduction in wet film thickness can cause misleading readings.

8.2 Locate an area sufficiently large to permit both end tabs of the gage to rest on the substrate in the same plane.

8.3 Push the gage perpendicularly into the wet film so that the two end tabs rest firmly on the substrate at the same time.

8.4 Or, set one end tab firmly on the substrate and lower the gage until the other end tab is firmly in contact with the substrate.

8.5 Remove the gage from the film and examine the tabs. The film thickness is determined as being between the clearance of the shortest tab wettedd and the clearance of the next shorter tab not wetted by the film.

8.6 Clean the gage immediately after each reading by wiping it on a dry or solvent-dampened cloth so that subsequent readings are not affected. Do not clean with metal scrapers.

8.7 Repeat the procedure in 8.2-8.5 for at least three locations on the film. The number of readings required to obtain a good estimate of the film thickness varies with the shape and size of the article being coated, with the operator's experience, and whether one or more of the following problems are encountered:

8.7.1 Some coatings may not wet (leave residue on) some metal gages. However, the film itself may show where contact was made. When reading the gage, look at both the gage and the film itself for verification of the reading.

8.7.2 The gage may slip on the surface. Ignore such readings.

8.7.3 The surface may be coarse and false readings produced. The spot where the gage is used must be as uniform as possible and questionable readings ignored.

8.8 Determine the mean and range of the readings.

9. Report

9.1 Report the mean and range of the readings.

PROCEDURE B

10. Apparatus

10.1 *Circular Notched Gage*,[4] thin metal disk, with calibrated notches of various depths spaced around its periphery

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[3] These gages are commercially available from various coating equipment and instrument suppliers.

[4] The "Hotcake" Wet Film Thickness Gage is covered by a patent held by Paul N. Gardner, Sr., 316 N.E. First Street, Pompano Beach, FL 33060. Interested parties are invited to submit information regarding the identification of acceptable alternatives to this patented item to the Committee on Standards, ASTM Headquarters, 100 Barr Harbor Drive., West Conshohocken, PA 19428. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

(see Fig. 2). Each notch has a recessed flat face. A hole is in the center of the disk.

10.2 Examples of the scale increments and ranges provided by the notches are:

10.2.1 25–µm increments between 25 µm to 100 µm (1 to 4 mils),

10.2.2 50–µm increments between 150 µm to 1500 µm (6 and 60 mils), and

10.2.3 100–µm increments between 1500 µm to 2000 µm(60 and 80 mils).

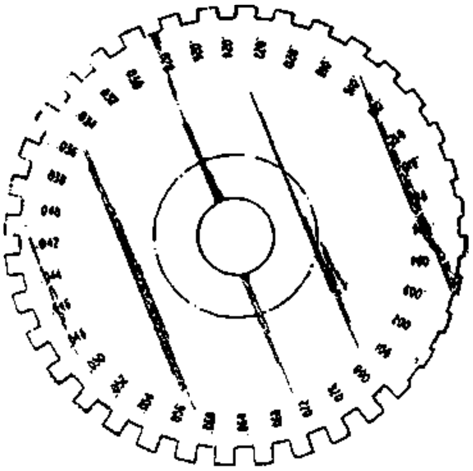

FIG. 2 Circular Notched Gage

11. Procedure

11.1 Select a gage that has a segment with a thickness scale appropriate for the expected range of wet-film thickness.

11.2 Locate areas on the rigid substrate sufficiently large to permit the gage to roll for at least 1½ in. (40 mm).

11.3 Apply the liquid coating to the substrate and immediately place the selected segment perpendicularly on the wet film and in firm contact with the substrate. Roll the gage across the film, holding the disk with a thumb and index finger in the center hole.

11.4 Remove the gage from the film and inspect the notch faces. The wet-film thickness is determined as being between the clearance of the deepest notch face wetted and the clearance of the next deeper notch face not wetted by the film.

11.5 Clean the gage immediately after each reading by wiping on a dry or solvent-dampened cloth so that subsequent readings are not affected. Do not clean with metal scrapers.

11.6 Repeat the procedure from 11.1-11.5 as described in 8.7.

11.7 Determine the mean and range of the readings.

12. Report

12.1 Report the mean and range of the readings.

13. Keywords

13.1 circular notched gage; rectangular notched gage

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Standard Test Methods for Measuring Adhesion by Tape Test[1]

This standard is issued under the fixed designation D 3359; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods cover procedures for assessing the adhesion of coating films to metallic substrates by applying and removing pressure-sensitive tape over cuts made in the film.

1.2 Test Method A is primarily intended for use at job sites while Test Method B is more suitable for use in the laboratory. Also, Test Method B is not considered suitable for films thicker than 5 mils (125μm).

NOTE 1—Subject to agreement between the purchaser and the seller, Test Method B can be used for thicker films if wider spaced cuts are employed.

1.3 These test methods are used to establish whether the adhesion of a coating to a substrate is at a generally adequate level. They do not distinguish between higher levels of adhesion for which more sophisticated methods of measurement are required.

NOTE 2—It should be recognized that differences in adherability of the coating surface can affect the results obtained with coatings having the same inherent adhesion.

1.4 In multicoat systems adhesion failure may occur between coats so that the adhesion of the coating system to the substrate is not determined.

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address 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:*

D 609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products[2]

D 823 Practice for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels[2]

D 1000 Test Methods For Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications[3]

D 1730 Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting[4]

D 2092 Guide for Preparation of Zinc-Coated (Galvanized) Steel Surfaces for Painting[5]

D 2197 Test Methods for Adhesion of Organic Coatings by Scrape Adhesion[2]

D 2370 Test Method for Tensile Properties of Organic Coatings[2]

D 3330 Test Method for Peel Adhesion of Pressure-Sensitive Tape of 180° Angle[6]

D 3924 Specification for Standard Environment for Conditioning and Tesing Paint, Varnish, Lacquers, and Related Materials[2]

D 4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser[2]

3. Summary of Test Methods

3.1 *Test Method A*—An X-cut is made in the film to the substrate, pressure-sensitive tape is applied over the cut and then removed, and adhesion is assessed qualitatively on the 0 to 5 scale.

3.2 *Test Method B*—A lattice pattern with either six or eleven cuts in each direction is made in the film to the substrate, pressure-sensitive tape is applied over the lattice and then removed, and adhesion is evaluated by comparison with descriptions and illustrations.

4. Significance and Use

4.1 If a coating is to fulfill its function of protecting or decorating a substrate, it must adhere to it for the expected service life. Because the substrate and its surface preparation (or lack of it) has a drastic effect on the adhesion of coatings, a method of evaluation adhesion of a coating to different substrates or surface treatments, or of different coatings to the same substrate and treatment, is of considerable usefulness in the industry.

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[1] These test methods are under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

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[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] *Annual Book of ASTM Standards*, Vol 10.01.

[4] *Annual Book of ASTM Standards*, Vol 02.05.

[5] *Annual Book of ASTM Standards*, Vol 06.02.

[6] *Annual Book of ASTM Standards*, Vol 15.09.

4.2 The limitations of all adhesion methods and the specific limitation of this test method to lower levels of adhesion (see 1.3) should be recognized before using it. The intra- and inter-laboratory precision of this test method is similar to other widely-accepted tests for coated substrates (for example, Test Method D 2370 and Test Method D 4060), but this is partly the result of it being insensitive to all but large differences in adhesion. The limited scale of 0 to 5 was selected deliberately to avoid a false impression of being sensitive.

TEST METHOD A—X-CUT TAPE TEST

5. Apparatus and Materials

5.1 *Cutting Tool*—Sharp razor blade, scalpel, knife or other cutting devices. It is of particular importance that the cutting edges be in good condition.

5.2 *Cutting Guide*—Steel or other hard metal straightedge to ensure straight cuts.

5.3 *Tape*—One-inch (25-mm) wide semitransparent pressure-sensitive tape with an adhesion strength agreed upon by the supplier and the user is needed[7]. Because of the variability in adhesion strength from batch-to-batch and with time, it is essential that tape from the same batch be used when tests are to be run in different laboratories. If this is not possible the test method should be used only for ranking a series of test coatings.

5.4 *Rubber Eraser*, on the end of a pencil.

5.5 *Illumination*—A light source is helpful in determining whether the cuts have been made through the film to the substrate.

6. Test Specimens

6.1 When this test method is used in the field, the specimen is the coated structure or article on which the adhesion is to be evaluated.

6.2 For laboratory use apply the materials to be tested to panels of the composition and surface conditions on which it is desired to determine the adhesion.

NOTE 3—Applicable test panel description and surface preparation methods are given in Practice D 609 and Practices D 1730 and D 2092.

NOTE 4—Coatings should be applied in accordance with Practice D 823, or as agreed upon between the purchaser and the seller.

NOTE 5—If desired or specified, the coated test panels may be subjected to a preliminary exposure such as water immersion, salt spray, or high humidity before conducting the tape test. The conditions and time of exposure will be governed by ultimate coating use or shall be agreed upon between the purchaser and seller.

7. Procedure

7.1 Select an area free of blemishes and minor surface imperfections. For tests in the field, ensure that the surface is clean and dry. Extremes in temperature or relative humidity may affect the adhesion of the tape or the coating.

7.2 Make two cuts in the film each about 1.5 in. (40 mm) long that intersect near their middle with a smaller angle of between 30 and 45°. When making the incisions, use the straightedge and cut through the coating to the substrate in one steady motion.

7.3 Inspect the incisions for reflection of light from the metal substrate to establish that the coating film has been penetrated. If the substrate has not been reached make another X in a different location. Do not attempt to deepen a previous cut as this may affect adhesion along the incision.

7.4 Remove two complete laps of the pressure-sensitive tape from the roll and discard. Remove an additional length at a steady (that is, not jerked) rate and cut a piece about 3 in. (75 mm) long.

7.5 Place the center of the tape at the intersection of the cuts with the tape running in the same direction as the smaller angles. Smooth the tape into place by finger in the area of the incisions and then rub firmly with the eraser on the end of a pencil. The color under the transparent tape is a useful indication of when good contact has been made.

7.6 Within 90 ± 30 s of application, remove the tape by seizing the free end and pulling it off rapidly (not jerked) back upon itself at as close to an angle of 180° as possible.

7.7 Inspect the X-cut area for removal of coating from the substrate or previous coating and rate the adhesion in accordance with the following scale:

5A	No peeling or removal,
4A	Trace peeling or removal along incisions or at their intersection,
3A	Jagged removal along incisions up to $\frac{1}{16}$ in. (1.6 mm) on either side,
2A	Jagged removal along most of incisions up to $\frac{1}{8}$ in. (3.2 mm) on either side,
1A	Removal from most of the area of the X under the tape, and
0A	Removal beyond the area of the X.

7.8 Repeat the test in two other locations on each test panel. For large structures make sufficient tests to ensure that the adhesion evaluation is representative of the whole surface.

7.9 After making several cuts examine the cutting edge and, if necessary, remove any flat spots or wire-edge by abrading lightly on a fine oil stone before using again. Discard cutting tools that develop nicks or other defects that tear the film.

8. Report

8.1 Report the number of tests, their mean and range, and for coating systems, where the failure occurred that is, between first coat and substrate, between first and second coat, etc.

8.2 For field tests report the structure or article tested, the location and the environmental conditions at the time of testing.

8.3 For test panels report the substrate employed, the type of coating, the method of cure, and the environmental conditions at the time of testing.

8.4 If the adhesion strength of the tape has been determined in accordance with Test Methods D 1000 or D 3330, report the results with the adhesion rating(s). If the adhesion strength of the tape has not been determined, report the specific tape used and its manufacturer.

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[7] Permacel 99, manufactured by Permacel, New Brunswick, NJ 08903, and available from various Permacel tape distributors, is reported to be suitable for this purpose. The manufacturer of this tape and the manufacturer of the tape used in the interlaboratory study (see RR: D01-1008), have advised this subcommittee that the properties of these tapes were changed. Users of it should, therefore, check whether current material gives comparable results to previous supplied material.

9. Precision and Bias [8]

9.1 In an interlaboratory study of this test method in which operators in six laboratories made one adhesion measurement on three panels each of three coatings covering a wide range of adhesion, the within-laboratories standard deviation was found to be 0.33 and the between-laboratories 0.44. Based on these standard deviations, the following criteria should be used for judging the acceptability of results at the 95 % confidence level:

9.1.1 *Repeatability*—Provided adhesion is uniform over a large surface, results obtained by the same operator should be considered suspect if they differ by more than 1 rating unit for two measurements.

9.1.2 *Reproducibility*—Two results, each the mean of triplicates, obtained by different operators should be considered suspect if they differ by more than 1.5 rating units.

9.2 Bias cannot be established for these test methods.

TEST METHOD B—CROSS-CUT TAPE TEST

10. Apparatus and Materials

10.1 *Cutting Tool*—Sharp razor blade, scalpel, knife or other cutting device having a cutting edge angle between 15 and 30° that will make either a single cut or several cuts at once[9]. It is of particular importance that the cutting edge or edges be in good condition.

10.2 *Cutting Guide*—If cuts are made manually (as opposed to a mechanical apparatus) a steel or other hard metal straightedge or template to ensure straight cuts.

10.3 *Rule*—Tempered steel rule graduated in 0.5 mm for measuring individual cuts.

10.4 *Tape*, as described in 5.3.

10.5 *Rubber Eraser*, on the end of a pencil.

10.6 *Illumination*, as described in 5.5.

10.7 *Magnifying Glass*—An illuminated magnifier to be used while making individual cuts and examining the test area.

11. Test Specimens

11.1 Test specimens shall be as described in Section 6. It should be noted, however, that multitip cutters provide good results only on test areas sufficiently plane[10] that all cutting edges contact the substrate to the same degree. Check for flatness with a straight edge such as that of the tempered steel rule (10.3).

12. Procedure

12.1 Where required or when agreed upon, subject the specimens to a preliminary test before conducting the tape test (see Note 3). After drying or testing the coating, conduct the tape test at room temperature as defined in Specification D 3924, unless D 3924 standard temperature is required or agreed.

12.2 Select an area free of blemishes and minor surface imperfections, place on a firm base, and under the illuminated magnifier, make parallel cuts as follows:

12.2.1 For coatings having a dry film thickness up to and including 2.0 mils (50 μm) space the cuts 1 mm apart and make eleven cuts unless otherwise agreed upon.

12.2.2 For coatings having a dry film thickness between 2.0 mils (50 μm) and 5 mils (125 μm), space the cuts 2 mm apart and make six cuts. For films thicker than 5 mils use Test Method A.[11]

12.2.3 Make all cuts about ¾ in. (20 mm) long. Cut through the film to the substrate in one steady motion using just sufficient pressure on the cutting tool to have the cutting edge reach the substrate. When making successive single cuts with the aid of a guide, place the guide on the uncut area.

12.3 After making the required cuts brush the film lightly with a soft brush or tissue to remove any detached flakes or ribbons of coatings.

12.4 Examine the cutting edge and, if necessary, remove any flat spots or wire-edge by abrading lightly on a fine oil stone. Make the additional number of cuts at 90° to and centered on the original cuts.

12.5 Brush the area as before and inspect the incisions for reflection of light from the substrate. If the metal has not been reached make another grid in a different location.

12.6 Remove two complete laps of tape and discard. Remove an additional length at a steady (that is, not jerked) rate and cut a piece about 3 in. (75 mm) long.

12.7 Place the center of the tape over the grid and in the area of the grid smooth into place by a finger. To ensure good contact with the film rub the tape firmly with the eraser on the end of a pencil. The color under the tape is a useful indication of when good contact has been made.

12.8 Within 90 ± 30 s of application, remove the tape by seizing the free end and rapidly (not jerked) back upon itself at as close to an angle of 180° as possible.

12.9 Inspect the grid area for removal of coating from the substrate or from a previous coating using the illuminated magnifier. Rate the adhesion in accordance with the following scale illustrated in Fig. 1:

5B	The edges of the cuts are completely smooth; none of the squares of the lattice is detached.
4B	Small flakes of the coating are detached at intersections; less than 5 % of the area is affected.
3B	Small flakes of the coating are detached along edges and at intersections of cuts. The area affected is 5 to 15 % of the lattice.
2B	The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35 % of the lattice.
1B	The coating has flaked along the edges of cuts in large ribbons and whole squares have detached. The area affected is 35 to 65 % of the lattice.
0B	Flaking and detachment worse than Grade 1.

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[8] Supporting data are available from ASTM Headquarters. Request RR: D01-1008.

[9] Multiblade cutters are available from a few sources that specialize in testing equipment for the paint industry. One supplier that has assisted in the refinement of these methods and of Test Methods D 2197 is given in footnote 10.

[10] The sole source of supply of the multitip cutter for coated pipe surfaces known to the committee at this time is Paul N. Gardner Co., 316 NE First St., Pompano Beach, FL 33060. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[11] Test Method B has been used successfully by some people on coatings greater than 5 mils (0.13 mm) by spacing the cuts 5 mm apart. However, the precision values given in 14.1 do not apply as they are based on coatings less than 5 mm (0.13 mm) in thickness.

CLASSIFICATION OF ADHESION TEST RESULTS

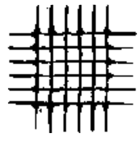
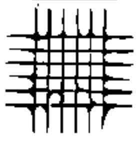
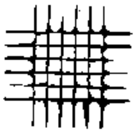
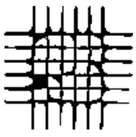
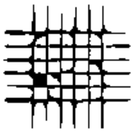
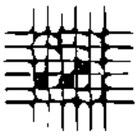
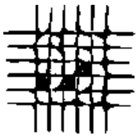
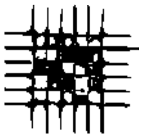
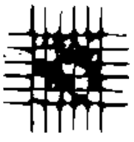
CLASSIFICATION	PERCENT AREA REMOVED	SURFACE OF CROSS-CUT AREA FROM WHICH FLAKING HAS OCCURRED FOR SIX PARALLEL CUTS AND ADHESION RANGE BY PERCENT
5B	0% None	
4B	Less than 5%	
3B	5 - 15%	 
2B	15 - 35%	 
1B	35 - 65%	 
0B	Greater than 65%	

FIG. 1 Classification of Adhesion Test Results

12.10 Repeat the test in two other locations on each test panel.

13. Report

13.1 Report the number of tests, their mean and range, and for coating systems, where the failure occurred, that is, between first coat and substrate, between first and second coat, etc.

13.2 Report the substrate employed, the type of coating and the method of cure.

13.3 If the adhesion strength has been determined in accordance with Test Methods D 1000 or D 3330, report the results with the adhesion rating(s). If the adhesion strength of the tape has not been determined, report the specific tape used and its manufacturer.

14. Precision and Bias [8]

14.1 On the basis of two interlaboratory tests of this test method in one of which operators in six laboratories made one adhesion measurement on three panels each of three coatings covering a wide range of adhesion and in the other operators in six laboratories made three measurements on two panels each of four different coatings applied over two other coatings, the pooled standard deviations for within- and between-laboratories were found to be 0.37 and 0.7. Based on these standard deviations, the following criteria should be used for judging the acceptability of results at the 95 % confidence level:

14.1.1 *Repeatability*—Provided adhesion is uniform over a large surface, results obtained by the same operator should be considered suspect if they differ by more than one rating unit for two measurements.

14.1.2 *Reproducibility*—Two results, each the mean of duplicates or triplicates, obtained by different operators should be considered suspect if they differ by more than two rating units.

14.2 Bias cannot be established for these test methods.

15. Keywords

15.1 adhesion; tape; crosscut adhesion test method; tape adhesion test method; X-cut adhesion test method

APPENDIX

(Nonmandatory Information)

X1. COMMENTARY

X1.1 Introduction

X1.1.1 Given the complexities of the adhesion process, can adhesion be measured? As Mittal **(1)**[12] has pointed out, the answer is both yes and no. It is reasonable to state that at the present time no test exists that can precisely assess the actual physical strength of an adhesive bond. But it can also be said that it is possible to obtain an indication of relative adhesion performance.

X1.1.2 Practical adhesion test methods are generally of two types: "*implied*" and "*direct*". "Implied" tests include indentation or scribe techniques, rub testing, and wear testing. Criticism of these tests arises when they are used to quantify the strength of adhesive bonding. But this, in fact, is not their purpose. An "implied" test should be used to assess coating performance under actual service conditions. "Direct" measurements, on the other hand, are intended expressly to measure adhesion. Meaningful tests of this type are highly sought after, primarily because the results are expressed by a single discrete quantity, the force required to rupture the coating/substrate bond under prescribed conditions. Direct tests include the Hesiometer and the Adherometer **(2)**. Common methods which approach the direct tests are peel, lap-shear, and tensile tests.

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[12] The boldface numbers in parentheses refer to the list of references at the end of this test method.

X1.2 Test Methods

X1.2.1 In practice, numerous types of tests have been used to attempt to evaluate adhesion by inducing bond rupture by different modes. Criteria deemed essential for a test to warrant large-scale acceptance are: use of a straightforward and unambiguous procedure; relevance to its intended application; repeatability and reproducibility; and quantifiability, including a meaningful rating scale for assessing performance.

X1.2.2 Test methods used for coatings on metals are: peel adhesion or "tape testing"; Gardner impact flexibility testing; and adhesive joint testing including shear (lap joint) and direct tensile (butt joint) testing. These tests do not strictly meet all the criteria listed, but an appealing aspect of these tests is that in most cases the equipment/instrumentation is readily available or can be obtained at reasonable cost.

X1.2.3 A wide diversity of tests methods have been developed over the years that measure aspects of adhesion **(1-5)**. There generally is difficulty, however, in relating these tests to basic adhesion phenomena.

X1.3 The Tape Test

X1.3.1 By far the most prevalent test for evaluating coating "adhesion" is the tape-and-peel test, which has been used since the 1930's. In its simplest version a piece of adhesive tape is pressed against the paint film and the resistance to and degree of film removal observed when the tape is pulled off. Since an intact film with appreciable adhesion is frequently not removed at all, the severity of the test is usually enhanced by cutting into the film a figure *X* or a cross hatched pattern, before applying and removing the tape. Adhesion is then rated by comparing film removed against an established rating scale. If an intact film is peeled cleanly by the tape, or if it debonds just by cutting into it without applying tape, then the adhesion is rated simply as poor or very poor, a more precise evaluation of such films not being within the capability of this test.

X1.3.2 The current widely-used version was first published in 1974; two test methods are covered in this standard. Both test methods are used to establish whether the adhesion of a coating to a substrate is at an adequate level; however they do not distinguish between higher levels of adhesion for which more sophisticated methods of measurement are required. Major limitations of the tape test are its low sensitivity, applicabiity only to coatings of relatively low bond strengths, and non-determination of adhesion to the substrate where failure occurs within a single coat, as when testing primers alone, or within or between coats in multicoat systems. For multicoat systems where adhesion failure may occur between or within coats, the adhesion of the coating system to the substrate is not determined.

X1.3.3 Repeatability within one rating unit is generally observed for coatings on metals for both methods, with reproducibility of one to two units. The tape test enjoys widespread popularity and is viewed as "simple" as well as low in cost. Applied to metals, it is economical to perform, lends itself to job site application, and most importantly, after decades of use, people feel comfortable with it.

X1.3.4 When a flexible adhesive tape is applied to a coated rigid substrate surface and then removed, the removal process has been described in terms of the "peel phenomenon," as illustrated in Fig. X1.1.

X1.3.5 Peeling begins at the "toothed" leading edge (at the right) and proceeds along the coating adhesive/interface or the coating/substrate interface, depending on the relative bond strengths. It is assumed that coating removal occurs when the tensile force generated along the latter interface, which is a function of the rheological properties of the backing and adhesive layer materials, is greater than the bond strength at the coating-substrate interface (or cohesive strength of the coating). In actuality, however, this force is distributed over a discrete distance (O-A) in Fig. X1.1, which relates directly to the properties described, not concentrated at a point (O) in Fig. X1.1 as in the theoretical case—though the tensile force is greatest at the origin for both. A significant compressive force arises from the response of the tape backing material to being stretched. Thus both tensile and compressive forces are involved in adhesion tape testing.

X1.3.6 Close scrutiny of the tape test with respect to the nature of the tape employed and certain aspects of the procedure itself reveal several factors, each or any combination of which can dramatically affect the results of the test as discussed **(6)**.

X1.4 Peel Adhesion Testing on Plastic Substrates

X1.4.1 Tape tests have been criticized when used for substrates other than metal, such as plastics. The central issues are that the test on plastics lacks reproducibility and does not relate to the intended application. Both concerns are well founded: poor precision is a direct result of several factors intrinsic to the materials employed and the procedure itself. More importantly, in this instance the test is being applied beyond its intended scope. These test methods were designed for relatively ductile coatings applied to metal substrates, not for coatings (often brittle) applied to plastic parts **(7)**. The unique functional requirements of coatings on plastic substrates cause the usual tape tests to be unsatisfactory for measuring adhesion performance in practice.

X1.5 The Tape Controversy

X1.5.1 With the withdrawal from commerce of the tape

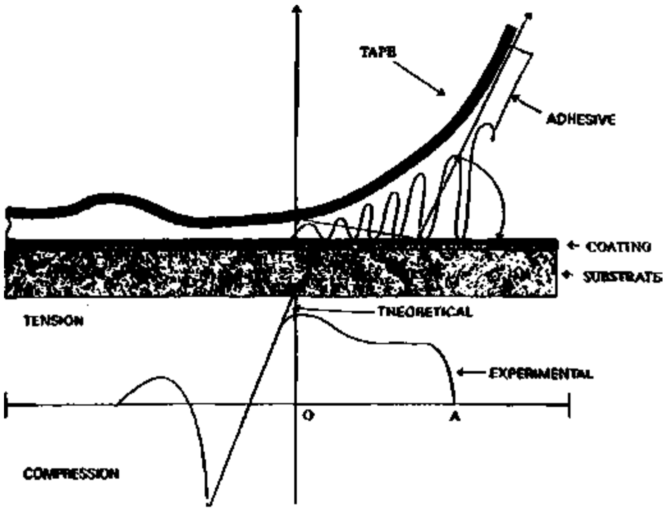

FIG. X1.1 Peel Profile (6)

specified originally, 3M No. 710, current test methods no longer identify a specific tape. Differences in tapes used can lead to different results as small changes in backing stiffness and adhesive rheology cause large changes in the tension area. Some commercial tapes are manufactured to meet minimum standards. A given lot may surpass these standards and thus be suitable for general market distribution; however, such a lot may be a source of serious and unexpected error in assessing adhesion. One commercially available tape test kit had included a tape with adhesion strength variations of up to 50 % claimed by the manufacturer. Also, because tapes change on storage, bond strengths of the tape may change over time **(7, 8)**.

X1.5.2 While there are tapes available that appear to deliver consistent performance, a given tape does not adhere equally well to all coatings. For example, when the peel removal force of the tape (from the coating) used earlier by Task Group D01.23.10 to establish precision of the method, by 3M No. 710 was examined with seven different electromagnetic interference/radio frequency interference (EMI/RFI) coatings, it was found that, while peel was indeed consistent for a given coating, the value varied by 25 % between the highest and lowest ratings among coatings. Several factors that contribute to these differences include coating composition and topology: as a result, no single tape is likely to be suitable for testing all coatings. Further, the tape test does not give an absolute value for the force required for bond rupture, but serves only as an indicator that some minimum value for bond strength was met or exceeded **(7, 8)**.

X1.6 Procedural Problems

X1.6.1 The tape test is operator intensive. By design it was made as simple as possible to perform, and requires a minimum of specialized equipment and materials that must meet certain specifications. The accuracy and precision depend largely upon the skill of the operator and the operator's ability to perform the test in a consistent manner. Key steps that directly reflect the importance of operator skill include the angle and rate of tape removal and the visual assessment of the tested sample. It is not unexpected that different operators might obtain different results **(7, 8)**.

X1.6.2 *Peel Angle and Rate*:

The standard requires that the free end of the tape be removed rapidly at as close to a 180° angle as possible. If the peel angle and rate vary, the force required to remove the tape can change dramatically. Nearly linear increases were observed in peel force approaching 100 % as peel angle was changed from 135 to 180, and similar large differences can be expected in peel force as peel rate varies. These effects are related as they reflect certain rheological properties of the backing and adhesive that are molecular in origin. Variation in pull rate and peel angle can effect large differences in test values and must be minimized to assure reproducibility **(9)**.

X1.6.3 *Visual Assessment*:

The final step in the test is visual assessment of the coating removed from the specimen, which is subjective in nature, so that the coatings can vary among individuals evaluating the same specimen **(9)**.

X1.6.3.1 Performance in the tape test is based on the amount of coating removed compared to a descriptive scale. The exposure of the substrate can be due to factors other than coating adhesion, including that arising from the requirement that the coating be cut (hence the synonym" cross-hatch adhesion test"). Justification for the cutting step is reasonable as cutting provides a free edge from which peeling can begin without having to overcome the cohesive strength of the coating layer.

X1.6.3.2 Cutting might be suitable for coatings applied to metal substrates, but for coatings applied to plastics or wood, the process can lead to a misleading indication of poor adhesion due to the unique interfacial zone. For coatings on soft substrates, issues include how deep should this cut penetrate, and is it possible to cut only to the interface?

X1.6.3.3 In general, if adhesion test panels are examined microscopically, it is often clearly evident that the coating removal results from substrate failure at or below the interface, and not from the adhesive failure between the coating and the substrate. Cohesive failure within the coating film is also frequently observed. However, with the tape test, failures within the substrate or coating layers are rare because the tape adhesive is not usually strong enough to exceed the cohesive strengths of normal substrates and organic coatings. Although some rather brittle coatings may exhibit cohesive failure, the tape test adhesion method does not make provision for giving failure locality **(7, 8)**.

X1.6.4 Use of the test method in the field can lead to variation in test results due to temperature and humidity changes and their effect upon tape, coating and substrate.

X1.7 Conclusion

X1.7.1 All the issues aside, if these test methods are used within the Scope Section and are performed carefully, some insight into the approximate, relative level of adhesion can be gained.

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Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers[1]

This standard is issued under the fixed designation D 4541; 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.

ϵ^1 Note—Research report added editorially in August 1995.

1. Scope

1.1 This test method covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating by determining either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail). Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive, coating system, and substrate, and will be exposed by the fracture surface. This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scratch or knife adhesion, and results may not be comparable. Further, pull-off strength measurements depend upon both material and instrumental parameters. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

1.2 This test method uses a class of apparatus known as portable pull-off adhesion testers.[2] They are capable of applying a concentric load and counter load to a single surface so that coatings can be tested even though only one side is accessible. Measurements are limited by the strength of adhesion bonds between the loading fixture and the specimen surface or the cohesive strengths of the adhesive, coating layers, and substrate.

1.3 This test can be destructive and spot repairs may be necessary.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

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:*

D 2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding[3]

D 3933 Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)[3]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[4]

2.2 *ANSI Standard:*

N512 Protective Coatings (Paints) for the Nuclear Industry[5]

2.3 *ISO Standard:*

4624 Paints and Varnish—Pull-Off Test for Adhesion[5]

3. Summary of Test Method

3.1 The general pull-off test is performed by securing a loading fixture (dolly, stud) normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The pull-off strength is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed. Pull-off strength results obtained using different devices may be different because the results depend on instrumental parameters (see Appendix X1).

4. Significance and Use

4.1 The pull-off strength of a coating is an important performance property that has been used in specifications. This test method serves as a means for uniformly preparing and testing coated surfaces, and evaluating and reporting the

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[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.46 on Industrial Protective Coating.

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[2] The term adhesion tester may be somewhat of a misnomer, but its adoption by two manufacturers and at least two patents indicates continued usage.

[3] *Annual Book of ASTM Standards*, Vol 15.06.

[4] *Annual Book of ASTM Standards*, Vol 06.01.

[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

results. This test method is applicable to any portable apparatus meeting the basic requirements for determining the pull-off strength of a coating.

4.2 Variations in results obtained using different devices or different substrates with the same coating are possible (see Appendix X1). Therefore, it is recommended that the type of apparatus and the substrate be mutually agreed upon between the interested parties.

5. Apparatus

5.1 *Adhesion Tester*, commercially available, or comparable apparatus specific examples of which are listed in Annex A1-Annex A4.

5.1.1 *Loading Fixtures*, having a flat surface on one end that can be adhered to the coating and a means of attachment to the tester on the other end.

5.1.2 *Detaching Assembly* (adhesion tester), having a central grip for engaging the fixture.

5.1.3 *Base*, on the detaching assembly, or an annular bearing ring if needed for uniformly pressing against the coating surface around the fixture either directly, or by way of an intermediate bearing ring. A means of aligning the base is needed so that the resultant force is normal to the surface.

5.1.4 Means of moving the grip away from the base in as smooth and continuous a manner as possible so that a torsion free, co-axial (opposing pull of the grip and push of the base along the same axis) force results between them.

5.1.5 *Timer*, or means of limiting the rate of stress to less than 150 psi/s (1 MPa/s) so that the maximum stress is obtained in less than about 100 s. A timer is the minimum equipment when used by the operator along with the force indicator in 5.1.6.

NOTE 1—Obtaining the maximum stress in 100 s or less by keeping the maximum rate of shear to less than 150 psi/s (1 MPa/s) is valid for the levels of pull-off strength measured with these types of apparatuses.

5.1.6 *Force Indicator and Calibration Information*, for determining the actual force delivered to the loading fixture.

5.2 *Solvent*, or other means for cleaning the loading fixture surface. Finger prints, moisture, and oxides tend to be the primary contaminants.

5.3 *Fine Sandpaper*, or other means of cleaning the coating that will not alter its integrity by chemical or solvent attack. If any light sanding is anticipated, choose only a very fine grade abrasive (400 grit or finer) that will not introduce flaws or leave a residue.

5.4 *Adhesive*, for securing the fixture to the coating that does not affect the coating properties. Two component epoxies[6] and acrylics[7] have been found to be the most versatile.

5.5 *Magnetic or Mechanical Clamps*, if needed, for holding the fixture in place while the adhesive cures.

5.6 *Cotton Swabs*, or other means for removing excess adhesive and defining the adhered area. Any method for removing excess adhesive that damages the surface, such as scoring, must generally be avoided since induced surface flaws may cause premature failure of the coating.

5.7 *Circular Hole Cutter* (optional), to score through to the substrate around the loading fixture.

6. Test Preparation

6.1 The method for selecting the coating sites to be prepared for testing depends upon the objectives of the test and agreements between the contracting parties. There are, however, a few physical restrictions imposed by the general method and apparatus. The following requirements apply to all sites:

6.1.1 The selected test area must be a flat surface large enough to accommodate the specified number of replicate tests. The surface may have any orientation with reference to gravitational pull. Each test site must be separated by at least the distance needed to accommodate the detaching apparatus. The size of a test site is essentially that of the secured loading fixture. At least three replications are usually required in order to statistically characterize the test area.

6.1.2 The selected test areas must also have enough perpendicular and radial clearance to accommodate the apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force. It should be noted that measurements close to an edge may not be representative of the coating as a whole.

6.2 Since the rigidity of the substrate affects pull-off strength results and is not a controllable test variable in field measurements, some knowledge of the substrate thickness and composition should be reported for subsequent analysis or laboratory comparisons. For example, steel substrate of less than ⅛-in. (3.2-mm) thickness usually reduce pull-off strength results compared to ¼-in. (6.4-mm) thick steel substrates.

6.3 Subject to the requirements of 6.1, select representative test areas and clean the surfaces in a manner that will not affect integrity of the coating or leave a residue. Surface abrasion may introduce flaws and should generally be avoided. A fine abrasive (see 5.3) should only be used if needed to remove loose or weakly adhered surface contaminants.

6.4 Clean the loading fixture surface as indicated by the apparatus manufacturer. Failures at the fixture-adhesive interface can often be avoided by treating the fixture surfaces in accordance with an appropriate ASTM standard practice for preparing metal surfaces for adhesive bonding.

NOTE 2—Guides D 2651 and D 3933 are typical of well-proven methods for improving adhesive bond strengths to metal surfaces.

6.5 Prepare the adhesive in accordance with the adhesive manufacturer's recommendations. Apply the adhesive to the fixture or the surface to be tested, or both, using a method recommended by the adhesive manufacturer. Be certain to apply the adhesive across the entire surface. Position fixture on the surface to be tested. Carefully remove the excess adhesive from around the fixture.

NOTE 3—**Caution:** Movement, especially twisting, can cause tiny bubbles to coalesce into large holidays that constitute stress discontinuities during testing.

6.6 Based on the adhesive manufacturer's recommendations

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[6] Araldite Adhesive, available from Ciba-Geigy Plastics, Duxford, Cambridge, CB2 4QA, England, Hysol Epoxy Patch Kit 907, available from Hysol Div., The Dexter Corp., Willow Pass Rd., Pittsburg, CA 94565, and Scotch Weld Adhesive 1838B/A, available from 3M, Adhesives, Coatings and Sealers Div., 3M Center, St. Paul, MN 55144, have been found satisfactory for this purpose.

[7] Versiloc 201 and 204 with accelerator, available from Lord Corp., Industrial Adhesive Div., 2000 W. Grandview Blvd., P.O. Box 10038, Erie, PA 16514, have been found satisfactory for this purpose.

and the anticipated environmental conditions, allow enough time for the adhesive to set up and reach the recommended cure. During the adhesive set and early cure stage, a constant contact pressure should be maintained on the fixture. Magnetic or mechanical clamping systems work well, but systems relying on tack, such as masking tape, should be used with care to ensure that they do not relax with time and allow air to intrude between the fixture and the test area.

6.7 Scoring around the fixture violates the fundamental in-situ test criterion that an unaltered coating be tested. If scoring around the test surface is employed, extreme care is required to prevent micro-cracking in the coating, since such cracks may cause failures at diminished strengths. Scored samples constitute a different test, and this procedure should be clearly reported with the results.

6.8 Note the approximate temperature and relative humidity during the time of test.

7. Test Procedure

7.1 The general procedure for conducting pull-off tests is described in this section. More specific procedures are given in Annex A1-Annex A4 for the types of testers used in the round-robin.

7.2 Select an adhesion-tester with a detaching assembly having a force calibration spanning the range of expected values along with its compatible loading fixture. Mid-range measurements are usually the best, but read the manufacturer's operating instructions before proceeding.

7.3 If a bearing ring or comparable device (5.1.3) is to be used, place it concentrically around the loading fixture on the coating surface. If shims are required when a bearing ring is employed, place them between the tester base and bearing ring rather than on the coating surface.

7.4 Carefully connect the central grip of the detaching assembly to the loading fixture without bumping, bending, or otherwise prestressing the sample and connect the detaching assembly to its control mechanism, if necessary. For nonhorizontal surfaces, support the detaching assembly so that its weight does not contribute to the force exerted in the test.

7.5 Align the device according to the manufacturer's instructions and set the force indicator to zero.

Note 4—Proper alignment is critical, see Appendix X2. If alignment is required, use the procedure recommended by the manufacturer of the adhesion tester and report the procedure used.

7.6 Increase the load to the fixture in as smooth and continuous a manner as possible, at a rate of less than 150 psi/s (1 MPa/s) so that failure occurs or the maximum stress is reached in about 100 s or less (see Note 1).

7.7 Record the force attained at failure or the maximum force applied.

7.8 If a plug of material is detached, label and store the fixture for qualification of the failed surface in accordance with 8.3.

7.9 Report any departures from the procedure such as possible misalignment, hesitations in the force application, etc.

8. Calculation and Interpretation of Results

8.1 If instructed by the manufacturer, use the instrument calibration factors to convert the indicated force for each test into the actual force applied in units of pounds-force (1 N = 0.1 kgf).

8.2 Either use the calibration chart supplied by the manufacturer or compute the relative stress applied to each coating sample as follows:

$$X = 4F/\pi d^2 \qquad (1)$$

where:

X = greatest mean pull-off stress applied during a pass/fail test, or the pull-off strength achieved at failure. Both have units of psi (MPa = 1 N/mm^2).

F = actual force applied to the test surface as determined in 8.1, and

d = equivalent diameter of the original surface area stressed having units of inches (or millimetres). This is usually equal to the diameter of the loading fixture.

8.3 For all tests to failure, estimate the percent of adhesive and cohesive failures in accordance to their respective areas and location within the test system comprised of coating and adhesive layers. A convenient scheme that describes the total test system is outlined in 8.3.1 through 8.3.3. (See ISO 4624.)

Note 5—A laboratory tensile testing machine is used in ISO 4624.

8.3.1 Describe the specimen as substrate *A*, upon which successive coating layers *B*, *C*, *D*, etc., have been applied, including the adhesive, *Y*, that secures the fixture, *Z*, to the top coat.

8.3.2 Designate cohesive failures by the layers within which they occur as *A*, *B*, *C*, etc., and the percent of each.

8.3.3 Designate adhesive failures by the interfaces at which they occur as *A/B*, *B/C*, *C/D*, etc., and the percent of each.

8.4 A result that is very different from most of the results may be caused by a mistake in recording or calculating. If either of these is not the cause, then examine the experimental circumstances surrounding this run. If an irregular result can be attributed to an experimental cause, drop this result from the analysis. However, do not discard a result unless there are valid nonstatistical reasons for doing so or unless the result is a statistical outlier. Valid nonstatistical reasons for dropping results include alignment of the apparatus that is not normal to the surface, poor definition of the area stressed due to improper application of the adhesive, poorly defined glue lines and boundaries, holidays in the adhesive caused by voids or inclusions, improperly prepared surfaces, and sliding or twisting the fixture during the initial cure. Scratched or scored samples may contain stress concentrations leading to premature fractures. Dixon's test, as described in Practice D 3980, may be used to detect outliers.

8.5 Further information relative to the interpretation of the test results is given in Appendix X2.

9. Report

9.1 Report the following information:

9.1.1 Brief description of the general nature of the test, such as, field or laboratory testing, generic type of coating, etc.

9.1.2 Temperature and relative humidity and any other pertinent environmental conditions during the test period.

9.1.3 Description of the apparatus used, including: apparatus manufacturer and model number, loading fixture type and dimensions, and bearing ring type and dimensions.

9.1.4 Description of the test system, if possible, by the indexing scheme outlined in 8.3 including: product identity and generic type for each coat and any other information supplied, the substrate identity (thickness, type, orientation, etc.), and the adhesive used.

9.1.5 Test results.

9.1.5.1 Date, test location, testing agent.

9.1.5.2 For pass/fail tests, stress applied along with the result, for example, pass or fail and note the plane of any failure (see 8.3 and ANSI N512).

9.1.5.3 For tests to failure, report all values computed in 8.2 along with the nature and location of the failures as specified in 8.3, or, if only the average strength is required, report the average strength along with the statistics.

9.1.5.4 If corrections of the results have been made, or if certain values have been omitted such as the lowest or highest values or others, reasons for the adjustments and criteria used.

9.1.5.5 For any test where scoring was employed, indicate it by placing a footnote superscript beside each data point affected and a footnote to that effect at the bottom of each page on which such data appears. Note any other deviations from the procedure.

10. Precision and Bias [8]

10.1 *Precision*—In an interlaboratory study of this test method, operators made measurements, generally in triplicate but in a few cases in duplicate, on coated panels covering a moderate range at the intermediate adhesion level using four different types of instruments (see Annex A1-Annex A4 and Appendix X1). The number of participating laboratories varied with each instrument and in the case of one instrument with the material. Only two laboratories had access to Type I instruments but two operators in each made the triplicate tests. During the statistical analysis of the results three individual results and one set of triplicates obtained with Type II instruments were rejected as outliers; one single test with Type III instruments and three single results with Type I instruments were rejected. The pooled intra- and inter-laboratory coefficients of variation were found to be those shown in Table 1. Based on these coefficients the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

10.1.1 *Replicate Repeatability*—Triplicate results obtained by the same operator using instruments from the same category should be considered suspect if they differ in percent relative by more than the values given in Table 1.

NOTE 6—Difference in percent relative to two results, x_1 and x_2, is the absolute value of

$$\frac{(x_1 - x_2)}{(x_1 + x_2)/2} \times 100. \qquad (2)$$

10.1.2 *Reproducibility*—Two results, each the mean of triplicates, obtained by operators in different laboratories using instruments of the same category should be considered suspect if they differ in percent relative by more than the values given in Table 1.

10.2 *Bias*—This test method has no bias statement since there is no acceptable reference material suitable for determining the bias of this test method.

11. Keywords

11.1 adhesion; coatings; field; paint; portable; pull-off strength; tensile test

TABLE 1 Precision of Adhesion Pull-Off Measurements

Instrument	Coefficient of Variation, v, %	Degrees of Freedom	Maximum Acceptable Difference, %
Intralaboratory Instrument:			
Type IV	8.5	48	29.0
Type I			
Type II	12.2	129	41.0
Type III			
Total		177	
Interlaboratory Instrument:			
Type IV	8.7	20	25.5
Type I			
Type II	20.6	58	58.7
Type III			
Total		78	

ANNEXES

(Mandatory Information)

A1. FIXED-ALIGNMENT ADHESION TESTER, TYPE I

A1.1 *Apparatus:*

A1.1.1 A fixed-alignment portable tester as shown in Fig. A1.1[9]

NOTE A1.1—Precision data for Type I instruments described in Table 1 were obtained using the devices illustrated in Fig. A1.1.

A1.1.2 The tester is comprised of detachable aluminum loading fixtures, 1.97 in. (50 mm) in diameter, screws with spherical heads that are screwed into the center of a fixture, a socket in the testing assembly that holds the head of the screw, pressure gage, dynamometer, wheel and crank.

A1.1.3 The testers are available in four models, with maximum tensile forces of 1125, 3375, 5625, and 11 250 lb (5, 15, 25, and 50 kN) respectively. For a fixture having a 1.97-in.

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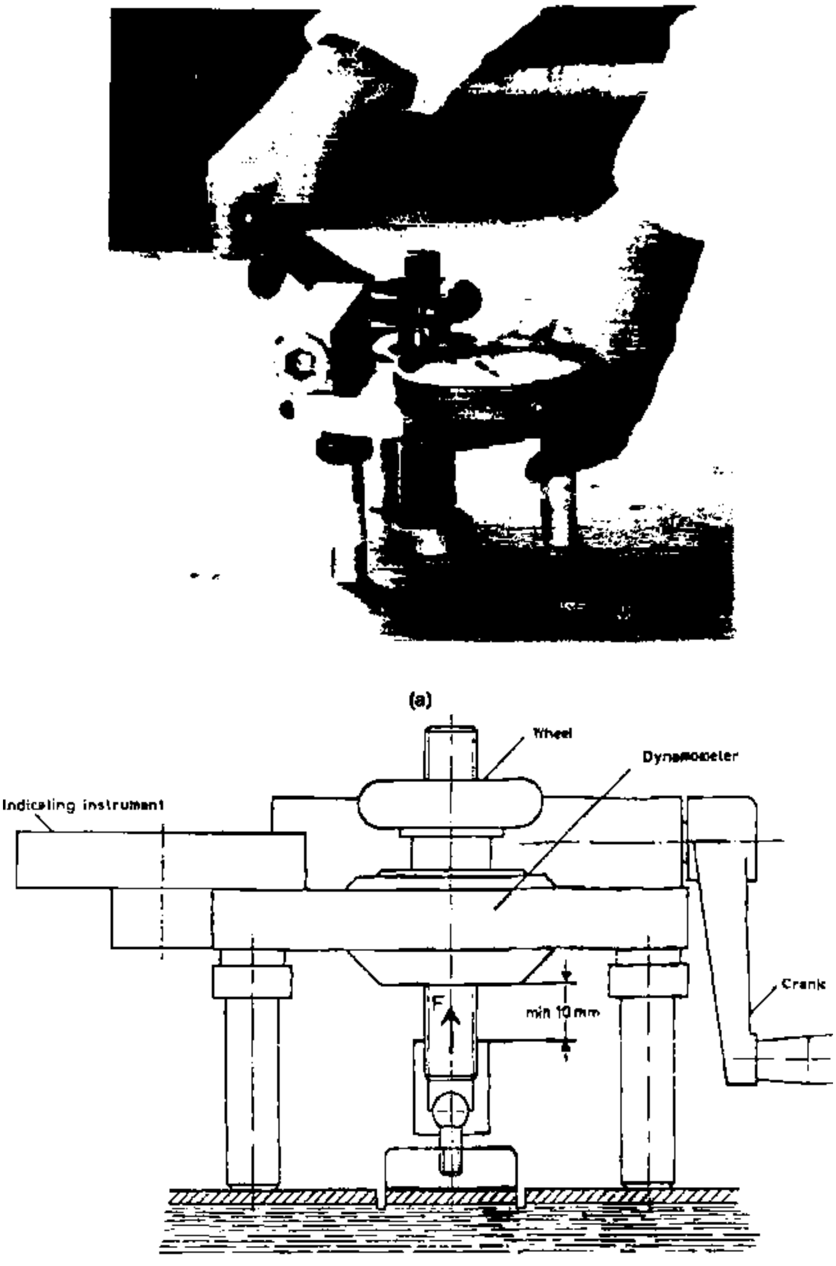
[8] Supporting data are available from ASTM Headquarters. Request RR: D01-1094.

[9] The Dyna Z5 tester is available from PROCEQ SA, Riesbachstrasse 57, CH-8034, Zurich, Switzerland.



(a)

(b)

FIG. A1.1 Photograph (a) and sketch (b) of Type I Instruments

(50-mm) diameter, a 5 kN device corresponds to a range of 0 to 360 psi (2.5 MPa).

A1.2 *Procedure:*

A1.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

A1.2.2 Set the pointer on the zero mark by first pressing the push-button located on the left of the indicator. While holding the push-button, turn the little knob located on the upper part of the indicator to set the pointer at zero. Set the zero after testing by pressing the push-button.

A1.2.3 After fixing a loading fixture to a substrate, insert a screw with a spherical head into the center of the fixture. Position the testing equipment on the metal disc. Then by means of the notched wheel, fix the head of the spherical screw into the socket at the base of the equipment. For the first mechanical approach, stop screwing down the wheel when the pointer on the indicator shifts from the ZERO mark. Tests are done by turning the crank. After each test, turn the crank in the opposite direction until it stops.

A2. FIXED-ALIGNMENT ADHESION TESTER TYPE II

A2.1 *Apparatus:*

A2.1.1 This is a fixed-alignment portable tester, as shown in Fig. A2.1.[10]

NOTE A2.1—Precision data for Table 1 were obtained using the devices illustrated in Fig. A2.1.

A2.1.2 The tester is comprised of detachable aluminum loading fixtures having a flat conic base that is 0.8 in. (20 mm) in diameter on one end for securing to the coating, and a circular *T*-bolt head on the other end, a central grip for engaging the loading fixture that is forced away from a tripod base by the interaction of a handwheel (or nut), and a coaxial bolt connected through a series of belleville washers, or springs in later models, that acts as both a torsion relief and a spring that displaces a dragging indicator with respect to a scale.

A2.1.3 The force is indicated by measuring the maximum spring displacement when loaded. Care should be taken to see that substrate bending does not influence its final position or the actual force delivered by the spring arrangement.

A2.1.4 The devices are available in four ranges: From 0 to 500, 0 to 1000, 0 to 2000, and 0 to 4000 psi (3.5, 7.0, 14, and 28 MPa).

A2.2 *Procedure:*

A2.2.1 Center the bearing ring on the coating surface concentric with the loading fixture. Turn the hand wheel or nut of the tester counter-clockwise, lowering the grip so that it slips under the head of the loading fixture.

A2.2.2 Align or shim the three instrument swivel pads of the tripod base so that the instrument will pull perpendicularly to the surface at the bearing ring.

A2.2.3 Take up the slack between the various members and slide the dragging (force) indicator located on the tester to zero.

A2.2.4 Firmly hold the instrument with one hand. Do not allow the base to move or slide during the test. With the other hand, turn the handwheel clockwise using as smooth and constant motion as possible. Do not jerk or exceed a stress rate of 150 psi/s (1 Mpa/s) that is attained by allowing in excess of 7 s/1000 psi (7 s/7 MPa), stress. If the 2000 or 4000 psi (14 or 28 MPa) models are used, the handwheel is replaced with a nut requiring a wrench for tightening. The wrench must be used in a plane parallel to the substrate so that the loading fixture will not be removed by a shearing force or misalignment, thus negating the results. The maximum stress must be reached within about 100 s.

A2.2.5 The pulling force applied to the loading fixture is increased to a maximum or until the system fails at its weakest locus. Upon failure, the scale will rise slightly, while the dragging indicator retains the apparent load. The apparatus scale indicates an approximate stress directly in pounds per square inch, but may be compared to a calibration curve.

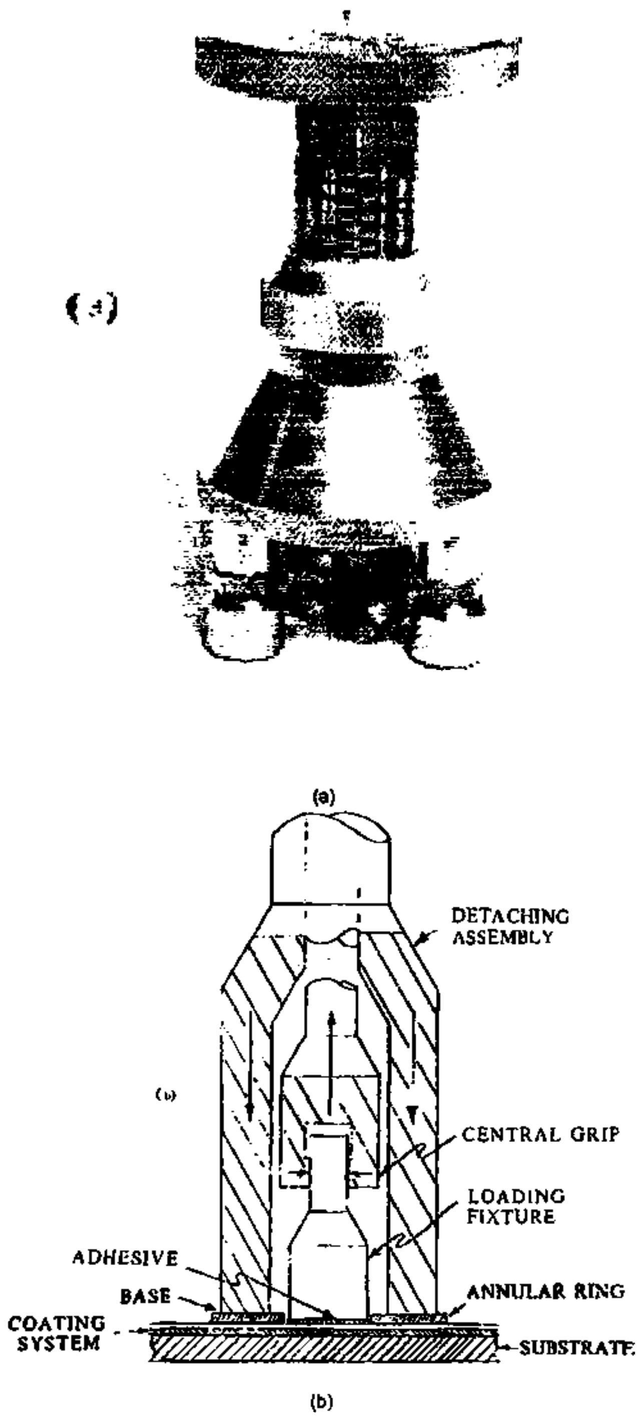


FIG. A2.1 Photograph (a) and schematic (b) of Type II, Fixed Alignment Pull-Off Tester

A2.2.6 Record the highest value attained by reading along the bottom of the dragging indicator.

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[10] The Elcometer, Model 106, adhesion tester is available from Elcometer Instruments, Ltd., Edge Lane, Droylston, Manchester M35 6UB, United Kingdom, England.

A3. SELF-ALIGNING ADHESION TESTER TYPE III

A3.1 *Apparatus:*

A3.1.1 This is a self-aligning tester, as shown in Fig. A3.1.[11]

NOTE A3.1—Precision data for Type II instruments shown in Table 1 were obtained using the devices described in Fig. A3.1.

A3.1.2 Load is applied through the center of the dolly by a hydraulic piston and pin. The diameter of the piston bore is sized so that the area of the bore is equal to the net area of the dolly. Therefore, the pressure reacted by the dolly is the same as the pressure in the bore and is transmitted directly to a pressure gage.

A3.1.3 The apparatus is comprised of: a dolly, 0.75-in. (19-mm) outside diameter, 0.125-in. (3-mm) inside diameter, hydraulic piston and pin by which load is applied to the dolly, hose, pressure gage, threaded plunger and handle.

A3.1.4 The force is indicated by the maximum hydraulic pressure as displayed on the gage, since the effective areas of the piston bore and the dolly are the same.

A3.1.5 The testers are available in three standard working ranges: 0 to 1500 psi (0 to 10 MPa), 0 to 2250 psi (0 to 15 MPa), 0 to 3000 psi (0 to 20 MPa). Special dollies shaped to test tubular sections are available.

A3.2 *Procedure:*

A3.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

A3.2.2 Insert a decreased TFE-fluorocarbon plug into the dolly until the tip protrudes from the surface of the dolly. When applying adhesive to the dolly, avoid getting adhesive on the plug. Remove plug after holding the dolly in place for 10 s.

A3.2.3 Ensure that the black needle of the tester is reading zero. Connect a test dolly to the head and increase the pressure by turning the handle clockwise until the pin protrudes from the dolly. Decrease pressure to zero and remove the test dolly.

A3.2.4 Connect the head to the dolly to be tested, by pulling back the snap-on ring, pushing the head and releasing the snap-on ring. Ensure the tester is held normal to the surface to be tested and that the hose is straight.

A3.2.5 Increase the pressure slowly by turning the handle clockwise until either the maximum stress or failure is reached.

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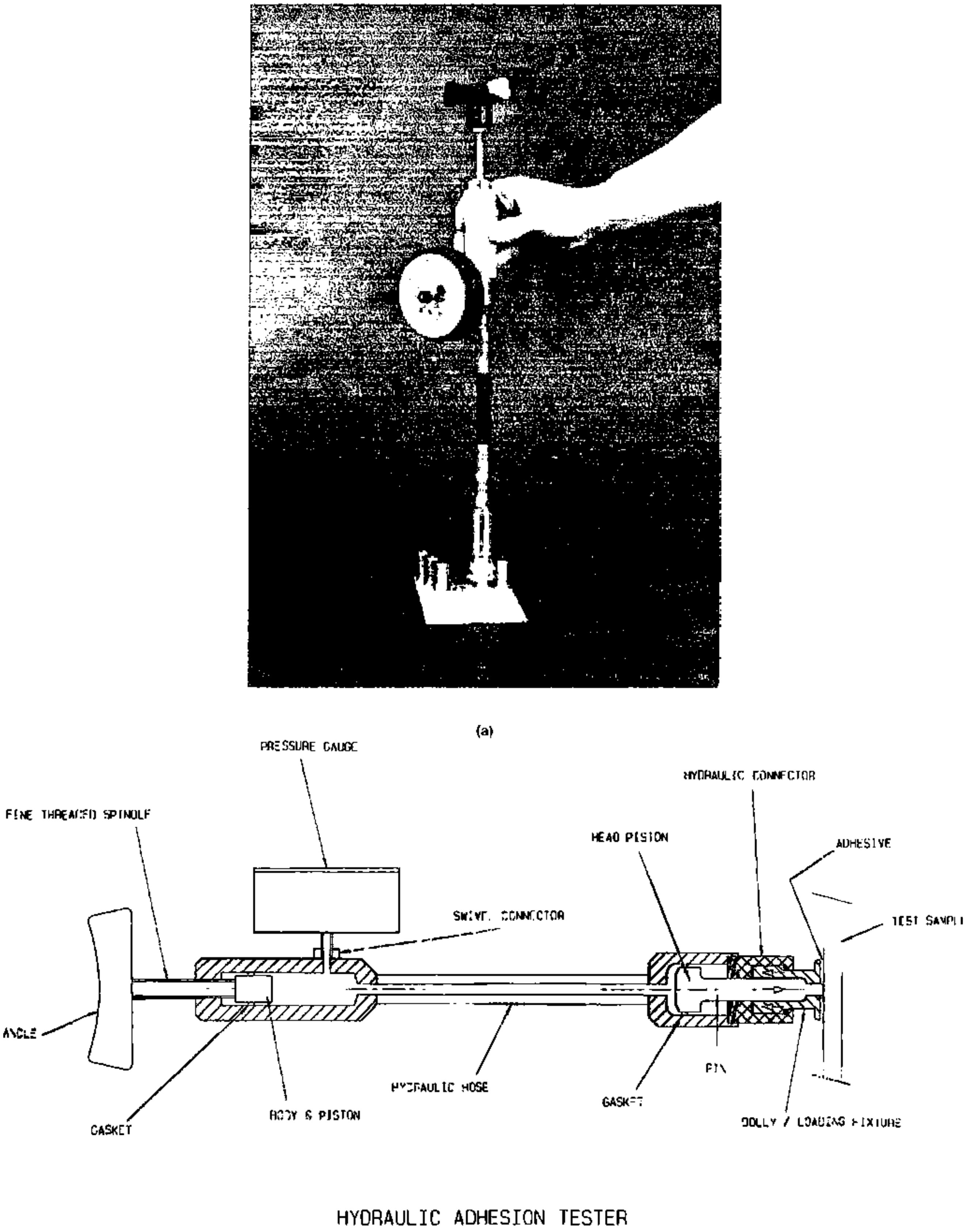
[11] The Hate Mark VII adhesion tester is available from Hydraulic Adhesion Test Equipment, Ltd., 629 Inlet Rd., North Palm Beach, FL 33408.



(a)

(b)

FIG. A3.1 Photograph (a) and schematic (b) of Type III, Self-Alignment Tester

A4. SELF-ALIGNMENT ADHESION TESTER TYPE IV

A4.1 *Apparatus:*

A4.1.1 This is a self-aligning tester, which may have a self-contained pressure source and has a measuring system that controls a choice of different load range detaching assemblies. It is shown in Fig. A4.1.[12]

NOTE A4.1—Precision data for Type IV instruments shown in Table 1 were obtained using the devices illustrated in Fig. A4.1.

A4.1.2 The apparatus is comprised of: (*1*) a loading fixture having a flat cylindrical base that is 0.5 in. (12.5 mm) in diameter on one end for attachment to the test coating and a cut-off ring used with the fixture to reproducibly define the area of adhesive. The other end of the fixture has 3/8-16 UNC threads; (*2*) a central threaded grip for engaging the loading fixture through the center of the detaching assembly that is forced away by the interaction of a self-aligning seal; and (*3*) a pressurized gas that enters the detaching assembly through a flexible hose connected to a pressurization rate controller and a pressure gage (or electronic sensor).

A4.1.3 The force is indicated by the maximum gas pressure times the active area of the detaching assembly and can be directly calibrated.

A4.1.4 The detaching assemblies are available in six standard ranges in multiples of two from 0 to 500 psi (3.5 MPa) to 10 000 psi (70 MPa). Special ranges are available.

A4.1.5 Three models of control modules that control all ranges of detaching assemblies are available.

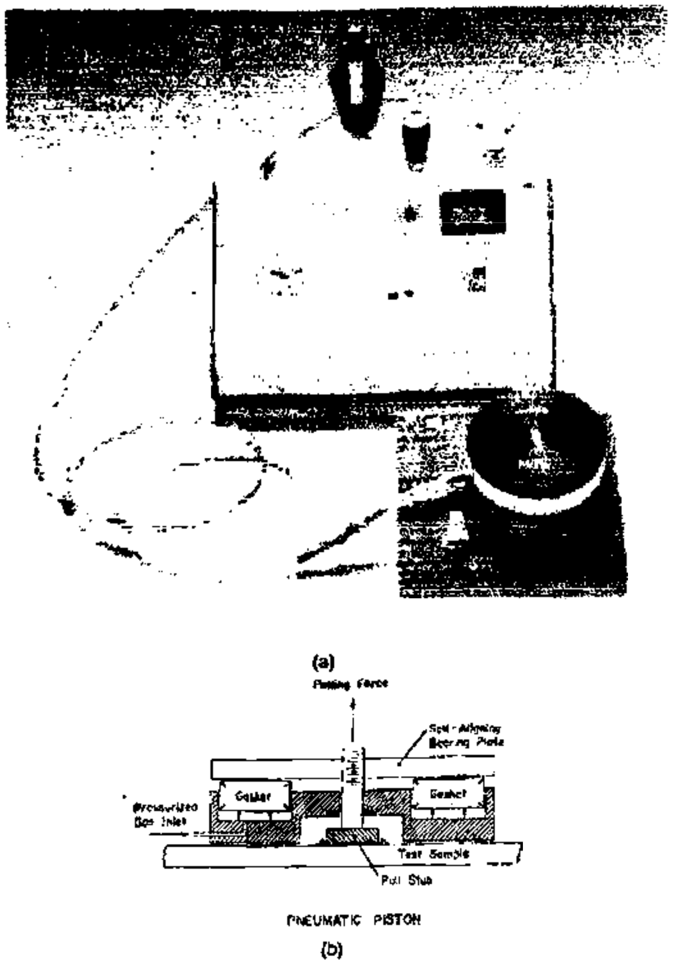
A4.2 *Procedure:*

A4.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to Type IV testers are described in the following section.

A4.2.2 Position the annular detaching assembly over the fixture attached to the coating to be tested, and loosely engage the fixture via the central threaded grip. Leave at least 1.16-in. (1.6-mm) clearance between the detaching assembly and the bottom of the threaded grip so that the seal can protrude enough to align itself when pressurized.

A4.2.3 Make the appropriate pneumatic connections and open the rate valve 1/4 turn.

A4.2.4 Zero the pressure measuring system.



(a)

(b)

FIG. A4.1 Photograph (a) and schematic of piston (b) of Type IV Self-Alignment Adhesion Tester

A4.2.5 Press the run button to control the gas flow to the detaching assembly and make final adjustment of rate valve so that rate of stress does not exceed 150 psi/s (1 MPa/s) yet reaches its maximum within 100 s.

A4.2.6 Record both the maximum pressure attained and the specific detaching assembly. Conversion to coating stress for ½-in. (12-mm) stud is found in a table supplied for each detaching assembly.

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[12] The PATTI self-alignment adhesion tester is available from SEMicro Corp., 15817 Crabbs Branch Way, Rockville, MD 20855.

APPENDIXES

(Nonmandatory Information)

X1. INTERLABORATORY PULL-OFF DATA

X1.1 Table X1.1 is a summary of the interlaboratory round-robin data. It is included in this appendix to illustrate the dependence of a pull-off result upon the type of testing device.

TABLE X1.1 Summary of Round-robin Data

Instrument	Type I	Type II	Type III	Type IV
Paint Sample	Mean of Three Results, psi (outliers discarded)			
A	201	586	1185	1160
B	185	674	1157	1099
C	190	827	1245	1333
D	297	888	1686	1678
	Range of Mean Results, psi			
	112	302	529	579

X2. STRESS CALCULATION

X2.1 The stress computed in 8.2 is equal to the uniform pull-off strength of the analogous rigid coating system if the applied force is distributed uniformly over the critical locus at the instant of failure. For any given continuous stress distribution where the peak-to-mean stress ratio is known, the uniform pull-off strength may be approximated as:

$$U = XR_o \qquad \text{(X2.1)}$$

where:

U = uniform pull-off strength, representing the greatest force that could be applied to the given surface area, psi (MPa),

X = measured in-situ pull-off strength calculated in 8.2, psi (MPa) and

R_o = peak-to-mean stress ratio for an aligned system.

It is important to note that a difference between these pull-off strengths does not necessarily constitute an error; rather the in-situ measurement simply reflects the actual character of the applied coating system with respect to the analogous ideal rigid system.

X2.2 An error is introduced if the alignment of the apparatus is not normal to the surface. An approximate correction by the peak-to-mean stress ratio is:

$$R = R_o(1 + 0.14\,\alpha z/d), \qquad \text{(X2.2)}$$

where:

z = distance from the surface to the first gimbal or the point at which the force and counter force are generated by the action of the driving mechanism, in. (mm),

d = diameter of the loading fixture, in. (mm),

α = angle of misalignment, degrees (less than 5), and

R = maximum peak-to-mean stress ratio for the misaligned rigid system.

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Standard Test Methods for Holiday Detection in Pipeline Coatings[1]

This standard is issued under the fixed designation G 62; 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 These test methods cover the apparatus and procedure for detecting holidays in pipeline type coatings.

1.2 Method A is designed to detect holidays such as pinholes and voids in thin-film coatings from 0.0254 to 0.254 mm (1 to 10 mils) in thickness using ordinary tap water and an applied voltage of less than 100 V d-c. It is effective on films up to 0.508 mm (20 mils) thickness if a wetting agent is used with the water. It should be noted, however, that this method will not detect thin spots in the coating, even those as thin as 0.635 mm (0.025 mils). This may be considered to be a nondestructive test because of the relatively low voltage.

1.3 Method B is designed to detect holidays such as pinholes and voids in pipeline coatings; but because of the higher applied voltages, it can also be used to detect thin spots in the coating. This method can be used on any thickness of pipeline coating and utilizes applied voltages between 900 and 20 000 V d-c.[2] This method is considered destructive because the high voltages involved generally destroy the coating at thin spots.

1.4 The values stated in SI units to three significant decimals are to be regarded as the standard. The values given in parentheses are for information only.

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:*

A 742/A 742M Specification for Steel Sheet, Metallic Coated and Polymer Precoated for Corrugated Steel Pipe[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *holiday*—small faults or pinholes that permit current drainage through protective coatings on steel pipe or polymeric precoated corrugated steel pipe.

3.1.2 *mil*—0.001 in.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *holiday detector*—A highly sensitive electrical device designed to locate holidays such as pinholes, voids, and thin spots in the coating, not easily seen by the naked eye. These are used on the coatings of relatively high-electrical resistance when such coatings are applied to the surface of materials of low-electrical resistance, such as steel pipe.

3.2.2 *pipeline type coating*—Coatings of relatively high-electrical resistance applied to surfaces of relatively low-electrical resistance, such as steel pipe.

4. Summary of Test Methods

4.1 Both methods rely on electrical contact being made through the pipeline coating because of a holiday or a low-resistance path created by metal particles, or thin spots in the coating. This electrical contact will activate an alarm alerting the operator of the incidence of a holiday.

4.2 In Method A, the applied voltage is 100 V d-c or less.

4.3 In Method B, the applied voltage is 900 to 20 000 V d-c.

5. Significance and Use

5.1 *Method A*—Method A describes a quick, safe method for determining if pinholes, voids, or metal particles are protruding through the coating. This method will not, however, find any thin spots in the coating. This method will determine the existence of any gross faults in thin-film pipeline coatings.

5.2 *Method B*—Method B describes a method for determining if pinholes, voids, or metal particles are protruding through the coating, and thin spots in pipeline coatings. This method can be used to verify minimum coating thicknesses as well as voids in quality-control applications.

6. Apparatus

6.1 *Low-Voltage Holiday Detector*—A holiday detector tester having an electrical energy source of less than 100 V d-c, such as a battery; an exploring electrode having a cellulose sponge dampened with an electrically conductive liquid such as tap water; and an audio indicator to signal a defect in a high-electrical resistance coating on a metal substrate. A ground wire connects the detector with the low-resistance metal surface.

6.2 *High-Voltage Holiday Detector*—A holiday detector

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[1] These test methods are under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.48 on Deterioration of Pipeline Coatings and Linings.

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[2] This was taken from the pamphlet "Operating Instructions for Tinker and Rasor Model EP Holiday Detector." Other manufacturers' holiday detectors can be expected to have similar voltage specifications.

[3] *Annual Book of ASTM Standards*, Vol 01.06.

tester having an electrical energy source of 900 to 20 000 V d-c; an exploring electrode consisting of wire brush, coil-spring, or conductive silicon electrode capable of moving along the pipeline coating; and an audio indicator to signal a defect in a high-electrical resistance coating on a metal substrate. A ground wire connects the detector with the low-resistance metal surface.

6.3 *Peak or Crest Reading Voltmeter*—A kilovoltmeter capable of detecting a single pulse and holding it long enough for the meter circuits to indicate.[4]

7. Reagents and Materials

7.1 *Tap Water*, plain or with a wetting agent.

Note 1—Ordinary tap water will suffice to wet the sponge electrode when inspecting coatings up to 0.254 mm (10 mils) in thickness. On films between 0.254 and 0.508 mm (10 and 20 mils), a nonsudsing type wetting agent added to the water is recommended to allow for faster penetration of the liquid into pinhole defects.

8. Test Specimen

8.1 The test specimen shall be a representative length of production-coated pipe or polymeric precoated corrugated steel pipe.

9. Standardization of Instruments

9.1 The instruments shall be standardized with respect to voltage output in accordance with the manufacturer's instructions, using a peak or crest reading voltmeter. This is used more commonly with Method B where voltage may vary from test to test but can also be used for verification of the voltage on a Method A test.

9.2 The low-voltage holiday detector shall be standardized with respect to sensitivity by having the alarm activated when a selected resistance, having a ½ W rating, is placed across its terminals. A common factory setting for sensitivity is 100 000 Ω. Most units can be reset to any predetermined sensitivity value in this manner.

10. Procedure for Method A

10.1 Use the low-voltage holiday detector described in 6.1.

10.2 Assemble the wand and electrode according to the manufacturer's instructions and attach the ground wire to the metal surface.

10.3 Attach the electrode clamps to the end of the wand, dampen the sponge electrode with tap water, and place it between the clamps. Then tighten the clamps with the screw until they are well down into the sponge electrode. Attach the ground wire (lead with battery clamp) and the wand to the terminals. Clip the ground wire to some point where the metal surface is bare. Now touch the electrode to a second point where the surface is bare and note that the audible signal will be activated. The detector is now ready to operate by passing the damp sponge over the coated surface. When a holiday is picked up by the audible alarm, the electrode can be turned on end and the exact spot of failure can be noted by searching with the tip of the electrode.

10.4 The voltage between the electrode (sponge) and the metal surface upon which the coating lies shall not exceed 100 V d-c, measured between the electrode sponge and the coated metal when the detector is in its normal operating position.

10.5 Prior to making the inspection, ensure that the coated surface is dry. This is particularly important if formed surfaces are to be inspected. If the surface is in an environment where electrolytes might form on the surface, such as salt spray, wash the coated surface with fresh water and allow to dry before testing. Take care to keep the electrolyte at least 12.7 mm (½ in.) from any bare sheared or slit edge.

10.6 A low-voltage holiday detector is not satisfactory for the inspection of pipeline coatings over 0.508 mm (20 mils) in thickness. This type of holiday detector will not detect thin spots in pipeline coatings.

11. Procedure for Method B

11.1 Use the high-voltage holiday detector.

11.2 Determine the test voltage desired by multiplying the dielectric breakdown voltage per millimetre (mil) of the coating (Note 2) times the minimum allowable thickness of the coating in millimetres (mils).

Note 2—The dielectric breakdown voltage per millimetre (mil) can be determined for each coating experimentally as follows: Increase the holiday detector voltage over a known coating thickness and measure the voltage at the point where the detector will just begin to ring. Divide this voltage by the known coating thickness to obtain the amount of volts per millimetre (mil). This can also be obtained from most coating manufacturers' literature.

11.2.1 An alternative method of determining test voltage is by use of one of the following equations depending on coating thickness.

11.2.2 If the coating thickness is less than 1.016 mm (40 mils):

$$V = M\sqrt{Tc} \qquad (1)$$

where:

V = test voltage
Tc = coating thickness
M = 3294 if Tc is in millimetres
M = 525 if Tc is in mils.

11.2.3 If the coating thickness is greater than 1.041 mm (41 mils):

$$V = K\sqrt{Tc} \qquad (2)$$

where:

V = test voltage
Tc = coating thickness
K = 7843 if Tc is in millimetres
K = 1250 if Tc is in mils

11.2.4 These equations are predicated on the amount of voltage needed to jump an air gap of the same length as the coating thickness. Therefore, they are useful for testing voids, pinholes and thin spots in the coating, but would not be useful as a coating thickness quality control tool.

11.3 Ground the test specimen by attaching the ground wire

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[4] The sole source of supply of a suitable peak or crest reading voltmeter known to the committee at this time is Itt-Jennings, 970 McLaughlin Ave., San Jose, Calif. 95116. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

DATA SHEET AND REPORT

Holiday Detection in Pipeline Coatings
Detector Type and Manufacturer ______________________ Report No. __________
Coating Manufacturer   age ________ of ____
Coating ______________________________
Production Date______________________________
Production Run No. __________ ______________________
Applied by ______________________________

Specimen	Coating Thickness		Detector Voltage	Test Method	Detector Resistance	Number of Holidays	Pipe Diameter	
	mm	mils			ohms		mm	in.

FIG. 1 Suggested Form for Use in Presenting Data for Method A and Method B

to a bare metal spot on the pipe surface. Plug the ground wire into the holiday detector. Then make up the searching electrode in accordance with the manufacturer's recommendations, using a brush wire or conductive silicon electrode. Plug the searching electrode into the holiday detector. Turn on the holiday detector.

11.3.1 **CAUTION:** Because of the high voltages involved, do not touch the ground wire and the metal part of the electrode at the same time if the instrument is on.

11.4 The detector is now ready to operate by passing the electrode over the test specimen. The detector will ring if it passes any void, pinhole, or area of the coating thinner than the minimum allowable thickness. When a holiday is detected by the audible alarm, the electrode can be repositioned to determine the exact holiday area by observing the origin of the spark jump.

11.5 Prior to making the inspection, ensure that the coated surface is dry. Dryness is critical in a high voltage test. Take care to keep the electrode at least 12.7 mm (½ in.) from any bare sheared or slit edge.

12. Report

12.1 The report shall include the following (see Fig. 1):

12.2 Complete identification of the specimen including names and code number of the coating, pipe diameter, source, production data, and production run number. For polymeric precoated corrugated steel pipe, the reporting requirements of Specification A 742/A 742M shall be used for identification,

12.3 Name and type of instrument used, method of standardization, and whether Method A or Method B was used, and

12.4 If Method B was used, state the test voltage, the method used to calculate the voltage, and the minimum allowable thickness in millimetres (mils) of the test sample.

13. Precision

13.1 Precision data are limited to adjacent specimens taken from the production-coated pipe as for the polymeric corrugated steel pipe assuming that the production process was uniform with respect to pipe surface condition and coating material. Specimens that were not adjacent in the as-produced condition, or were taken from different lengths of pipe, may represent differing process conditions.

13.2 *Repeatability*—When the same instrument is used by the same operator, duplicate measurements on the same specimen shall agree within ±5 %.

13.3 *Reproducibility*—Different operators using different instruments, set at the same voltage, inspecting the same specimen shall obtain average results agreeing with each other within ±10 %.

14. Keywords

14.1 holidays; holiday detector; piping; pinhole; wet sponge detector

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