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16. Abstract

In 1979, during the planning stage of the Metropolitan Dade County Transit System, the need was expressed for a corrosion control manual oriented to urban rapid transit system use. This manual responds to that need. The objective of the manual is to aid rail rapid transit agencies by providing practical solutions to selected corrosion problems.

The scope of the manual encompasses corrosion problems of the facilities of rapid transit systems: structures and tracks, platforms and stations, power and signals, and cars. It also discusses stray electric current corrosion. Both design and maintenance solutions are provided for each problem. Also included are descriptions of the types of corrosion and their causes, descriptions of rapid transit properties, a list of corrosion control committees and NASA, DOD, and ASTM specifications and design criteria to which reference is made in the manual. A bibliography of papers and excerpts of reports and a glossary of frequently used terms are provided.

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A CORROSION CONTROL MANUAL FOR RAIL RAPID TRANSIT

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U. S. Department of Transportation
Urban Mass Transportation Administration
Office of Technical Assistance

March 1982

PREFACE

This manual represents a cooperative effort by the National Aeronautics and Space Administration (NASA) and the Urban Mass Transportation Administration (UMTA), with assistance from the U.S. Army Armament Materiel Readiness Command (ARRCOM), the American Public Transit Association (APTA), The Hinchman Company, and SRI International. The objective of the manual is to aid rail rapid transit properties by providing practical solutions to selected corrosion problems.

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- The Corrosion Control Manual Liaison Board for its user agency review: Messrs. James Stewart of the Chicago Transit Authority; Jason Rosen and Edward Sherman of the Massachusetts Bay Transit Authority; Michael Merrick of the Metropolitan Atlanta Rapid Transit Authority; Irving Barry, Richard Duin, and Michael Sammon of the New York City Transit Authority; Eulogio Castiello of the Port Authority Trans-Hudson Corporation; Alfred M. Trotta of the Port Authority Transit Corporation; Peter Todd of the San Francisco Bay Area Rapid Transit District; Dale Rhodes of the Southeastern Pennsylvania Transit Authority; and Arthur Thue of the Washington Metropolitan Area Transit Authority.
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GLOSSARY

Anode (corrosion)	The electrode of an electrochemical cell at which oxidation (corrosion) occurs; in corrosion processes, it is usually the electrode that has the greater tendency to ionize. These ions are positively charged.
Anode (cathodic protection)	The expendable material, usually buried, through which direct current flows into the soil (e.g., graphite, high-silicon cast iron, magnesium, and zinc).
Aspergillus nigrus	A variety of related fungi with chains of spores attached to stalks on the swollen end of a threadlike branch (e.g., yellow mildew).
Austenitic stainless steel	A corrosion-resistant type of steel that contains chromium and nickel.
Autocatalytic decomposition	The chemical change of a material--namely, the breaking up into constituent elements, which is assisted by the presence of the product generated by an initial reaction.
Bent-loop specimens	Special specimens that are bent to place the rubber coating under tensile stress.
Bonding	The process of establishing electrical continuity through the use of a metallic conductor.
Calibrated shunt	A short conductor of known resistance inserted into an electrical circuit. By measurement of the voltage drop across the shunt, the current flow in the circuit can be determined.

Capillary intrusion	The result of adhesion, cohesion, and surface tension in liquids that are in contact with solids; depending on whether the adhesive or cohesive force is greater, the liquid either rises or falls in a tiny space or tube.
Catenary	The overhead contact wire of an electrified railroad or rapid transit system.
Cathodic protection	The reduction or prevention of corrosion of a metal surface by making that surface the cathode of an electrochemical cell. Typical techniques use galvanic anodes or impressed currents.
Cathode (corrosion)	The electrode of an electrochemical cell at which reduction occurs; in corrosion processes, the cathode is the area that does not corrode.
Cathode (cathodic protection)	The structure that receives direct current from the anode(s) and is to be protected.
Chromate primer	An undercoating composed of a salt of chromic acid and used to prepare a surface for painting.
Coating resistance	The electrical resistance of a coating to the flow of current. (The unit of measurement is ohms square feet.)
Conformal coating	A coating that does not modify the effective shape or cross section of the object to which it is applied.
Current density	The current per unit area of an electrode, usually expressed in terms of milliamperes per square foot.
Desiccator	A substance that has a drying influence.
Dielectric coating	A substance applied to the surface of a metal that provides an electrical resistance between the metal and the environment (e.g., such organic coatings as polyethylene tape, coal-tar enamel, and extruded polyethylene).

Dielectric strength (of a coating)	The dielectric strength of a coating refers to the voltage at which the coating material will break down. (The unit of measurement is volts per mil.)
Diode	A solid-state semiconductor device that permits current passage in only one direction.
Electrical continuity	The property of a structure to allow conduction of electrical currents by way of a continuous metallic pathway.
Electrolyte	A chemical substance, the moist soil or a liquid solution, that is adjacent to and in contact with a buried or submerged metallic structure and that contains ions that migrate in an electric field.
Electrode	A conductor used to establish electrical contact with the electrolyte part of a circuit (e.g., an anode or cathode).
Enzymatic material	A mixture containing an organic substance that causes changes in other substances by catalytic action.
Ester	An organic compound formed by the reaction between an acid and an alcohol.
Exposure (stray current effects)	The discharge of direct current from a metallic structure into the surrounding electrolyte. In a rail system, the metallic structure is the track.
Faying surface	The area at which two objects are joined.
Flash-coat	A layer of paint or other material applied to weatherproof an exposed surface area.
Floating slab construction	A concrete track slab that is mechanically isolated from a subway structure for acoustical damping.
Forging plane	The direction perpendicular to the forging direction.

Galvanic anode	A metal that because of its relative position in the galvanic series provides cathodic protection when coupled in an electrolyte to metal or metals that are lower in the series (i.e., one type of cathodic protection).
Galvanic cell	A galvanic coupling of dissimilar metals in an electrolyte.
Grain boundaries	The edges of the grains within a metal.
Gusset	A bracket or angular piece of metal for strengthening angles of a structure.
Halogen	Any one of the five active nonmetallic chemical elements: fluorine, chlorine, bromine, astatine, and iodine.
Humectant	A substance that promotes retention of moisture.
Hydrophobic coating	A coating that does not absorb water or other liquids.
Impressed current	Direct current supplied by a device using a power source external to the electrode system used for cathodic protection.
Insulated fittings	Unions, couplings, or flanges that permit metallic and electrical separation of one section of a structure from another.
Interference bond	A metallic connection between structures that can be used to mitigate corrosion damage by controlling the current interchange resulting from cathodic protection.
Intermittent weld	A weld that is not continuous, thereby leaving some segments unsealed.
Lap joint	The extension of one part over another part at the point where they meet.
Leakage currents	Direct current that follows a path other than along the intended traction power circuit.

Metalloid	A nonmetal that can combine with a metal to form an alloy; a nonmetal that resembles a metal.
Monocoque	A type of construction in which structural strength is provided by the skin and skin formers.
Negative system	The return path for traction power current.
Rail clips	The portion of a rail fastener that transfers force from the fastening bolts to the rail flange.
Ready-bolt	An angular rod or pin to attach a structural member to concrete.
Spall	A chip or flake of stone, metal, or concrete.
Stray current	Current flowing through paths other than the intended circuit.
Stray current bond	A metallic connection to allow stray current to return to the negative return system.
Stray current drainage	The flow of stray current through a metallic bonding connection, mechanical contactor, or diode.
Sump area	A pit or well in which liquids collect.
Tannate	A salt or compound of tannic acid. (Tannic acid is a yellowish, astringent substance derived from plant sources.)
Thermite (or thermit)	A mixture of finely granulated aluminum and an oxide of iron or other metal that reacts to produce molten metal for welding.
Tie-coat	An intermediate layer of material to bind one thing to another (usually a topcoat of paint to a primer).
Traction power	The system that supplies the traction force to draw the train over the tracks at some variable velocity opposed by inertial, frictional, and windage forces.

Transverse grain	The grain of a metal that runs perpendicular to the direction of rolling.
Tubercle	A small round projection or nodule.
Web (rail)	The vertical portion of a rail that connects the ball and the base.
Zerk-type fitting	A type of grease fitting.

I INTRODUCTION

A. Background

Corrosion is defined as an undesirable interaction of a material with its environment. This interaction is usually a chemical action that gradually eats away the material. Corrosion is often the factor that establishes the lifetime of equipment. According to studies by the Materials Technology Institute, the total cost of corrosion loss in the United States in 1976 was $70 billion--a marked increase from $8 billion in 1965. Added to the direct costs of corrosion are the resource costs for energy (about 3.5% of the U.S. energy demand) and for metallic ores. (Use of current corrosion-control technology could reduce the annual demand for the metallic ore by more than 2%.[*]) Other costs, which should not be minimized, relate to safety and health hazards for equipment users.

The rapid transit industry is not free of corrosion problems. During a survey in 1980[**], SRI, the National Aeronautics and Space Administration, Kennedy Space Center (NASA-KSC) and the U.S. Army Armament Materiel Readiness Command (ARRCOM) identified 117 corrosion or material deterioration problems affecting the following rail rapid transit properties:

- Chicago Transit Authority (CTA)
- Massachusetts Bay Transportation Authority (MBTA)
- Metropolitan Atlanta Rapid Transit Authority (MARTA)
- Metropolitan Dade County, Office of Transportation Administration
- New York City Transit Authority (NYCTA)

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[*] Obzut, John J., "Corrosion is Our National Disgrace, Iron Age, p. 41, April 3, 1978.

[**] The survey was conducted under contract NAS10-9745, "Corrosion Control Technology Transfer: Phase I," co-funded by NASA and the Urban Mass Transportation Administration (UMTA) in 1979.

- Port Authority Transit Corporation (PATCO)
- San Francisco Bay Area Rapid Transit District (BART)
- San Francisco Municipal Railway (Muni)
- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Washington Metropolitan Area Transit Authority (WMATA)

The corrosive environments of various areas of the United States are mapped in Figure 1. As shown, the greatest corrosive effects are experienced in the coastal and Great Lakes regions--the locations of most rapid transit properties. Urban rapid transit managers and engineers must give greater attention to corrosion control so as to design and build transit systems with long service lives at reasonable maintenance costs. The most economical form of corrosion control can be realized when hardware is properly designed, fabricated, and maintained. Indeed, "virtually all corrosion failures result from improper application, carelessness on the part of the user, or poor choice of materials or configuration by the designer" (ibid).

In 1979, during the planning stage of the Metropolitan Dade County Transit System, many NASA and Department of Defense (DOD) corrosion control documents were identified for technology transfer to the transit property. Much of the material contained in these documents did not apply to the transit industry, however, and other material required some interpretation by the transit engineer. The need was expressed for a corrosion control manual oriented to urban rapid transit property use. This manual responds to that need.

B. Manual Development

The manual was developed during 1980 and 1981 under the technical direction of the Design Engineering Directorate at NASA-KSC. Funding was provided by NASA and the Urban Mass Transportation Administration (UMTA).* Management of manual development was provided by Mr. Ray Gilbert of NASA's Technology Utilization Branch and Mr. Roy Field of UMTA's Office of Technical Assistance, Safety & Security. Mr. Lloyd O. Gilbert, Chemist and Corrosion Consultant at ARRCOM was responsible for the authorship of a major portion of the manual with the assistance of Mr. Joseph T. Menke, his associate at ARRCOM. Mr. Gilbert and Mr. Menke are the instructors of the Prevention of Material Deterioration: Corrosion Control Course presented by ARRCOM. Portions of the manual that consider corrosion problems related to the electrical system were authored by John H. Fitzgerald, P.E., President of The Hinchman Company. Assistance with the writing, organizing and editing of the manual was provided by SRI,

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*Contract NAS10-10040, "Corrosion Control Technology Transfer: Phase II," co-funded by NASA and UMTA in 1981.

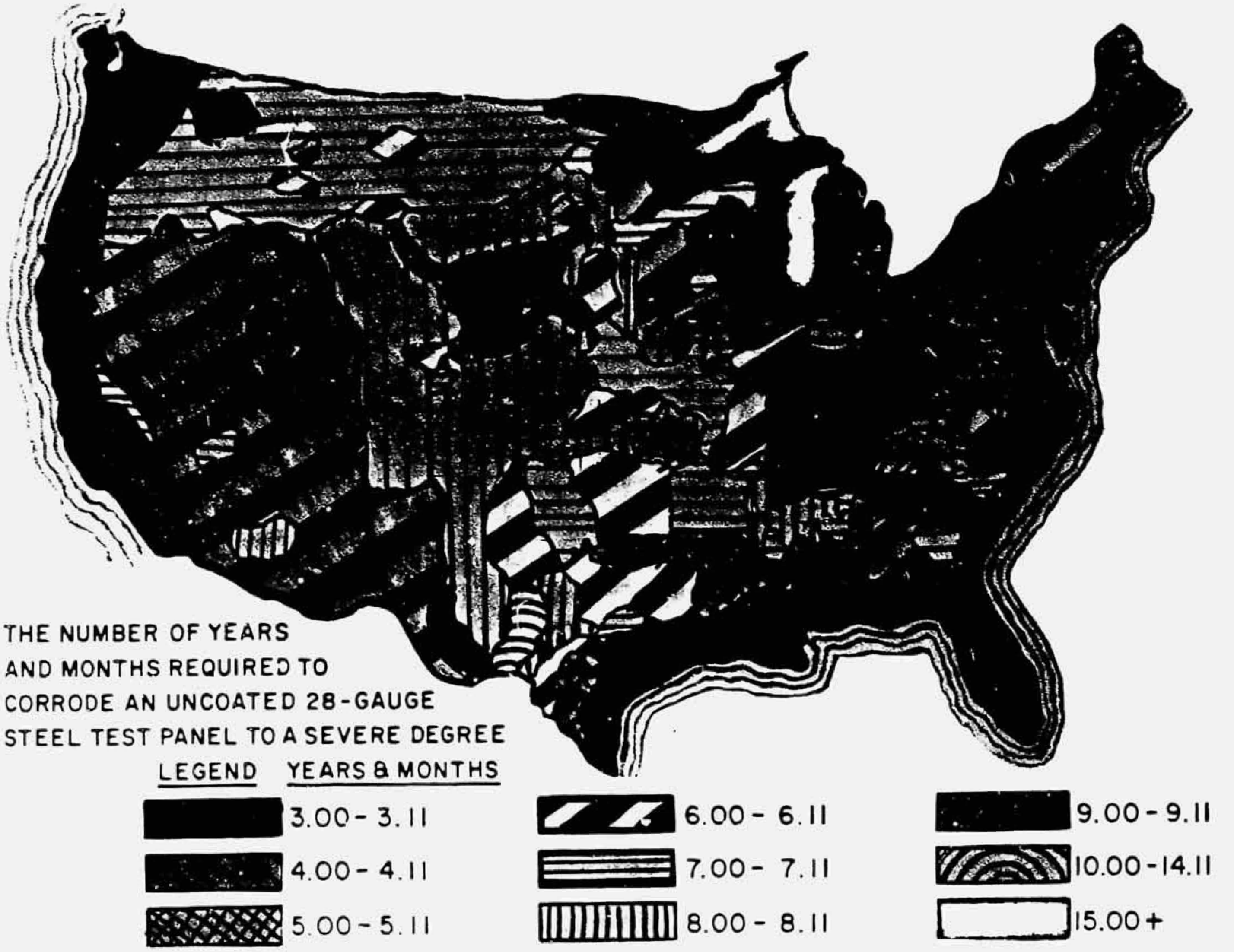

FIGURE 1 MAP OF THE UNITED STATES
SHOWING CORROSION EFFECTS IN VARIOUS AREAS

which received user agency advice from a special liaison board formed by Mr. Frank Cihak and Mr. Carl Buhlman of the American Public Transit Association (APTA).

C. Manual Content and Instructions for Manual Use

Because the rapid transit systems in North America are in various stages of construction and operation, the manual addressed corrosion problems in design, construction, and maintenance. Most important is the solution breakdown. Both design and maintenance solutions are provided for each problem. Practical and proven corrosion control techniques are provided. The scope encompasses all facilities of urban rapid transit systems: structures and track, platforms and stations, power and signals, and cars. The design and maintenance solutions contain references to commercial products. These references are included for the convenience of the transit engineer and are not endorsed by the authors or the sponsoring agencies.

Appended to the manual are descriptions of different types of corrosion and their causes; descriptions of selected rapid transit properties; a list of corrosion control committees; and NASA, DOD, and ASTM specifications and design criteria to which reference has been made in the manual. A bibliography of papers and excerpts of reports, uncovered during a literature search on corrosion control for rapid transit, precedes the appendices. For reader convenience, a glossary of frequently used terms is provided in the front of the manual.

The authors are aware that the manual does not address every corrosion problem faced by rapid transit properties. It concentrates on those problems identified during the site survey. The inclusion of problems was limited further by the availability of practical, proven solutions. The manual addresses some problems of older systems that are not applicable to new systems with improved designs. For certain problems, particularly those related to stray current corrosion, a corrosion specialist should be consulted.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

II STRUCTURES AND TRACK: SURFACE AND AERIAL

A. Structural Members

1. Location and Orientation

a. Problem

Corrosion or a need for excessive maintenance of structural steel can be the result of orientation of the structural members. Vibration may either contribute to the accumulation of sand, dust, and other debris on channel beams, angle beams, H- and I-beams, or may discharge such accumulation when these members are properly oriented. For example, the vibration of channel beams with the flanges oriented in an upward position does not prevent the retention of debris. Girders are then subject to poultice corrosion as debris and water accumulate at locations where beams join the vertical columns or join one another. (In Figure 2, poultice corrosion is caused by poor drainage.)

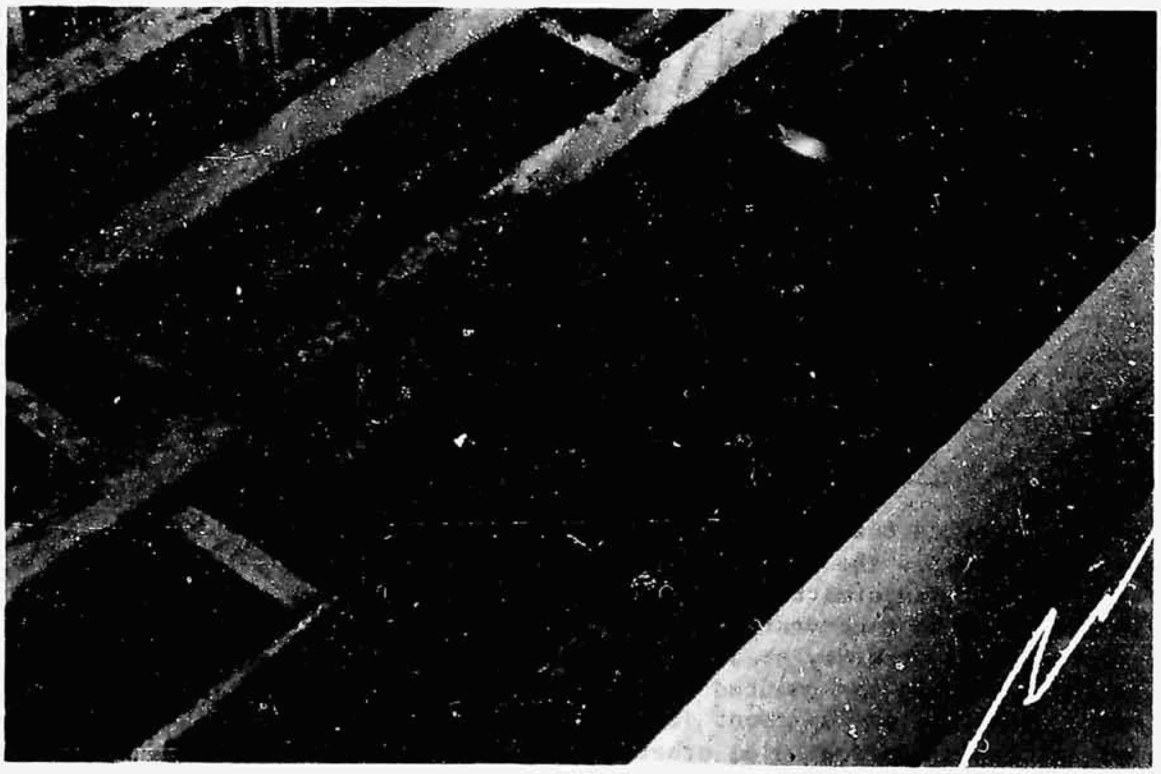

FIGURE 2. POULTICE CORROSION OF AERIAL STRUCTURE

b. Design and Maintenance Solution

Debris in channels with flanges placed in a downward position will be flushed by rain or loosened by vibration. (See Figure 3.) To prevent the retention of moisture in channel beams and at interfaces between beams and vertical columns, drain slots should be cut at the sump area. Drain slots are preferred over simple drain holes provided that structural considerations permit their use. Both water and debris will be discharged from a slot, whereas a drain hole in the same general location may become plugged with debris. A statement to ensure the above criteria should be a part of the design criteria.

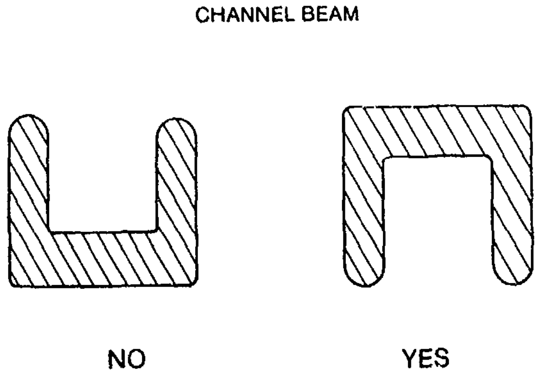

FIGURE 3 ORIENTATION OF STRUCTURAL MEMBERS

2. Joints and Fasteners

a. Problem

A common practice that has led to corrosion difficulties in rapid transit systems is the use of two channel beams fastened together web-to-web with intermittent welds. (see Figure 4.) Even when prime-coated with a conventional lead chromate primer, these assemblies crevice-corrode, thereby creating serious maintenance problems. When rust forms between the painted surfaces and washes out during rain storms, it stains the adjacent structural members and concrete footings, often initiating corrosion of other members. Any lap joint between spacers or nut plates constitutes a potential corrosion problem due to the capillary intrusion of water between these adjacent surfaces. Nut plates, gussets, and spacers inserted between girder webs are also subject to corrosion, as are the webs. Intermittent welds, usually used to prevent warping of the mating surfaces, also invite corrosion due to the capillary intrusion of water.

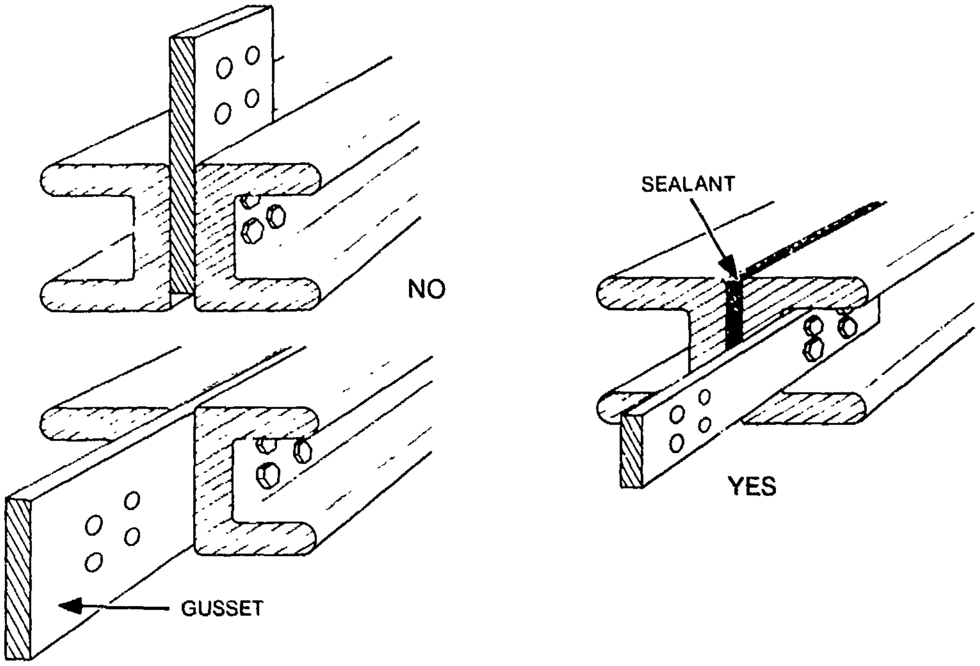

FIGURE 4 ATTACHMENT OF PLATES TO GIRDERS

Welds, rivets, and bolts are commonly used to fasten structural members. Structural integrity often depends on the integrity of the fasteners. With conventional methods of construction, which require rivets or high-strength bolts, structural integrity may be lost as a result of rivet stretch or bolt breakage. Crevice corrosion between mating surfaces produces a volume of corrosion product that is greater than the volume of the parent metal. The wedging force created by the corrosion product distorts mating surfaces, stretches rivets, and breaks welds and high-strength bolts.

Oxygen concentration cell (crevice) corrosion may occur under rivet and bolt heads at the cathode even though a coating has been applied. Corrosion may also develop in weld areas if weld spatter is not removed before paint or coating is applied. (See Figure 5.) When weld spatter is present, the paint thickness may be less than that prescribed; hence, the protection against corrosion may be less than adequate. If the spatter is allowed to adhere, tuberculation corrosion may develop beneath the paint. In Figure 5, weld spatter corrosion may be seen on the steel vertical stiffener and tuberculation corrosion on the vertical support column. Weld areas between the steel web flange stiffener and girder flange and at weldments on vertical supports may develop knifeline corrosion (weld decay) in the heat-affected zone, caused by contact with deicing salts and other electrolytic materials, and be abetted by the insufficiency of the paint coat. Paint discoloration (e.g., a bluish tint) is caused by the alkali that results from the corrosion process. Weld decay can result in structural deterioration.

a. Vertical stiffener

b. Weld spatter on vertical stiffener

c. Tuberculation corrosion of aerial support

FIGURE 5 WELD SPATTER AND TUBERCULATION CORROSION ON AERIAL STRUCTURES

b. Design Solution

To avoid the problems of crevice corrosion between adjacent members or lap joints, either an elastomeric sealant such as MIL-S-81733 (an inhibited elastomeric polysulfide) should be used, or both faying surfaces should be coated with a zinc-rich primer. Wherever precut or mill-primed steel is used, the common practice of masking faying surface areas should be specifically prohibited. In the past, the Steel Structures Painting Council recommended that all faying surfaces be masked (not painted). Unfortunately, this leads to crevice corrosion and subsequent loss of structural strength. Seal-welding of the edges of the faying members to exclude water and debris is ineffective primarily because weld-cracking then results from thermal expansion and contraction or from subsequent pressure of structural loads.

The need to accommodate slight movement between faying surfaces makes the application of the elastomeric sealant the preferred method even when both faying surfaces have been pre-primed. If an unprimed or unsealed joint is assembled without a means for excluding water, a mass of rust will be formed by crevice corrosion of the steel between the surfaces.

In the not-too-distant past, the only faying-surface sealant used was a coat of primer applied at assembly. It is now known that even a slight thermal expansion caused by warm weather conditions breaks the brittle primer and regenerates the crevice. Hence, the superiority of the elastomeric sealants in these applications to accommodate slight movement is obvious.

Fastener plates should not be attached between two channel or angle beams because the resulting gap between beams would be too wide to retain a sealant and too narrow for coating or recoating. Instead, the plates should be attached at the flange or inner angle as shown in Figure 4.

An application of alkali-resistant paint, such as an epoxy or urethane, to bolts and other fasteners after installation will prevent alkali damage and subsequent corrosion caused by moisture retention.

c. Maintenance Solution

The mating surfaces of metals, especially metals with dissimilar thermal expansion properties, should be protected against corrosion by an elastomeric sealant such as MIL-S-81733 to accommodate the different expansions, contractions, and the vibrational movement. Paints and other coatings should not be used because cracks may form in the protective barrier and lead to corrosion and subsequent loss of structural strength. Weld spatter and weld flux must be removed before any coating is applied to ensure that the coating thickness will be even (Figure 6). These can be removed most effectively by chipping or abrasive blasting, followed by grinding of the weld to remove pockets in accordance with Steel Structures Painting Counsel SP-10. (A weld pocket is a gas bubble in the weld.) If neither chipping nor abrasive blast is possible, an application of tannic acid* followed by a water rinse should be made to transform the iron oxide into an innocuous iron tannate.* (See Figure 7.)

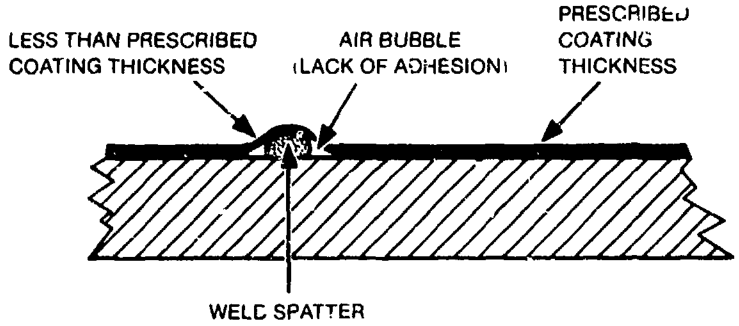

FIGURE 6 ADVERSE EFFECT OF WELD SPATTER ON COATING THICKNESS

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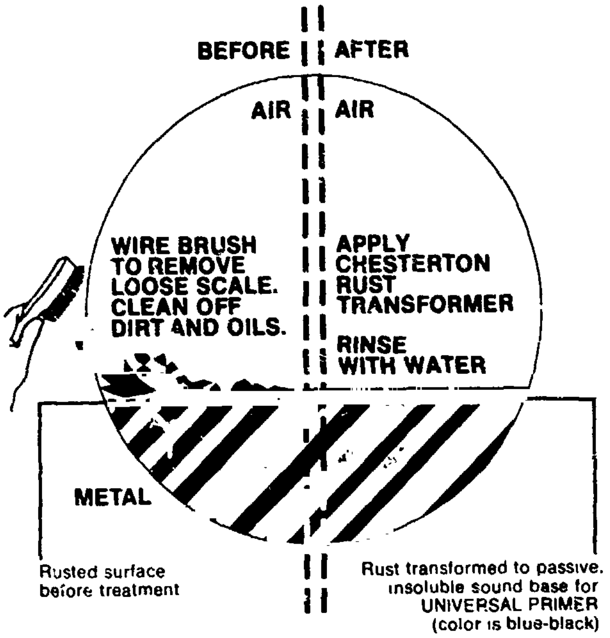
*For example, Chesterton Rust Treatment manufactured by A. W. Chesterton Co. of Stoneham, Massachusetts.



Source: A. W. Chesterton Co., Stoneham, MA

FIGURE 7 ELECTROCHEMICAL REMOVAL OF RUST, BRITTLE METAL SCALE, WELD SPATTER, AND WELD FLUX

As stated above, corrosion of a fastener plate that has been attached between two mated channel or angle beams has no maintenance solution. The gap created behind the plate will be too wide for retention of an elastomeric sealant and too narrow for surface coating. Corrosion control of channel beams with intermittent welds is possible, however, by edge-sealing the beams with an elastomeric sealant, such as MIL-S-81733 or MIL-S-8802.

3. Materials

a. Metals

(1) Problem

Several problems are inherent in the use of metal for aerial and surface structures. Certain trade-offs--including aesthetic and safety considerations--must be made in the choice of an appropriate alloy (and its heat treatment) for rapid tr sit systems. The selection of a weathering type of structural steel in conjunction with concrete may result in heavy rust staining of the concrete. Before the steel's rust-protective layer can stabilize, rust will slough from the steel and may permanently stain the concrete. In addition, although the benefit of weathering steel is that it requires no maintenance, in a moist atmosphere it is continuously rusting, and hence the protective layer is repeatedly sloughed. Thus, weathering steel is not suitable for use in coastal areas, underground, or in structures that are partially buried, (such as signposts not set on a concrete base). Weathering steels are recommended for construction in most other locations. During the short period of prestabilized sloughing, the concrete can be protected by a plastic sheet.

It is difficult to predict the specific corrosion resistance of alloys, particularly in the case of aluminum alloys. The stronger the aluminum, the more susceptible it is to corrosion. (See Table A-1 in Appendix A for a ranking of alloys according to their susceptibility to galvanic corrosion.)

Oxygen concentration cell corrosion may result from unsealed faying surfaces, intermittent welds, and other situations that entail any metal structure in contact with another. The susceptibility of metal alloys to corrosion varies, and the alloy that is most resistant to crevice corrosion may not offer superior strength or overall corrosion resistance and may not be available in the shape/form required or at an acceptable price.

Austenitic stainless steels are widely used because they are generally corrosion resistant. Because they are normally used without a paint coating, they are susceptible to oxygen concentration cell corrosion and such subsequent problems as discoloration (yellowing) and eventually surface rusting. A high chloride environment will accelerate the breakdown of the protective oxide coating.

(2) Design and Maintenance Solution

Structural members should be erected on suitable footings with "ready-bolts." If prestabilized (weathering) steel is used, footings are less likely to become stained. (Prestabilized steel is more impermeable than steel that has weathered for roughly 1 year before it is used in construction.)

Exposed safety railings should be constructed of either a 5XXX or 6XXX series aluminum alloy anodized to provide supplemental corrosion resistance to deicing salt and other damaging residues. (In cases where particularly strong structures are required, it may be necessary to use the 2XXX or 7XXX series aluminum alloy that is highly susceptible to corrosion. In such cases, special care should be taken , such as anodizing followed by an epoxy coat.) These residues include herbicides, spilled food and drink, dust, mud, and trash. (Metal should be cleaned on a regular basis to ensure the removal of any potentially corrosive particulate material.)

b. Coatings, Sealants, Plastics, and Elastomers

(1) Zinc-Rich Coatings

(a) Problem

Exposed conventional mill-primed structural steel with a modified alkyd resin paint top-coating requires frequent repainting, abrasive blasting, and a new top coat. In many cases, such maintenance is necessary every 2-4 years.

(b) Design Solution

The National Association of Corrosion Engineers has indicated in its guidelines that 1 additional year added to the useful life of a coating system doubles the value of the coating. In one test, a near-white abrasive blasted structure coated with a 4 mil to 6 mil zinc-rich coating used at the Kennedy Space Center in Florida required no maintenance over an 18-year period. (See Appendix D, NASA Shelf Master.) This test proves that the incremental cost of abrasive blasting in conjunction with the application of a zinc-rich coating is a much more cost-effective anticorrosion technique than the mill prime modified alkyd method.

If zinc-rich coatings are used on structures, the use of a top coat should be discouraged, except in a case where aesthetic considerations are significant. If a top coat is applied, however, a suitable "tie-coat" helps to ensure top coat adhesion on the zinc-rich surface. The use of a zinc-rich coating makes periodic blasting unnecessary, except in spots where rust is beginning to form. In the best of circumstances, a new organic zinc-rich coating can be directly applied over a previous zinc-rich coating (either organic or inorganic).

The two types of zinc-rich coatings, inorganic and organic, differ according to the binder used in them. A widely-used inorganic zinc-rich coating consists of 75% to 95% powdered zinc and 5% to 25% sodium silicate or potassium silicate. In comparison, an organic zinc-rich coating consists of the same conventional organic resin binder usually found in ordinary paint. Organic zinc-rich coatings are available in epoxy, phenolic, phenoxy, alkyd, and vinyl resin varieties. Inorganic coating provides better corrosion resistance, better mechanical durability, and better heat resistance. Yet, where a top coat is necessary, an organic coating is preferable. On buried or underwater structures, a 4 mil to 6 mil coating of coal-tar epoxy prevents the rapid depletion of the zinc in the zinc-rich coating.

A combination zinc-aluminum pigmented inorganic coating product that has unique properties with respect to lightning strike protection and electrostatic charge dissipation is available.[*] Although this room temperature-cured coating is nonconductive as applied, it can become conductive, drain off a charge, and then become nonconductive again. It both protects against corrosion and retains its lightning strike and static dissipation properties even after it is covered with a top coat.

(c) Maintenance Solution

A primary consideration in selecting a coating product, particularly an inorganic zinc-rich coating, for structures is its ease of application. The higher zinc content (86% by weight) single package inorganic coating, for example, is easier to apply than the multipackage (2 or 3) inorganic coating product.

(2) Urethane Paints

(a) Problem

A severe environment--such as that found in many rapid transit systems--leads to all types of corrosion. Frequent maintenance means higher labor costs and inconvenience to passengers.

(b) Design Solution

Although silicone alkyd paints have a longer service life (more than 4 years) than do modified alkyd paints, the more expensive alkali-resistant, catalyzed urethane paints can last as long as 5 to 10 years without repainting. In addition, the latter types of paints retain their gloss, shed dirt, and are chip-resistant.

The elastomeric nature of the urethane enamels obtained under MIL-C-83286 serves to prevent chipping and abrasive damage even under foot traffic when applied over an epoxy primer such as MIL-P-23377. Both the urethane and epoxy coatings should be applied at a minimum dry thickness of 1 mil for a total dry thickness minimum of 2 mil. Resistance to felt pen and marker graffiti is also superior to that of the modified alkyd resin coatings. Cleaning is minimized because of the dirt-shedding characteristics and the high gloss. Furthermore, wheel debris (rust, oil, and abrasives) is less likely to adhere and is easily removed if it does adhere. Rotary brush automated cleaning will not produce the microscratch pattern generally encountered with the acrylic or alkyd modified vinyl type of coatings.

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[*] Available from Sermetal Inc., Limerick Road, Limerick, PA.

(c) Maintenance Solution

A spray coating of the polyamide epoxy primer (MIL-P-23377 or NASA-KSC -C-0001) should be followed by a top coat of polyurethane (MIL-C-83286). To ensure adequate top-coat adhesion, the polyamide epoxy primer should be applied within 10 hours.

(3) Hydrophobic Coatings

(a) Problem

If not kept clean, third-rail porcelain insulators may develop water absorption and arc-over problems that can result in cracking of the insulators. That is, insulators encrusted with salt, dirt, iron dust, and other particulate materials can direct stray currents into the ground.

(b) Design and Maintenance Solution

Application of a hydrophobic coating (MIL-R-81589) to the glazed surface of a porcelain insulator prevents water from streaming across the dielectric by causing the water to "bead up," thereby eliminating the formation of a continuous conductive path. The coating can be applied to a cloth pad and rubbed on a glazed surface where it forms a monomolecular film. No film buildup will occur, and removal occurs only by wear. Thus, the surface of a porcelain insulator to which a hydrophobic coating is applied becomes nonwettable and resistant to ultraviolet radiation and other weather conditions. It also remains free of dust and track debris. (Hydrophobic coatings are available from Unelko Corp, 727 E. 110th Street, Chicago, IL.)

(4) Sealants

(a) Problem

In the past, steel structures were assembled without sealing the faying surfaces of structural members. Consequently, water intruded and caused a significant amount of rust; in fact, the expanding volume of rust caused stretched rivets, broken welds and high-strength bolts, and broken fasteners, and distorted metal structures. The ultimate result was impaired structural integrity.

(b) Design and Maintenance Solution

Two methods are being used for preventing structural decay without dismantling of the members. First, the mating surfaces can be edge-sealed with an inhibited elastomeric sealant such as MIL-S-81733. This sealant will prevent water intrusion because the sealant will not crack when exposed to thermal (solar) radiation or vibrational loading. Second, a hole can be drilled (or tapped) into the center of a large faying surface area, a zerk-type fitting set in the hole, and sealant injected into the space.

A combination of these two techniques has been successfully used on bridge structures where heavy intermittent loading results in rust. As the rust works its way out from between the faying surfaces, it loosens fasteners and impairs load-carrying capacity.

(5) Ozone-Resistant Elastomers

(a) Problem

If rubber is under tension and exposed to ozone, as in elastomeric insulation pads, it develops cracks. When rubber is under compression, it extrudes and the extruded portion is under tensile stress and susceptible to ozone cracking.

(b) Design and Maintenance Solution

The application of an ozone-resistant elastomer such as neoprene can prevent cracks in the rubber unless the rubber compound contains a large amount of reclaim stock or process oil. The neoprene product should be tested before application to ensure its compliance with ASTM D 2000, paragraph 4.2.32 and 4.3. Bent loop specimens in accordance wich ASTM D 580, Type B should also be tested.

Rubber should never be painted or coated with the commercially available rubber/vinyl preservative coatings. Although these coatings help to control the number of cracks that form, the cracks that do occur are larger and more damaging.

If elastomeric products are supplied without antiozonant, topical application of the antiozonant MIL-D-50,000 is acceptable, with equal amounts of dioctylparaphenylenediamine and acetone applied to the surface of the rubber. Two coats applied in accordance with ASTM specifications as identified above will ensure complete ozone resistance. Care should be taken not to stain painted surfaces.

(6) Polyurethane Enamel

(a) Problem

Erosion of third-rail covers results from chalking of the polyester resin binder used in the coating. In particular, polyester or epoxy composites are susceptible to ultraviolet radiation that causes delamination and ultimate deterioration of the covers.

(b) Design and Maintenance Solution

Deterioration of third-rail covers can be prevented by the application of a spray coat of polyurethane enamel such as MIL-C-83286. This coating is not affected by ultraviolet radiation or weathering, it retains its gloss, and it is available in all colors. Because the fiber glass polyester or epoxy and urethane adhere to each other, a primer is not required.

B. Track

1. Third Rail

a. Problem

The application of colloidal graphite/glycol mixtures to the third rail as an antiicer under sleeting conditions accelerates the corrosion of track and fastener components. Graphite is a metaloid that is cathodic to all metals except platinum or gold. As a result, it accelerates the corrosion of all structural metals. Because it is a conductive material, graphite also contributes to stray current problems associated with the track.

b. Design and Maintenance Solution

The use of colloidal graphite/glycol mixtures as a maintenance procedure in severe weather should be avoided. Instead, submicron size silica materials should be used and mixed with the glycol as a track antiicing material.

2. Concrete Ties

a. Problem

Concrete ties are susceptible to chloride penetration and subsequent deterioration. Chloride attacks the steel reinforcing rods thereby causing corrosion. Because the corrosion product occupies a volume greater than the metal from which it is formed, the concrete cracks, spalls, and exposes the rebar to direct atmospheric attack.

b. Design Solution

The design should specify an impermeable concrete. To make the surface of concrete ties more resistant to wear, chloride penetration, and moisture, a sodium silicate coating can be applied. Four parts of silicate to one part of water by volume that is applied to concrete that has been kept wet and covered for 24 hours will provide a surface film that seals the concrete. Should the concrete become wet within 6 hours after the application, the sodium silicate treatment (one part silicate, one part water) should be reapplied.

Reinforcing bars can be protected from corrosion by an application of epoxy paint (MIL-P-23377, Type IA) or inorganic zinc-rich coating [MIL-P-23236A (SH), Type I, Class 3 and NASA-KSC-C-0001].

c. Maintenance Procedure

Aged concrete should be cleaned with an appropriate concrete cleaner. After the cleaning is completed, a sodium silicate solution should be applied. On concrete that is more than 1 month old, a surface seal can be effected by brushing with a mixture of four parts water and one part sodium silicate.

III TRACK AND STRUCTURES: SUBWAY

A. Tunnel

1. Invert

a. Joints

(1) Problem

In metal-lined tunnels, the invert of reinforced concrete is constructed after the tunnel can be lined with the metal segments. For concrete-lined tunnels, the invert is an integral part of the liner with construction joints, which are sealed, along the sides. In the latter case, cracks may develop as a result of shrinkage, faulty curing, or temperature changes. Inadequate sealing at the joint between the invert and tunnel liner allows moisture intrusion that deteriorates the invert and liner. Moisture leaks through cracks and causes a high humidity in the subway tunnel, resulting in track bed deterioration and crevice corrosion between the rail and rail fastener.

(2) Design Solution

If steel is used to reinforce an invert, the steel should be completely covered with a 3-in. minimum thickness of concrete. Liquid grouting materials should be applied to the interior and exterior invert joints constructed of reinforced concrete.* Sealing is accomplished with MIL-S-81733 inhibited sealant. (Additional information can be obtained from the American Concrete Institute's "Guide to Joint Sealant for Concrete Structures," ACI-504R-77.) The design must also provide for drainage of the track bed to ensure that moisture is not retained in the event that leakage occurs.

(3) Maintenance Solution

Inadequately sealed or leaking invert joints should be treated with an appropriate grouting or sealant. Urethane ester materials should not be used for sealing because high humidity tends to break down these materials. The use of room-temperature vulcanizing (RTV) silicone sealants that emit acetic acid vapors should also be avoided unless adequate ventilation or dissipation of the vapors is provided. Sand-filled epoxy is an excellent material for sealing the concrete or for the repair of deteriorated/cracked concrete structures. (See Section B.2.b.)

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*Quartz or similar material manufactured by Belzona Molecular Incorporated, 224 Seventh St., Garden City, NY 11530.

b. Reinforced Concrete

(1) Problem

Relatively high amounts of sulfate or sulfide with low pH (high acid) in soils external to concrete tunnels may cause premature deterioration of the concrete. Water seepage, which will be acid with corresponding amounts of sulfate, can attack the reinforced concrete invert. Concerns for chemical attack to external surfaces of tunnels are related to public safety and economic losses due to structural deterioration.

If sulfides are present in soils of an area where concrete tunnels are planned, water pumping to lower the water table temporarily to facilitate construction may result in an acid soil with a high sulfate content. The sulfide in the soil above the lower water table will no longer be protected by a stable environment and will eventually oxidize to the sulfate with resultant acid soil. When the replenishing waters from either rain or flow from adjacent areas leach the area, construction proceeds in an earth and ground water characterized by a low pH and high sulfate (sulfuric).

(2) Design Solution

The component in cement that is attacked by the sulfate is tricalcium aluminate. Hence, the amount of calcium aluminate in the portland cement concrete should be lower than normal to inhibit sulfate attack. The use of Type II ASTM C-150 cement will keep the aluminate below 8% and should be used for soils with a pH below 5.5. The use of Type V cement will lower the aluminate to a maximum of 5% and should be used where soils are more acidic.

Additional guidance for barrier protection against chemical attack of undergound concrete can be obtained from American Concrete Institute Publication, ACI 515R-66, "Guide for the Protection of Concrete Against Chemical Attack by Means of Coating and Other Corrosion Resistant Materials." Coatings such as a sodium silicate can be used on concrete structures to prevent moisture and acid penetration. A diluted solution of one part (by volume) sodium silicate and 4 parts water is brushed on the concrete.* Two or more coats, applied at 24-hr intervals, will be required to saturate the pores.

(3) Maintenance Solution

When conventional concrete deteriorates such that cracking and chipping are observed, the invert may be reinforced with a sand-filled epoxy. Small holes may be drilled in the invert into which a sand-filled epoxy is troweled and allowed to cure.

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*Available from PQ Corporation, Valley Forge, PA 19482.

2. Tunnel Liners and Appurtenances

a. Problem

In most underground structures, high humidity results from moisture intrusion and subsequent condensation. Steel or cast iron tunnel liners and other structural steel components in subway areas corrode (rust) as a result of poor or nonexistent protective coatings. Steel components include the galvanized steel pipe for the fire-extinguishing sprinkler system. Inadequate ventilation and plugged drains may also contribute to the problem.

b. Design Solution

Steel components used for internal underground structures should be precoated with a zinc-rich primer prior to assembly. External surfaces of tunnel liners should be given a 7- to 10-mil coating of coal-tar epoxy if cathodic protection is being utilized. If no cathodic protection is used, coating with a coal-tar epoxy should be preceded by the application of 3-4 mils of a zinc-rich primer [MIL-P-23236A(SH), Type I, Class 3 and NASA-KSC-C-0001].

Adequate drainage must be provided to eliminate any accumulation of water. In addition, adequate ventilation is required to provide dry air in the subway shaft or tunnel. Ventilation is also required during the construction period since the "pumping effect" of trains passing through cannot dry out the tunnel at this time.

c. Maintenance Solution

Maintenance procedures will depend on the degree to which the structure has deteriorated, that is, locally or throughout the structure. Long-term maintenance versus temporary repair procedures must also be considered.

Abrasive blasting the steel and applying a zinc-rich primer [NASA-KSC-C-0001 and MIL-P-23236A(SH), Type I, Class 3] will provide long-term corrosion protection. For short-term protection on steel without abrasive blasting, wire brushing followed by tannate treatments and epoxy primers (such as MIL-P-23377) can be utilized. (See Chapter II, Section A.2.c.). Regular and effective cleaning practices especially in the station areas must be provided to ensure that debris does not clog drains.

3. Control Boxes

a. Problem

The presence of high humidity and pollutants/contaminants seriously degrades electrical equipment in control boxes in subway areas. Ozone generated as a result of arcing from shoes on the third rail contributes to the corrosive environment inside these boxes (see Figure 8.) Ozone in contact with air produces nitrogen oxides (NO_x).

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FIGURE 8 CORROSION OF ELECTRIC CONTROL BOXES IN SUBWAY AREAS

b. Design Solution

The use of copper for electrical control boxes will solve the corrosion problem. However, copper is expensive. An inexpensive solution may be provided by free-breathing desiccators or vapor corrosion inhibitors (VCIs). These items are installed inside closed and otherwise inadequately sealed boxes to prevent deterioration of the contents. The VCIs are available in capsule form and provide effective protection for as long as 1 year.* Inside the closed box, the VCIs generate a slight vapor pressure that tends to minimize moisture condensation. The vapors form a thin protective film that does not interfere with the electrical function. Both NASA and the U.S. Army use VCIs.

Printed circuit boards in control boxes should be conformally coated to protect against short circuiting between the traces when condensation occurs. Epoxy and urethane conformal coatings can serve as protective materials. The conformal coating should ensure coverage of the board up to and onto the gold-plated connector tabs, especially when the circuits consist of lead-tin solder plate, to prevent dissimilar metal corrosion at the gold/lead-tin interface. (See Figure 9.)

Vertical placement of printed circuit boards prevents moisture retention and also minimizes the accumulation of dust and other debris that become conductive in the presence of moisture and cause early failure of the boards. Vertical placement allows for better convective cooling of the boards and reduces the possibility of intermittent contact due to vibrational shock.

c. Maintenance Procedures

Yearly replacement of the VCI capsules, discussed in Subsection A.4.b above, will provide the necessary protection. The capsules should be replaced during periodic inspection of the equipment.

B. Track

1. Rails and Rail Plates

a. Problem

Humidity in underground structures causes moisture intrusion between the rail and adjacent tie plates or insulation that can result in crevice corrosion of the bottom flange. The high moisture level deteriorates fasteners and contributes to an incomplete cure, and subsequent deterioration of amino-cured, epoxy potting materials. Stray current corrosion can cause damage when moisture or other conductive contaminants bridge the gap between rail and invert.

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*Available from Eaton Corporation under the brand name Cutler-Hammer Oxidation Inhibitor.

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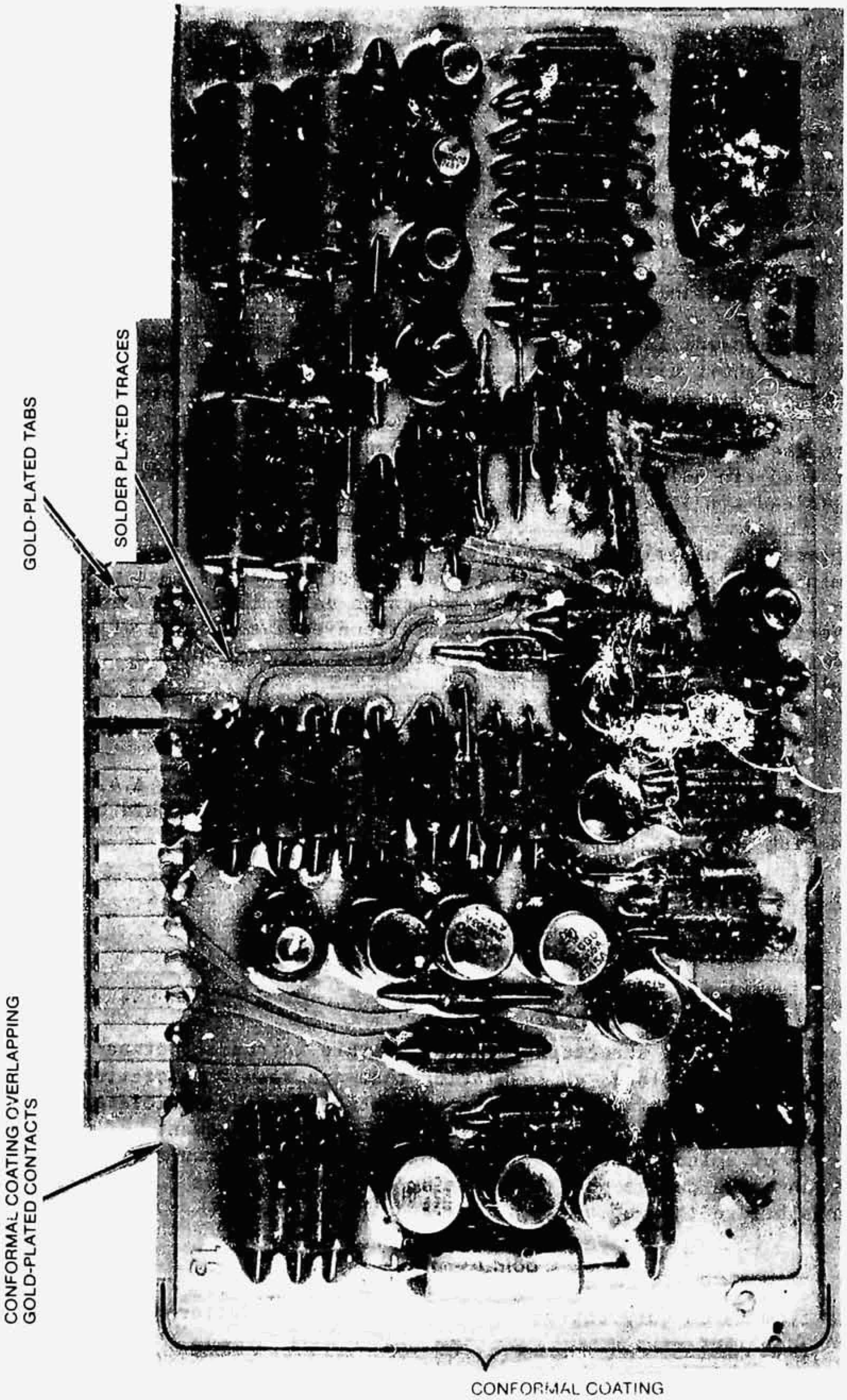

FIGURE 9 CONFORMAL COATING OF PRINTED CIRCUIT BOARD

b. Design Solution

The bottom flange-tieplate/insulation interface should be sealed with MIL-S-81733 sealant to prevent water intrusion. Track fastener hardware should be cadmium-plated (0.5 mil minimum), and sand-filled epoxy* should be used as a potting material. The sand-filled epoxy will increase the side-load carrying strength and prevent flexing and eventual failure of the joint.

c. Maintenance Solution

Repair of corroded rail fasteners, including cadmium-plated fasteners after the cadmium has been sacrificed, requires cleaning by an abrasive blast to near white, followed by coating with an inorganic zinc-rich product, such as MIL-P-23236A(SH), Type I, Class 3 or NASA-KSC-C-0001. For short-term protection, a tannate treatment followed by an epoxy coating application may be sufficient. A tannate treatment consists of the application (usually by brush) of a tannic acid formulation to transform the iron oxide (rust) into a harmless iron tannate.**

The retention of moisture or other conductive contaminants beneath the rails must be prevented. This is achieved by the proper maintenance of drainage and ventilation systems by regular cleaning.

2. Joints and Fasteners

a. Problem

Bolts are used routinely as rail fasteners. If crevice corrosion develops between mating surfaces, the volume of the corrosive product produced creates a wedging force. This corrosion combined with vibration causes loosening of the fastener.

b. Design and Maintenance Solution

To avoid crevice corrosion between mating surfaces and under bolt heads, design specifications should require the application of an elastomeric sealant such as MIL-S-81733, or the coating of both faying surfaces with a zinc-rich primer. Faying surfaces should not be masked. (Previous recommendations of the Steel Structures Painting Council stated that faying surfaces should be masked, not painted.)

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*A sand-filled epoxy is available from the Sandstrom Products Company, Port Byron, IL.

**A tannate formulation is availabe from A. W. Chesterton Co., Stoneham, MA.

The necessity for accommodating slight movement between faying surfaces or different thermal expansion rates makes the application of the elastomeric sealant the preferred corrosion control method even when both surfaces have been pre-primed. An application of alkali-resistant paint, such as an epoxy or urethane, to bolts will prevent alkali damage and subsequent corrosion due to moisture retention.

IV POWER AND SIGNALS

A. Stray Current Corrosion

1. General Effect of Stray Current Corrosion

a. Effect on Existing Utility Systems

(1) The Problem

Rail transit systems utilize a third rail or an overhead wire to provide current to the cars. After passing through the traction motors, the current then returns to the substation via the running rails. Such a system generates stray current because:

- The voltage drop through the running rails cannot be reduced to zero.

- The rail-to-earth resistance cannot be increased to infinity.

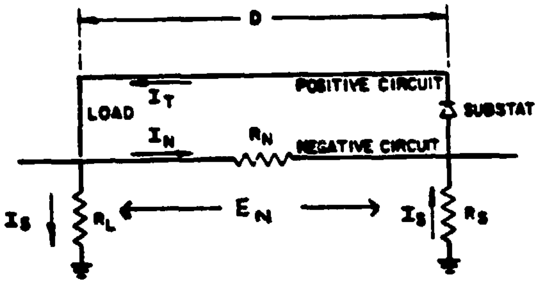
Because the earth is a parallel conductor to the rails, some current will flow into the earth. The level of stray current depends upon many factors. Among these are:

- Magnitude of the propulsion current
- Traction power substation spacing and grounding
- Conductance of negative conductors
- Number and location of track crossbonds
- Track-to-earth resistance.

In the past, most stray current control has been a matter of attempting to control currents or to reduce them to tolerable levels once they were detected on underground structures. The concept of controlling the source of stray current is relatively new. Consequently, criteria have not been established for permissible levels of stray current from modern transit systems. There are, however, some modern transit systems operating at stray current levels of 0.5 amperes or less per 1000 feet of track.

Many thousands of amperes are required to operate heavy rail systems. Smaller currents, perhaps in the hundreds of amperes, are used for light rail or trolley car lines. Larger currents occur during times of peak operation. The stray current situation is therefore dynamic, and a careful analysis of actual current, conductor resistance, and track-to-ground resistance is necessary to determine the stray current patterns.

Figure 10 illustrates the relationship of the various circuit elements that are important to the development and control of stray currents on a transit system. R_N and D are generally fixed by load and economic factors; consequently, stray current is most practicably controlled by maximizing R_L and R_S.



E_N	Voltage produced in negative conductors by I_N
D	DISTANCE BETWEEN SUBSTATION AND LOAD
R_N	RESISTANCE THROUGH NEGATIVE CONDUCTORS (PRINCIPALLY RAILS)
R_L	NEGATIVE SYSTEM TO EARTH RESISTANCE AT LOAD END
R_S	NEGATIVE SYSTEM TO EARTH RESISTANCE AT SUBSTATION END
I_T	TRAIN OPERATING CURRENT
I_N	CURRENT RETURNING THROUGH NEGATIVE CONDUCTORS
I_S	CURRENT RETURNING THROUGH EARTH

(ALL RESISTANCES IN OHMS AND CURRENTS IN AMPERES)

FIGURE 10 BASIC RAPID TRANSIT STRAY CURRENT CONTROL CIRCUIT

As can be seen from this figure, the magnitude of stray current, I_S is described approximately by the equation:

$$I_S = I_T \left(\frac{R_N}{R_L + R_S + R_N} \right)$$

The voltage (E_N) is produced by I_N which, for a system with good stray current control, is essentially I_T (total load current) flowing through R_N, the resistance of the negative return system between the load and the power substation. The value of R_N in most systems consists essentially of the four running rails in parallel because of crossbonds between tracks. The resistance of the four running rails is approximately 0.0025 ohm/1000 ft. An eight-car train under maximum acceleration and loading will peak at 10,000 to 12,000 amperes (A), depending on the location within the system; thus, E_N could attain a value of 50 V for a load of 10,000 A (I_T) at a distance of 2,000 ft between the load and the traction power substation.

Stray current from an improperly designed or constructed transit line can result in destruction of various metallic components belonging to both the transit company itself and to utility and other owners of underground structures. Probably of greatest economic impact would be the effects on underground utilities; many of these structures may have been constructed in such a manner that the mitigation of stray current effects is not feasible without major modifications and considerable financial outlay.

The effects of uncontrolled stray current on the safety of various underground utility lines also must be considered. Stray current can lead to severe corrosion; a resultant leak in a gas or oil line could cause an explosion or a fire. A telephone or power cable could fail, disrupting service to a hospital or other critical facility.

(2) Design Solution

Through proper engineering and design, stray current levels can be reduced to tolerable values. To construct a modern transit system without such attention to stray current control would leave the operator open to all manner of damage claims. It is apparent, therefore, that the aim of an effective stray current control program is to reduce the magnitude of stray currents to such low levels that their corrosive effect on buried structures is negligible. In the design of new transit systems, this is best accomplished through a carefully organized program of corrosion engineering.

The transit engineer needs to consider the impact that stray current will have on neighboring underground structures. What may be an entirely acceptable level of stray current on a remote trolley line, for example, may cause catastrophic damage in a metropolitan area. Thus, each transit system and indeed single portions of individual systems need to be carefully analyzed and corrosion control criteria established.

Corrosion engineering for a transit system should include a number of considerations. These are briefly described below.

Corrosion Survey--A corrosion survey includes a general review of the environmental conditions along the rights-of-way. The purpose of such a survey is to determine the impact of stray current on local utilities and to ascertain the effects of environmental corrosion on the transit structures themselves. The survey should also assess soil conditions. This is discussed in Section B at the end of this chapter.

A detailed study of the traction power plans should be made, including a computer analysis of the probable stray current to be expected from such parameters as different substation locations, rail-to-ground resistances and train operating conditions. From the survey, the transit corrosion engineer can develop criteria for the control of underground, stray current, and atmospheric corrosion.

At this time, initial liaison with local utility companies should begin. This is best done through the local corrosion coordinating committee. Appendix C lists many of the corrosion coordinating committees throughout the United States.

Careful coordination should be effected with local utility companies with regard to the protection of relocated lines. Gas companies, for example, are in most cases required by federal law to provide corrosion protection to their pipelines.

Preparation of Plans and Specifications--Standard drawings, design criteria, and specifications for corrosion control need to be prepared. These should be made part of the overall plans and specifications for the system.

Review of Designers' Documents--Most transit systems have many engineering firms working for them. The corrosion engineer needs to review the work of these designers to make sure that corrosion control criteria are being met.

Construction Inspection and Tests--The corrosion engineer needs to inspect construction to see that corrosion control items are being properly installed and that the various corrosion control criteria are being met. Tests are made to determine track-to-ground resistance and to check for any short circuits that may have developed. Utility corrosion engineers should obtain base-line data during transit construction. These data can be compared with data taken after transit operation begins to determine if there are any effects from the transit system.

Stray Current Tests--Tests should be made to establish the levels and effects of stray current before the system is energized, during test train operation, and subsequent to revenue operation. This work requires close coordination with utility corrosion engineers. Any stray current mitigation that may be necessary should be engineered at this time.

Operation and Maintenance--Procedures for maintenance of corrosion control must be developed in the design solution and made part of the overall system maintenance manuals. Establishment of the types and frequency of tests, manpower, and equipment is needed.

(3) Maintenance Solution

Many corrosion engineers with stray current experience have worked with strays from old surface streetcars, interurbans, subways, or mine railroads. They have been confronted with mechanically joined and supposedly bonded rails, often laid on wooden ties and often in intimate contact with the earth. Track maintenance may have been poor. Traction power substations were frequently spaced 3 to 5 miles apart.

In most stray current areas, however, buried utility networks have been designed to facilitate drainage of strays back to the transit system. Engineers responsible for underground structures are usually familiar with stray current control practices--such things as drainage bonds and electrical continuity have become common practice.

Many older systems are expanding, however, as the need for rail rapid transit increases. This often means construction of transit lines in areas where there has been no stray current or where stray current ceased to exist years ago with the abandonment of streetcar lines. When such expansion occurs, both the utility and the transit engineers are faced with problems similar to those experienced in areas where new rapid transit lines are being built or planned.

Where stray current problems are suspected or are found to exist, detailed surveys should be made. Through proper correlation of data, it is possible to establish the extent of the problem; often a survey may reveal that the problem is not nearly so severe as first suspected.

It is essential that the transit corrosion engineer of an operating system be an active member of the local corrosion coordinating committee (See Appendix C). Existing stray current mitigation bonds must be maintained, and often this requires cooperation with the local utility companies.

Of paramount importance is an understanding of the effect of stray current mitigation or drainage bonds. Many engineers in established stray current areas are familiar with these drains; all too often, however, a drain bond may be established simply because some stray current activity has been detected.

On older systems, with low track-to-earth resistance, the establishment of a drain bond probably will not materially affect this resistance. If the utility structure is electrically continuous, a drain bond may be an effective way of mitigating stray current corrosion. Many such bonds usually are connected to older systems, and procedures for testing and installing drain bonds are usually well established. Bonds require routine testing to ensure proper functioning.

On new systems, where control of stray current is vested largely in the design of the traction power and track networks, installation of a drain bond may seriously reduce the track-to-earth resistance. A domino effect on other utility lines may also occur. Installation of a drain from one line may create stray current corrosion on another.

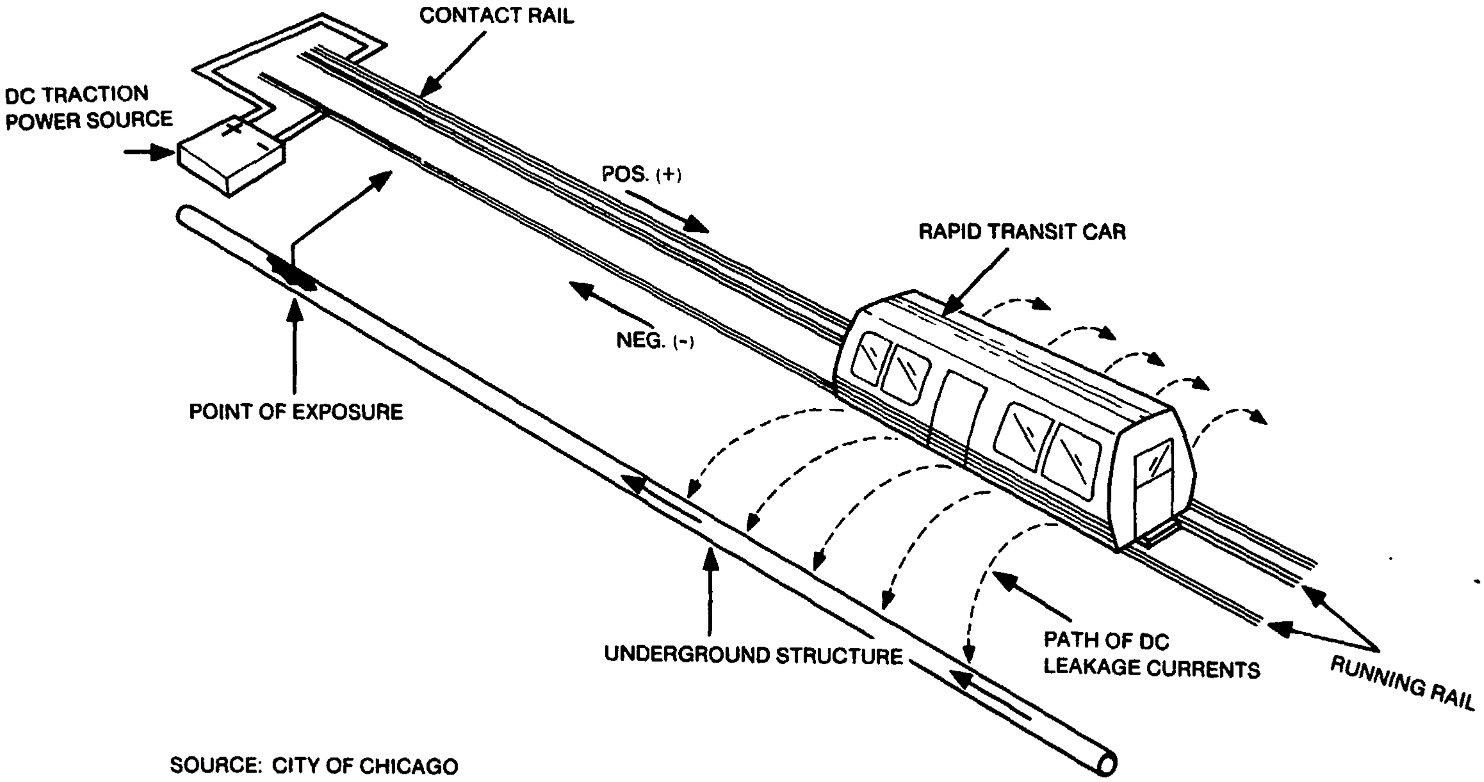
When a problem is suspected, an engineering study should be made to establish that a significant corrosive condition exists and that it is attributable to the operation of the rapid transit system. If the problem cannot be resolved by some correction to the transit system, then a drain bond may be justified.

In the maintenance of newly constructed transit systems, corrosion control parameters must be kept in mind. Rights of way must be kept clean and properly drained. Track insulation and other corrosion control devices must be properly maintained to minimize stray current.

b. Effect on Transit Structures

(1) The Problem

Stray current from the transit system can lead to corrosion of such items as reinforcing steel in concrete structures, transit utility lines (chilled water, steam, etc.), hydraulic elevator cylinders, pipes, cables, tunnel liners, and the rails themselves. (See Figure 11.) The problems of stray current corrosion on transit structures, in effect, are about the same as those described for utilities. (See Section A.1.a. above.) Underground corrosion of transit structures is discussed in Section B of this chapter.



SOURCE: CITY OF CHICAGO

FIGURE 11 EXPOSURE ON UNDERGROUND STRUCTURE RESULTING FROM DC LEAKAGE CURRENTS

(2) Design Solution

Where feasible, underground structures should be made of nonmetallic materials. Metallic pipelines and similar underground structures are usually protected in a conventional manner by coating, cathodic protection, insulating, and bonding. The structures should be electrically continuous. Dielectric insulators are frequently used in transit system metallic piping as a means of stray current control.

Tunnel liners may be made of steel, cast iron, or reinforced concrete. Tunnel segments may be bonded together to provide electrical continuity and thus guard against possible stray current corrosion.

Reinforcing steel, particularly that in concrete track inverts, tunnels, and retaining walls, is made electrically continuous as a precaution against stray current corrosion. Reinforced tunnel liners are made electrically continuous by tack-welding longitudinal bars at joints; the longitudinal bars are tack-welded to transverse rings, and 250 MCM copper cables are used to provide electrical continuity across the joint. (See Figure 12.) Provisions should be made for test wires; cables to the reinforcing steel may be included at traction power substations; these will make possible stray current drainage should it ever be necessary.

Soldier piles and foundation piles are usually bonded together to provide electrical continuity.

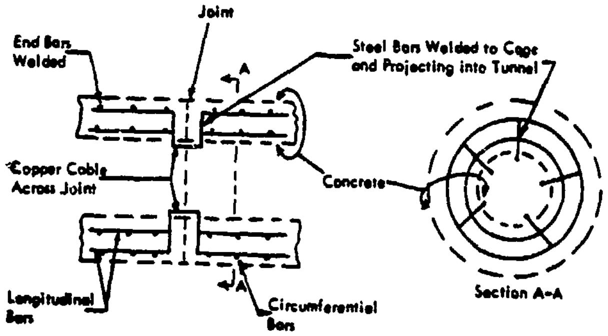
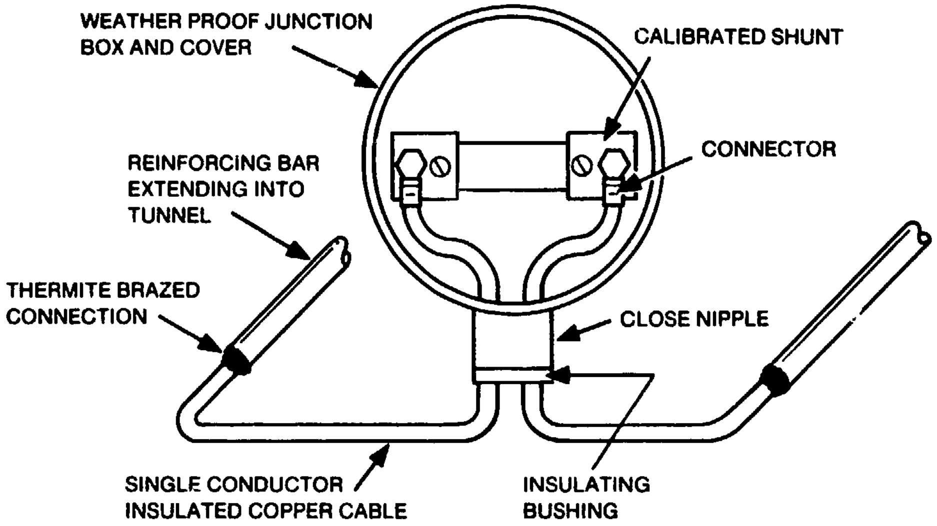


Figure 12 BONDING OF REINFORCING STEEL

For the construction of new systems, the design should include installations for verifying and testing stray current control. For example, to measure the magnitude and direction of current flow in tunnel structures, measured lengths of tunnel can be calibrated. Some systems are using calibrated shunts (see Figure 13). Electrical continuity of reinforcing steel should be measured and the results compared with theoretical resistances.



SOURCE: CITY OF CHICAGO

FIGURE 13 BONDING OF REINFORCING STEEL--
JUNCTION BOX DETAIL

Another testing technique that should be part of the design is to provide the capability to monitor those critical utility structures that are installed under concrete by installing permanent copper/copper sulfate or other reference electrodes. Such electrodes will allow for observing the effects of stray currents and cathodic protection systems where testing would otherwise be nearly impossible due to physical circumstances.

(3) Maintenance Solutions

On older systems where stray current control has not been part of design, efforts should be made to prevent increases in the stray current being generated. Cleanliness of the trackway should receive attention. Debris, brake dust, and rail/wheel shavings should not be allowed to build up on the tracks. Any corrosion failures should be investigated promptly. If stray current is apparent, measures should be taken to control it.

Several maintenance procedures should be followed. Tests should be conducted with owners of foreign structures to ensure that the operation of the transit system (including the associated cathodic protection systems) is not adversely affecting other underground metallic structures. Structure-to-soil potential and other measurements should be observed to evaluate the stray current conditions and the effectiveness of the cathodic protection systems. Test rods that are removable for periodic inspection can protrude into surrounding soil and water from tunnel liners. Maintenance tests on the rods are conducted by removing, cleaning and examining the physical condition of the rod, measuring pit depth, and replacing the rod.

Bonded structure continuity tests should be made annually.

2. Substations

a. The Problem

One source of stray current is the traction power substation. Substation spacing and grounding affect the amount of stray current to be expected. Returning stray current will concentrate around grounded substations.

b. Design Solution

The spacing of traction power substations many miles apart, as is typical of many older transit systems, increases the voltage drop in the running rails and tends to increase stray current. In new systems, spacing between substations should be more on the order of about 1 mile or so. Optimal spacing should be determined by analyzing load conditions, stray current, voltage drops in positive and negative conductors, and economics.

Reference to the equation in Figure 10 shows that another factor relative to the reduction of R_N is the reduction of the distance between the load and the traction power substation. From a practical standpoint, this requires a reduction in the spacing of the substations, or stated another way, by the use of additional substations within the system. It should be emphasized that this simplistic circuit does not truly represent a modern transit system traction power configuration where several substations will be feeding a common positive bus. Nevertheless, the principle remains the same. New systems are designed to ensure that the required loads can be provided at all points within the system under the conditions of anticipated demands with some substations actually out of service. This conservative design concept usually provides for spacing of substations at an average of about 1 mile distance throughout the system. Closer spacing would require additional expenditures and from a practical standpoint can seldom be justified. Thus, the practical reduction of the voltage drop (E_N) within the negative system is accomplished by combination of the conductance within the four rails and the spacing of the substations.

One of the major sources of stray current is grounding of the substation negative. This reduces the effective track-to-ground resistance by reducing R_S in the equation of Figure 10 and permits concentration of returning stray current in the substation area. New transit systems and extensions of older ones should be designed with the DC negative ungrounded. This has been shown to be a safe and practicable method of reducing stray currents.

All negative traction power cables should be fully insulated from ground. In the design of new substations, provisions should be made for stray current drainage should it ever become necessary. As mentioned earlier, however, the installation of a stray current drainage bond should be considered a last resort.

As part of the corrosion survey (see Section A.1.a. of this chapter.), a study should be made to determine the effect of taking a substation out of service. This will increase the voltage drop along the rails and in turn increase stray current. The operating characteristics of the system need to be evaluated in this light.

c. Maintenance Solution

On transit systems with operating stray current mitigation bonds, these bonds must be maintained. Loss of a bond could cause a serious safety hazard for the utility line to which it is connected. Substations should not be taken out of service (except in an emergency) without an analysis of the probable stray current effects. Track-to-earth voltages that will develop when a substation is taken out of service should be determined because they may reach dangerous levels.

It is essential that ungrounded substations remain so; the engineer should ensure that no inadvertant contacts to ground occur. He should also ensure that no unauthorized stray current mitigation bonds are installed.

3. Negative Return System

a. The Problem

The magnitude of stray current is affected largely by the resistance of the negative system (R_N), the rail-to-ground resistance (R_L) and, as discussed above, the substation-to-ground resistance (R_S). The lower the resistance of the negative circuit, the lower the voltage drop will be along the rail. Serious safety and stray current problems can arise if these factors are ignored.

Moisture or foreign materials forming a conductive film on the surfaces of insulators present a significant problem on maintaining effective track-to-earth resistance. Moisture on the surface or absorbed into the timber tie can change the timber from a fair insulator to a good conductor.

Rail conductance depends on rail size and method of joining. The old bolted, bonded, and often poorly maintained track joints were notorious sources of high resistance in trackage.

b. Design Solution

High track-to-earth resistance is one of the most important aspects of stray current control. This must be combined with ungrounded traction power substations.

Careful attention to trackwork design and construction can ensure both track insulation and high track-to-ground resistance. For tunnel or other construction where the track is laid on a concrete invert, insulated direct fixation fasteners are usually used, as shown in Figure 14.

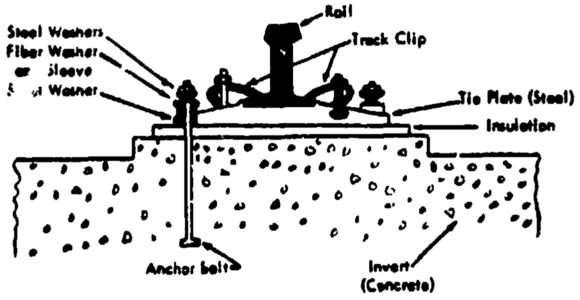


FIGURE 14 TRACK FASTENER INSULATION

These fasteners consist essentially of a pad of high dielectric material between the rail and the invert. (The pad material must be antiozonate as discussed in Chapter VI, Section A.7.) The rail is fastened to the pad that is fastened to the invert. A good quality, low-permeability concrete invert is also desirable; a track-to-ground resistance of 500 ohms per 1000 feet of single track has been shown to be a reasonable value.

Tie and ballast construction is sometimes difficult to insulate effectively. Many systems use rail directly spiked to timber ties. Resistance of about 20 ohms per 100 feet of single track might be expected. It is better to use concrete ties with either direct fixation fasteners or similarly insulated pad under the rails, although some use has been made of insulated direct fixation fasteners with timber ties. Ballast should be clean and well drained and not in contact with the rails.

Special trackwork consists of timber tie and ballast construction. Of special importance is the insulation of switch throw rods and switch heaters. Care must be taken to avoid accidental electrical contact to ground.

The design solution must address the problem of controlling moisture or foreign materials forming a conductive film acrose the sufaces of the track insulators and thereby affecting track-to-earth resistance. To maintain proper levels of track insulation and maximize rail-to-earth resistance, proper water drainage must be provided. These factors must be recognized and reasonable levels of variation in track-to-earth resistance accepted.

Trackwork in yards and shops requires special attention. Shops usually require grounded rails for personnel safety. Yards and shops should be insulated from main lines with insulated track joints to prevent grounding of the main line tracks. Insulated track joints should be provided between the yard and the shop also. A separate traction power substation should be provided for the yard and one for the shop.

Aerial construction usually will have high resistance to ground if proper design is followed. Electrical continuity should be provided for the invert reinforcing steel, but there should not be electrical continuity between the invert and the aerial structure supports.

Floating slab construction aids in increasing rail-to-earth resistance. As in other construction, it is important that no electrical contacts be permitted between the rails and the earth.

Light rail systems often have tracks in streets. It becomes difficult to obtain high track-to-earth resistance. Attempts have been made to encase the track slab in a plastic or neoprene membrane. Possibly some type of dielectric material could be poured around the rails themselves. Here again, all reasonable precautions need to be taken to obtain as high as possible a resistance between track and ground.

It is essential that there be no electrical contacts between the rails and earth. Negative cables should not be interconnected to ground in the traction power substation. Any supplementary negative copper wire paralleling the rails must be insulated. Switch throw rods, switch heaters, and other trackside equipment must not provide electrical contact to ground.

The lower the resistance of the negative circuit (R_N), the lower the voltage drop within the rail. The point to which reduction in R_N is practical becomes a matter of economics. Reduction of the resistance of the rail negative return system is accomplished by the use of all welded rail. Additional reduction in the resistance of the negative return circuit would require the installation of additional conductance, either built into the rail or by the use of insulated cable. A few calculations can show how costly the use of additional conductance can be compared to the benefits when the fact that reducing the unit value of R_N to one-half might require an equivalent conductance of about 4 million circular mils of copper cable. Because of this cost, system designers on recent transit construction within the United States have tended to rely on the conductance provided by the rails for the negative return circuit. Conductance is often aided by the use of track cross-bonds, usually installed in conjunction with impedance bonds at perhaps 1500-ft intervals.

c. Maintenance Solution

Procedures should be established to maintain proper rail conductance and rail-to-ground resistance. Where mechanically joined rail is used, joint bonds must be maintained. This is particularly important in older transit systems with grounded traction power. Although it may be very difficult to maintain bonds on trolley lines having tracks in the street, everything possible should be done to maximize track conductance.

Rights-of-way should be kept as clean as possible. Buildup of debris and conductive material such as rail and wheel shavings should be avoided. Track insulators must be maintained. Procedures should be established to ensure that track-to-ground resistance is kept as high as possible. This is most important in newer systems that use ungrounded traction power; on older, grounded systems, rail-to-ground resistance is already low, but precautions should be taken to avoid lowering it further. Deicing salts, for example, should not be used on the tracks.

Operational procedures need to be developed for yards and shops. Cars must not be parked across insulated track joints. Switch rods must remain insulated. Grounding within the shop itself must be maintained for personnel safety.

During construction of new or expanded systems, visual and electrical inspections should be made to ensure that direct fixation fasteners and rail clips are properly installed. After construction is completed, rights-of-way, tunnels, stations, etc. need to be cleaned so as to establish proper rail-to-ground resistance.

A regular test program should be established. Rail-to-earth resistance tests should be made annually, as should bonded structure continuity and structure-to-earth potential tests. These tests will reveal problem areas that may lead to increased stray current. Procedures to solve the problems found must also be established.

Track and tunnel drainage and cleanliness are important. Buildup of debris or ponds of water in tunnels will cause a decrease in track-to-ground resistance. Tie and ballast sections must also be kept clean and drainage maintained. Ballast must be kept from coming in contact with the rails. Periodic tamping may be required. It is imperative to ensure that inadvertent contact to ground be prevented. All of these aspects are best accomplished by a good track inspection and testing program.

4. Positive Conductor

a. The Problem

Because the positive conductor--contact rail or catenary--is usually well insulated from earth, it tends to generate virtually no stray current.

b. Design Sclution

The common design practice is to provide for high resistance to earth through insulated supports. To save energy, it is also desirable to minimize the voltage drop in the third (contact) rail. A recent development here is the use of a composite rail. This consists of the steel contact rail with perhaps an aluminum extrusion fitted into the web of the rail. The high conductivity of the aluminum plus the enlarged cross section of the rail increases the conductance. Care must be taken, however, through proper design and use of sealants (such as MIL-S-81733), to prevent galvanic corrosion between the two metals. The spacing of traction power substations should not be increased, however, if the composite rail is used.

c. Maintenance Solution

Positive conductor insulators must be maintained. Where composite third rails are used, elastomeric sealants (MIL-S-81733) must be maintained. Positive cables between the trackway and substations need an annual check to ensure that insulation is effective.

B. Soil Corrosion

1. The Problem

Buried transit structures such as piping, tanks, hydraulic cylinders and metallic tunnel liners may be subject to soil corrosion. Corrosion control needs to be considered to prevent failures. Additional information on this subject is presented in Chapter V.

2. Design and Maintenance Solutions

The corrosion survey discussed in Secton A.1.a. of this chapter should also include an evaluation of soil corrosion. For example, representative soil borings and water samples should be tested to determine the following properties:

Soil Borings	Water Samples
pH (electrometric)	pH (electrometric)
Electrical resistivity (soil box method)	Electrical resistivity (soil box method)
Chlorides(mg/l NaCl	Tests per AWWA Public Health Assn(mg/l)
Sulfates(mg/l SO_4)	Carbonates
Presence of sulfides	Bicarbonates
	Free CO_2
	Hardness
	Chlorides
	Sulfates

The sulfate content of soil and water should also be measured to ensure appropriate concrete selection. Sulfate resistance of Portland cement is as follows:*

SO_4 Content of Water (mg/l)	Water-Soluble SO_4 in Soil (mg/l)	Cement Needed
Below 150	Below 1000	Type I
150-1000	1000-2000	Type II
Above 1000	Above 2000	Type V

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*Concrete Pipe Field Manual, p. 40 (1962).

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The proper cement must be specified for concrete structures. Chlorides should be excluded from any concrete mix to prevent corrosion of reinforcing steel.

Generally, where soil resistivity is below 5,000 ohm centimeters, cast iron should have cathodic protection. Steel tanks and piping are usually provided with coating and cathodic protection in nearly all soils.

Either galvanic anodes (Figure 15) or an impressed current system (Figure 16) is used for cathodic protection. The galvanic anode system typically consists of prepackaged magnesium or zinc anodes spaced along and directly connected to the structure. The impressed current system usually consists of anodes (generally of cast iron, graphite, or platinum) connected to the structure through a rectifier. The positive header cable is connected with the negative structure wires to the respective terminals of the rectifier supplying the protective direct current. Where cathodic protection systems are used, they should be designed and installed in accordance with the National Association of Corrosion Engineers recommended practice RP-01-69.

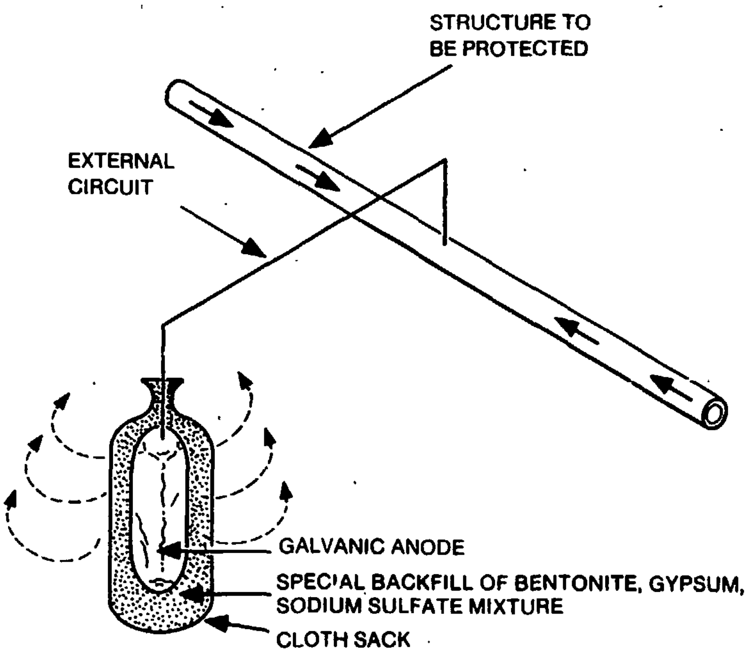

FIGURE 15 CATHODIC PROTECTION BY GALVANIC ANODE METHOD

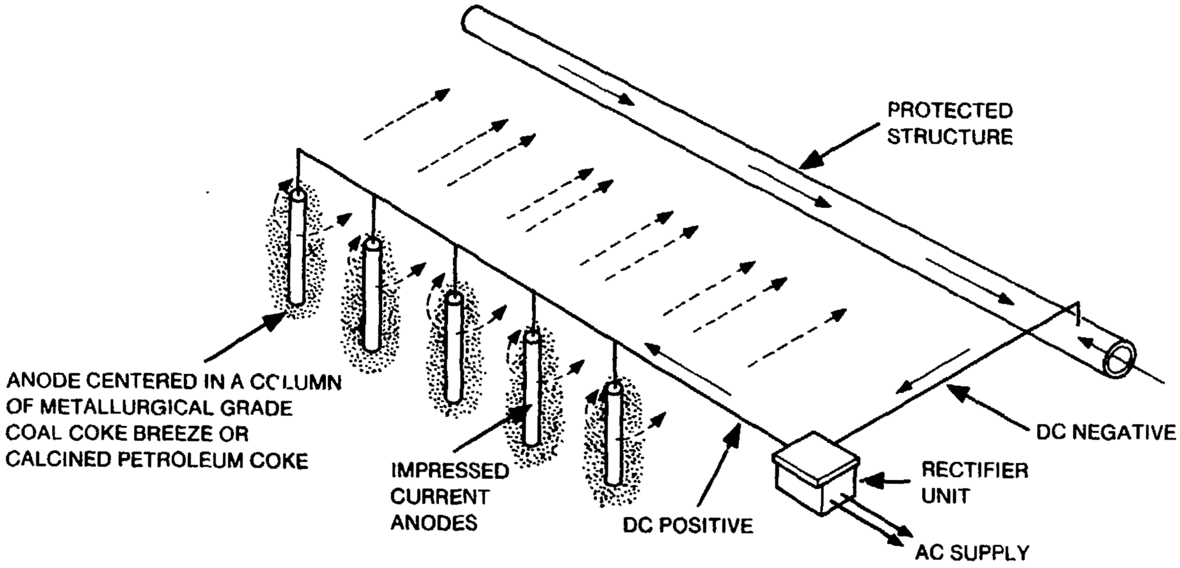

FIGURE 16 CATHODIC PROTECTION BY IMPRESSED CURRENT METHOD

Tunnel liners of steel or cast iron generally require little exterior corrosion control other than perhaps a good-quality epoxy coating. Tunnel liner interiors may be painted with an inorganic zinc silicate primer [MIL-P-23236A(SH) Type I or III, Class 3 or NASA-KSC-C-0001]. This must be applied in strict accordance with the manufacturer's recommendations. A top coat is unnecessary unless preferred for aesthetic reasons.

Nonmetallic jacketed cable is recommended for electric cables. Where lead sheath cable or associated metallic components are underground, however, cathodic protection may be necessary, especially in areas contaminated by deicing salts. Nonmetallic ducts should be used wherever possible.

V PLATFORMS AND STATIONS

A. Platform Structures

1. Resistance to Ground

a. Problem

In ungrounded traction power systems, under certain fault conditions, it is possible for high voltages to appear between track and ground. Because the car body is electrically connected through the trucks to the rails, these voltages can also appear between the car body and ground. Shock hazard to passengers and other personnel and stray current corrosion may exist if platform-to-ground resistance is inadequate.

b. Design and Maintenance Solution

Platform surfaces should be constructed of materials with high resistance to ground. Clay tiles, latex portland cement grout, granite, and similar materials have been found to be satisfactory. A bed of latex portland cement under the platform surface will also increase platform-to-ground resistance. Vitrified clay or quarry tiles are wear-resistant and can be placed up to about 1 ft from the edge of the platform.

Handrails and other metallic structures that are within reaching distance of a car body should be insulated from ground. In addition, insulative coatings might be used. Any grounded metallic structures must be far enough from the edge of the platform that no one can touch both the car body and the structure at the same time.

No criteria for platform-to-ground resistance have yet been established, but resistances from a few hundred to several hundred thousand ohms have been reported. It is important to note that rain and deicing salts can materially reduce platform-to-ground resistance. Tests have shown that the resistance to ground of a wet platform can be 60% to 99% less than that of a dry platform.

2. Concrete Deck Supports

a. Problem

Concrete support structures are susceptible to chloride penetration and subsequent deterioration. Chloride attacks the steel reinforcing rods and thereby causes corrosion. Because the corrosion product occupies greater volume than the metal from which it is formed, the concrete begins to crack and eventually to spall (chip), and the rebar is exposed to direct atmospheric attack.

b. Design Solution

The component in cement that is attacked by the chloride is tricalcium aluminate. Hence, the amount of calcium aluminate in the portland cement concrete should be lower than normal to inhibit chloride attack. The use of Type II ASTM C-150 cement will keep the aluminate below 8%.

Corrosion of reinforcing bars can be minimized by specifying that they be galvanized or epoxy coated (MIL-P-23377, Type IA).

c. Maintenance Procedure

Aged concrete should be cleaned with an appropriate concrete cleaner. The sodium silicate solution should then be applied by brushing.[*] The formulation for aged concrete (i.e., more than 4 months) is four parts water and one part sodium silicate.

3. Structural Members

a. Problem

In the past, steel structures were assembled without the faying surfaces of structural members being sealed; consequently, water intruded and caused a significant crevice corrosion problem (see Figure 17). Weathering steels may be attractive because they require no maintenance; however, they are susceptible to continual rusting, particularly when subjected to dust, deicing salts, mud, herbicides, and trash. The water intrusion also causes stretched rivets, broken welds and high-strength bolts, and distorted metal structures.

More so than pure metals, metal alloys have varying degrees of susceptibility to corrosion. In fact, the strongest metal alloys can be those most susceptible to corrosion, particularly oxygen concentration cell corrosion. Oxygen concentration cell corrosion may occur at unsealed faying surfaces, intermittant welds, and the location of joints or fasteners where one metal structure is in contact with another. Such corrosion may also occur under rivet and bolt heads even though the fasteners have been treated, unless the treatment is a zinc-rich coating, cadmium plating, or galvanizing.

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[*] Known manufacturers include PQ Corporation, P.O. Box 840, Valley Forge, PA 19482.

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FIGURE 17 CREVICE CORROSION OF PLATFORM STRUCTURE

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Dissimilar metal corrosion can result from the use of a general-purpose weld rod that contains silicon, copper, and other cathodic alloying materials, or from the use of graphite lubricants.

b. Design Solution

To prevent dissimilar metal corrosion, aluminum and steel should not be in contact with each other. They should be separated by an elastomeric sealant such as MIL-S-81733. When the dissimilar metals are steel and stainless steel, all faying surfaces of both metals should receive a zinc-rich coating such as MIL-P-23236A (SH), Type I, Class 3 or NASA-KSC-C-0001.

To prevent corrosion when joints and fasteners have dissimilar metals, either a paint or a Mylar^R barrier tape should be applied to the surface (the cathode). (See Figure 18.) The tape is applied before fastener attachment; it should not be a polyvinyl chloride product.

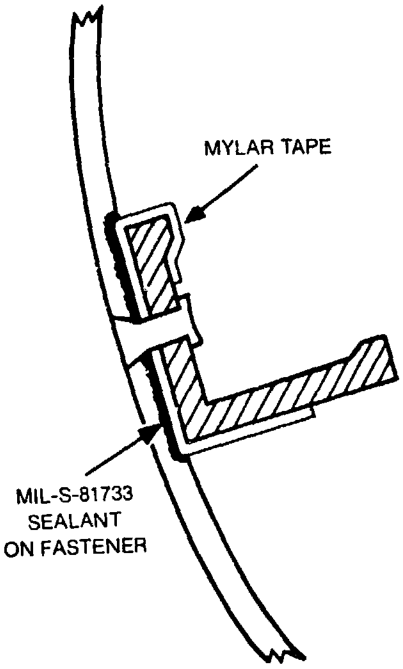

FIGURE 18 MOISTURE BARRIER TAPE BETWEEN DISSIMILAR METALS

When spot welding is used, the "Weld-bond" process can prevent crevice corrosion. Weld bonding includes the cleaning of both faying surfaces, the application of a sealant (such as MIL-S-81733) to the faying surfaces, and immediate spot welding while the sealant is still in a liquefied state.

To avoid corrosion due to water intrusion, all rivets and threaded fasteners should be dipped in a sealant (e.g., MIL S-81733) before they are inserted. They should be installed immediately before polymerization occurs.

c. Maintenance Solution

Metal should be cleaned on a regular basis to prevent the buildup of potentially corrosive residue on its surface. An application of alkali-resistant paint, such as epoxy or urethane, to bolts and other fasteners will prevent alkali damage and subsequent corrosion due to moisture retention. The use of epoxy or urethane paints prevents filiform corrosion of steel or aluminum fixtures and also resists aspergillus-nigris. These materials are resistant to mildew and other organisms.

B. Stations

1. Stairs

a. Problem

A primary concern of station personnel is poultice corrosion that results when dirt and debris, including car wheel debris, collect in corners and crevices of metal stairs. (See Figure 19.) Wheel debris such as rust and abrasives in contact with metal components may cause dissimilar metal corrosion as well. Stainless steel components are also susceptible if abrasive wear or graffiti has caused a breakdown of the passive film.

b. Design and Maintenance Solution

To prevent the corrosion of station components, a coating of an alkali-resistant catalyzed paint should be applied. Alkali-resistant catalyzed urethane paints, although more expensive, are longer lasting than silicone alkyd paints; they also retain their gloss and shed dirt. Urethane enamels (MIL-C-83286) applied over an epoxy primer (NASA-KSC-C-0001; MIL-P-23377) make building components more resistant to abrasive wear and to graffiti.

The use of a monofilament-wound grating material (Tetracore) for steps would eliminate many of the current problems. This material is strong and does not abosorb moisture. A resin contains the filament-wound core. Debris will not accumulate on the grating, and it is extremely wear-resistant. The structural design is shown in Figure 20.

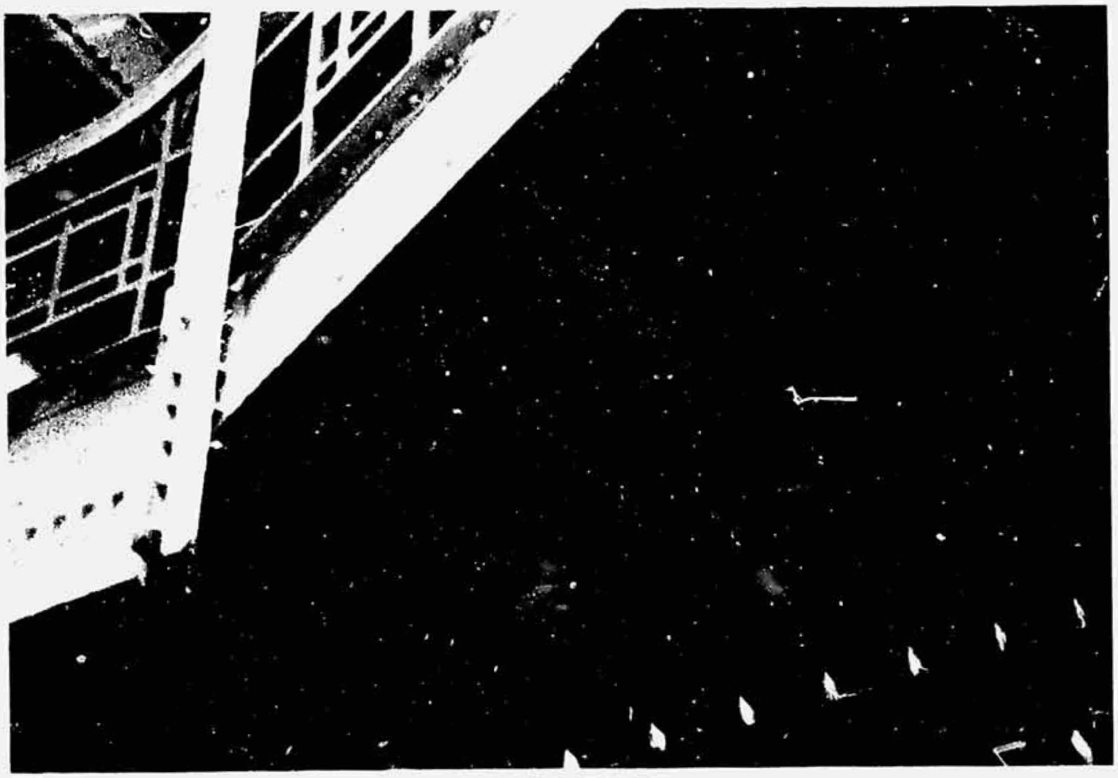

FIGURE 19 POULTICE CORROSION OF STAIRS

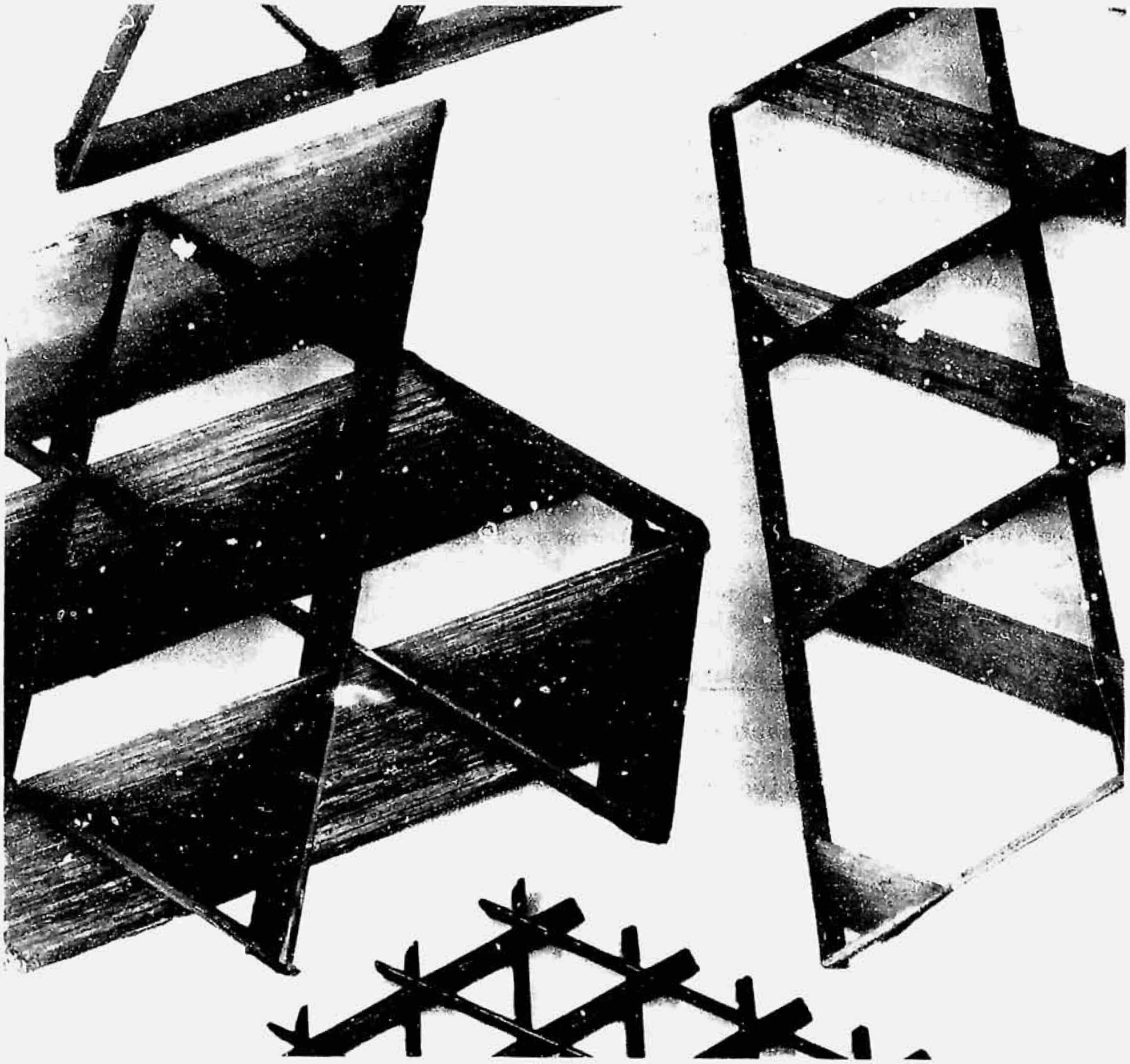

FIGURE 20 FILAMENT-WOUND GRATING MATERIAL

2. Lighting and Heating Equipment

a. Problem

Station heaters and lighting fixtures may be particularly susceptible to corrosion. Moisture on aluminum reflectors may lead to pitting corrosion. If the reflectors have been painted, moisture may accumulate beneath the paint, causing filiform corrosion. (See Figure 21.)

b. Design and Maintenance Solution

Painting of aluminum is recommended to prevent pitting corrosion. Alkali-resistant catalyzed urethane paints, although more expensive, are longer-lasting than silicone alkyd paints; they also retain their gloss and shed dirt. Urethane enamels (MIL-C-83286) applied over an epoxy primer (MIL-P-23377) make building components more resistant to abrasive wear and to graffiti markings. Good adhesion must be ensured.

C. Electromechanical Systems

1. Escalators

a. Problem

Because outdoor escalators and related electrical equipment are exposed to rain, snow, salt, and other elements of the outdoor environment, as well as debris, they are susceptible to corrosion. Stair treads retain salt and dirt. Efforts such as applying grease in large quantities to improve mechanical operation are not always sucessful.

b. Design Solution

Using a solid film lubrication (MIL-L-46010) on the chains and gears of escalators will ensure more reliable escalator operation. Adequate drainage and ventilation should also be provided in the escalator chamber to keep it dry and to minimize humidity.

c. Maintenance Solutions

Debris should be removed routinely. The entire area should be sprayed with water (if the electrical controls are waterproof) to remove any salt residue.

2. Hydraulic Elevators

a. The Problem

Corrosion of hydraulic elevator cylinders can lead to cylinder failure. It is possible that a catastrophic failure could occur on older cylinders that have only a single bulkhead bottom. Cylinder failure means replacement and attendant shutdown of the elevator.

FIGURE 21 FILIFORM CORROSION ON AN ALUMINUM HEATER

b. Design Solution

Hydraulic elevator cylinders should generally be provided with cathodic protection. In new construction, sealed fiber glass casings (sleeves) have been found to be practicable. Magnesium ribbon anodes are used inside the casing to protect the cylinder should any moisture get into the casing. Where steel casings are used, or where no casing is used, impressed current cathodic protection is usually required.

Double-wall cylinders may also be used. Although these may not be corrosion-free, they can be expected to have a longer life than single-wall cylinders. Cathodic protection may be used with double-wall cylinders, but generally it is not installed.

c. Maintenance Solution

Elevators without cathodic protection should be inspected in accordance with regular elevator procedures. If there is any indication that the cylinder is leaking, it should be replaced with a new one that is properly protected against corrosion.

Where cathodic protection is used, regular inspections of the protection system are required. Rectifiers (cathodic protection power sources) need to be checked once a month, and a corrosion engineer should inspect the protection system once a year to ensure that it is working properly.

D. Fuel Tanks

1. Problem

The exterior surface of the storage tank may corrode if exposed to the harsh elements of the outdoor environment. Burial also results in potential damage to the tanks. Interior corrosion may occur due to condensation. Perforation of fuel tanks can lead to fuel leakage and subsequent fire hazards.

2. Design and Maintenance Solution

If the fuel is stored above ground, application of a zinc-rich coating helps to prevent external damage to the tank. If aesthetic consideration dictates the need for a top coat, then a urethane paint should be used; otherwise, a top coat is not required.

Cathodic protection of underground fuel tanks should be considered, because coating alone provides insufficient protection. Current fire protection codes (e.g, National Fire Protection Association NFPA-30 and the Uniform Fire Code) require corrosion control for buried tanks. When cathodic protection is required, either galvanic anodes or impressed current may be used. (See Section B-2 of Chapter IV.)

Fiber glass tanks may also be used for buried service. These tanks are inert and require no corrosion protection. Careful installation is necessary, however, to prevent structural damage to the tank.

VI CARS

Each rapid transit car can be divided into three distinct parts: the body exterior, the body interior, and the truck. Various components of these parts have different corrosion problems.

A. Body Exterior

Car body exteriors are constructed of steel, stainless steel and aluminum alloys. Each metal has advantages and disadvantages as discussed below. Advantages and disadvantages of car body materials are also discussed in a report for UMTA.*

1. Body Skin

Because stainless steel and aluminum alloy are almost exclusively the materials used for car bodies, especially skins, their advantages and disadvantages should be carefully weighed during the initial stages of transit car design. The tabulation below lists the advantages and disadvantages of the two materials, as well as those of steel.

Stainless Steel	Aluminum	Steel
Advantages	Advantages	Advantages
Corrosion resistance Ease of cleaning Structural strength	Light weight Low cost Easy forming Good paint adhesion when chromate conversion-coated (MIL C-5541)	Low cost Structural strength Ease of repair
Disadvantages	Disadvantages	Disadvantages
High cost Tends to develop crevices during assembly	Tendency toward pitting, exfoliation, and stress corrosion cracking Need for frequent cleaning Poor compatibility with many cleaning compounds	Tendency toward oxygen concentration cell corrosion Heavy weight

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*"Morris, R. E., et al, "An Investigation of Rail Rapid Transit Carbody Materials," Report No. 1T-06-0175-79-1, The Decision Group, Inc., McLean, VA (March 1980).

a. Problem

If both stainless steel and aluminum are used for skin construction (e.g., an aluminum roof or trim and stainless-steel side panels) for car bodies or if a stainless-steel or aluminum skin is attached to a steel frame, dissimilar metal corrosion may result. [See Figure 22 (a) and (b).] An aluminum roof or trim will also contribute to the rusting of stainless-steel sides if alkali cleaning fluid reacts with the aluminum.

b. Design Solution

To prevent dissimilar metal corrosion in car bodies, the design should specify that only one metal be used or that dissimilar metals in the body skins should not be in direct contact. Dissimilar metals must be separated by an elastomeric sealant such as MIL-S-81733. To prevent the electrolytic path when dissimilar metals are used in the stiffener and fastener, either one dissimilar metal should be replaced or Mylar^R barrier tape should be attached to the stiffener surface (the cathode) as illustrated in Figure 18 (Chapter V, Section A.3). The tape should be applied to the fastener before attachment is made. Polyvinyl chloride (PVC) should not be used. When the dissimilar metals are steel and stainless steel, all interior surfaces of both metals should receive a zinc-rich coating [MIL P-23236A(SH), Type 1, Class B or NASA-KSC-C-0001].

c. Maintenance Solution

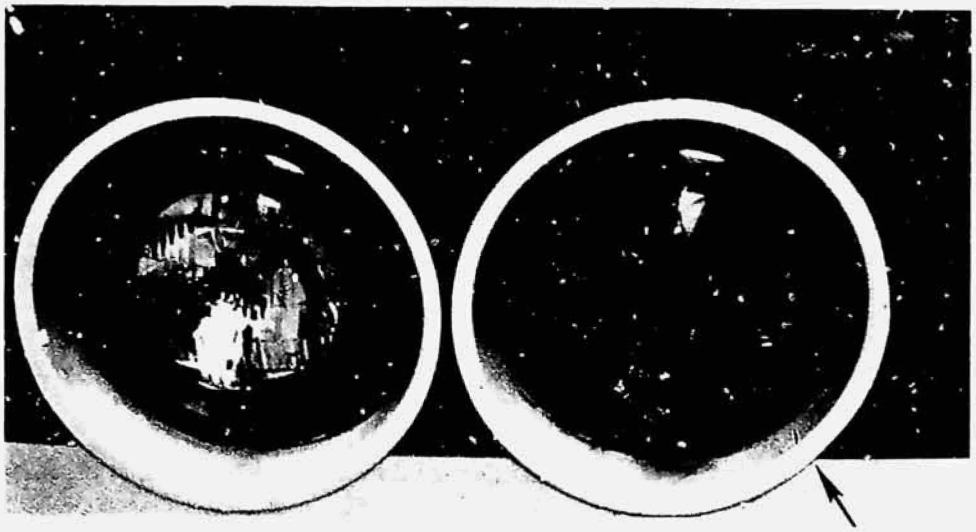
Aluminum is attacked by strongly alkaline cleaners, necessitating the selection of a special nonetching cleaner. A cleaner containing sodium metasilicate is recommended. The dark etching corrosion product that forms on unpainted aluminum surfaces may be removed with an acidic enzymatic cleaner, such as International Enzyme Corporation's Super-Cleaner^R.

Because painted steel bodies may also be etched by the residues of alkaline cleaners, all painted surfaces should be washed with a nonionic wetting agent or an acidic enzymatic cleaner. (Residues of ionic wetting agents and enzymatic cleaners will not cause a loss of paint gloss.)

2. Stiffeners

a. Problem

When nonmonocoque exterior skins are strengthened with angular or channel stiffeners, moisture may be retained in the stiffener elbow or at the skin/stiffener interface. This causes crevice corrosion.



a. Headlight Housings

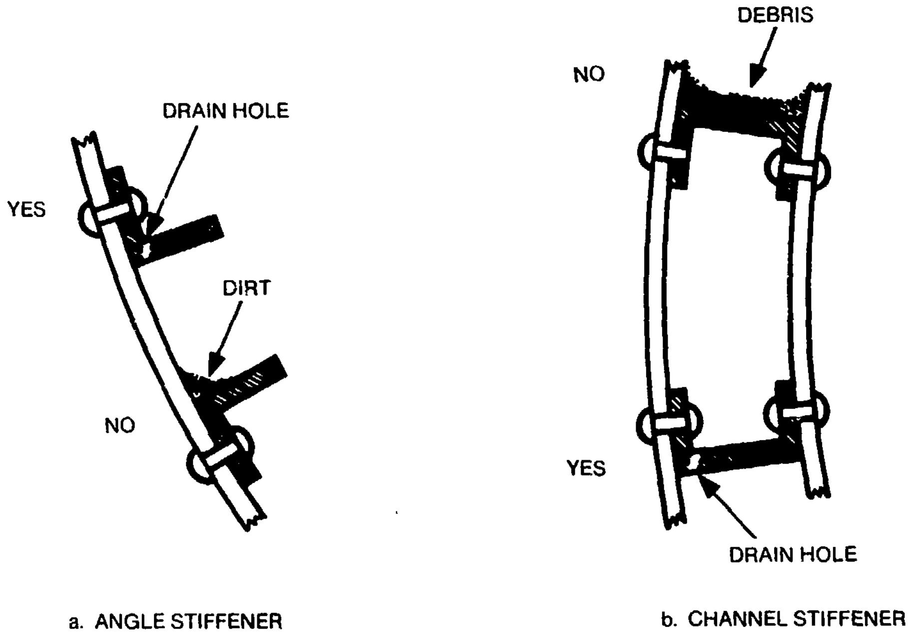
b. Door Frame

FIGURE 22 DISSIMILAR METAL CORRROSION OF THE CAR BODY

b. Design Solution

To prevent the retention of moisture by angle stiffeners, the design should call for stiffeners containing drain slots to allow condensation to flow to a central discharge point. The stiffener "leg" must be oriented toward the direction of flow, as illustrated in Figure 23. This orientation also resists poultice corrosion by directing dirt as well as water toward the drain slot.

To prevent corrosion between the stiffener and the skin, particularly with aluminum, a primer such as an epoxy polyamid (MIL-P-23377 or NASA-KSC-C-0001) should be applied to both faying surfaces. The most effective primer for aluminum, stainless steel, and mild steel would be a zinc-rich coating.



a. ANGLE STIFFENER

b. CHANNEL STIFFENER

FIGURE 23 STIFFENER ORIENTATION

When a channel stiffener is used to support both the interior and exterior skins, the drain slot should be located at the lowest point to ensure total removal of water, as shown in Figure 23 above. (This practice is followed by aircraft and automobile manufacturers.)

c. Maintenance Solution

The prevention of moisture retention by angle stiffeners can be accomplished by leveling the skin-stiffener joint with a caulking compound to encourage water runoff. Repair of a corroded interface between the skin and a channel stiffener requires removal of the skin and reorientation of the stiffener as discussed in the design solution above. Alternatively, positive ventilation [an air scoop, vent, or drilled hole(s)] from the car interior will maintain a drier condition to slow the corrosion process. (Air from the car interior will not contain sufficient moisture for condensation.)

3. Skin Construction

a. Problem

The tongue-and-groove construction of extruded aluminum skins can retain moisture and dirt if the tongue and groove are incorrectly oriented. This condition can lead to exfoliation corrosion.

b. Design Solution

Aluminum skins with tongue-and-groove construction can be repaired easily by the simple replacement of panels. However, if the groove is correctly located above the tongue, the accumulation of moisture-retaining dirt can be prevented and panel replacement avoided (see Figure 24). The application of a sealant, such as MIL-S-81733, during assembly is essential.

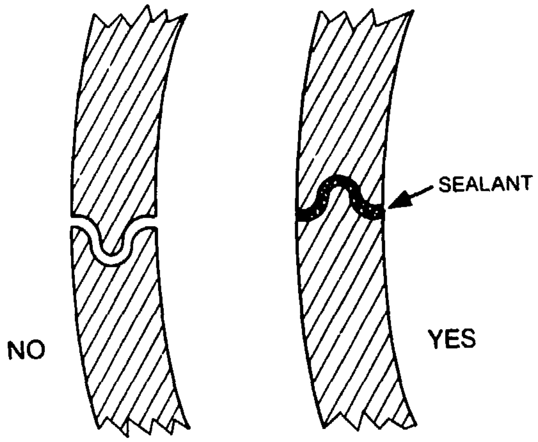


FIGURE 24 TONGUE-AND-GROOVE CONSTRUCTION OF ALUMINUM SKIN

c. Maintenance Solution

Washing and paint stripping of the cars may cause deterioration or dislodging of the sealant. Thus, the edge groove of the joint should be resealed with an elastomeric sealant (MIL-S-81733), as illustrated.

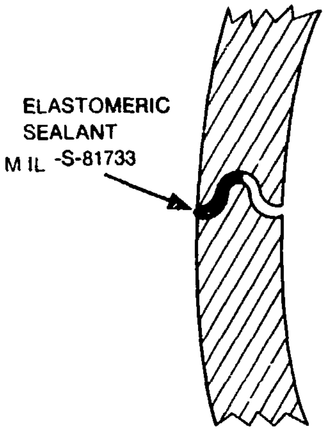
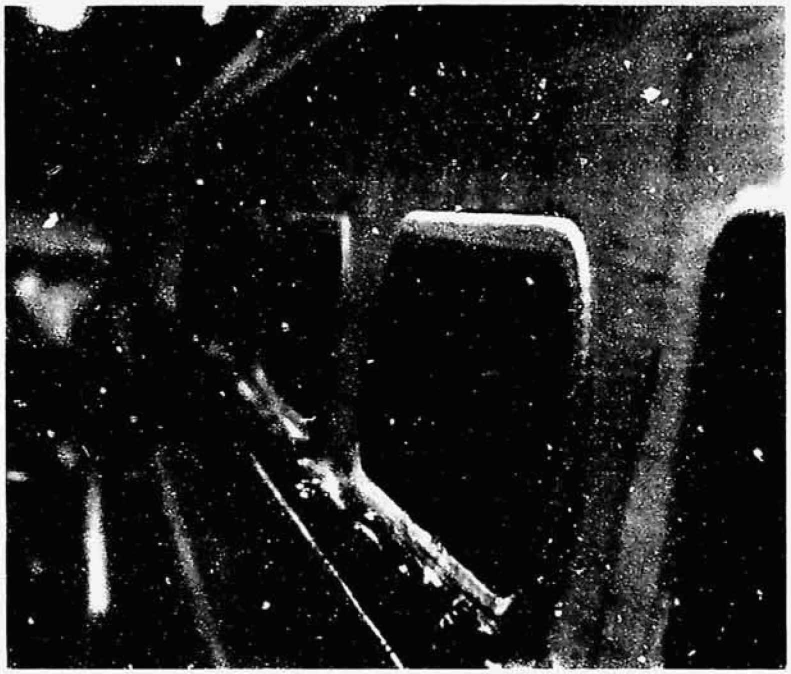


FIGURE 25 TONGUE-AND-GROOVE EDGE SEALING

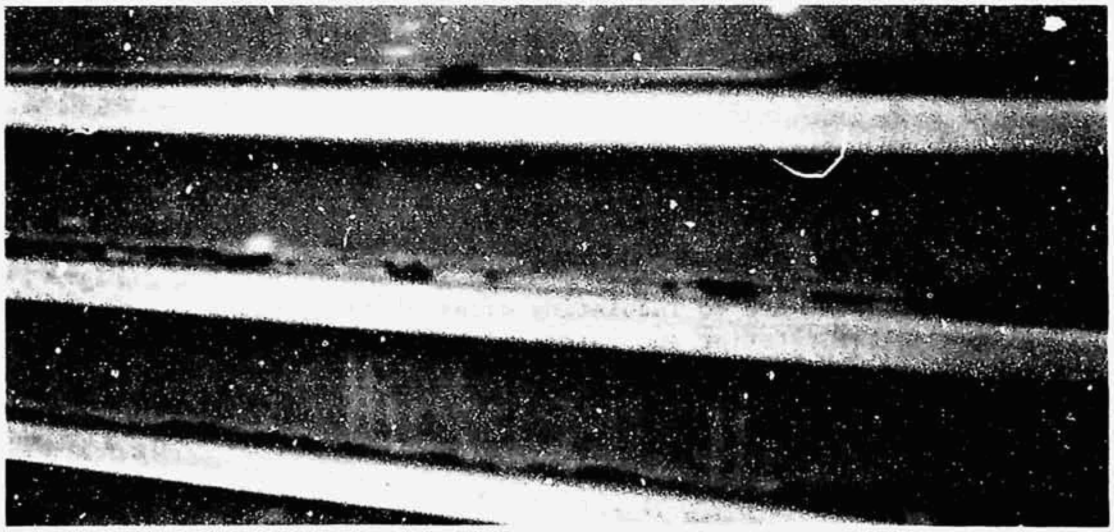
4. Gutters and Corrugations

a. Problem

When gutters are attached to the car body, moisture may collect at the juncture and seep between the paint and the metal. Moisture beneath the paint leads to tuberculation corrosion [Figure 26 (a)]. As with stiffeners, gutters and corrugations can retain dirt and debris that absorb moisture and invite poultice corrosion. Internal corners are particularly susceptible. The corrugation of Figure 26(b) illustrates this problem.



a. Tuberculation Corrosion of Gutters



b. Poultice Corrosion of Corrugations

FIGURE 26 CORROSION OF GUTTERS AND CORRUGATION

b. Design and Maintenance Solution

When gutter (or sill) is attached to the car body, it must be sealed to the body skin with an elastomeric sealant (MIL-S-81733) to prevent the forming of tuberculation corrosion beneath the paint. If the structural material is steel, the body skin and the sill or gutter should be protected. That is, a zinc-rich coating should be applied to both members. The applications should be made prior to the attachment, and the attachment should include MIL-S-81733 sealant applied to faying surfaces. (Details are provided in Appendix D.) To avoid poultice corrosion of gutters and corrugations, the design should feature liberal radii as shown in Figure 27.

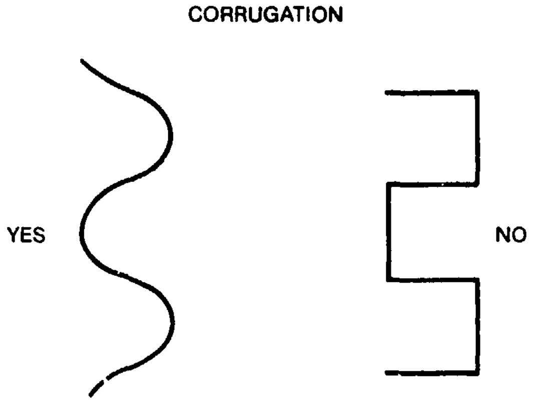


FIGURE 27 CORRUGATION DESIGN

5. Car Body Insulation

a. Problem

Many older car bodies have an insulating material of urethane foam or plymetal between the exterior and interior skins. These materials absorb and retain water, thereby causing the skins to corrode. [See Figure 28 (a) and (b)].

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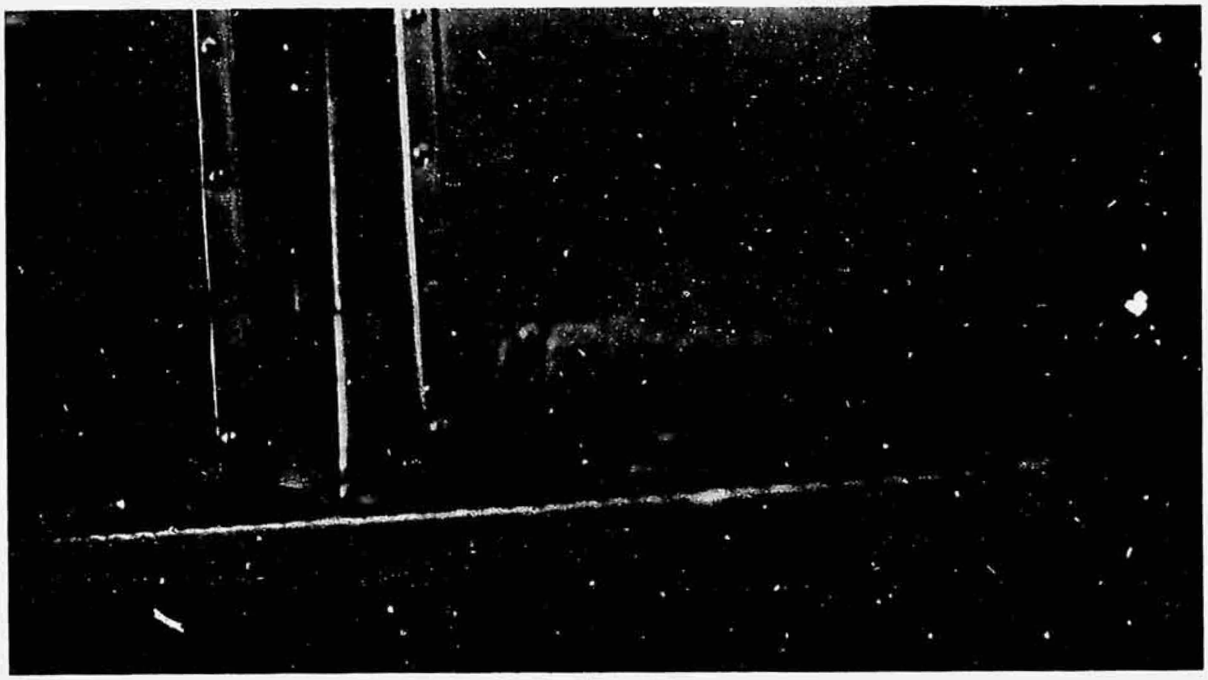
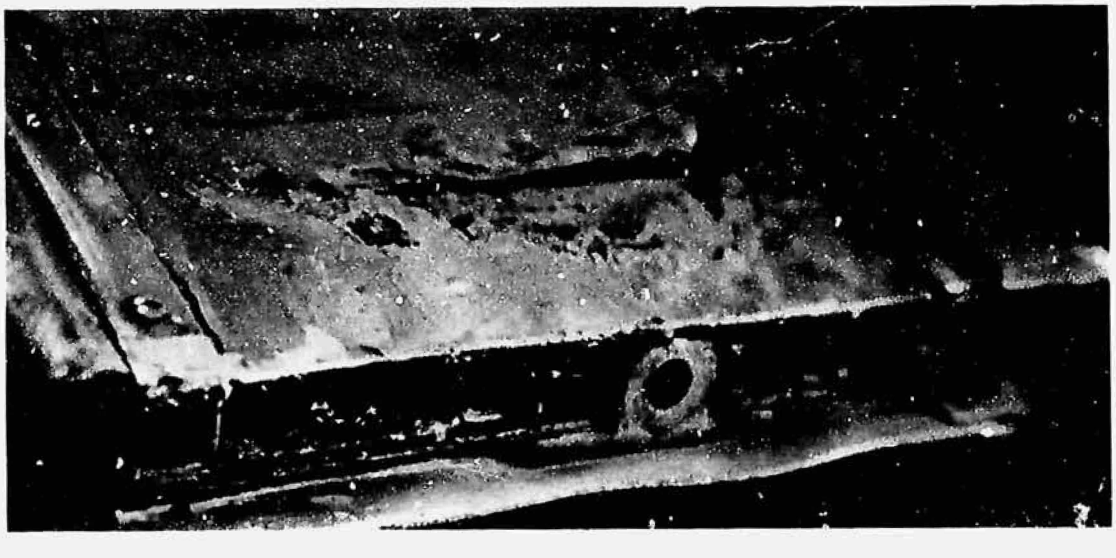


a. Exterior Door Panel Corrosion



b. Interior Door Panel Corrosion

FIGURE 28 CORROSION OF CAR BODY SKINS DUE TO THE RETENTION OF WATER BY INSULATING MATERIALS

b. Design and Maintenance Solution

All metal surfaces of a car body should be coated with an epoxy primer (MIL-P-23377 or KSC-C-0001) prior to the application of the foamed-in-place insulation to ensure adhesion of the foam to the metal surfaces. Water retention should be alleviated by drainage slots at the bottoms of doors and body sections.

Repairs to damaged skins can be made with a flush patch inserted into the skin after the corroded section has been cut out. When securing a flush patch to a damaged area, a sealant (MIL-S-81733) should be applied to both faying surfaces to exclude water and prevent a recurrence of the damage. All bolts, rivets, and threaded fasteners should be wet-set. That is, the fasteners should be dipped in sealant before insertion and immediately set in place before polymerization occurs. To prevent subsequent paint deterioration and moisture penetration of a flush patch, the interior edges should be filleted with a sealant.

6. Joints and Fasteners

a. Problem

The presence of an electrolyte (e.g., water) combined with a lack of oxygen beneath lap joints, rivets, bolts, and other fasteners often causes crevice corrosion between the faying surfaces. (See Figure 29.) Dissimilar metal corrosion can result from the use of a weld rod that contains silicon, copper, and other materials.

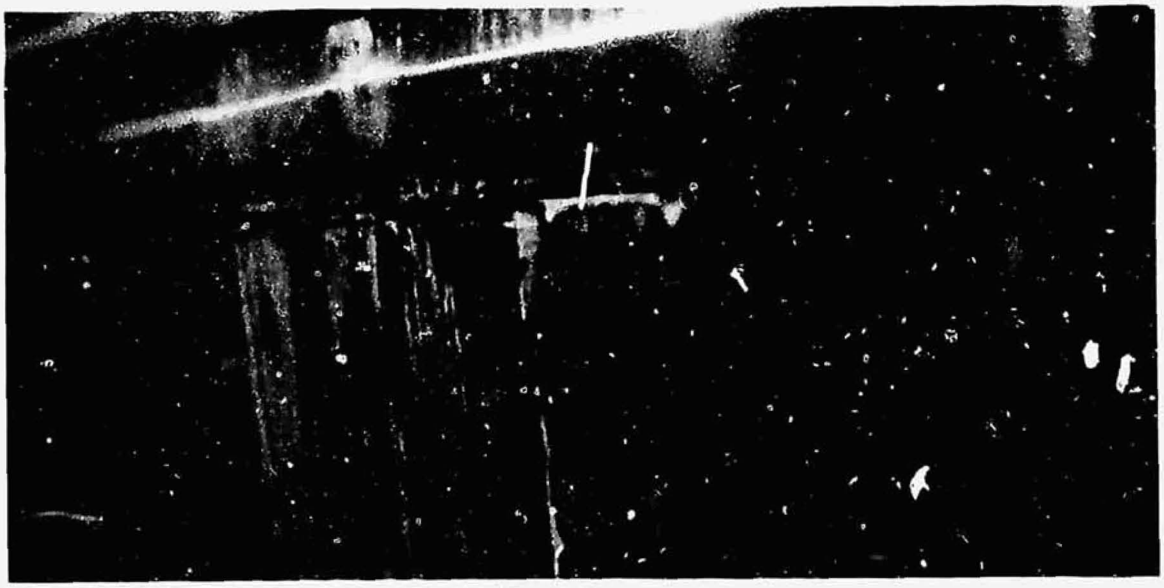


FIGURE 29 CREVICE CORROSION AT LAP JOINTS

When subjected to welding temperatures in the 850°F to 1,550°F range, stainless steels precipitate chromium carbides in the grain boundaries. The presence of these carbides can cause weld decay. The seriousness of the problem of joint and fastener corrosion is related to the loss of structural integrity that can ensue.

b. Design and Maintenance Solution

The problem of precipitated carbides in the grain boundaries can be eliminated if the more expensive low-carbon alloys are used (e.g., 304L, 321L, 347M). If the required weldments are small, the conventional stainless steel alloys may be used, provided that a re-solution heat is employed after welding. When spot-welding either aluminum or stainless steel, the process should include the application of a sealant to prevent crevice corrosion. Both faying surfaces should be oxidized with an acidic oxide stripping product; a sealant (such as MIL-S-81733) should be applied to the faying surfaces and spot-welds made while the sealant is still in a liquefied state.

To avoid corrosion due to water intrusion, all rivets and threaded fasteners should be dipped in a sealant (e.g., MIL-S-81733) before insertion and installed immediately before polymerization occurs. The surfaces to be joined should also be coated with a sealant and assembled immediately to prevent crevice corrosion. Excess sealant should be removed. (This technique is followed in the assembly of all aircraft structures.) To prevent crevice corrosion between stainless steel lap joints, all joints must be sealed with MIL-S-81733 as discussed above. The use of antisqueak compounds (e.g., burlap with tar-like coating) should be avoided. In time, water will permeate the compound and cause oxygen concentation cell corrosion with rust bleeding from between the lap joints.

To prevent dissimilar metal corrosion of welded body skin areas, the weld rod must be a compatible weld rod; that is, it must have essentially the same composition as the metal being welded. Weld decay on a stainless steel car will not be a problem if a low-carbon or stabilized stainless-steel alloy, such as 304L, 316L, 321L, or 347M [American Iron and Steel Institute (AISI) designations] is specified.

7. Windows

a. Problem

Condensation of moisture within dual- or triple-glazed windows can lead to crevice corrosion of the sills and staining of the windows by compounds leached from the rubber. Rubber seal strips around the panes not only permit the seepage of water between glazes, but also obstruct its escape. Sealed double-glazed windows may also be subject to moisture penetration if internal pressures break the seal.

b. Design Solution

To prevent condensation within window panes, a continual presence of dry air is required. Dry air can be provided by a device beneath the window that combines silica gel to absorb moisture and a rubber bladder to accommodate breathing. A small tube carries air to and from the window, as illustrated in Figure 30. The bladder and silica gel device is placed under the inner skin and requires no maintenance. To prevent discoloration of the window pane, the tubing should not be made of polyvinyl chloride (PVC) because the volatile plasticizer will sublime and condense on the glass.

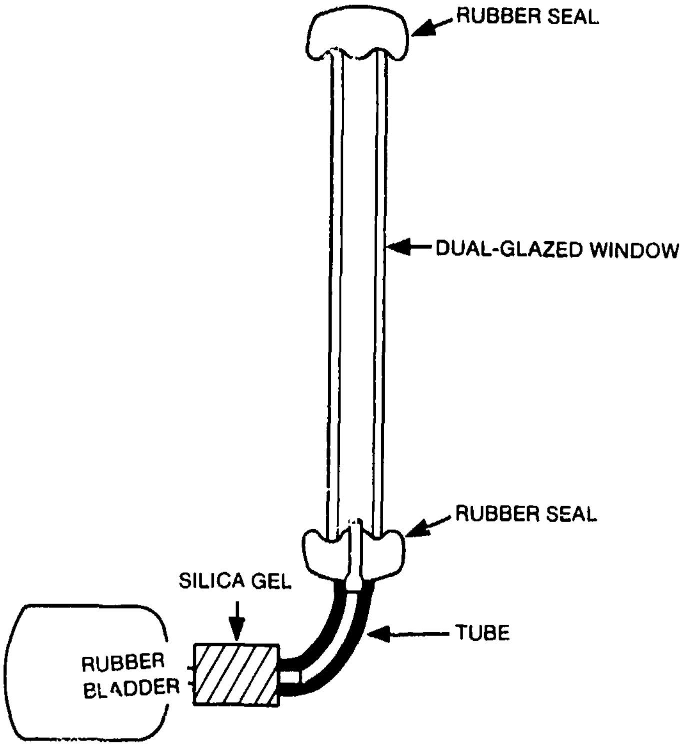


FIGURE 30 MOISTURE PREVENTIVE DEVICE FOR WINDOW

To ensure that the rubber seal strip provides maximum sealing capacity, it should contain an antiozonant to prevent ozone cracking, as designated in ASTM D-2000, C12 suffix (see Appendix D). Alternatively, an ozone-resistant rubber such as neoprene may be designated; however, the use of neoprene does not ensure freedom from cracking if the formulation contains large amounts of process oil or reclaimed rubber.

c. Maintenance Solution

If a bladder and silica gel device has been installed on windows without an ozone-resistant rubber seal strip, a topical application of antiozonant can be made. This method of treatment is specifically suited for vulcanizates that do not have an antiozonant incorporated in them at the time of manufacture or vulcanizates that are difficult to protect from ozone attack even with an antiozonant, such as oil-extended butadiene rubber (BR) or peroxide-cured styrene butadiene, nitrile butadiene rubber, or natural rubber (SBR, NBR or NR), incorporated at the time of manufacture. A list of commercially available antiozonants for elastomers is provided in Appendix D.

The recommended solution is 1:1 parts by volume of acetone and N,N'-dioctyl-p-phenylenediamine (MIL-D-50000), when staining is not a factor. The recommended method of application is brushing or dipping, not spraying. (If two coats of solution are applied, the time allowed between application of the first and second coats should be 4 hr. It takes 15 hr or overnight for items containing two coats of solution to dry completely.)

Even though the external method of protection does provide excellent ozone resistance to SBR, NBR, and NR vulcanizates, it is considered less satisfactory than incorporating an antiozonant into the rubber at the time of manufacture (where this is feasible) for the following reasons:

- Cost of application and hazards related thereto (toxicity, fire, etc.).
- Possibility of misuse of coating and missing of spots during application.
- Items will not be protected during the storage interval betwee procurement and application of the coating.

8. Doors

a. Problem

Plymetal doors in older cars are susceptible to moisture intrusion (see Figure 28 Section A.5. of this chapter). Plymetal is a lamination of two metal sheets (either aluminum or steel) on a plywood core. The metal is subject to severe oxygen concentration cell corrosion if the wood is moist. Moisture from rain and washings is drawn between the wood core and the metal surfaces by the wicking action of the wood. Rotting and swelling of the wood accelerate the corrosion problem.

b. Design and Maintenance Solution

The use of plymetal in doors is discouraged. However, for existing problems, two improvements may be made. The first consideration is the incorporation of a sealed metal cap to prevent moisture intrusion along the edges. The second consideration is the application of an inhibitive primer (MIL-P-23377) to the aluminum surface that is being bonded to the plywood. If moisture enters, corrosion will be minimized for a longer period of time. Eventually, delamination will occur, however, as a result of the susceptibility of the adhesive to deterioration from moisture intrusion. Future door structures should be weld-sealed.

9. Hinges

a. Problem

Much of the pitting on aluminum skins is caused by graphite-pigmented greases. Graphite behaves [illegible] metal. When placed in direct contact with another metal, graphite causes dissimilar metal corrosion. Door hinges may also exhibit general pitting corrosion.

b. Design and Maintenance Solution

When lubricative pigmentation is necessary, the use of a rust-inhibitive grease, such as MIL-G-10924 pigmented with inhibited molybdenum disulfide powder,* is recommended. In all cases, a lubricant that does not contain graphite should be used. Replacements for graphite lubricants are listed in Table 1.

General pitting corrosion of door hinges can be prevented through the use of solid lubricant (MIL-L-46010 and MIL-L-46147). Solid-film lubricants should be applied to both moving surfaces to increase wear life. (An added advantage is that the solid lubricant does not attract dirt as does the petroleum-based lubricant.)

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*For example, SPL-532, a product of Sandstrom Products Laboratory, Port Byron, IL.

Table 1

REPLACEMENTS FOR GRAPHITIC LUBRICANTS

Graphitic (corrosive) Lubricants	Usage	Noncorrosive Replacement
TT-A-580	Antiseize	MIL-L-25681
SS-G-659	Dry lubricant	MIL-M-7866
JAN-A-669	Antiseize	MIL-L-25681
VV-G-671	Dry lubricant	MIL-M-7866
MIL-A-907	Antiseize	MIL-L-25681
MIL-T-5544	Antiseize	MIL-L-25681
MIL-T-5544	General lubricant	MIL-L-21164*
MIL-G-13912	Antiseize	MIL-L-25681
MIL-L-3572	Silicon oil lubricant	MIL-L-25681**
MIL-G-6711 (Cancelled 4 Mar 71)	Dry lubricant	MIL-M-7866
MIL-G-7187 (Cancelled 12 Nov 65)	General lubricant	MIL-G-21164*
MIL-L-8937	Heat cure (solid film)	MIL-L-46010
MIL-L-23398	Air dry (solid film)	MIL-L-46147

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*For problems with noncompatibility of elastomers with this synthetic lubricant, use MIL-G-23549.

**Where use of a silicone oil-base lubricant is impractical, MIL-G-81322 also may be substituted for MIL-L-3572, except where use of an oil is mandatory (i.e., poor access, configuration, etc.).

10. Underbody Equipment

a. Electric Control Box--Seal

(1) Problem

Electric control boxes are sealed by means of gaskets or O-rings, (i.e., not hermetically sealed). Condensation can occur as a result of ozone cracking, compression set, and unfilled voids in the gaskets or O-rings. Unsealed boxes (i.e., boxes secured with set screws or latches) experience general environmental corrosion if not adequately protected. (See Figure 31.)

(2) Design and Maintenance Solution

To eliminate the effects of condensation in electric control boxes, a drain slot, a vapor corrosion inhibiting (VCI) material, or suitable breathing device must be incorporated into the system (see Section A.4 of Chapter III). VCI materials can prevent moisture condensation and subsequent corrosion of unsealed boxes. (A time-release vapor capsule is produced by the Eaton Corporation under the brand name Cutler-Hammer Oxidation Inhibitor.)

b. Electric Control Box--Printed Circuit Boards

(1) Problem

Printed circuit boards (PCBs) in control boxes will corrode. They will also short-circuit between the traces when condensation occurs.

(2) Design and Maintenance Solution

Protection should be provided the PCBs with an epoxy or urethane conformal coating. The conformal coating must cover the gold-plated connectors to prevent dissimilar metal corrosion, especially if the circuits consist of a lead-tin solder plate. (See Figure 9 in Chapter III.) Silver-plated contact connectors should be avoided if possible due to the silver's tendency to migrate across non-conductive materials and cause a shorting of the circuit.

The vertical placement of PCBs restricts the retention of moisture and of dust and dirt that become conductive in the presence of moisture. Vertical placement also permits conductive cooling of the boards.

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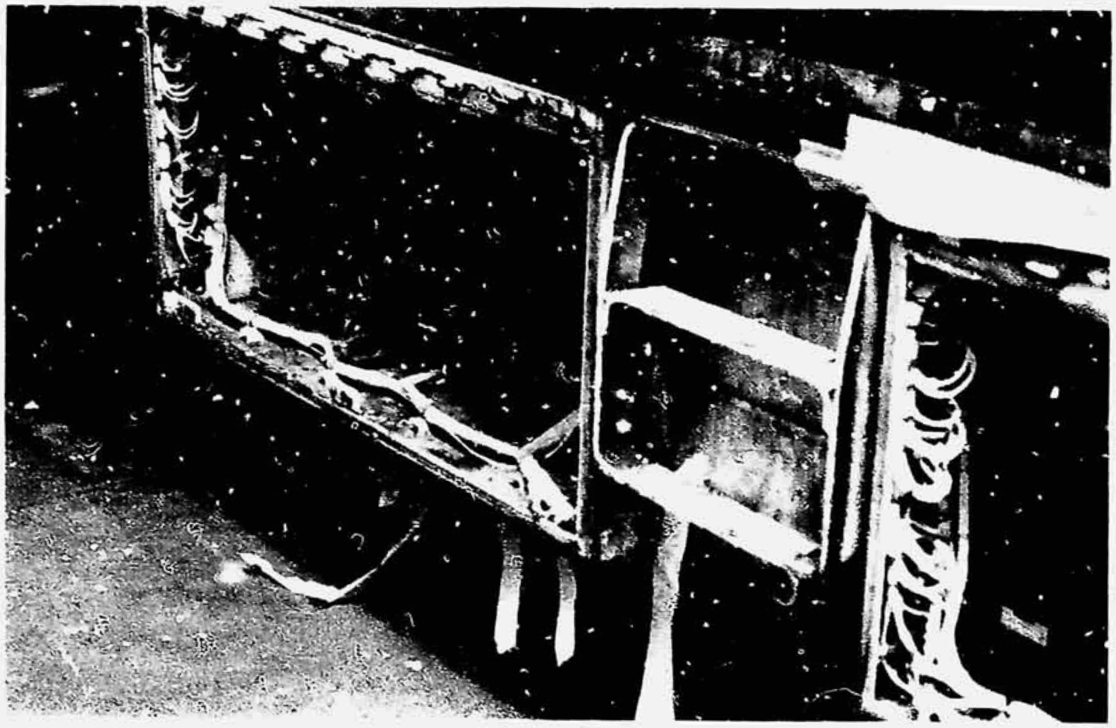
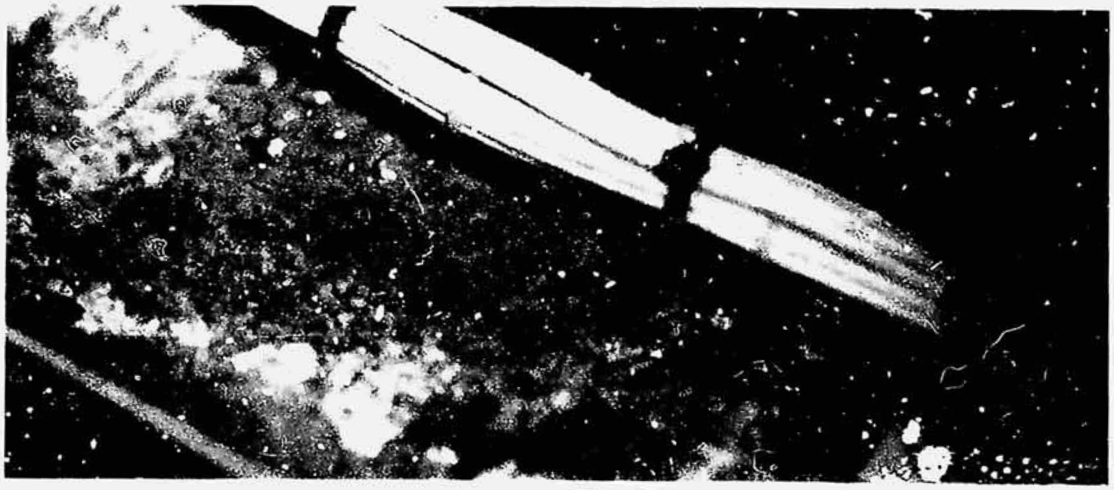


a. Corroded Electric Control Box



b. Undrained Bottom Panel of Electric Control Box

FIGURE 31 GENERAL CORROSION OF AN ELECTRIC CONTROL BOX

c. Electric Control Box--Insulation

(1) Problem

Over a period of time, polyvinyl chloride (PVC) insulation undergoes autocatalytic decomposition that results in the generation of toxic and corrosive vapors. These vapors consist primarily of hydrogen chloride that reacts with water to form hydrochloric acid. The hydrochloric acid attacks most metals used in electronic components. The resulting halogen pitting is especially prevalent on cadmium-plated aluminum connectors and aluminum chasses. Other materials that can generate corrosive vapors include acetic acid from room temperature vulcanizing (RTV) silicones, formic acid from the curing of alkyd paints, ammonia from uncured phenol-formaldehyde resins, and potassium chloride (humectant) from nylon coil bobbins.

(2) Design and Maintenance Solution

To prevent the formation of hydrochloric acid and the resulting halogen pitting, nonchlorinated insulation materials (e.g., Teflon^R and polyolefin) should be used. To prevent the generation of acetic acid vapors from RTV silicones, noncorrosive methanol-emitting sealing compounds should be used.

B. Body Interior

1. Floor

a. Problem

Plymetal is a combination of two metal sheets (either aluminum or steel) on a plywood core. The metal is subject to severe oxygen concentration cell corrosion if the wood is moist. Plymetal floors are susceptible to moisture intrusion. Moisture from rain and washings is drawn between the wood core and the metal surfaces by the wicking action of the wood. Rotting and swelling of the wood accelerates the corrosion problem. Floor sections become "spongy" and eventually perforate, causing a potential hazard to passengers.

If foam-backed carpet is placed in direct contact with a metal or plymetal floor (as seen in Figure 32), crevice corrosion may develop in the presence of water. That is, rainwater and washwater, which are retained by the carpet that covers the metal floor, become an electrolyte.

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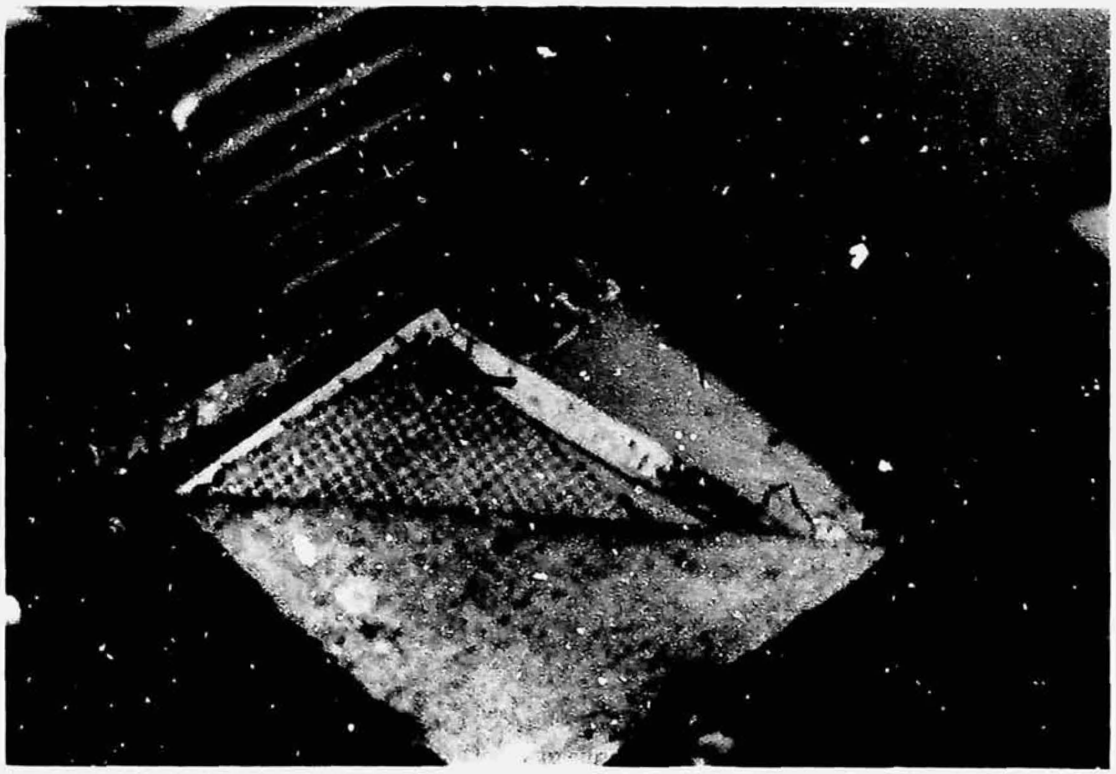

FIGURE 32 WATER RETENTION BY FOAM-BACKED CARPET ON A PLYMETAL FLOOR

b. Design and Maintenance Solution

Current plymetal structures need two design improvements. The first is the incorporation of a sealed metal cap (Figure 33) to prevent moisture intrusion along the edges. The cap should be of the same metal as the plymetal surface and should be attached with blind rivets, as illustrated. The cap should be sealed with MIL-S-81733. The second is the application of an inhibitive primer (MIL-P-23377 or KSC-C-0001) to the metal surface that is being bonded to the plywood.

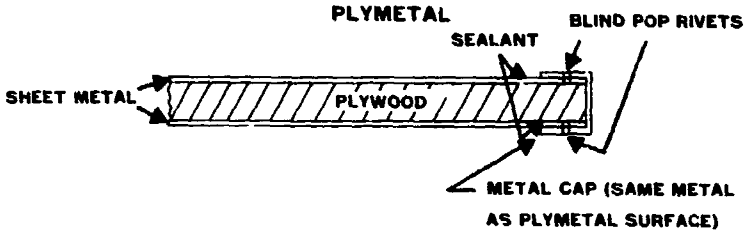

FIGURE 33 SEALED METAL CAPPING PROCEDURE

In future structures, consideration might be given to incorporating a tetracore structure to replace the plymetal. Tetracore is a monofilament-wound grating that is strong and lightweight and does not absorb moisture. (See Figure 20.) The paint-primed metal and the sealed capping procedure should also be used to prevent deterioration of the adhesive.

Rework of corroded plymetal structures must include inhibitive priming of the metal surfaces prior to rebonding. The edges of the plymetal structure must be capped with metal to prevent similar failures in the future, as illustrated in Figure 33.

Crevice corrosion of metal and plymetal floors beneath foam-backed carpet can be avoided by applying an alkali-resistant coating (e.g., an epoxy primer with a urethane top coat such as MIL-P-23377 and MIL-C-83286) to the metal surface. Alternatively, the metal may be coated with an organic zinc-rich primer (NASA Shelf Master, Appendix D). Fire-retardant synthetic fiber carpeting and vinyl tiles have a potential for producing corrosive and toxic vapors in the event of a fire. Therefore, the use of these materials for carpeting should be avoided. Instead, wool carpet and asbestos tiles are recommended.

2. Doorways

a. Problem

Door sills (also called threshold plates) collect dust, dirt, and debris. Poultice corrosion develops in the presence of moisture in these areas.

b. Design and Maintenance Solution

Door sills should be flush with the floor to prevent the collection of dirt and debris. Edges of the sills should be sealed with an elastomeric material (MIL-S-81733) to prevent the intrusion of water and to facilitate cleaning. The use of an elastomeric sealant, rather than a caulk, is advised to prevent the seal from dislodging as a result of vehicular vibration. If a smooth seal cannot be made, a strip of plastic (e.g, polyethylene, cellophane, or Mylar^R tape) may be placed over the seal until the seal polymerizes. A smooth seal is required to prevent a recurrence of the poultice corrosion. Welding of wear plates also provides protection against poultice and crevice corrosion; however, maintenance is more difficult because weld cutting is necessary for plate replacement.

3. Wiring

a. Problem

A hot-wire short in wiring that is insulated with polyvinyl chloride (PVC) can lead to corrosion and is also a fire hazard. PVC emits corrosive and toxic vapors at high temperatures. The vapors corrode all exposed metal, including the metal wire.

b. Design and Maintenance Solution

PVC should not be used to insulate wires. Instead, a high-temperature-resistant insulating material should be used. Materials such as Teflon^R, FEP^R (fluorinated ethylene propylene), Kynar^R (polyvinylidine fluoride), and Kapton^R (polyimide) should be used.

C. Truck

1. Car Couplers

a. Problem

Car couplers are subject to corrosion in the lubrication areas--that is, the contact surfaces of the moving parts. Routinely, these surfaces are lubricated with a graphite-pigmented grease. Because graphite behaves as a metal, dissimilar metal corrosion may occur when the graphite is placed in direct contact with the steel coupler.

b. Design and Maintenance Solution

To prevent car coupler corrosion and impact damage, the use of a solid-film lubricant (MIL-L-46010), a very durable high-temperature bake lubricant, or an air-dry lubricant (MIL-L-46147), is recommended. Although application of the solid-film lubricant to both moving surfaces is advised for optimal wear life, an application to one surface may be adequate.

2. Journal Bearings

a. Problem

Wear and corrosion on journal bearings result from heavy loads during use and the presence of graphite-containing lubricants. Because graphite is a metalloid (capable of acting as a metal) and is cathodic to all structural metals, it accelerates the rate at which the structural metals corrode.

b. Design and Maintenance Solution

The addition of an inhibitive dry lubricant powder (see Subsection A.9.b of this chapter) to a rust-preventative grease is the recommended alternative to the use of graphite on bearings. The formulation for the inhibitive powder is 50% molybdenum disulfide, 30% antimony trioxide, and 20% dibasic lead phosphite.

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Appendix A

TYPES OF CORROSION AND THEIR CAUSES

Appendix A

TYPES OF CORROSION AND THEIR CAUSES

The basic nature of electrochemical corrosion is the a flow of direct current from one metal surface (anode) to another (cathode) through a conductive solution (electrolyte). This flow destructively alters the metal at the anode. (The anode and cathode may be on the same piece or on two different pieces of metal that are electrically connected.) As may be seen in Figure A-1, the corrosion cell is similar to a battery. The electrolyte consists basically of hydrogen (H^+) and hydroxyl [$(OH)^-$] ions. Metal particles (positively charged ions) at the anode dissolve into the electrolyte and leave the negatively charged electrons behind on the surface of the anode. The electrons flow or migrate through the return circuit to the cathode. Because the electrolyte must remain electrically neutral, some positive ions must be displaced to adjust for the positive ions that have been added at the anode. (The flow of electrons is also necessary to complete the electrochemical process, but this flow remains within the metal.)

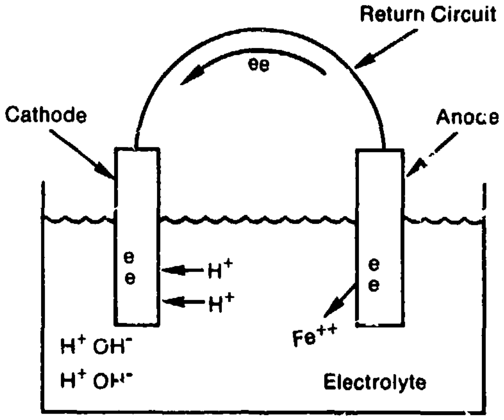


FIGURE A-1 BASIC CORROSION CELL

Electrocorrosion is caused by the migration of ions (metal particles) into the electrolyte at the anode and from the electrolyte at the cathode. Since the anode and cathode are connected by the return circuit, a so-called flow of current continues back to the anode. In Figure A-2, this process is shown as it occurs on a pipeline. When the metal is steel, ferrous ions migrate into the electrolyte at the anode, carrying two positive charges. Rust forms when the ferrous ions react with the hydroxyl ions of water to form ferrous hydroxide.

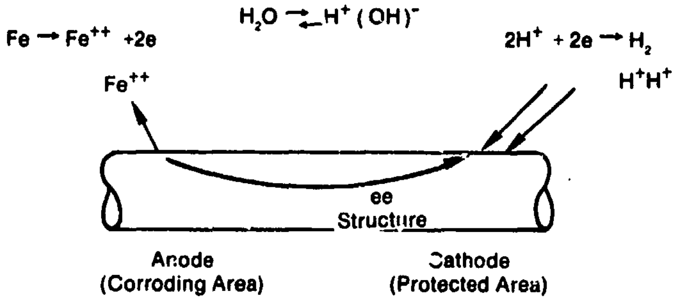


FIGURE A-2 ION AND ELECTRON FLOW IN CORROSION

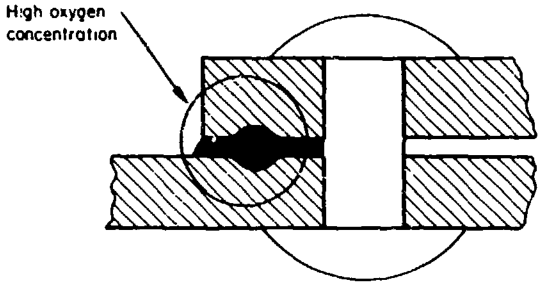
Although basically the same in nature, there are many types of corrosion. During their survey of the transit properties, the authors of this manual uncovered nine types of corrosion. On the following pages, these types of corrosion are described. The most prevalent type on transit structures and cars--oxygen concentration cell corrosion--heads the list, followed by dissimilar metals or galvanic corrosion, stray currents corrosion--which has the greatest impact on other structures, stress corrosion cracking, fatigue corrosion, pitting corrosion, uniform etch, fretting corrosion, and weld decay.

1. Oxygen Concentration Cell Corrosion

Oxygen concentration cells are present in crevices, adherent deposits, deep recesses, and at water lines--areas wherein the diffusion of oxygen is hindered and thus sets up differences in solution concentration of dissolved oxygen. These low-oxygen areas are anodic and are prone to corrosion.
The four primary oxygen concentration cell corrosions are crevice corrosion, poultice corrosion, filiform corrosion, and tuberculation corrosion. Each of these is described below.

a. Crevice Corrosion

Crevice corrosion is produced in the region of contact beteween two metals or between a metal and other nonmetallic materials where capillary action can draw moisture into the crevice between faying surfaces. It may be found under fasteners and ball bearings, at joints, and between laminates. Even when free of pitting nuclei, stainless steel is susceptible to crevice corrosion because a nucleus is not necessary. (See Figure A-3.)

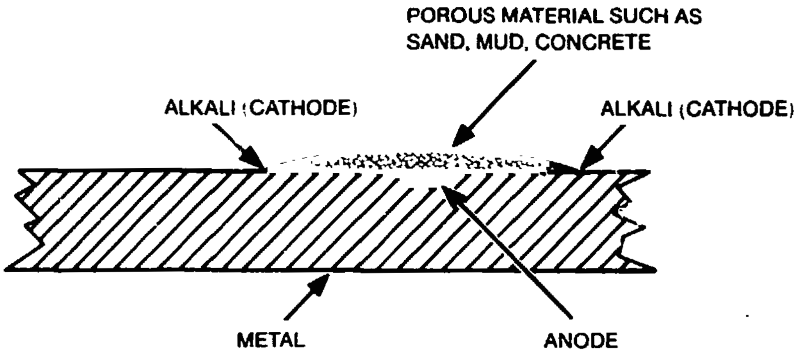


Source: Pludek, V. Roger, Design and Corrosion Control, printed in Great Britain by Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, 1977.

FIGURE A-3 CREVICE CORROSION

b. Poultice Corrosion

Like crevice corrosion, poultice corrosion is produced by moisture wicking between two metals or between a metal and other nonmetallic materials. However, one of the metallic or nonmetallic materials must be porous. Examples are sand, paper (including wastepaper), metallic dust, and mud that may form a poultice when laden with moisture. In time, the poultice becomes a crusty mass as the alkali produces a cement. (See Figure A-4.)



Source: Pludek, V. Roger, <u>Design and Corrosion Control</u>, printed in Great Britain by Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, 1977.

FIGURE A-4 POULTRICE CORROSION

c. <u>Filiform Corrosion</u>

Filiform corrosion occurs on painted or plated metals. A radial worm-like corrosion path emanates from a central core of corrosion under the paint or plating. The cause is poor adhesion that permits moisture permeation. (See Figure A-5.)

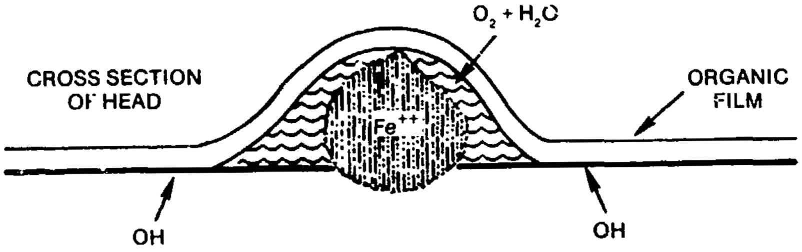


FIGURE A-5 FILIFORM CORROSION

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d. Tuberculation

Tuberculation corrosion forms as a scattered corrosion product over an entire metal surface. Its knot-like mounds enable easy identification. (See Figure A-6.)

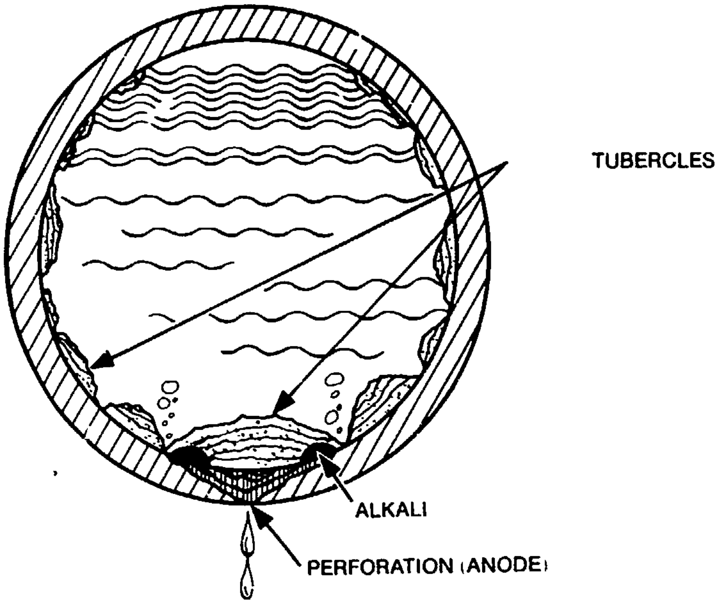

FIGURE A-6 TUBERCULATION CORROSION

2. Dissimilar Metals or Galvanic Corrosion

Galvanic corrosion is produced by the electrochemical action of two dissimilar metals, in direct contact, in the presence of an electrolyte and a conductive path. That is, a current is generated and one metal becomes the anode and the other the cathode. (See Figure A-7.) Table A-1 presents the galvanic series of metals and alloys. The most anodic metal (magnesium) leads the list and is followed by metals that are increasingly less anodic. The farther apart the metals are in the table, the greater will be the galvanic tendency as can be seen by measuring the electrical potential difference.

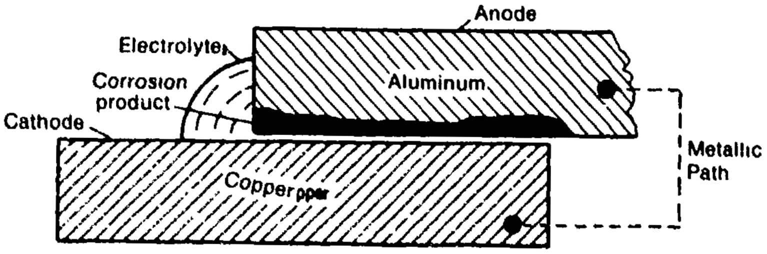

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FIGURE A-7 GALVANIC CORROSION

Table A-1

GALVANIC SERIES OF METALS AND ALLOYS IN SEA WATER

Anodic
  Magnesium
  Zinc
  Beryllium
  Aluminum alloys
  Mild steel, cast iron
  Low alloy steel
  Austenitic nickel cast iron
  Aluminum bronze
  Naval brass, yellow brass, red brass
  Tin
  Copper
  Pb-Sn solder (50/50)
  Admiralty brass, aluminum brass
  Manganese bronze
  Silicon bronze
  Tin bronze (G & M)
  Stainless steel--Types 410, 416*
  Nickel silver
  90-10 copper-nickel
  80-20 copper-nickel
  Stainless steel--Type 430*
  Lead
  70/30 copper nickel
  Nickel-aluminum bronze
  Nickel-chromium alloy 600*
  Silver braze alloys
  Nickel 200
  Silver
  Stainless steel--Types 302, 304, 321, 347*
  Nickel-copper alloys 400, K-500
  Stainless steel--Types 316, 317*
  Alloy "20" stainless steels, cast and wrought
  Nickel-iron-chromium alloy 825
  Ni-Cr-Mo-Cu-Si alloy B
Cathodic
  Titanium
  Ni-Cr-Mo alloy C
  Platinum
  Graphite

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*Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys in low-velocity or poorly aerated water, and at shielded areas, may become active.

Source: Reprinted courtesy of the International Nickel Company, Inc.

3. Stray Current Corrosion

Stray current or electrolytic corrosion results when uncontrolled electrical currents [primarily direct current (dc)] from an external source follow unintended paths. That is, the currents stray or leak from the intended structural path and are picked up and carried by another structure. Corrosion occurs at the point where the stray currents are discharged from the other structure. (See Figure A-8.)

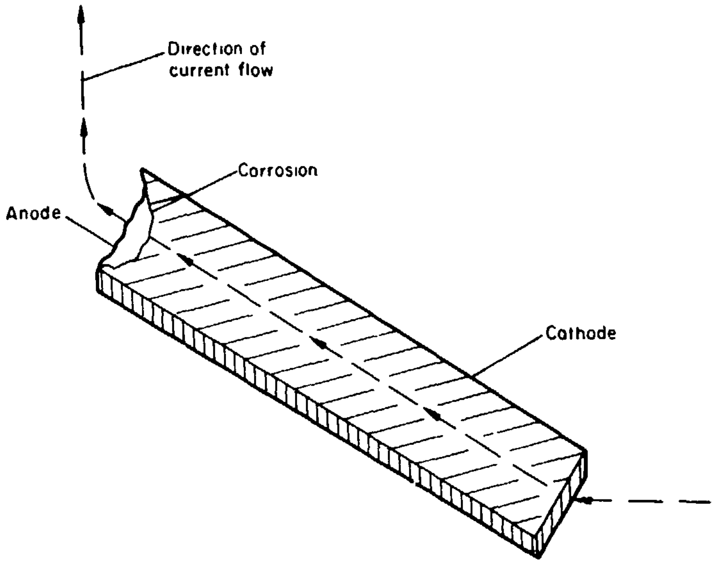

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FIGURE A-8 STRAY CURRENT CORROSION

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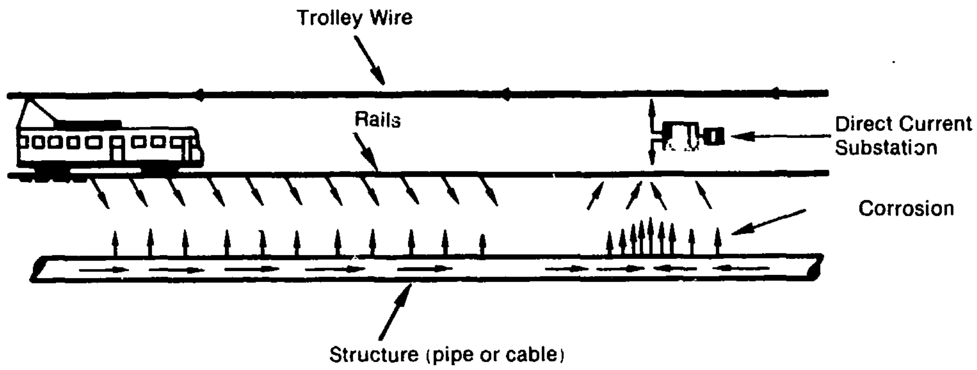
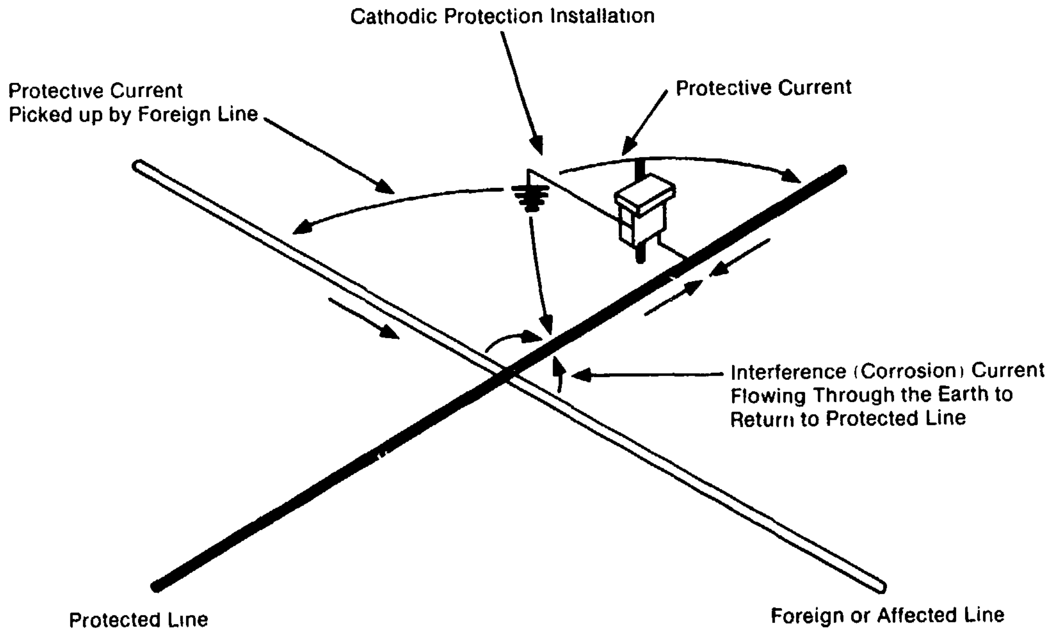
Stray current corrosion may be found in two forms: dynamic and static. As the name implies, dynamic or fluctuating current corrosion occurs in locations where the current varies over a period of time (e.g., railroads, rapid transit systems, welding shops, and mines). Static, or steady-state, stray currents are commonly found around impressed current cathodic protection systems or high voltage dc transmission lines when some or all of the current flows in the earth. Illustrations of the two stray current types are provided in Figure A-9.



a. Dynamic Stray Current Corrosion



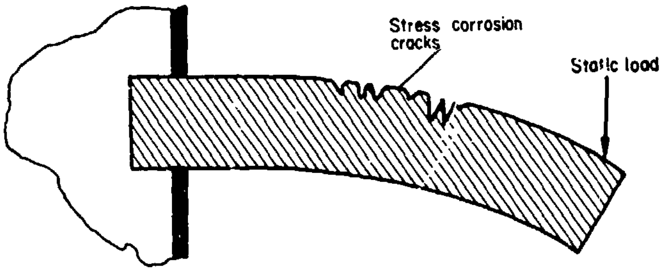
b. Static Stray Current Corrosion

FIGURE A-9 TWO TYPES OF STRAY CURRENT CORROSION

Alternating current (ac) also can cause corrosion of some metals, specifically lead, aluminum, and copper. Oxide films can form on the surfaces of these metals and cause the ac to be rectified to dc. When ac is superimposed on a galvanic corrosion cell, the rate of corrosion may increase.

4. Stress Corrosion Cracking

Stress corrosion cracking results when tensile stress is combined with surface corrosion. Stress may be internally applied (e.g., non-uniform deformation during cold-working or variations in the cool-down from high temperatures) or externally applied (e.g., press or shrink fits). The magnitude of the stresses varies from point to point within the metal. Usually, only those stresses that exceed the metal's yield strength will cause stress corrosion cracking. (See Figure A-10.)

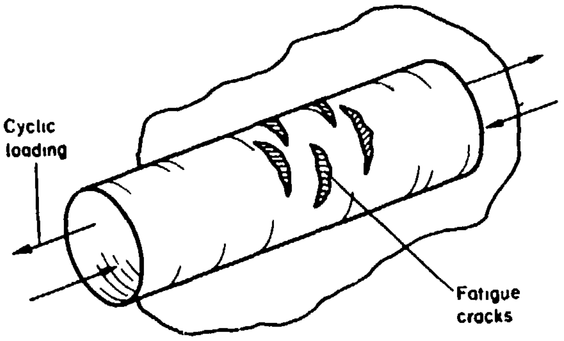


Source: Pludek, V. Roger, Design and Corrosion Control, printed in Great Britain by Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, 1977.

FIGURE A-10 STRESS CORROSION CRACKING

5. Corrosion Fatigue

Similar to stress corrosion cracking, corrosion fatigue is attributed to stress cracks in the presence of a corrosive environment. Unlike stress corrosion cracking, which is related to static loads (tensile stress), corrosion fatigue relates to dynamic or cyclic loads, particularly alternating ones (Figure A-11). In the absence of a corrosive environment, the metal will not crack even after an infinite number of cycles provided that its endurance limit (i.e., critical stress value) is not exceeded. In a corrosive environment, however, the metal will, in time, fail no matter how low the stresses. Environments that lead to stress corrosion fatigue differ with different metals, as indicated in Table A-2.



Source: Pludek, V. Roger, Design and Corrosion Control, printed in Great Britain by Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, 1977.

FIGURE A-11 CORROSION FATIGUE

Table A-2

ENVIRONMENTS CAUSING STRESS CORROSION

Material	Environment
Aluminum	Water and steam; NaCl, including sea atmospheres and waters; air, water vapor
Copper	Tropical atmospheres; mercury; $HgNO_3$; bromides; ammonia; ammoniated organics
Aluminum bronzes	Water and steam; H_2SO_4; caustics
Austenitic stainless steels	Chlorides, including $FeCl_3$, NaCl; sea environments; H_2SO_4; fluorides; condensing steam from chloride waters
Ferritic stainless steels	Chlorides, including NaCl; fluorides; bromides; iodides; caustics; nitrates; water; steam
Carbon and low-alloy steels	HCl; caustics; nitrates; HNO_3; HCN; molten zinc and Na-Pb alloys; H_2S; H_2SO_4-H_2NO_3; H_2SO_4; sea water
High-strength alloy steels (yield strength 200,000 psi plus)	Sea and industrial environments
Magnesium	NaCl, including sea environments; water and steam; caustics; N_2O_4; rural and coastal atmosphere; distilled water

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Table A-2 (concluded)

Material	Environment
Lead	Lead acetate solutions
Nickel	Bromides; caustics; H_2SO_4
Monel	Fused caustic soda; hydrochloric and hydrofluoric acids
Inconel	Caustic soda solutions; high purity water with few ppm oxygen
Titanium	Sea environments; mercury; molten cadmium; silver and AgCl; methanols with halides; fuming red HNO_3; N_2O_4; chlorinated or fluorinated hydrocarbons

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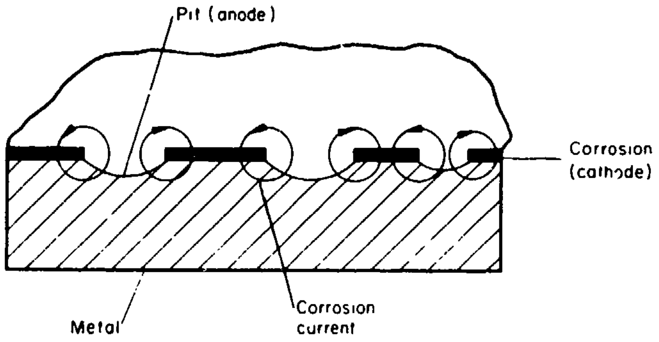
Source: Pludek, V. Roger, Design and Corrosion Control, printed in Great Britain by Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, 1977.

6. Pitting Corrosion

Pitting is the most common form of corrosion on aluminum and magnesium alloys. When protective films break down, pitting occurs. Pitting corrosion appears first as a white or gray powdery deposit. Beneath this deposit, tiny pits are forming. The seriousness of the pitting corrosion problem relates to the rapid rate of penetration into the metal due to the smallness of the anode. Each pit acts as a small anode, with the surface film becoming a large cathode, as shown in Figure A-12.

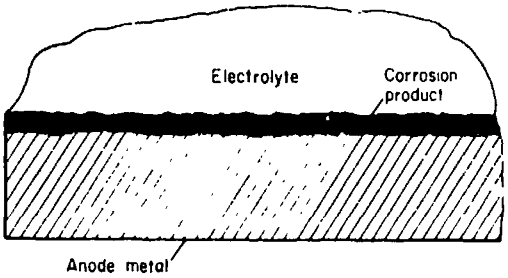


Source: **Pludek, V. Roger, Design and Corrosion Control, printed in Great Britain by Unwin Brothers Limited, The Gresham Press. Old Woking, Surrey, 1977.**

FIGURE A-12 PITTING CORROSION

7. Uniform Etch Corrosion

With uniform etch corrosion, no distinguishable area of the metal surface is wholly anodic or cathodic. (See Figure A-13.) The anode and the cathode are indistinguishable. This corrosion appears as an overall disintegration of the metal. Examples include high-temperature oxidation, tarnishing, and the general rusting of metals. The initial rate of attack is usually far greater than the final rate because the corrosion product tends to form a protective layer. For this reason, the exposure time should always be given when corrosion rates (milligrams per square decimeter per day) are reported.

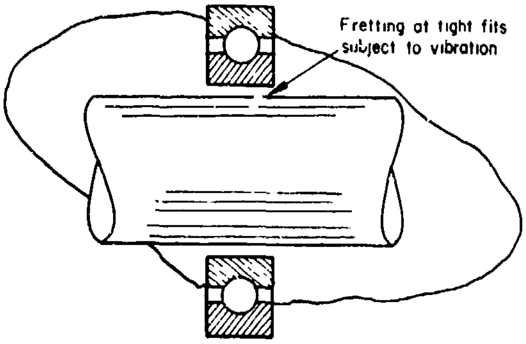


Source: Pludek, V. Roger, Design and Corrosion Control, printed in Great Britain by Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, 1977.

FIGURE A-13 UNIFORM CORROSION (GENERAL CORROSION)

8. Fretting Corrosion

The rapid corrosion that occurs at the interface between tightly fitted metal surfaces under slight vibratory conditions is known as fretting corrosion. It is most common on load-bearing surfaces of machinery (e.g., connecting rods, shafts, and supports) but is also found on structural supports where relative motion occurs between members. As its name implies, fretting corrosion appears as a set or series of ridges. (See Figure A-14.)



Source: Pludek, V. Roger, Design and Corrosion Control, printed in Great Britain by Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, 1977.

FIGURE A-14 FRETTING CORROSION

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9. Knifeline Corrosion and Weld Decay

Weld decay and knifeline attack in mild and stainless steels are closely related in a heat-affected zone on either side of a weld; the temperature induces the formation of chromium carbide precipitates, thus removing chromium and preventing it from functioning as a corrosion-resistant alloying element. (See Figure A-15.) Stabilized austenitic stainless steels may also be attacked in a "knifeline" close to the weld. Stabilization by addition of columbium occurs when columbium carbides instead of chromium carbides form, thus leaving chromium in solution to serve its intended purpose. Knifeline attack occurs when postweld heating (to the range 950°F to 1,400°F) is enough to precipitate chromium carbide but insufficient to obtain preferential formation of columbium carbide from dissolved columbium and carbon.

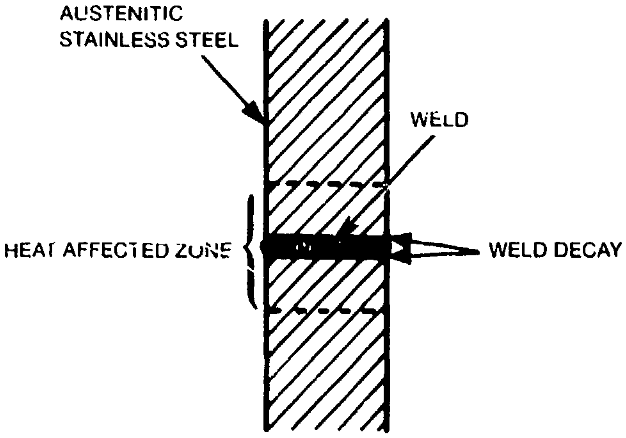
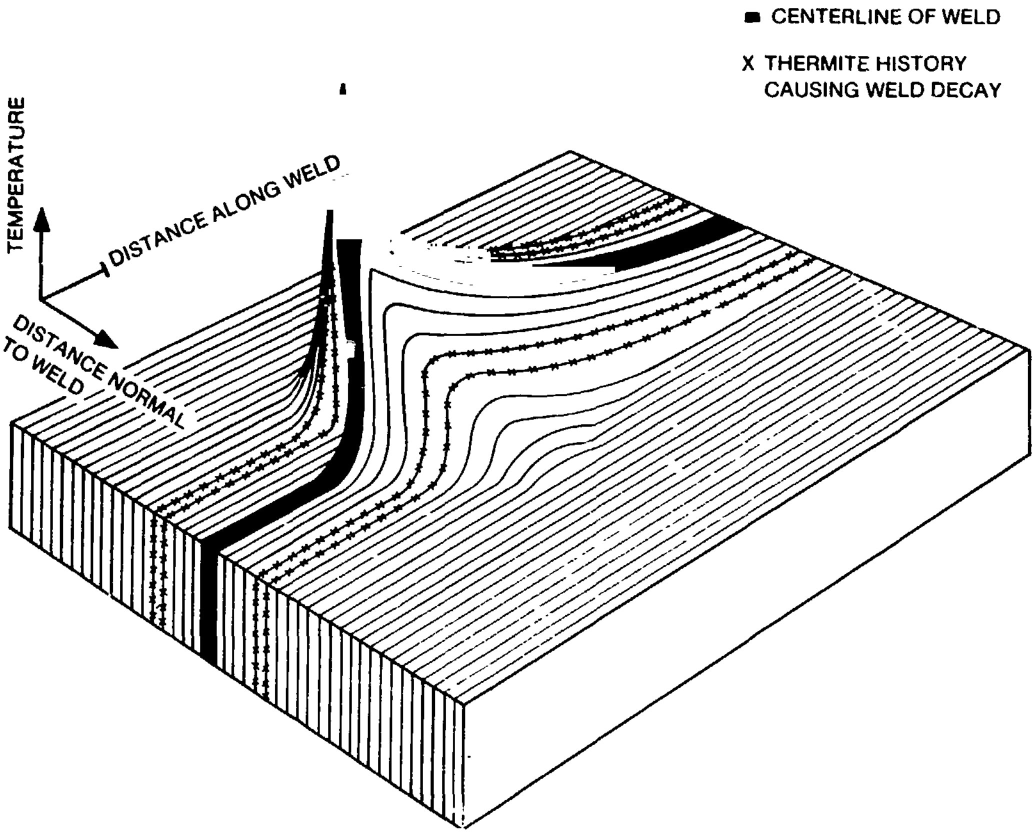


FIGURE A-15 KNIFELINE CORROSION

Figure A-16 shows how the temperature on either side of the weld pass may increase to a range where dissolved chromium is depleted by the formation of carbide precipitates. Weld decay occurs at the chromium depleted region that behaves as a narrow anode in contact with a large cathode surface.



Source: Fontana, Mars, G., The Ohio State University, Columbus, Ohio.

FIGURE A-16 ANALOGY OF HEAT FLOW AND TEMPERATURES DURING WELDING

Appendix B

GENERAL DESCRIPTIONS OF SELECTED RAPID TRANSIT PROPERTIES

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CHICAGO TRANSIT AUTHORITY

The Chicago Transit Authority (CTA) rapid transit system serves a population of 3,694,500 in the city of Chicago and 38 surrounding suburbs. The 6 routes consist of 192 mi of track: 20 mi in subway, 11 mi at grade (with street crossings), 84 mi of elevated structure, 32 mi on elevated embankment, 2 mi of below-grade open cut, and 43 mi on expressway median. The system is accessed by means of 140 stations.

Plans for expansion of the system include an 8-mi extension linking O'Hare Airport with the downtown area. This two-track line, which should be operable by late 1982, is located in the median strips of an expressway and the airport access road and includes a 3,500-ft tunnel.

The 600 V of direct current are converted from 1200 V of alternating current. The traction power is ungrounded. Substations are located at about 2-mi intervals, with crossbonds at 1,000-ft intervals.

The CTA has a fleet of 1,100 rapid transit cars. Some of the cars are aluminum, and some (the newer ones) are stainless steel. Delivery of an additional 300 new cars is expected by 1984.

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GREATER CLEVELAND REGIONAL TRANSIT AUTHORITY

The Greater Cleveland Regional Transit Authority (GCRTA) became operational in 1975 in order to combine the bus network and rail line of the Cleveland Transit System with the light rail lines of the city of Shaker Heights. The GCRTA's high-platform or heavy-rail rapid line consists of a single route that extends 20 miles, 13.2 mi of which are light rail. The double-track system generally parallels railroad rights-of-way and thus bypasses most of the heavier population centers. The system has 6 mi of light rail grade-separated track located in a median strip. An 0.7-mi subway section was constructed by the cut-and-cover method.

The liners of the tunnel in the subway sections are concrete. There are no elevated sections per se. Raised embankments are interspersed throughout the at-grade sections.

The system has no third rail. The 600 V of direct current are contained in an overhead catenary.

The system has 85 steel cars and 30 stainless-steel cars. Each car has four 100-hp motors.

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

The Massachusetts Bay Transportation Authority (MBTA) manages a rapid transit system consisting of approximately 94 mi of track connecting 78 stations in the Boston area. The system has 18.6 mi of subway track; 75 mi are elevated or at ground level. One section of the elevated system is currently being replaced by an at-grade track; construction of this section should be completed by 1985. The system serves a population of about 2,800,000. The traction power system is grounded on the old system and ungrounded on the new extensions. The nominal traction power is 600 V of direct current.

The MBTA operates 358 rapid transit cars, of which 130 are light rail. Weathering steel and aluminum have been used extensively for car bodies.

MASS TRANSIT ADMINISTRATION OF MARYLAND

The Mass Transit Administration (MTA) of the Maryland Department of Transportation is building the Baltimore Region Rapid Transit System. The 13.6-mi Baltimore Metro will service a dense public transportation corridor from the center of the city to the northwest suburbs of the county. An estimated 100,000 people within a 150 sq mi area will be served. As of the end of 1981, construction was 87% complete for the city portion (7.5 mi), and design was 70% complete for the county portion (6.1 mi). The system will have 4.2 mi of subway tunnels, 6.4 mi of track at grade, and 3.0 mi of elevated structure. There will be 12 substations.

The parallel tunnel portions include cut-and-cover areas, as well as shield-driven tunnel areas. Steel bracing beams and a concrete box form the frame of the subway.

The traction power system is ungrounded. Negative power is returned through continuously welded running rails, with crossbonds at 2,000-ft intervals.

Cars will operate on 650 V (full load) of direct current power, and regenerative brakes will feed energy back into the third rail. The system's 100 cars will be unpainted, corrugated stainless steel with fiber glass front ends.

METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY

The Metropolitan Atlanta Rapid Transit Authority (MARTA) system is designed to serve the city's approximately 1,700,000 people. A referendum in 1971 approved construction of a 53-mi system within the city of Atlanta, Fulton County, and DeKalb County; other counties have the option to join MARTA in the future. The system will provide service to a number of incorporated communities within the metropolitan area and to the Atlanta airport. The first section of the system--7 mi in length --opened in mid-1979. The entire MARTA system is scheduled for completion by the end of this decade.

As of the end of 1981, construction of 4.5 mi of subway, 5.6 mi of at-grade track, and 3.6 mi of elevated structure had been completed. About one-half the 38 stations planned had been completed or were nearing completion.

To route the system through downtown Atlanta and Decatur, deep-rock tunnel construction is required. In soft-ground tunnel sections, rigid steel liners are being used (in the subdrain system) to minimize siltation.

Running rail is installed in continuously welded 1/4 mi sections. The 750-V (direct current) contact rail is also continuously welded, but in shorter sections. The traction power system is ungrounded.

The MARTA system's 120 cars are fabricated from machine-welded aluminum extrusions. Each car is powered by four separate motors in parallel single-reduction gearing. The motors are regulated through a regenerative thyristor chopper control.

METROPOLITAN DADE COUNTY OFFICE OF TRANSPORTATION ADMINISTRATION

The Metropolitan Dade County Office of Transportation Administration (OTA) began construction on Miami's Stage 1 Metrorail transit line in mid-1979 to serve the county's approximately 1,700,000 inhabitants within a 2,460 square mile area. The 22-mi, 20 station line is expected to open in 1984 . A portion of the Stage 2 Metrorail alignment is located on a 9.5-mi right-of-way purchased from the Florida East Coast Railway; the remainder of the system follows existing streets. Most of the line, with the exception of two short at-grade sections totaling 1.5 mi, is being constructed on an aerial guideway. The high water table made subway construction infeasible.

Double-T girders of pretensioned, precast concrete are being used for spans of 40-80 ft. For spans as long as 110 ft, prestressed, precast concrete box girder sections are being used. The track will be continuously welded. For tangent track or long radius curves, a standard control-cooled carbon-steel rail will be used; however, a high-performance chromium alloy rail has been selected for high-rate braking points.

The 700-V direct current power supply will entail a composite third rail. Traction will be supplied from 18 transformer-rectifier substations. The traction power system is ungrounded.

The system will have a total of 136 cars. Car bodies will be constructed of stainless steel in a flat-sided design.

NEW YORK CITY TRANSIT AUTHORITY

New York's transit system, operated by the New York City Transit Authority (NYCTA), began service in 1904. The newest completed section was constructed in the late 1920s and the early 1930s. However, construction began again in the late 1970s. The system's 830 mi of subway track, 415 mi of at-grade track, and 415 mi of elevated structure are served by 750 stations. NYCTA operates within four boroughs and is used by 3.5 million passengers per day. (The extended system will increase these numbers.)

Because of the characteristics of the area, both rock and soft ground tunnels have been built. The system contains the first concrete segmental tunnel to be constructed on any U.S. rapid transit system. Many of the street tunnels are cast iron or steel tubes, either shield-driven or encased in concrete.

The third rail provides 600 V of direct current. The traction power system is ungrounded. NYCTA uses a variety of techniques to control negative power return. On some sections, the running rails are used--most often a single track circuit; however, in certain places, double rail track circuits return the negative power.

There are 6300 cars, of which about 4740 are operational at one time. The newest cars operate on an air-spring suspension system rather than steel coil springs. Each car has four 100- or 115-hp motors.

PORT AUTHORITY TRANS-HUDSON CORPORATION

The Port Authority Trans-Hudson Corporation (PATH) line serves the New York-New Jersey metropolitan area with an approximate population of [illegible] million people. Daily ridership on the system is about 170,000 persons, most of which is represented by the New Jersey community of commuters.

PATH has 15 mi of subway track and 12.8 mi of at-grade track. There are 13 stations. PATH has 201 cars.

The traction power system is ungrounded. The nominal traction power voltage is 600 V of direct current.

PORT AUTHORITY TRANSIT CORPORATION

The Port Authority Transit Corporation (PATCO) line runs from the suburban community of Lindenwold, New Jersey to the center of Philadelphia. Population density varies along the 14.5-mi double track line that connects suburbs, the inner city, and the downtown business district. (The entire region has a population of 4.5 million people.) The system consists of: 2.4 mi of subway, 1 mi at grade, 10.1 mi of elevated (1 mi of viaduct, 1.5 mi on suspension bridge, and 7.6 mi on elevated fill), and 1 mi of open top trench construction below grade. The system serves 13 stations and has 121 rapid transit cars.

Nominal traction power voltage is 700 V. The traction power system is ungrounded.

SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT

Bay Area Rapid Transit (BART) construction began in the San Francisco area in 1964 and was completed in 1973. BART stretches a total of 71 miles and has 34 stations. Of the total route mileage, 20 miles are subway and tunnel, 24 miles are elevated, and 27 miles are at grade level. The system serves Alameda, Contra Costa, and San Francisco counties with an area of 1,512 square miles and a population of 2,441,600 in 1980.

The transbay tube between Oakland and San Francisco is a [illegible]-bore concrete and steel structure buried in a trench 75-135 ft below San Francsico Bay. To prevent corrosion of the steel skin of the tube from saltwater electrolysis, the tube has a cathodic protection system utilizing impressed current anodes placed about 250 ft apart on both sides of the tube.

The BART system has 439 cars. Although all the cars have aluminum bodies, some (the "lead" cars) have fiber glass cabs. The cars are propelled by one 150-hp motor per axle and each car has four motors. The power in the third rail is 1000 V of direct current.

Like many other direct current traction systems, BART uses continuously welded and bonded steel running rails for negative current return. The traction power system is diode-grounded.

SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY

The rapid transit system of the Southeastern Pennsylvania Transportation Authority (SEPTA) operates almost entirely within the Philadelphia city limits--two stations on the Market Street Elevated line are outside the limits. The system's 55 stations serve 15.1 mi of subway track and 9.5 mi of elevated track. In subway sections, the concrete tunnel liners were cast-in-place. The elevated deckc are concrete with steel/iron pillars.

Nominal traction power voltage is grounded for 13.1 mi and ungrounded for 11.5 mi. There are approximately 2,460 cars on the SEPTA system.

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

The Washington Metropolitan Area Transit Authority (WMATA) rapid transit system opened in 1976. The system services the Washington Metropolitan Area that consists of the District of Columbia and the counties of Montgomery and Prince George's in Maryland and the cities of Alexandria and Falls Church in Virginia. In 1980, the area had a population of 2,763,400 people. The 101-mi METRO system is expected to be completed by the end of 1990.

Approximately 48 mi of the track (and 49 stations) will be underground; 44 miles (and 33 stations) will be at grade, and 9 mi of the track (and 4 stations) will be elevated. The traction power system is ungrounded.

The completed system will have 740 cars; in late 1981, 294 cars (all aluminum) were operating. Each car has four 150-hp motors drawing 1100 amp at 750 V of direct current.

APPENDIX C

CORROSION COORDINATING COMMITTEES

Appendix C

CORROSION COORDINATING COMMITTEES

Corrosion coordinating committees exist in most of the urban areas of the United States. They are sometimes called committees on corrosion or electrolysis committees. Consisting of representatives of utility companies, rapid transit authorities, pipeline companies, and others who own and operate underground structures, the committees serve as clearing houses for information on corrosion control. They are particularly useful in providing information on cathodic protection and other causes of stray current. Tests are arranged, and stray current problems are studied and frequently solved through the cooperation of committee members.

It is essential that rapid transit authorities have a representative on the local corrosion coordinating committee. Close liaison between utility and transit engineers is necessary to foster good relations. On older transit systems where many stray current problems exist, transit engineers can assist utility personnel in locating, testing, and frequently in solving these problems. On new systems, or on extensions to older systems, the transit lines are frequently constructed in areas where there have been no stray current problems for many years. Through the corrosion coordinating committee, the utility companies can be informed of the transit authority's plans for stray current control. The committees represent an excellent forum through which to obtain the good will and assistance of the utility companies.

The following is a list of corrosion coordinating committees that are affiliated with the National Association of Corrosion Engineers.

CORROSION COORDINATING COMMITTEES

NACE* Designation		
T-108-1.1	Southern Florida Corrosion Coordinating Committee Chairman unassigned	
T-108-1.2	Western New York State Corrosion Committee P. F. Hammond, Chairman Rochester Gas & Electric Company 89 East Avenue Rochester, NY 14649	(716) 546-2700
T-108-1.3	Kentucky Corrosion Coordinating Committee Terry Hendricks, Chairman Ashland Pipe Company R.R.1 Pleasant Valley Owensboro, KY 42301	(502) 683-2485
T-108-1.4	San Francisco Bay Corrosion Committee Galen Sarno, Chairman San Francisco Public Utilities Commission 693 Vermont Street San Francsico, CA 94107	(415) 558-4986
T-108-1.5	Illinois-St. Louis Committee on Underground Corrosion D. R. Spitzer, Chairman Illinois Power Company 500 South 27th Street Decatur, IL 62525	(217) 424-6600
T-108-1.6	Indiana Corrosion Society T. A. Widin, Chairman Sohio Pipeline Company P.O. Box 189 Vandalia, OH 45377	(513) 878-9606

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*National Association of Corrosion Engineers

NACE Designation

T-108-1.7 Chicago Area Joint Electrolysis Committee

Bruno Leginski, Chairman
Con Edison Company (312) 450-5589
1319 First Avenue
Maywock, IL 60153

T-108.1.8 West Virginia's Corrosion Control Coordinating Committee

William R. Scott, Chairman (412) 832-0294

T-108-1.9 Western Pennsylvania Corrosion Control Committee

Tom Masterson, Chairman
Bell of Pennsylvania (412) 633-3798
201 Stanwix Street
Pittsburgh, PA 15222

T-108-1.10 NOT ASSIGNED

T-108-1.11 Milwaukee Area Corrosion Committee

D. R. Grayson, Chairman
Wisconsin Gas Company (414) 291-6724
626 E. Wisconsin Avenue
Milwaukee, WI 53202

T-108-1.12 New Jersey Committee on Corrosion

Jack Sharp, Chairman
Elizabethtown Gas Company (201) 289-5000
No. 1 Elizabethtown Plaza
Elizabeth, NJ 07202

T-108-1.13 Southern California Cathodic Protection Committee

William Goings, Jr., Chairman
Southern California Edison Company (213) 572-2674
2244 Walnut Grove Avenue
Rosemead, CA 91770

T-108-1.14 Wyoming Underground Corrosion Committee

Gregory Bloom, Chairman
Northern Utilities, Inc. (307) 266-3674
P.O. Box 2800
Casper, Wy 82601

T-108-1.15 Southern Idaho-Eastern Oregon Underground Corrosion Committee

Eldon Book, Chairman
Intermountain Gas Industries Inc. (208) 467-7491
2921 Caldwell Boulevard
Nampa, ID 83605

NACE
Designation

T-108-1.16 San Francisco Bay Corrosion Committee

Don N. Miller, Chairman
Southern Pacific Pipe Lines Inc. (213) 629-6697
610 S. Main Street
Los Angeles, CA 90014

T-108-1.17 Central Ohio Committee on Corrosion

Tom Fisher, Chairman
Columbia Gas of Ohio (614) 439-1306
210 Highland Avenue
Cambridge, OH 43725

T-108-1.18 El Paso Area Corrosion Correlating Committee

W. J. Meister, Chairman (915) 772-1411
P.O. Box 20002
El Paso, TX 79998

T-108-1.19 Toledo and Northwestern Ohio Committee on Corrosion

Warren Bible, Chairman
Buckeye Pipeline Company (419) 223-4015
Drawer B
Lima, OH 45802

T-108-1.20 Eastern Ohio Committee on Corrosion

A. E. Hulek, Jr., Chairman
The East Ohio Gas Company (216) 361-2960
1201 E. 55th Street
Cleveland, OH 44103

T-108-1.21 Eastern New York State Committee on Corrosion

B. P. Strini, Chairman (518) 471-2662
158 State Street, Room 107P
Albany, NY 12201

T-108-1.22 Eastern Pennsylvania Corrosion Committee

David Krause, Chairman
Buckeye Pipeline Company (215) 967-3131
Emmaus, PA 18049

T-108-1.23 Eastern Montreal Electrolysis Committee

E. Zakaib, Chairman
Petrofino Canada (514) 645-9221
P.O. Box 50
Pointe-aux-Trembles H1B 5K2

T-108-1.24 The Society in Ontario for Controlling Electrolysis

B. F. Cammaart, Chairman
Union Gas Ltd. (519) 325-3100
50 Keil Drive North
Chatham, Ontario N7M 5M1

NACE
Designation

T-108-1.25 Greater New York Committee on Corrosion

Thomas Naples, Chairman
Brooklyn Union Gas (212) 643-2000
2071 Clove Road (Brooklyn, General Offices)
Staton Island, NY 10301

T-108-1.26 Central California Cathodic Protection Committee

Stefan Zellner, Secretary
Getty Oil Company (805) 399-2961
P.O. Box 5237
Bakersfield, CA 93301

T-108-1.27 Eastern Ohio Corrosion Committee

Ronald Revlock, Chairman
East Ohio Gas Company (216) 456-0535
1020 N. Market Avenue
Canton, OH 44702

T-108-1.28 Northwest Electrolysis Coordinating Committee

Joseph Smart, Chairman
El Paso Natural Gas Company
2710 N. E. 78th Street
Vancouver, WA 98665

T-108-1.29 Southwest British Columbia Coordinating Committee

A. L. Verheil, Chairman (604) 876-6711
400 E. Broadway
Vancouver, British Columbia

T-108-1.30 Michigan Electrolysis Committee

Richard Colgen, Chairman (517) 788-0277
212 W. Michigan Avenue
Jackson, MI 49201

T-108-1.31 South Louisiana Corrosion Coordinating Committee

Robert Niebling, Jr., Chairman
Marathon Pipeline Company (713) 629-6600
P.O. Box 3128
Houston, TX 77056

T-108-1.32 Philadelphia Electrolysis Committee

George LeQuier, Chairman
2301 Market Street
Philadelphia, PA 19101

T-108-1.33 OKLA-ARK-LA-TEX Corrosion Committee

G. D. Taylor, Chairman (318) 865-6381
P.O. Box 3610
Shreveport, LA 71103

NACE
Designation

T-108-1.34 Massachusetts Committee on Corrosion

Curtis Blake, Jr., Chairman
Commonwealth Gas Company (617) 481-7900
157 Cordaville Road
Southboro, MA 01772

T-108-1.35 Omaha and Council Bluffs Electrolysis Committee

R. I. Allbright, Chairman
Omaha Public Power District (402) 554-1900
1623 Harney Street
Omaha, NE 68102

T-108-1.36 Central Maryland Underground Corrosion Committee

A. A. Thue, Chairman (202) 637-1359
Washington Metropolitan Area Transit Authority
600 5th Street, NW
Washington, DC 20001

T-108-1.37 UNASSIGNED

T-108-1.38 Alabama Corrosion Coordinating Committee

T-108-1.39 Corrosion Subcommittee (H. L. Wills Induction Coordinating Committee)

Pennon Lockhard, Chairman (404) 391-2271
100 Perimeter Center Parkway, Room 258
Atlanta, GA 30346

T-108-1.40 Southern Nevada Cathodic Protection Committee

Michael Reago, Chairman
Las Vegas Valley Water District (702) 870-2011
Box 4427
Las Vegas, NV 89153

T-108-1.41 Province of Quebec Electrolysis Committee

E. J. Zakaib, Chairman
Petrofina Canada (514) 645-9221
P.O. Box 50
Pointe-aux-Trembles H1B 5K2

T-108-1.42 Arizona Corrosion Correlating Committee

John Brodar, Chairman (602) 273-5750
Salt River Project
P.O. Box 1980
Phoenix, AZ 85001

T-108-1.43 Chicago Regional Committee on Underground Corrosion

Robert Young, Chairman
Natural Gas Pipeline Company (217) 262-3298
Box 157
Hammond, IL 61929

Appendix D

SPECIFICATIONS AND PRODUCT INFORMATION

Appendix D

SPECIFICATIONS AND PRODUCT INFORMATION

Specification briefs and product information contained in Appendix D are as follows:

- Military Specification MIL-C-83286B, "Coating, Urethane, Aliphatic Isocyanate, for Aerospace Applications."
- Military Specification DOD-P-23236A(SH), "Paint Coating Systems, Steel Ship Tank, Fuel and Salt Water Ballast." (Formerly MIL-P-23236 (Ships))
- Military Specification MIL-P-2337D, (superseding MIL-P-23377C), "Primer Coatings: Epoxy-Polyamide, Chemical and Solvent Resistant."
- Military Specification MIL-S-81733C, "Sealing and Coating Compound, Corrosion Inhibitive."
- NASA Specification KSC-STD-C-0001, "Corrosion Control of Launch Structures and Ground Support Equipment, Standard for."
- NASA Shelf Master 1980 (D) Section 09890, "Finishes."
- ASTM D-2000, "Commercial Chemical Antiozonants for Elastomers."

To obtain complete military specifications, the reader should contact:

Commanding Officer
Naval Publications and Form Center
5801 Tabor Avenue
Philadelphia, PA 19120

or

Global Engineering
Documentation Services
2625 Hickory Street
Santa Ana, CA 92707

To obtain complete NASA/KSC specifications, the reader should contact:

KSC Library
Specifications & Standards
NWSI-S
Kennedy Space Center, FL 32899

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MIL-C-83286B(USAF)
5 October 1973
SUPERSEDING
MIL-C-83286A(USAF)
20 June 1973
MIL-C-38412 (USAF)
3 October 1966

MILITARY SPECIFICATION

COATING, URETHANE, ALIPHATIC ISOCYANATE, FOR AEROSPACE APPLICATIONS

* 1. SCOPE

1.1 Scope. This specification establishes requirements for two component aliphatic isocyanate based oil free urethane coating materials suitable for exterior application on aerospace equipment. The type I and type II coatings are suitable for use under local AIR POLLUTION CONTROL REGULATIONS.

* 1.2 Classification

1.2.1 Components. The aliphatic urethane coating shall consist of the following components, as specified: (see 3.2).

Component I - shall consist of pigmented polyester resin.

Component II - shall consist of clear aliphatic isocyanate.

1.2.2 Types. The coating material shall be furnished, as specified:

Type I - suitable for application by conventional pressurized air spray techniques.

Type II - suitable for application by unheated, airless spray techniques.

1.3 Colors. The coating shall be furnished in any color and gloss range, as designated in FED-STD-595. Limited special colors shall be furnished, as specified by the procuring activity. Following is a list of colors most frequently required.

FSC 8010

METRIC

DOD-P-23236A(SH)
13 November 1979
SUPERSEDING
MIL-P-23236(SHIPS)
28 June 1962
(Sec 6.6 and 6.7)

MILITARY SPECIFICATION

PAINT COATING SYSTEMS, STEEL SHIP TANK, FUEL AND SALT WATER BALLAST (METRIC)

This specification is approved for use by the Naval Sea Systems Command, Department of the Navy, and is available for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers paint coating systems for application on steel surfaces subjected to fuel and salt water, such as in shipboard fuel and salt water ballast tanks.

1.2 Classification. Coating systems shall be of the following types and classes, as specified (see 6.2.1).

Type I - General use.
Type III - Limited solvent content (for use where air pollution regulations apply).

Class 1 - Epoxy
Class 2 - Coal tar-epoxy (not for fuel tanks)
Class 3 - Silicate, phosphate, or silicone zinc
Class 4 - Urethane

2. APPLICABLE DOCUMENTS

2.1 Issues of documents. The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

FEDERAL

TT-N-95 - Naptha, Aliphatic.
TT-T-548 - Toluene, Technical.
TT-X-916 - Xylene (For Use in Organic Coatings).
PPP-P-1892 - Paint, Varnish, Lacquer, and Related Materials: Packaging, Packing, and Marking of.

MILITARY

MIL-G-5572 - Gasoline, Aviation: Grades 80/87, 100/130, 115/145.
MIL-T-5624 - Turbine Fuel, Aviation, Grades JP-4 and JP-5.
MIL-I-45208 - Inspection System Requirements

PSC 8030

MIL-P-2337D
14 March 1978
SUPERSEDING
MIL-P-23377C
26 August 1969
(See 6.6)

MILITARY SPECIFICATION

PRIMER COATINGS: EPOXY-POLYAMIDE, CHEMICAL AND SOLVENT RESISTANT

This specification is approved for use by all Departments and Agencies of the Department of Defense

1. SCOPE

1.1 Scope. This specification covers the requirements for two-component, epoxy-polyamide, chemical and solvent resistant techniques. They shall be compatible with aliphatic polyurethane topcoats and shall be suitable for use under Air Pollution Regulations.

1.2 Classification. The epoxy-polyamide primer coatings shall be furnished in the following types as specified (see 6.5):

Type I	Standard
Type II	Low Infrared Reflective (IR)

1.2.1 Components. The epoxy-polyamide primer coatings shall be of the following components as specified (see 3.4):

Component A -Shall consist of the epoxy resin and shall contain all of the pigments and corrosion inhibitors.

Component B -Shall consist of the clear polyamide resin.

FSC 8010

MIL-S-81733C
13 March 1980
SUPERSEDING
MIL-S-81733B(AS)
7 June 1976

MILITARY SPECIFICATION

SEALING AND COATING COMPOUND, CORROSION INHIBITIVE

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers accelerated, room temperature curing synthetic rubber compounds used in the sealing and coating of metal components on weapons and aircraft systems for protection against corrosion. The sealant is effective over a continuous operating temperature range of -54° to +93°C (-65° to +200°F).

1.2 Classification. The sealing compound shall be of the following types as specified (see 6.2):

Type I - For brush or dip applications
Type II - For extrusion application, gun or spatula
Type III - For spray gun application
Type IV - For faying surface application, gun or spatula

1.2.1 Dash numbers. The following dash numbers shall be used to designate the minimum application time in hours.

Type I - Dash numbers shall be -1/2 and -2
Type II - Dash numbers shall be -1/2, -2 and -4
Type III - Dash number shall be -1
Type IV - Dash numbers shall be -12, -24, -40 and -48

Example - Type I-½ shall designate a brushable material having an application time of ½ hour. Type I-2 shall designate an application time of 2 hours. All other types and dash numbers shall be designated in a similar manner.

KSC-STD-C-0001

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CORROSION CONTROL
OF
LAUNCH STRUCTURES AND GROUND SUPPORT EQUIPMENT, STANDARD FOR

DESIGN ENGINEERING DIRECTORATE

National Aeronautics and
Space Administration

John F. Kennedy Space Center

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KSC-STD-C-0001

CORROSION CONTROL
OF
LAUNCH STRUCTURES AND GROUND SUPPORT EQUIPMENT, STANDARD FOR

PREPARED BY
PLANNING RESEARCH CORPORATION
Systems Services Company
for
DESIGN ENGINEERING
JOHN F. KENNEDY SPACE CENTER, NASA

PRC CONTROL NUMBER: 293–1217

Approved:

Peter A. Minderman
Director of Design Engineering

JOHN F. KENNEDY SPACE CENTER, NASA

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ABBREVIATIONS AND ACRONYMS

ASTM	American Society for Testing and Materials
DFT	dry-film thickness
FED	Federal
FSN	Federal stock number
FSS	fixed service structure
KHB	Kennedy handbook
KSC	John F. Kennedy Space Center
NACE	National Association of Corrosion Engineers
NASA	National Aeronautics and Space Administration
no.	number
OSHA	Occupational Safety and Health Act
psi	pound per square inch
SSPC	Steel Structures Painting Council
STD	Standard

JOHN F. KENNEDY SPACE CENTER, NASA

CORROSION CONTROL OF LAUNCH STRUCTURES AND GROUND SUPPORT EQUIPMENT, STANDARD FOR

1. SCOPE

This document estabishes standard procedures for the prevention of atmospheric corrosion of exposed carbon steel, stainless steel, and aluminum through the application of protective coatings. It defines the requirements for materials, equipment, safety, procedures, and quality assurance inspection.

2. APPLICABLE DOCUMENTS

The following documents of the issue in effect on date of invitation for bids or request for proposals form a part of the standard to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this standard, the contents of this standard shall be considered a superseding requirement.

2.1 Governmental.

2.1.1 Standards.

John F. Kennedy Space Center (KSC), NASA

KSC-STD-S-0004	Color Coding of Fluid Systems Piping

Federal

FED-STD-595	Colors

2.1.2 Other Documents.

John F.Kennedy Space Center (KSC), NASA

KHB 1710.2	KSC Safety Practices Handbook

Military

T.O. 1-1-2	Technical Manual, Corrosion Prevention and Control for Aerospace Equipment

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with the application of this procedure should be obtained from the procuring activity or as directed by the Contracting Officer.)

2.2 Non-Governmental.

American Society for Testing and Materials (ASTM)

ASTM A 123	Zinc (Hot-Galvanized) Coatings on Products Fabricated From Rolled, Pressed, and Forged Steel Shapes, Plates, Bars, and Strip
ASTM A 153	Zinc Coating (Hot-Dip) on Iron and Steel Hardware
ASTM A 525	General Requirements for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.)

National Association of Corrosion Engineers (NACE)

NACE STD TM-01-70	Visual Standard for Surfaces of New Steel Airblast Cleaned With Sand Abrasive

(Application for copies should be addressed to the National Association of Corrosion Engineers, P.O. Box 218340, Houston, Tex. 77218.)

Steel Structures Painting Council (SSPC)

SSPC-PA2	Measurement of Dry Paint Thickness With Magnetic Gages
SSPC-SP-10	Near White Blast Cleaning

(Application for copies should be addressed to the Steel Structures Painting Council, 4400 Fifth Avenue, Pittsburgh, Pa. 15213.)

3. MATERIALS

3.1 Abrasives. - One of the following abrasives shall be used when specified in section 6.

3.1.1 Abrasive Blasting Material.

3.1.1.1 Silica Sand. - The silica sand shall be unused, standard, commercial-grade, blasting sand. The size shall be medium (approximately 20/30) mesh for blasting carbon steel and fine (approximately 30/65) mesh for blasting aluminum.

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3.1.1.2 Nut Shells. - The nut-shell abrasive shall be Shellblast, manufactured by Agrashell, Inc., R.D. No. 2, Bethlehem, Pa. 18017, telephone (215) 837-6705, or equal. The size shall be 14/30 mesh for general use. Other sizes may be used as circumstances dictate.

3.1.2 Abrasive Sanding Discs and Sheets. - The sanding discs shall be type D, and the sanding sheets shall be Tri-M-Ite Wetordry, manufactured by 3M Automotive Trades Division, St. Paul, Minn. 55144, or equal.

3.1.3 Abrasive Discs. - The abrasive discs shall be Scotch-Brite Clean 'N' Strip discs manufactured by 3M Cleaning Products Division, St. Paul, Minn. 55144, or equal.

3.2 Protective Coatings. - The following coatings, or approved equals, shall be used when specified in section 6. Company addresses are given in 3.4.

3.2.1 Inorganic Zinc, Polyamide Epoxy, and Aliphatic Polyurethane Coatings. - Refer to table 1.

Table 1. Inorganic Zinc, Polyamide Epoxy, and Aliphatic Polyurethane Coatings

Inorganic Zinc Coating/Primer	Inhibitive Polyamide Epoxy Primer/Intermediate	Aliphatic Polyurethane Finish Coat	Manufacturer
Dimetcote 6 or EZ	Amercoat 182	Amercoat 450GL	Ameron P.C.D.
Carbo Zinc 11	Carboline 193 PR	Carboline 134	Carboline Company
Galva-Pac 101	Copoxy 920-Y-134	Acrothane 975-426	Cook Paint and Varnish Co.
Catha-Coat 304	Devran 201	Devthane 239	Devoe & Raynolds Co.
Ganicin 347-931	Corlar 825-Y-9031	Imron	E. I. Dupont deNemours
Mobilzinc 7	Val-Chem 13-R-60	Val-Chem 40	Mobile Chemical Co.
NAPKO 5Z 1375	Epoxycote 5616	Nap-Thane 5900	The O'Brien Corp.
Zincguard No. 3	EPOXYSEA No. 1 HF	Seathane	Seaguard
Galvanox Type V	Capox A 8051	Subthane 3000	Subox Division, Carboline Company

3.2.2 High-Solids Aluminum Epoxy Mastic Coatings. - Refer to table 2.

Table 2. High-Solids Aluminum Epoxy Mastic Coatings

Product	Manufacturer
Amercoat 390	Ameron P.C.D.
Carbomastic 15	Carboline Company
Alumapoxy 75-A-1	Mobile Chemical Co.

3.2.3 Inorganic Topcoats. - Refer to table 3.

Table 3. Inorganic Topcoats

Product	Manufacturer
Amercoat 741	Ameron P.C.D.
Cook No. 411-A700	Cook Paint and Varnish Co.

3.2.4 Vinyl Primers and Vinyl Acrylic Finish Coats. - Refer to table 4.

Table 4. Vinyl Primers and Vinyl Acrylic Finish Coats

Primer	Finish Coat	Manufacturer
Amercoat 187	Amercoat 35	Ameron P.C.D.
Chem-VY-Kote P-62	Chem-VY-Kote 151xx	Devoe & Raynolds Co.
Glid-Guard 5521	Glid-Guard 5523	Glidden Coatings & Resins
Val-Chem 80-R-8	Val-Chem 80 Series	Mobil Chemical Co.

3.2.5 Aerocoat AR-7. - Aerocoat AR-7, manufactured by B. F. Goodrich Aerospace and Defense Products. This is available at KSC Supply under Federal stock number (FSN) 8030-00-485-3656.

3.3 Sealants/Caulking. - The sealant shall be a self-curing, single-component, polysulfide-rubber type. This is available at KSC Supply under FSN 8030-01-008-0969 or 8030-00-965-2397.

3.4 Manufacturers' Addresses. - Manufacturers of the products listed in this section can be contacted at the following addresses:

a. Ameron P.C.D.
201 N. Berry Street
Brea, Calif. 92621
(714) 529-1951

b. Carboline Company
350 Hanley Industrial Court
St. Louis, Mo. 63144
(314) 644-1000

c. Cook Paint and Varnish Co.
P.O. Box 389
Kansas City, Mo. 64141
(816) 391-6000

d. Devoe & Raynolds Co.
P.O. Box 7600
Louisville, Ky. 40207
(502) 897-9861

e. E. I. duPont deNemours
1007 Market Street
Wilmington, Del. 19898
(302) 774-8279

f. Glidden Coatings & Resins
Division of SCM Corp.
900 Union Commerce Building
Cleveland, Ohio 44115
(216) 344-8000

g. Mobil Chemical Co.
P.O. Box 250
Edison, N.J. 08817
(201) 321-6000

h. The O'Brien Corp.
NAPKO Division
P.O. Box 14509
Houston, Tex. 77021
(713) 641-0661

i. Seaguard
P.O. Box 669
Portsmouth, Va. 23705
(804) 488-4611

j. Subox Division
Carboline Company
40 Burlews Court
Hackensack, N.J. 07601
(201) 343-6533

4. EQUIPMENT

4.1 Compressed Air. - The compressed air system shall be capable of delivering a continuous nozzle pressure of 90 pounds per square inch (psi) to each blast nozzle in operation. The required air capacity will depend upon the configuration of the abrasive blasting system used. The air system should comply with the instructions and recommendations of the manufacturer of the abrasive blasting system. The compressed air system shall be equipped with oil and moisture separators to ensure only clean, dry air is provided to the service outlet.

4.2 Abrasive Blasting System. - The abrasive blasting system shall be an Occupational Safety and Health Act (OSHA)-approved configuration consisting of, but not limited to, a remote-controlled welded pressure pot conforming to American Society of Mechanical Engineers standards, the required length of blast hose, a tungsten carbide venturi nozzle, a respiratory air line filter, and a blast hood approved by the Mine Safety and Health Administration/National Institute of Occupational Safety and Health with the required length of air hose. The blasting system shall be designed to produce a minimum nozzle pressure of 90 psi when coupled with the available compressed air supply.

4.3 High-Pressure Water System. - The high-pressure cleaning system shall be capable of delivering a minimum operating pressure of 1,000 psi at a minimum production volume of 3.5 gallons per minute. The system shall be capable of chemical pickup and desposition.

4.4 Needle Scaler. - The needle scaler shall be of the type and size required to perform the work described in 6.1.3.1. The needles shall be replaced when they become dull and rounded.

4.5 Coating Application System. - The coating application equipment shall be an airless spray system or a conventional spray system, or both, in accordance with the coating manufacturer's recommendations.

4.6 Inspection Instruments. - The following inspection items shall be used in accordance with the requirements of section 7.

4.6.1 Instruments for Determining Ambient Weather Conditions. - The following instruments shall be used for determining ambient weather conditions:

a. Psychrometer - temperature, humidity, and dewpoint

b. Surface temperature gage

4.6.2 Instruments and Materials for Checking Surface Preparation. - The following shall be used to determine compliance with surface preparation requirements:

a. Clean, white cloth - compresed air oil contamination

b. Hypodermic needle air pressure gage

c. Surface preparation visual standards

d. Surface profile gage or comparator

4.6.3 Instruments and Materials for Checking Coating Application. - The following shall be used to determine compliance with coating application requirements:

a. Magnetic dry-film thickness (DFT) gage

b. Calibration standards

5. SAFETY REQUIREMENTS

Necessary precautions, in accordance with OSHA regulations and KHB 1710.2, shall be taken to ensure the safety of personnel performing the work required by this document and personnel who may be affected by such work. Some of the material handled in accordance with this document are combustible, or toxic, or both. The contractor shall be responsible for providing equipment as required for safe application and for instructing the users regarding the hazards and proper handling procedures to prevent damage to health or possible explosion.

6. PROCEDURES

6.1 Preparation of Surfaces. - All surfaces to be coated shall be clean, dry, and free from oil, grease, dirt, dust, corrosion, peeling paint, weld spatter, and any other surface contaminants. Sharp edges and rough welds shall be rounded off, and all weld spatter shall be removed. All surfaces that will become inaccessible after erection or installation, or both, shall be prepared and coated while accessible. Carbon steel faying surfaces that are part of the friction-type joints shall be abrasive blasted and coated with inorganic zinc, in accordance with 6.2, prior to installation. Surface preparation and coating operations shall be sequenced so that freshly applied coatings will not be contaminated by dust or foreign matter. All equipment and adjacent surfaces not to be coated shall be protected from surface preparation operations. Working mechanisms shall be protected against intrusion of abrasive. All surfaces shall be degreased, as required, prior to subsequent surface preparation procedures or the application of protective coatings, or both.

6.1.1 Degreasing. - Surfaces shall be degreased by solvent cleaning, detergent washing, or steam cleaning.

6.1.2 Abrasive Blasting. - Surfaces shall be abrasive blasted according to 6.1.2.1 and 6.1.2.2. The abrasive blasting material shall be clean and dry and shall conform to 3.1. Abrasive residue shall be removed from the surface, leaving it clean and dry prior to the application of coatings.

6.1.2.1 Carbon Steel. - Carbon steel shall be abrasive blasted to near-white metal (NACE no. 2 in accordance with NACE STD TM-01-70) with silica sand conforming to the requirements in 3.1.1.1. The anchor profile of the blasted surface shall be 1.0 to 2.0 mils, as indicated by a Keane-Tator surface profile comparator, or similar device. All rust shall be completely removed from pits and depressions. All weld slag and foreign matter shall be removed from welds. A minimum blast nozzle pressure of 90 psi shall be maintained throughout all operating periods.

6.1.2.2 Aluminum.

CAUTION

> Aluminum is susceptible to distortion when it is abrasive blasted with silica sand. Special care shall be taken to ensure against any metal distortion by reducing blast nozzle pressure and increasing the working distance from nozzle to surface. In some cases, such as in the surface preparation of light-gage aluminum sheet, these precautions may not be sufficient to prevent distortion, and an alternate procedure, such as sanding or mechanical cleaning, must be used to remove corrosion or roughen the surface.

Aluminum shall be abrasive blasted with fine silica sand conforming to the requirements in 3.1.1.1 to remove corrosion or roughen the surfaces. Nut-shell abrasive, mesh size conforming to 3.1.1.2, shall be used for removing old coating from aluminum that is in good condition.

6.1.3 Mechanical Methods. - Surfaces shall be prepared by mechanical methods according to 6.1.3.1 and 6.1.3.2.

6.1.3.1 Carbon Steel. - Carbon steel shall be mechanically cleaned using needle scalers and/or abrasive discs or wheels. All corrosion and foreign matter shall be removed, leaving the surface cleanliness equivalent to near-white metal (SSPC-SP-10 for rust removal only).

6.1.3.2 Stainless Steel and Aluminum. - Stainless steel and aluminum shall be mechanically cleaned using abrasive discs or abrasive sanding sheets or discs conforming to 3.1. All corrosion and foreign matter shall be completely removed.

6.1.4 High-Pressure Water Wash. - Surfaces shall be prepared by washing with potable water under high pressure (1,000 psi, minimum). Chemical cleaning with detergent, bleach, or other cleaning agents may be required to remove surface contaiminants prior to washing with water. Surfaces shall be free of all foreign matter, such as dirt, loose coating, and surface chalk.

6.1.5 Chemical Treatment. - Surfaces shall be chemically treated with a phosphoric acid solution of sufficient concentration to provide a uniformly etched surface. Reaction products and residue shall be completely removed from the surface prior to the application of coatings.

6.2 Application of Coatings. - All prepared surfaces shall be coated within 6 hours after completion of surface preparation and before rusting or recontamination occurs. Any surface not coated within 6 hours or that shows rusting or contamination, regardless of the length of time after preparation, shall be reprepared.

The application and handling characteristics of all coatings will vary. To obtain optimum performance, adequate instructions from the manufacturer are essential and must be closely followed, in conjunction with the requirements defined herein. The manufacturer's recommendations for thinning, mixing, handling, and applying his product shall be considered a part of this document. In the event of conflict between the requirements of this document and the manufacturer's recommendations, this document shall take precedence.

All coatings shall be thoroughly worked into all joints, crevices, and open spaces. All newly coated surfaces shall be protected from damage. All equipment and adjacent surfaces not to be coated shall be protected from overspray.

6.2.1 Coating Systems. - Coating systems for specific uses and substrates shall be as defined in 6.6, 6.7, and 6.8 and shall conform to 3.2. All coatings, thinners, and cleaners shall be a product of the same manufacturer. Coating systems consisting of more than one coat shall be products of the same manufacturer. Continuity of the coating manufacturer's system shall be maintained for the duration of an individual project. Inorganic zinc coatings shall be tinted green similar to FED-STD-595, color no. 34226, with a fugitive pigment that will fade to gray when left untopcoated and exposed to a salt-weathering environment. Finish coat colors for general service shall approximate FED-STD-595, color no. 16473, gray. Color coding for fluid system piping shall be in accordance with KSC-STD-S-0004.

6.2.2 Storage of Coating Materials. - Coating materials shall be stored in their original containers bearing the manufacturer's name, product identification, and batch number. Coatings, thinners, and cleaners shall be stored in tightly closed containers in a covered, well-ventilated area where they will not be exposed to sparks, flame, direct sunlight, or rainfall. The manufacturer's instructions for temperature limitations shall be followed.

6.2.3 Mixing and Application Instructions. - Coating materials shall be thoroughly mixed prior to application with a mechanical mixing instrument, such as a Jiffy Mixer, manufactured by the Jiffy Mixer Company, Inc., San Francisco, Calif., or equal. The mixer shall be powered by an air motor or an explosion-proof electric motor. The material shall be agitated slowly during application to maintain uniform suspension of solids. Continuous rapid agitation shall be avoided. The mixed coating material shall be strained through a 30- by 60-mesh screen prior to application. Thinning shall be for workability and improved spray characteristics only. The manufacturer's recommended thinner and amount shall be used. Spray equipment shall be adjusted to produce an even, wet coat with minimum overspray. The conventional pressure pot, when used, shall be kept at approximately the same level or above the spray gun for proper material delivery. Coatings shall be applied in even, parallel passes, overlapping 50 percent. Special attention shall be paid to welds, cutouts, sharp edges, rivets, crevices, and bolts to ensure complete coverage and proper thickness.

6.2.4 Environmental Conditions. - No coating shall be applied when rain is imminent or when the temperature or humidity is outside limits recommended by the coating manufacturer. To prevent moisture condensation during application, surface temperature must be at least 5 degrees Fahrenheit (-15 degrees Celsius) above the dewpoint.

6.2.5 Methods of Application. - Coatings shall be applied with airless or conventional spray equipment, or both, according to 4.5. Application with brushes will be permitted for minor touchup and when spray application is prohibited in the area of work.

6.2.6 Coating Finish. - Each coat of material applied shall be free of runs, sags, blisters, bubbles, and mudcracking; variations in color, gloss, and texture; and holidays (missed areas), excessive film buildup, foreign contaminants, dry overspray, etc. Special care shall be taken to ensure complete coverage and proper thickness on welds, corners, crevices, sharp edges, bolts, nuts, and rivets.

6.2.7 Coating DFT. - Inorganic zinc coatings shall be applied to a DFT of 4.0 mils, minimum, to 8.0 mils, maximum, when they will be left untopcoated. When the zinc coatings are to be topcoated, the DFT shall be reduced to 2.5 mils, minimum, to 4.0 mils, maximum. All other coatings shall be applied to the DFT recommended by the manufacturer. The film thickness of the topcoats shall be sufficient to ensure uniform coverage and color. The proper DFT for each coat shall be obtained in a single application, which may consist of multiple passes.

6.2.8 Coating Drying and Curing. - The coating manufacturer's recommended drying and curing times for handling, recoating, and topcoating shall be followed.

6.3 Sealing/Caulking. The perimeter of all faying surfaces, joints open less than 1/2 inch (1.27 centimeters), and skip-welded joints that will be exposed to the exterior environment shall be completely sealed. The sealant shall be a self-curing, single-component, polysulfide-rubber type, conforming to 3.3. The sealant shall be gray in color and applied to the joint with a caulking gun following the application of the inorganic zinc primer. The bead shall be hand tooled to a smooth and uniform finish.

6.4 Galvanizing. - Galvanizing shall be accomplished after fabrication by the hot-dip process conforming to ASTM A 123, ASTM A 153, or ASTM A 525, as required in 6.6. The weight of the zinc coating shall be not less than 2.0 ounces per square foot of surface.

6.5 Zones of Exposure. - The following zones of exposure are established to define coating system requirements for surfaces located in specific environments:

a. Zone 1. Surfaces that receive rocket engine exhaust impingement

b. Zone 2. Surfaces that receive elevated temperatures [above 150 degrees Fahrenheit (65 degrees Celsius)] and acid deposition from solid rocket booster exhaust with no exhaust impingement

c. Zone 3. Surfaces, other than those located in zones 1 or 2, that receive acid deposition from solid rocket booster exhaust products

d. Zone 4. Surfaces not located in the launch environment

6.6 Specific Protection Requirements. - Specific requirements for new work and complete refurbishment projects are defined in 6.6.1, 6.6.2, and 6.6.3. Maintenance procedures for applied coatings are defined in 6.7.

6.6.1 Protection of Carbon Steel. - Carbon steel surfaces shall be protected from exterior atmospheric corrosion through the application of an inorganic zinc coating or by hot-dip galvanizing, as defined herein. Whenever possible, new structural components, such as stair treads, grating, handrails, pipes, hardware (nuts, bolts, and fasteners), and corrugated steel sheets shall be hot-dip galvanized in accordance with 6.5, as applicable. All other carbon steel surfaces shall be coated with inorganic zinc conforming to 3.2 in accordance with 6.2. The zinc coatings may require topcoating with additional protective coatings, as specified herein.

6.6.1.1 Surface Preparation. - Carbon steel shall be prepared for the application of an inorganic zinc coating by abrasive blasting in accordance with 6.1. Galvanized carbon steel shall be prepared by using one of, or a combination of, the surface preparation methods specified in 6.1. Choice of method will depend upon the condition and configuration of the surface. The zinc coatings shall be maintained or rendered clean, dry, and free from contaminants prior to the application of topcoat systems. The galvanized steel shall be oil and grease free and slightly roughened.

6.6.1.2 Topcoat Systems for Zinc Coatings. - The following topcoat systems shall be applied over the zinc coatings as required for each zone of exposure described in 6.5:

a. Zone 1. Zinc coatings shall be left untopcoated.

b. Zone 2. An inorganic topcoat conforming to 3.2.3 shall be applied in accordance with 6.2.

c. Zone 3. An epoxy intermediate/tie coat and a polyurethane finish coat conforming to 3.2 shall be applied in accordance with 6.2. (Note: Structural members of the fixed service structures (FSS's) are coated with a vinyl acrylic coating and shall be maintained according to 6.7.)

d. Zone 4. No topcoats are required, except for color coding, safety, identification, or special conditions.

6.6.2 Protection of Stainless Steel. - Stainless steel surfaces shall be protected as follows.

6.6.2.1 Surface Preparation. - Stainless steel shall be prepared according to 6.1 in accordance with 6.1.1 or 6.1.3, or both, as required by the condition of the surface.

6.6.2.2 Protective Costing. - A nitrile rubber base aluminum coating conforming to 3.2.5 shall be applied to all exposed stainless steel in accordance with 6.2.

6.6.3 Protection of Aluminum. - All aluminum surfaces shall be protected as follows.

6.6.3.1 Surface Preparation. - Aluminum shall be prepared according to 6.1 in accordance with 6.1.1 through 6.1.4, as required by the condition and configuration of the surface.

6.6.3.2 Protective Coatings. - The following protective coatings shall be applied to aluminum surfaces as required for each zone of exposure described in 6.5:

a. Zones 1 and 2. Aluminum shall be left untopcoated.

b. Zone 3. An epoxy primer and a polyurethane finish coat conforming to 3.2 shall be applied in accordance with 6.2.

c. Zone 4. No protective coatings are required for normal atmospheric service; however, aluminum that is located within 2 to 3 miles of the coastline should be coated according to item b. above.

6.7 Repair and Maintenance of Applied Coatings. - Existing previously applied coatings and newly applied coatings shall be repaired and maintained in accordance with the following schedule (refer to table 5). Choice of surface preparation method and subsequent coating required shall be determined by factors such as the present condition of the surface and operational restrictions in the area of work. Corroded surfaces shall be abrasive blasted whenever possible. Mechanical methods should be used only when abrasive blasting is impractical or prohibited in the area of work.

6.8 Provision for Nonskid Surfaces. - Where a nonskid walking surface is required, an aggregate such as sand, walnut shells, aluminum oxide, or pumice can be incorporated into the finish coat to provide uniform roughness as required.

7. QUALITY ASSURANCE PROVISIONS

7.1 Inspection Prior to Surface Preparation and Coating Application. - The following conditions shall be inspected prior to commencement of surface preparation and coating application operations.

7.1.1 Surface Condition. - The surface condition shall be visually inspected for compliance with 6.1. All grease and oil must be completely removed. Sharp edges and rough welds must be rounded off, and all weld spatter must be removed.

7.1.2 Protection of Adjacent Surfaces. - Surfaces shall be visually inspected for adequate protection of adjacent surfaces in accordance with 6.1

7.1.3 Ambient Weather Conditions. - The ambient weather conditions at the actual location of the work shall be determined before and during surface preparation and coating application operations to ensure they are correct for

Table 5. Repair of Existing Applied Coatings

Existing Coating	Surface Preparation Method	Repair Coating
Inorganic zinc		
Zone 1	Abrasive blast/mechanical clean	Inorganic zinc
Zone 2	Abrasive blast/mechanical clean	Inorganic zinc/inorganic topcoat
Zone 3	Abrasive blast/mechanical clean	Inorganic zinc (optional)/epoxy/polyurethane system
Zone 4	Abrasive blast/mechanical clean	Inorganic zinc (spray); epoxy mastic (brush)
Galvanized steel		
Zone 1	Abrasive blast/mechanical clean	Inorganic zinc
Zone 2	Abrasive blast/mechanical clean	Inorganic zinc/inorganic topcoat
Zone 3	Abrasive blast/mechanical clean	Inorganic zinc (optional)/epoxy/polyurethane system
Zone 4	Abrasive blast/mechanical clean	Inorganic zinc (spray); epoxy mastic (brush)
Organic zinc-rich*		
Zone 1	Abrasive blast	Replace with inorganic zinc
Zone 2	Abrasive blast	Replace with inorganic zinc/inorganic topcoat
Zone 3, FSS	Abrasive blast/mechanical clean	Vinyl primer/vinyl acrylic system
Zone 3, all other areas	Abrasive blast/mechanical clean	Epoxy/polyurethane system
Zone 4	Abrasive blast/mechanical clean	Replace with inorganic zinc
Polyurethane*		
Zone 1	Abrasive blast	Replace with inorganic zinc
Zone 2	Abrasive blast	Replace with inorganic zinc/inorganic topcoat
Zone 3	Abrasive blast/mechanical clean	Epoxy/polyurethane system
Zone 4	Abrasive blast/mechanical clean	Epoxy/polyurethane system
Vinyl acrylic*		
Zone 1	Abrasive blast	Replace with inorganic zinc
Zone 2	Abrasive blast	Replace with inorganic zinc/inorganic topcoat
Zone 3	Abrasive blast/mechanical clean	Vinyl primer/vinyl acrylic sytem
Zone 4	Abrasive blast/mechanical clean	Vinyl primer/vinyl acrylic sytem

*When this coating is replaced with inorganic zinc, complete removal of the existing coating is required.

the work being conducted. The air temperature, relative humidity, and dew-point shall be determined through the use of a psychrometer in accordance with the manufacturer's instructions. The surface temperature shall be determined by using a magnetic surface temperature thermometer.

7.1.4 Compressed Air Cleanliness. - The compressed air supply shall be inspected for the use of inline moisture and oil traps. Proper functioning of the traps shall be periodically evaluated by allowing the air supply (downline from the traps) to blow against a clean, white cloth for several minutes. No moisture or oil should be deposited on the cloth.

7.2 Surface Preparation Inspection. - The following inspections shall be made to ensure compliance with the surface preparation requirements in 6.1.

7.2.1 Abrasive Blasting Material. - The abrasive blasting material shall be inspected for compliance with 3.1 and section 6.

7.2.2 Blast Nozzle Air Pressure. - The air pressure at the blast nozzle shall be determined through the use of a hypodermic needle air pressure gage. The needle of the gage should be inserted as close to the nozzle as practically possible and in the direction of the nozzle. Pressure readings should be taken with the blasting system in complete operation. The nozzle pressure shall conform to 6.1.2.1.

7.2.3 Degree of Surface Cleanliness. - The surface cleanliness shall be inspected after the completion of surface preparation procedures to determine compliance with the applicable requirements of 6.1. The degree of cleanliness of abrasive-blasted carbon steel shall be verified through the use of visual standards in accordance with 6.1.2.1. The surface preparation cleanliness requirements defined in 6.1 shall be applicable to 100 percent of the subject area, including places that are difficult to reach.

7.2.4 Surface Profile or Roughness. - The anchor profile of a sandblasted carbon steel surface shall be determined by using a surface profile gage or comparator. The profile shall be in accordance with 6.1.2.1. Aluminum surfaces shall be visually inspected as required for slight roughening in accordance with 6.1.2.2.

7.3 Coating Application Inspection. - The following inspections shall be made to ensure compliance with the coating application requirements defined in 6.2.

7.3.1 Surface Condition. - The prepared surface shall be visually inspected and the time before coating shall be monitored for compliance with 6.2 before coatings are applied.

7.3.2 Coating Materials. - The coating materials shall be visually inspected for compliance with 6.2.1.

7.3.3 Storage of Coating Materials. - Coating material storage conditions shall be periodically inspected for compliance with 6.2.2.

7.3.4 Mixing and Application of Coatings. - The mixing and application of all coatings shall be visually inspected to ensure compliance with 6.2.3, 6.2.5, and 6.2.8.

7.3.5 Coating Finish and DFT. - The finish and DFT of the applied coating shall be inspected for compliance with 6.2.6 and 6.2.7. The DFT measurement shall be taken using a magnetic gage in accordance with SSPC-PA2.

7.4 Caulking Inspection. - All surfaces shall be inspected to determine compliance with the requirements for sealing and caulking defined in 6.3.

7.5 Galvanizing Inspection. - Galvanized carbon steel shall be inspected in accordance with the applicable ASTM standard as defined in 6.4.

8. NOTES

For information and guidance on dissimilar metals, corrosion-inhibiting lubricants, corrosion of electrical equipment, etc., refer to T.O. 1-1-2.

NOTICE. When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

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Design Engineering Directorate

SECTION 09890

PROTECTIVE COATING OF STRUCTURAL CARBON STEEL

-- End of Section --

NASA SHELF MASTER 1980 (D)

SECTION 09890

PROTECTIVE COATING OF STRUCTURAL CARBON STEEL

PART 1 GENERAL

1.1 Scope

This section covers coating systems, materials, surface preparation, and application of protective coatings on structural carbon steel.

1.2 Delivery, Handling and Storage

Materials shall be delivered in their original, unbroken containers bearing the manufacturer's name, product identification and batch number.

Coatings, thinners, and cleaners shall be stored in tightly closed containers in a covered, well-ventilated area where they will not be exposed to extreme cold or heat, sparks, flame, direct sunlight, or rainfall.

1.3 Protection of Equipment and Adjacent Surfaces

All equipment and adjacent surfaces shall be protected from damage such as, but not limited to, abrasive intrusion, overblast, overspray, etc.

1.4 Personnel Safety

Necessary precautions shall be taken in accordance with OSHA regulations to ensure safety of personnel engaged in these operations and personnel who may be affected by such operations. Some of the materials to be handled under this specification are combustible and/or toxic. Using material safety information provided by the manufacturer, the Contractor shall be responsible for providing equipment as required for safe application and instructing the users regarding the hazards and proper handling procedures to prevent damage to health or possible explosion.

1.5 Contractor Submittals and Requirements

The following information and documentation shall be submitted.

a. Identification of subcontractor, when applicable.

b. A list of all materials proposed for use on this project and the manufacturer's catalog data on each.

c. Color chart for finish coats, when applicable.

PART 2 PRODUCTS

2.1 Abrasive Blasting Material

The blasting abrasive shall be unused sharp silica sand, medium mesh, (approximately 20/30).

2.2 Sealant Compound

The sealant shall be a self-curing, single component, polysulfide-rubber type conforming to FS TT-S-230. The sealant shall be gray in color and capable of being applied into the joint with a caulking gun.

2.3 Protective Coatings

2.3.1 Coatings

Coatings shall be selected from table 1 and included in the submittals of 1.5b. No substitution shall be made without the approval of the Contracting Officer. All coatings, thinners, and cleaners shall be a product of the same manufacturer. Coating systems consisting of more than one coat shall be products of the same manufacturer.

Inorganic zinc shall be tinted green, similiar to FED-STD-595 #34226 with a fugitive pigment that will fade to gray when left untopcoated and exposed to a salt weathering environment. Finish coat color shall be as specified in the coating schedule (3.8).

Table 1. Coating Types

INORGANIC ZINC	INHIBITIVE POLYAMIDE EPOXY	ALIPHATIC POLYURETHANE	MANUFACTURER
Dimetcote 6 or EZ	Amercoat 182	Amercoat 450GL	Ameron P.C.D. 201 N. Berry Street Brea, California 92621 714/529-1951
Carbo Zinc 11	Carboline 193 PR	Carboline 134	Carboline Company 350 Hanley Industrial Ct. St. Louis, Missouri 63144 314/644-1000
Galva-Pac 101	Copoxy 920-Y-134	Acrothane 975-426	Cook Paint & Varnish Company P.O. Box 389 Kansas City, Missouri 64141 816/391-6000
Catha-Coat 304	Devran 201	Devthane 239	Devoe & Raynolds Company P. O. Box 7600 Louisville, Ky. 40207 502/897-9861
Ganicin 347-931	Corlar 825-Y-9031	Imron	DuPont 1007 Market Street Wilmington, DE 19898 302/774-8279
Mobilzinc 7	Val-Chem 13-R-60	Val-Chem 40	Mobil Chemical Company P.O. Box 250 Edison, New Jersey 08817 201/321-6000
NAPKO 5Z 1375	Epoxycote 5616	Nap-Thane 5900	The O'Brien Corp. NAPKO Division P. O. Box 14509 Houston, Texas 77021 713/641-0661
Zincguard no. 3	EPOXSEA no. 1 HF	Seathane	Seaguard P. O. Box 669 Portsmouth, Virginia 23705 804/488-4411
Galvanox type V	Capox A 8051	Subthane 3000	Subox Div., Carboline Co. 40 Burlews Court Hackensack, New Jersey 07601 201/343-6533

2.3.2 Finish Colors

Finish colors for coating system no. 2 (see 2.3.1 for color of no. 1 coating system) shall conform to the following FED-STD-595 numbers when specified in 3.8.

White #17875
Blue #15102 (Safety)
Yellow (Std.) #13538
Yellow (Safety) #13655
Red #11136
Red (Safety) #11105
Black #17038
Green #14110 (Safety)
Gray #16473
Gray (Safety) #16187
Brown #10080 (Safety)

PART 3 EXECUTION

3.1 Surface Preparation

3.1.1 General

All surfaces which will become inaccessible after installation, and faying surfaces which are part of friction-type joints, shall be prepared and coated with inorganic zinc only prior to installation.

All prepared surfaces shall be coated within 6 hours after completion of surface preparation and before rusting or recontamination occurs. Any surfaces not coated within 6 hours or which show rusting or contamination, regardless of the length of time after preparation, shall be reprepared.

Surface preparation and coating operations shall be sequenced so that freshly applied coatings will not be contaminated by dust or foreign matter.

All surfaces shall be inspected and degreased as required prior to subsequent surface preparation and/or the application of protective coatings.

3.1.2 Abrasive Blasting (AB)

Abrasive blasting shall conform to NACE Standard TM-01-70, NACE #2.

Compressed air used for abrasive blasting shall be free of moisture and oil.

Surfaces not to be blasted are:

Galvanized steel, except when specified in the coating schedule
Piston rods and bearing surfaces
Prefinished surfaces having ceramic and baked enamel finish coats
Conduit
Factory primed electrical boxes, panels, and supporting accessories, lighting fixtures and electrical cable installation.

Abrasive blast with clean dry silica sand, mesh size as defined in 2.1.

Maintain a minimum nozzle pressure of 90 psi.

Remove all weld slag and foreign matter from welds.

Blast to achieve a 1 to 2 mil anchor profile as indicated by a Keane Tator Surface Profile Comparator or similar device.

Completely remove all rust and corrosion from pits and depressions.

Do not reuse sand.

Remove all traces of abrasive residue and/or dust from the surface leaving it clean and dry.

3.1.3 Mechanical Cleaning (MC)

Where mechanical cleaning is specified in the coating schedule (3.8), needle scalers and/or abrasive discs or wheels shall be used.

3.1.4 Inspection of Surface Preparation

Immediately after the surface is prepared, it will be inspected by the Contracting Officer to determine compliance with the specification for surface preparation. Any areas not meeting the surface preparation requirements shall be recleaned until approved. No coatings shall be applied until the surface preparation is approved.

3.2 Coating Systems

The following coating systems shall be used when specified in 3.8.

No. 1	Inorganic zinc
No. 2	Inorganic zinc (first coat) Inhibitive polyamide epoxy (second coat) Aliphatic polyurethane (finish coat)

3.3 Coating Application

3.3.1 General

The application and handling characteristics of all coatings will vary. To obtain optimum performance, adequate instructions from the manufacturer are essential and must be closely followed, in conjunction with the requirements of this specification.

The manufacturers' recommendations for thinning, mixing, handling, and applying his product shall be considered a part of this specification. In the event of conflict between the requirements of this specification and the manufacturers recommendations, this specification shall take precedence.

Compressed air used for spraying coatings shall be free or moisture and oil.

Each coat of material applied shall be free from runs, sags, blisters, bubbles, mud cracking, variations in color, gloss and texture, holidays (missed areas), excessive film build, foreign contaminants, dry overspray, etc.

No coating shall be applied when rain is imminent or when the temperature and/or humidity is outside the limits recommended by the coating manufacturer.

All coatings shall be thoroughly worked into all joints, crevices, and open spaces.

All newly coated surfaces shall be adequately protected from damage.

To prevent moisture condensation during application, surface temperature must be at least 5 degrees F (3 degrees C) above the dew point.

Apply all coatings by airless and/or conventional spray per 3.3.2. Airless shall be used for large surface areas. Conventional shall be used for small areas of intricate configuration and touchup.

3.3.2 Mixing and Application Procedures

Stir material thoroughly with a mixing instrument such as a Jiffy Mixer, manufactured by the Jiffy Mixer Company, Inc., San Francisco, California, or equal. Mixer must be powered by an air motor or an explosion-proof electric motor.

Strain the mixed material through a 30 to 60 mesh screen.

Provide continuous slow agitation during application of all coatings to maintain uniform suspension. Avoid continuous rapid agitation.

Thin for workability and improved spray characteristics only. Use only the manufacturers' recommended thinner and amount.

Adjust spray equipment to produce an even wet coat with minimum overspray.

Apply in even parallel passes, overlapping 50 percent. Pay special attention to welds, cut-outs, sharp edges, rivets, crevices, and bolts to ensure proper coverage and thickness.

Keep pressure pot, when used, at the same level or above the spray gun for proper material delivery.

When dry through (dry to handle), check the film thickness with a nondestructive dry film thickness gage such as a Mikrotest. If less than specified thickness, apply additional material as required.

3.3.3 Dry Film Thickness (DFT)

The coatings shall be applied to the following dry film thicknesses.

a. Inorganic zinc (coating system no. 1) - 4 (minimum) to 8 (maximum) mils

b. Inorganic zinc (coating system no. 2) - 3 (minimum) to 4 (maximum) mils

c. Inhibitive polyamide epoxy - 2 mils (minimum)

d. Aliphatic polyurethane - 2 mils (minimum), but sufficient to cover previous coat.

3.4 Touchup

Abrasions that occurred during shipment or erection shall be touched up as follows:

a. Inorganic zinc for touchup and repair of itself

b. Inhibitive polyamide epoxy and aliphatic polyurethane for touchup and repair of the complete system

Surface preparation shall be as specified in 3.1.2 and/or 3.1.3. Application shall conform to 3.3.

3.5 Caulking

Caulking shall be accomplished after application and cure of the inorganic zinc coating.

All exterior joints shall be caulked, including but not limited to, the following:

a. Perimeter of faying and bearing surfaces of structural members.

b. Perimeter of structural bolt heads and nuts.

c. Joints in members between intermittent welds.

d. Perimeter of bearing surfaces between floor plates and supporting members (inside, outside, top, and bottom).

e. Stair treads where joined to channel stringers.

f. All openings of 1/2 inch or smaller. Use foam filler back-up material as required.

3.6 Inspection

The work as described herein will be inspected for compliance with this specification by the Contracting Officer.

In addition, the Contractor shall provide for inspection of his work to assure these specification requirements are fulfilled.

3.7 Cleanup

Upon completion of each days work, the Contractor shall remove all discarded and/or surplus material and secure all equipment and materials to a safe and organized state.

3.8 Coating Schedule

SURFACE DESCRIPTION	SURFACE PREP. (SEE 3.1)	COATING SYSTEM (SEE 3.2)	FINISH COLOR FOR COATING SYSTEM NO. 2 (SEE 2.3.2)

-- End of Section --

ASTM D-2000

COMMERCIAL CHEMICAL ANTIOZONANTS FOR ELASTOMERS

Chemical Name	Trade Name	Supplier
N,N'-bis (1-ethyl-3-methyl pentyl)-p-phenylenediamine	U.O.P. 88	UOP Inc UPO Process Division 10 UPO Plaza Des Plaines, IL 60016
or		
N,N'-di-3 (5 methylheptyl) p-phenylenediamine	Antozite 2	R. T. Vanderbilt Co., 30 Winfield St. East Norwalk, CT 06855
	Santoflex 17	Monsanto Company 800 N. Lindbergh Blvd. St. Louis, MO 63166
	ANTO$_3$ "B"	Pennwalt Corp. Three Pky. Philadelphia, PA 19102
	Flexzone 8L	Uniroyal, Inc. Chemical Division Rubber Avenue Naugatuck, CT 06770
N,N'-bis (1-methylheptyl)-p-phenylenediamine	U.O.P. 288	UOP Inc.
or		
N,N'-di-2-octyl-p phenylenediamine	Antozite 1	R. T. Vanderbilt Co.
	Santoflex 217	Monsanto Company
	ANTO$_3$ "D"	Pennwalt Corp.

Chemical Name	Trade Name	Supplier
N,N'-bis (1, 4-dimethyl pentyl) -p-phenylenediamine	Cyzone DH	American Cyanamid Co. Rubber Chemicals Dept. Easton Turnpike Bound Brook, NJ 08805
	Santoflex 77	Monsanto Copmpany
	U.O.P. 788	UOP Inc.
	Antozite MPD	R. T. Vanderbilt Co.
	Flexzone 4L	Uniroyal Chemical
	Eastozone 33	Eastman Chemical Prod. 200 S. Wilcox Kingsport, TN 37662
	Antiozidant 4030	Mobay Chemical Co. Penn Lincoln Parkway West Pittsburgh, PA 15205
N-isopropyl-N'-phenyl-p-phenylenediamine	Flexzone 30	Uniroyal Chemical
	Antiozidant 4010NA	Mobay Chemical Co.
	Santoflex IP	Monsanto Company
N-phenyl-N'-cyclohexyl-p-phenylenediamine	Flexzone 6H	Uniroyal Chemical
N-sec. butyl-N'-phenyl-p-phenylenediamine	Flexzone 5L	Uniroyal Chemical
6-ethoxy-1, 2-dihydro-2, 2, 4-trimethylquinoline	Santoflex AW	Monsanto Company
N-phenyl-N'-(1, 3 dimethyl butyl)-p-phenylenediamine	Flexzone 7L	Uniroyal Chemical
	Antozite 67	R. T. Vanderbilt Co.
	Santoflex 13	Monsanto Company
	Antiozidant 4020	Mobay Chemical Co.
	Wingstay 300	Goodyear Tire & Rubber Co.

Chemical Name	Trade Name	Supplier
N,N'-diphenyl-p-phenylenediamine	Agerite DPPD	R. T. Vanderbilt Co., Inc.
	SZF	Uniroyal Chemical
Complex blend of diaryl-alkyl, aryl-p-phenylenediamines	Wingstay 250	Goodyear Tire & Rubber Co.
	Wingstay 275	Goodyear Tire & Rubber Co.
p,p'-diaminodiphenylmethane (also called) 4,4'-methylenedianiline	Tonox	Uniroyal Chemical
A synergistic blend of antiozonants, antioxidants, and anti suncheck agents	Ozone	Sterwin Chemicals 90 Park Avenue New York, NY 10016
Nickel dibutyl dithiocarbamate	NBC	E. I. DuPont de Nemours & Co. Organic Chemicals Dept. 1007 Market Street Wilmington, DE 19898
1, 3 dibutyl thiourea or 1, 3 dibutyl-2-thiourea	Pennzone B	Pennwalt Corp.
Furan resins (recommended for neoprene)	Fura-Tone NC 1008	3M Co. 3M Center St. Paul, MN 55101
N-hexyl-N' -phenyl-p-phenylenediamine	U.O.P. 588	UOP Inc.
	$ANTO_3$ "E"	Pennwalt Corp.
N-octyl-N'-phenyl-p-phenylenediamine	U.O.P. 688	UOP, Inc.
	$ANTO_3$ "F"	Pennwalt Corp.
Hindered diaryl-p-phenylenediamine (recommended for Neoprene)	Akroflex AZ	E. I. DuPont de Nemours & Co.
	Wingstay 100	Goodyear Tire & Rubber Co.
	Wingstay 200	Goodyear Tire & Rubber Co.

Chemical Name	Trade Name	Supplier
Free flowing powder	Ozone Protector 80	C. P. Hall Co. 7300 S. Central Avenue Chicago, IL 60638
N,N'-dicyclohexyl-p-phenylenediamine	U.O.P. 26	UOP Inc
1/1/1 blend of dioctyl, phenyl hexyl, and phenyl-octyl-p-phenylenediamines	ANTO$_3$ "C"	Pennwalt Corp.
N,N'-diheptyl-p-phenylenediamine	ANTO$_3$ "G"	Pennwalt Corp.
Blend of alkyl and aryl derivatures of -p-phenylenediamines	Flexzone 10L	Uniroyal Chemical
	Flexzone 11L	Uniroyal Chemical
	Flexzone 12L	Uniroyal Chemical
Antiozonant/solvent coating	Age-Master #1	Chem-Pro Manufacturing Company, Inc. 9215 Hillview Drive Clarence, NY 14031

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