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(Status Report)

Study of Corrosion Protection Methods for GSE Applications at Kennedy Space Center

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ABSTRACT

This is a status report covering the work accomplished from February, 1970 to April, 1972 on a program, conducted for the llechanical Design Division by the Materials Testing Branch, to evaluate corrosion control' and treatment methods for GSE at KSC. Present methods, as defined in a corrosion control and treatment manual prepared by DD-MDD-1, are based on sound, established practices. However, the applicability of these methods for the extremely corrosive KSC environment was not known. The purpose of the program was to evaluate the procedures recommended in the manual, using actual hardware items with the relevant treatments applied. Samples of stainless steel, aluminum, carbon steel. and galvanized steel parts were obtained and treated with various corrosion-preventive materials. such as chemical conversion coatings, paint systems, vapor-phase corrosion inhibitors. fluidized-bed coatings, tapes, solvent-cutback compounds, and greases. Duplicate sets of all specimens were prcparcd and placed at the KSC Corrosion Test Site, one set being placed in an exposed location and the other in a sheltered location. The samples were evaluated by visual inspection.

Conclusions reached after two years of exposure testing are as follows:

1. For aluminum alloys, a three-coat paint system and inorganic zinc paint have given complete protection. A chemical conversion coating (MIL-C-554) was useful for short-term protection.

2. For stainless steels, sacrificial type coatings (such as zinc-rich and aluminum-rich paints), polyethylene tape, and a fluidized-bed epoxy coating, gave excellent protection. A solvent cutback material, MIL-C-16173, Grade 2, was satisfactory for short-term protection.

3. For galvanized steel parts, none of the treatments evaluated significantly extended the life of the zinc coating.

4. For carbon steels, a vapor-phase corrosion-inhibiting compound (MIL-L-46002) protected internal surfaces of enclosures subject to moisture intrusion. None of the treatments applied to external surfaces, directly exposed to the seacoast environment, gave adequate long-tern] protection, although some of the MIL-C-16173 compounds were useful for short-ten exposures.

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1.0 INTRODUCTION

1.1 This is a status report; covering the period, from February 1970 (program initiation) to April 1972, of a study conducted by the Materials Testing Branch (MTB) for the Mechanical Design Division, Design Engineering Directorate, on corrosion control and treatment methods at KSC. Corrosion damage to ground support equipment at KSC is typical of that experienced in semi-tropical seacoast environments throughout the world.

1.2 Economic loss resulting from corrosion of metallic parts in many residential and commercial installations and in vehicles is substantial in this environment, largely because of deficiencies in both design and materials selection. In industrial installations. much greater control of corrosion is usually effected by proper control practices. However, the range of metallic materials found in a given industrial installation may be relatively narrow. For example, a large facility, accounting for thousands of tons of metallic materials, may be constructed primarily of carbon steel structural shapes, for which the corrosion control practices are fairly well established.

1.3 The selection of metallic materials for GSE applications at KSC is necessarily based on many factors, because of the complexity of the operations conducted. Corrosion susceptibility is only one of these factors. Consequently, the range of metallic materials employed is relatively wide and includes carbon steels, high-strength constructional steel, austenitic stainless steels, martensitic stainless steels, precipitation-hardenable stainless steels, ultra-high-strength low-alloy steels, zinc-, cadmium-, and chromium-plated steel parts, aluminum alloys, and copper alloys. Obviously, such a range of materials complicates corrosion control and treatment practices.

1.4 In an attempt to cope with this problem, the Mechanical Design Division has prepared a comprehensive corrosion control and treatment manual (TM-584) that describes specific methods to control corrosion in the major materials systems employed for GSE at KSC. The particular treatments specified in the manual represent the best known and documented practices, as derived from Military Specifications and industrial experience and recommendations. However, many of the treatments were previously untested at KSC, and it is questionable whether some of the treatments. though adequate for most environments, can provide sufficient protection for use in the KSC area.

1.5 The objectives of this study are, therefore, to evaluate the effectiveness of the corrosion control methods described in TM-584, and to develop improved methods for any prescribed treatments that prove to be inadequate.

2.0 EXPERIMENTAL PROGRAM

2.1 The experimental program consists basically of evaluating the corrosion control methods described in TM-584 with samples exposed to the beach environment. When possible, actual service components to be protected have been used for test specimens. When service components were not available. other hardware simulating the components have been used. The various treatments have been applied to specimens of each type of component, and an additional specimen of each type was left untreated as a control. The specimens were secured to support racks, which were placed on a support frame at the corrosion test site. This frame has a roofed section, which provides shelter from direct rain impingement and sunlight, and an exposed section in which there is no shelter from rain or sunlight. Duplicate sets of specimens were prepared, and one set was placed in each section of the frame. Evaluation of corrosion perfomiance of the various control treatments has been based on periodic visual inspections of the specimens. From these observations, each treatment method can bc evaluated against the control (untreated) specimen in each group.

2.2 The test specimens consisted of a wide variety of hardware items, including aluminum alloy pipe, iron pipe, Unistrut clamps attached to stainless steel tubing, stainless steel tubing fittings, stainless steel fasteners, steel cabling, steel piano hinges. galvanized steel turnbucklcs, and carbon steel rods. The various corrosion control treatments applied include chemical conversion coatings, paint systems, vapor-phase corrosion inhibitors, fluidized-bed-applied coatings, plastic tape wrapping, solid-film (heat-cured) lubricant coatings, solvent-cutback corrosion-preventive compounds. water-displacing corrosion-preventive compounds, and corrosion-preventive greases. Table 1 lists all of the testspecimens and the corrosion-control treatment applied to each. The aluminum tubing was the 6061 alloy in the T-G condition, representative of a large amount of tubing and piping at KSC. The carbon steel pipe with capped ends simulated "closed" tubular structural members that can accumulate moisture because of incomplete closure and "breathing" of humid air (water vapor pumping associated with cyclic temperature changes). The 1/2" diameter hole in the bottom caps allowed moist air intrusion. The Unistrut clamps wore similar to those used to'secure stainless steel tubing hardlines and fittings. The stainless steel tubing used was Type 304 with KC fittings (Type 316). The stainless steel "flange" bolts and nuts were Type 304, 3/8" - 16 UC, similar to those used to secure flanges on the larger stainless steel fluid lines. The steel cable assemblies were fabricated from 1/4" carbon steel cable, with eyes at either end formed over galvanized steel thimbles and secured by swaged sleeves. These assemblies are small replicas of cable used on mechanical actuators on various systems. The piano hinge was carbon steel, similar to that used on doors and covers for large electrical distribution boxes. The turnbuckles were galvanized carbon steel, about 10" in over-all length, and similar to those used to tighten cable assemblies. The carbon steel rods were 1" in diameter and simulated the pistons used in pneumatic and hydraulic actuators.

2.3 An outline of the corrosion control treatments, and surface preparation prior to their application, are given in Table 2. The paints were spray-applied to the tubing specimens and tubing assemblies. Application of the organic zinc paint to the Unistrut clamps and the flange bolts and nuts was accomplished by brushing. The application to the flange bolts and nuts was done after they had been attached to a section of 1/4" - thick stainless steel plate (used to simulate their installation in a flange). The cold-application solvent-cutback compounds (MIL-C-16173, Grades 2, 3, and 4) were applied by dipping the part to be coated in the compound and withdrawing it at a rate of 4" per minute. The coated part was then suspended by a fine wire at least 48 hours while solvent evaporation occurred. The hot-application corrosion-preventive compound (MIL-G-11796) was applied by dipping the part to be coated in the compound, which had been heated to the temperature range of 155" to 200°F, and withdrawing the part at a rate of 4" per minute (leaving a film of approximately 1.5 mils in thickness). The grease materials (MIL-G-81322 and MIL-T-5544) were applied by brushing them on the parts. The tapes were wrapped with 50% overlap, The Teflon tape was "tied" with a loop at the end of the wrapped area. The polyethylene tape, which is self-sealing, was stretched to approximately 50% greater than its original length to assure proper sealing. The water-displacing compound (LPS-1) was applied from a pressurized spray-can, as supplied by the manufacturer. The dry-film lubricant (MIL-L-46010) was applied by brush to the parts, which were air dried for 30 minutes and then cured by baking for 2 hours at 300°F.

2.4 These specimens. as described, constituted the basic materials for evaluation by beach exposure, in terms of the initial concept of the program. The specimens were mounted in wooden support racks, the cables and turnbuckles being suspended horizontally by nylon tic cords. The other samples, with the exception of the carbon steel pipes, were also mounted horizontally, being attached by circular clamping straps to cross members on the racks. The carbon steel capped pipes were mounted vertically, with the 1/2" drilled hole in the lower cap. The sample racks were transported to the CKAFS corrosion test site and installed in a support frame located approximately 375 feet from mean high tide. Most of the samples were placed at the corrosion site on February 18, 19, or 28, 1970. One group, the aluminum tubes coated with inorganic zinc rich paint, was installed on April 1, 1970. One complete set of sample racks was placed in the exposed section of the exposure frame, and the other set was placed in the sheltered section. The support frame with the sample racks installed is shown in Figure 1. In this view, the four racks in the exposed section of the frame can be seen. The other four racks are located under the roofed section.

2.5 The sample racks remained at the Cape corrosion test site from February 1970 until November 1971. At this time, the general area that included the corrosion test frames became a target site for missile test firings, and it was necessary to relocate the sample support frames. The sample racks containing the test samples for the subject program were removed from the Cape test site on November 8, 1971. They were kept in indoor storage until November 24, 1971, at which time the support frame was placed at the newly acquired KSC corrosion test site. located on the Cape Road North, approximately midway between Complex 41 and Complex 39, Pad A. At this test site. the support frames were approximately 140 feet from mean high tide.

2.6 In addition to the basic tests previously described, some special tests were conducted with the solvent-cutback corrosion preventive compounds specified in MIL-C-16173. It should be noted that three of the grades (2, 3, and 4) were applied to several types of hardware in the basic program. The purpose of the additional tests was to directly compare the effectiveness of four grades of the compound in protecting carbon steel in the seacoast environment. Carbon steel panels, 4" x 6" x 1/8", were sandblasted to "white metal" and were then coated with Grades 1, 2, 3, and 4 of the compound. Duplicate panels were prepared with coatings of each of the four grades. These samples were placed at the KSC corrosion test site on August 12, 1971, one set of samples completely exposed to the elements and the other sheltered with a stainless steel cover. The racks used to contain these samples were the conventional ASTM Type, utilizing porcelain insulators to support the samples. The racks were positioned in their support frame at an angle of 30° to the horizontal.

2.7 In the area of "improved methods for corrosion control", a coating material developed in connection with a related program is applicable to the subject study. This coating, now available from Goodrich under the trade name "Aerocoat AR-7", was compounded to a formula developed by the MTB particularly for sealing small perforations in stainless steel vacuum-jacketed lines and for the prevention of further corrosion in the stainless steel. The coating is basically a nitrile rubber in methyl ethyl ketone with phenolic resins added for improved adhesion characteristics and aluminum powder (actually "microflakes") added for improved film strength and sacrificial protection from corrosion. Several formulations, containing from 20% to 80% by weight aluminum, have been tested. However, only two of the formulations, one with 40% aluminum and the other with 70% aluminum, have been fairly extensively evaluated. The formulations with the lower aluminum contents were developed for use on stainless steel and it was found in the related program that the 40% aluminum material is preferred particularly for optimum sealing and for corrosion prevention. In the cured film, aluminum levels of 40% and higher result in a coating that is electrically conductive from the base metal to the surface, a requirement for a sacrificially protective material. The 70% aluminum material was specifically compounded for use on carbon steel, for which it was believed that a higher aluminum content was essential and could result in protection equivalent to that provided by the zinc-rich paints. Considerable experience with the 40% aluminum coating applied to stainless steel samples of various configurations has been obtained in the related program (1)[1]

[1]. Numbers in parentheses refer to List of References appended to the report.

and in actual field use at KSC. The initial test panels of carbon steel (both flat panels and the Tator type[2] panels) were coated with the 70%aluminum material and other similar panels were coated with the 40%-aluminum material. Two Tator panels were also coated with a fonulation containing 80% aluminum. The coatings were spray-applied to a thickness of 2 to 4 mils. These samples, designed to provide a comparative evaluation of various aluminum contents, were placed in standard ASTM racks at the KSC corrosion test site in July and August, 1371.

3.0 TEST RESULTS

3.1 Performance of the test samples was evaluated by periodic inspections, to determine the time of initiation of significant corrosion activity and the rate at which the severity of corrosion increased. On carbon steels, the corrosion activity is the general type, in which relatively large areas experience uniform attack. On aluminum alloys and stainless steels, corrosion activity usually involves pitting and crevice corrosion, and the affected areas are very small in the initiating stages. Photographs of the test samples in the basic program were taken after six months of exposure and again after approximately two years of exposure. The special test samples, involving the addition21 tests with Compound NIL-C-16173 and the newly developed Aerocoat AR-7, were photographed at suitable intervals to show development of significant corrosion features.

3.2 Descriptive evaluation of the degree of corrosion affecting the test specimens involved an arbitrary scale, divided into five steps, as follows:

A. No corrosion evident.

B. Corrosion initiation period (for pitting or general corrosion).

C. Extensive corrosion (advanced condition of B).

D. Severe corrosion (further development of condition but part still marginally serviceable).

E. Failed (corroded to the degree that the part is no longer considered serviceable).

In addition, parts that were coated with zinc paint or zinc galvanizing were evaluated as to the degree of "white rust" (corrosion of zinc coating), prior to the

2. A proprietary carbon-steel corrosion test panel with a steel channel section welded to the face (Kenneth Tator Associates, Coraopolis, Pa.)

development of corrosion of the base metal. This is usually evident as a white, powdery deposit on the coating.

3.3 The test results are summarized in Figure 2, which is a bar graph defining the progression of corrosion in terms of the scale described, for each group of test specimens. The results for both the exposed and the sheltered specimens of each group are presented together, so that the effects of these two different types of exposure on corrosion rate can be evaluated. The photographic documentation of specimen condition after six months of exposure is presented in Figures 3 through 10. These photographs, and those taken after two years of exposure, were made in color. Unfortunately, it is not economically feasible to present a complete set of these photographs with each copy of the report. The half-tones shown here give some indication of specimen condition and also depict the arrangement and attachment of the specimens in the support rack. A complete set of all of the color photbgraphs taken for the program is maintaincd by the Materials Testing Branch, and this is available for inspection by interested individuals.

3.4 The condition of the carbon steel tubes treated with MIL-L-46002 cannot be evaluated from these photographs, since the application of the corrosion preventive compound was made to the internal surfaces. One set of the tubes (those from the sheltered section of the exposure frame) were removed, brought to the laboratory and sectioned longitudinally to expose the internal surfaces. Photographs taken of this set of samples are shown in Figure 11. Again, an adequate appreciation of the sample condition cannot be obtained from these black-and-white photographs. However, as is evident, some corrosion of the untreated sample had occurred, whereas the treated sample remained essentially free of corrosion for the two-year exposure period.

3.5 From the data presented in Figure 2, the following observations are made with regard to the various sample groups and the corrosion control treatments applied.

3.5.1 <u>Aluminum Tubes</u>

Pitting corrosion initiated quickly on both control (untreated) specimens, but its development was more rapid on the sheltered specimen. The conversion coating treatment (NIL-C-5541) delayed the initiation of corrosion and reduced its severity in both exposures. Both of the other treatments---the three-coat paint system and the inorganic zinc---have afforded excellent protection. There is no evidence of corrosion initiation on any of the specimens, other than a very light white rust on the zinc-coated sheltered specimen.

3.5.2 Carbon Steel Pipes

The vapor-phase treatment---MIL-L-46002---has been effective for approximately two years in protecting the internal surfaces of the pipes. There is slight evidence of corrosion initiation on the lower end caps of the treated samples.

3.5.3 Unistrut Clamps

Corrosion of the control specimens involves both pitting over the clamp surface and crevice corrosion near the bolt head used to assemble the clamps. This corrosion developed more rapidly on the sheltered specimens than on the exposed specimens. The organic zinc paint began to flake extensively on specimens, in both exposures after about 9 months. In spite of this flaking, however, there was no significant evidence of pitting or crevice corrosion of the stainless steel in two years of exposure. Apparently, enough of the zinc coating has remained on the clamps to afford sacrificial protection. The epoxy coating has remained completely effective for the entire exposure period. As is seen in the photographs (Figures 5 and 6), the Unistrut clamps were attached to sections of stainless steel tubing in four different "conditions" in the area of clamp attachment: bare (passivatcd only), wrapped with self-sealing polyethylene tape, wrapped with Teflon tape, and coated with organic zinc paint. With regard to the tape wrapping, it was observed that the polyethylene tape tended to retain moisture, contributing to pitting of the stainless steel tubing in the clamp area. Complete sealing could not be maintained because of damage to the tape by the clamp. The thinner, more loosely wrapped Teflon tape did not tend to retain moisture, and its use appears preferable. The organic zinc paint was a satisfactory treatment for the tubing in the clamp attachment area. However, some blistering of the zinc coating, particularly on the sheltered specimens, was noted.

3.5.4 Stainless Steel Tubing Assemblies

Pitting corrosion initiated rapidly on the control specimens, and evidence of crevice corrosion at fittings was seen after about three months. As has been noted on other groups of stainless steel specimens, the corrosion developed more rapidly on sheltered samples. The solid-film lubricant---MIL-L-46010---afforded no significant protection from pitting or crevice corrosion. The organic zinc paint has completely protected the assemblies for two years, as has the polyethylene tape. On these specimens the tape completely encased the assembly and has evidently been effective in excluding moisture. The solvent-cutback material---MIL-C-16173. Grade 2---afforded good short-term protection for the assemblies, particularly on the sheltered specimen. Considerable removal of the material occurred on the exposed specimen, probably because of both sunlight effects and rain impingement. Both specimens show some evidence of pitting'and crevice corrosion after two years of exposure.

3.5.5 Stainless Steel Flange Bolts

The course of corrosion development on the stainless, steel flange bolts and nuts has essentially paralleled that of the other stainless steel specimens. Pitting occurred quickly on the control specimens and was more severe on the sheltered sample. The organic zinc paint has prevented corrosion of the stainless steel, although some white rust of the zinc is evident. The MIL-L-16173, Grade 2, afforded protection for 15 to 22 months, (the longer period on the sheltered sample).

3.5.6 Carbon Steel Cables

The control specimens corroded rapidly and were considered to have failed after about three months of exposure. The specimens treated with MIL-C-16173, Grade 4, had developed severe corrosion after about nine months of exposure and were considered to have failed after approximately 18 months. The grease---MIL-G-81322---has afforded better protection, particularly for the sheltered specimen. It should be noted that for many applications at KSC stainless steel cable assemblies, rather than carbon steel assemblies, are used. It is probable that both the MIL-C-16173, Grade 4 and the ML-G-81322 treatments would afford good short-ten protection (that is, about one to two years) for the stainless steel cables.

3.5.7 Carbon Steel Piano Hinge

ileither the MIL-C-16173, Grade 3 nor the LPS-1 offered significant protection for the carbon steel hinge specimens, and all samples had failed within two to four months of exposure.

3.5.8 Galvanized Carbon Steel Turnbucklcs

With galvanized parts of this type, to which a relatively heavy zinc coating has been applied by the hot-dip process, the only evidence of corrosion for an extended period is the white rusting of the zinc. In this group, white rusting was considerably more rapid on the sheltered samples, and some corrosion of the steel base was noted on the lock nuts and threads after about eight months. The exposed specimens resisted base metal corrosion for about 20 to 22 months. ilone of the treatments applied significantly reduced the white rusting of the zinc galvanizing or prevented the eventual rusting of the base metal.

3.5.9 Carbon Steel Rods

The corrosion behavior of the carbon steel rods was similar to that of the piano hinge material. The controls had corroded severely within one month of exposure. All of the samples had corroded to the "failure" condition within seven months.

3.6 The additional experiments with the solvent cutback corrosion-preventive compounds specified in MIL-C-16173, as described in paragraph 2.6, yielded some interesting and definitive results with regard to selection of the proper grades for different exposure conditions with carbon steels. Figures 12 and 13 show the carbon steel panels coated with four grades---1, 2, 3 and 4---of the material. The exposed specimens are shown in Figure 12 and the sheltered specimens in Figure 13. After about seven months of exposure, the panels coated with Grade 1 and Grade 4 remained in fairly good condition, with corrosion only along the panel edges. Grades 2 and 3 had been completely removed from the exposed panel, and the panels had undergone extensive corrosion. After an equivalent period, the sheltered specimen coated with the Grade 3 material was badly corroded, and the Grade 1 specimen had corroded extensively. The Grade 4 panel was much less corroded than the Grades 1 and 3 panels, but some penetration of the coating had occurred, and some light corrosion was scattered over the panel surface. The Grade 2 panel showed little or no corrosion away from the panel edges. These results are surprising, in view of the intended applications as stated in the specification (MIL-C-16173). with Grade 1 being recommended for the most severe corrosion service. Obviously, the type of exposure involved (that is, the extent of sheltering of the treated objects) has a profound effect on the degree of protection provided by most grades of the compound. If the exposure conditions are complex, or cannot be predicted with assurance, the selection of the Grade 4 material would appear to offer the best compromise.

3.7 In Figure 14, results of some of the tests involving the application of the aluminized material---Goodrich Aerocoat AR-7---to carbon steel and to stainless steel test panels are shown. These panels had been exposed to the beach environment for approximately six months when the photograph was made. The particular coating formulations are indicated on the Figure. Two stainless steel panels were used in these tests, and they were coated with the 40%-aluminum material. These panels are the two at the lower right corner of the photograph. The effectiveness of this coating in protecting stainless steel is evident. There is only slight evidence of corrosion, and this is seen only along the panel edges, where there was incomplete coverage. The effectiveness of the 40%-aluminum material in protecting carbon steel is highly dependent on the amount of coating applied. Two carbon steel flat panels in the rack are located immediately above the stainless steel panels. The panel on the right, showing extensive corrosive attack, was coated with the 40%-aluminum AR-7 to a thickness of 1 to 2 mils, whereas the panel to its left was coated with the same material to a thickness of 4 to 5 niils. Note that the only evidence of corrosion on this latter specimen is along the panel edges and at the punched hole near the top of the panel. Similarly, the two Tator panels coated with the 40%-aluminum material showed corrosion mainly in the areas of the welded channels, whcro adequate coating thickness is difficult to obtain. The carbon steel panels coated to a thickness of 5 to 6 mils with the 70%-aluminum material (one flat panel and two Tator panels near the top of the rack) show much less evidence of corrosion, this being mainly some spots in the channel area of one of the Tator panels. Two Tator panels were coated with 4 to 5 mils of GO%-aluminum material, and these are shown at the lower center portion of the sample rack. This material is less effective than the 70%-aluminum material and is probably not as effective as the 40%-aluminum material. The poorer corrosion protection of the CO%-aluminum coating is attributed, at least partly, to its poor adhesion to the carbon steel base metal, which is in turn probably a result of an excessive amount of aluminum filler. It appears that the 70%-aluminum material is probably near the maximum acceptable aluminum content for good adhesion properties.

4.0 CONCLUSIONS

The following conclusions, based on the results of two years of beach exposure testing, are stated with regard to the performance of the corrosion control treatment methods evaluated in this program.

4.1 For aluminum alloys, both the three-coat paint system (HIL-C-8514, MIL-P-8585, MIL-E-15934) and inorganic zinc paint over a sandblasted surface gave complete protection for two years in sheltered and unsheltered exposures; The chemical conversion coating (MIL-C-5541) was useful for short-term protection but did not prevent pitting.

4.2 For stainless steels, sacrificial type coatings, including zinc-rich paints and an aluminum-rich coating (Goodrich Acrocoat AR-7) gave excellent protection. The AR-7 has superior adhesion and, for many applications, appears preferable to organic zinc-rich paint. For parts that were entirely encapsulated by its application, the self-sealing polyethylene tape gave complete protection. For short-term protection, the corrnsion-preventive compound, MIL-C-16173, Grade 2, was satisfactory. This material is more effective in sheltered locations. For small stainless steel parts, coating with epoxy by the fluidized-bed technique results in excellent protection. Vinyl or nylon coatings applied by this technique should also be satisfactory.

4.3 For galvanized carbon steel parts (e.g. turnbuckles), none of the treatments evaluated prevented some corrosion of the base metal for the two-year exposure period, and there was no significant difference in the degree of corrosion of the treated parts and the control specimens. It is doubtful, therefore, whether any of the passive type coating materials, such as the solvent-cutback compounds, can significantly extend the service life of galvanized carbon steel. Based on the results of some tests performed, in another study. on plated carbon steel parts (2), it is believed that the aluminum-filled coating, AR-7, may be a promising material for application to galvanized parts.

4.4 For protecting the internal surfaces of enclosed carbon steel structural parts (such as tubing members) that may occlude moisture, the MIL-L-46002 vapor-phase corrosion-inhibiting oil gave very effective protection for two years. For protection of carbon steel parts directly exposed to the environment (whether sheltered or unsheltered), most of the methods evaluated were unsatisfactory. The treated parts corroded severely within a matter of weeks, after which they could not be distinguished from the controls. For short-term protection, some of the MIL-C-16173 compounds were fairly effective, Grades 1 and 4 for unsheltered situations and Grades 2 and 4 for sheltered situations.

5.0 FUTURE WORK

It is proposed that the exposure testing of thk "unfailed" specimens be continued, to obtain a more complete assessment of the effectiveness of the treatments applied. It is also proposed that some additional evaluations be undertaken to define methods that will be more effective in protecting carbon steel "working parts", such as hinges, and for application to galvanized parts, to extend the useful life of the zinc coating. These activities would be consistent with the stated goals of the KSC Technical Ilanagement Team Study, "Corrosion Prevention and Treatment Elethods for KSC Facilities and Equipment.'

REFERENCES

1. "Corrosion Study of Bare and Coated Stainless Steel." Interim Report MAB 431-68 to DD-MUD by SO-LAB-4, February 1971.

2. "Evaluation of Corrosion-Preventive' Coatings for Latches Used on Timing Terminal Unit Cabinets," Letter Report MTB 310-71 to Federal Electric Corporation, FEC 220, by SO-LAB-4, March 7, 1972.

Table 1

Specimen Groups and Treatments Applied

Group No.	Specimen Type	Treatment
1	Aluminum tubing (2" diameter Type 6061-T6)	a. Bare (no treatment) b. MIL-C-5541 (chemical conversion coating) c. MIL-C-8514, MIL-P-8585A, MIL-E-15934 (2 coats) d. Inorganic zinc paint over sandblasted surface
2	Carbon steel pipe (capped with 1/2" drain hole in bottom cap)	a. Bare (no treatment) b. Filled and drained - MIL-L-46002, Grade 1
3	Unistrut clamps (stainless steel)	a. Bare (no treatment) b. Painted - organic zinc paint c. Epoxy coated by fluidized-bed technique
	NOTE: Each of Group 3 attached to a section of Type 304 stainless steel tubing with each of the following treatments:	a. Bare - passivated in 20% HNO_3 b. Painted - organic zinc paint c. Wrapped - Teflon tape d. Wrapped - self-sealing polyethylene tape
4	Stainless steel tubing assemblies (with KC fittings)	a. Bare (no treatment) b. Wrapped - self-sealing polyethylene tape c. Painted - organic zinc paint d. Coated - dry-film lubricant, MIL-L-46010 e. Coated - MIL-C-16173, Grade 2
5	Stainless steel flange bolts and nuts	a. Bare (no treatment) b. Painted - organic zinc paint c. Coated - MIL-C-16173. Grade 2
6	Steel Cable Assemblies	a. Bare (no treatment) b. Coated - MIL-C-16173, Grade 4 c. Coated - MIL-G-81322

Table 1 (Continued)

Group [lo.	Specimen Type	Treatment
7	Piano Hinge (carbon steel)	a. Bare (no treatment) b. Coated - NIL-C-16173, Grade 3 c. Coated - LPS-1
8	Turnbuckles' (galvanized steel)	a. Bare (no treatment) b. Coated - MIL-C-11796 c. Coated - IIIL-C-16173, Grade 2 d. Coated - NIL-T-5544
9	Metal Pistons (carbon steel rods)	a. Bare (no treatment) b. Coated - MIL-C-16173, Grade 2 c. Coated - LPS-1 d. Coated - dry-film lubricant, MIL-L-46010

Table 2

Outline of Corrosion Control Treatments

Treatment	Type	Applied To	Prior Surface Preparation	Treatment Applied By
MIL-C-5541	Chemical Conversion Coating (Chromium silicate; e.g., Alodine, Iridite)	Aluminum Tubing	(Shop practice)	Bendix Technical Shops
Paint System:		Aluminum Tubing	Solvent cleaned (with MEK)	Bendix Technical Shops
MIL-G-8514	Wash primer			
MIL-P-8585A	Zinc chromate primer			
NIL-E-15934 (2 coats)	Enamel top-coat			
Inorganic zinc paint	KSC-SPEC-F-0020. Type I, Class 1	Aluminum Tubing	Sandblasted with 20-30 mesh silica sand	MTB
MIL-L-46002, Grade 1	Lubricating oil with vapor-phase corrosion inhibitor	Carbon steel pipe (specimens filled with oil and then drained, leaving surface film)	Solvent cleaned (with MEK)	MTB
Epoxy Coating	Applied by fluidized-bed technique to a nominal thickness of 10 mils.	Stainless steel Unistrut clamps	Solvent cleaned (with MEK)	MTB
Organic zinc paint	KSC-SPEC-F-0020, Type II, Class 1	Stainless steel Unistrut clamps tubing, tubing fittings, flange bolts and nuts.	Solvent cleaned (with MEK) then MIL-M 10578, Type 2	MTB

Table 2 (Continued)

Treatment	Type	Applied To	Prior Surface Preparation	Treatment Applied
Teflon Tape	1/2" width, 3 mil thickness (e.g., Dutch Brand No. 420)	Stainless steel tubing (at area of attachment of Unistrut clamps) Wrapped with 50% overlap.	Passivated for 30 min. in 20% nitric acid at 80°F	MTB
Polyethylene Tape	3/4" width, 20 mil thickness self-sealing type (e.g. Bishop Bi-Seal)	Stainless steel tubing (at area of attachment of Unistrut clamps) Wrapped with 50% overlap and stretched approximately 50%.	Passivated for 30 min. in 20% nitric acid at 80°F	HTB
MIL-L-46010	Heat-cured dry-film lubricant; corrosion inhibitor added.	Stainless steel tubing assemblies with fittings; carbon steel rods	Solvent cleaned (with MEK)	MTB
MIL-C-16173:	Corrosion preventive compound solvent cutback, cold-application			
Grade 2	Soft film	Stainless steel tubing assemblies; stainless steel flange bolts and nuts, turnbuckles, carbon steel rods.	Solvent cleaned (with MEK)	MTB
Grade 3	Soft film, water displacing	Piano hinge	Solvent cleaned (with MEK)	MTB
Grade 4	Transparent, non-tacky film	Steel cable assemblies	Solvent cleaned (with MEK)	MTB

Table 2 (Continued)

Treatment	Type	Applied To	Prior Surface Preparation	Treatment Applied By
MIL-G-81322	Grease, Aircraft, General Purpose	Steel cable assemblies	Solvent cleaned (with MEK)	MTB
NIL-C-11796	Corrosion preventive compound, Petrolatum, Hot-application	Turnbuckles	Solvent cleaned (with MEK)	MTB
LPS-1	Water displacing (ML-C-23411 Type)	Piano hinges, carbon steel rods	Solvent cleaned (with MEK)	MTB
ML-T-5544	Thread compound, Antiseize, Graphite-Petrolatum	Turnbuckles	Solvent cleaned (with MEK)	MTB

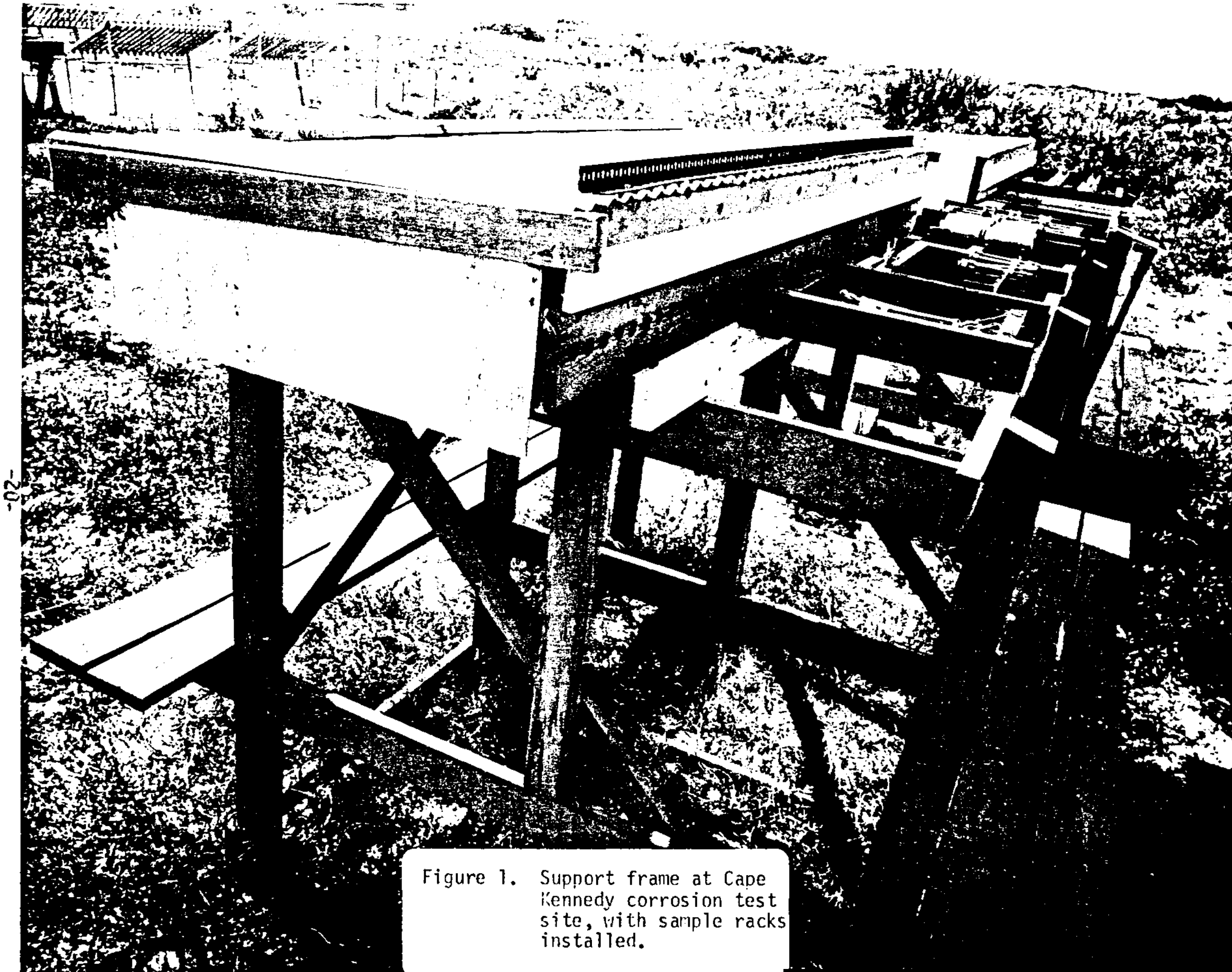


Figure 1. Support frame at Cape Kennedy corrosion test site, with sample racks installed.

Figure 2

Corrosion Performance of Test Specimens in Basic Exposure Program

Sample Code	Test Specimen	Treatment	Exposure
1-1	Aluminum Tubes	None	Exposed
1-2	Aluminum Tubes	MIL-C-5541	Exposed
1-3	Aluminum Tubes	3 Coat Paint System	Exposed
1-4	Aluminum Tubes	Inorganic Zinc	Exposed
1-5	Aluminum Tubes	None	Sheltered
1-6	Aluminum Tubes	MIL-C-5541	Sheltered
1-7	Aluminum Tubes	3 Coat Paint System	Sheltered
1-8	Aluminum Tubes	Inorganic Zinc	Sheltered
2-1	Carbon Steel Pipes	None	Exposed
2-2	Carbon Steel Pipes	MIL-L-46002	Exposed
2-3	Carbon Steel Pipes	None	Sheltered
2-4	Carbon Steel Pipes	MIL-L-46002	Sheltered
3-1	Unistrut Clamps	None	Exposed
3-2	Unistrut Clamps	Organic Zinc	Exposed
3-3	Unistrut Clamps	Epoxy	Exposed
3-4	Unistrut Clamps	None	Sheltered
3-5	Unistrut Clamps	Organic Zinc	Sheltered
3-6	Unistrut Clamps	Epoxy	Sheltered

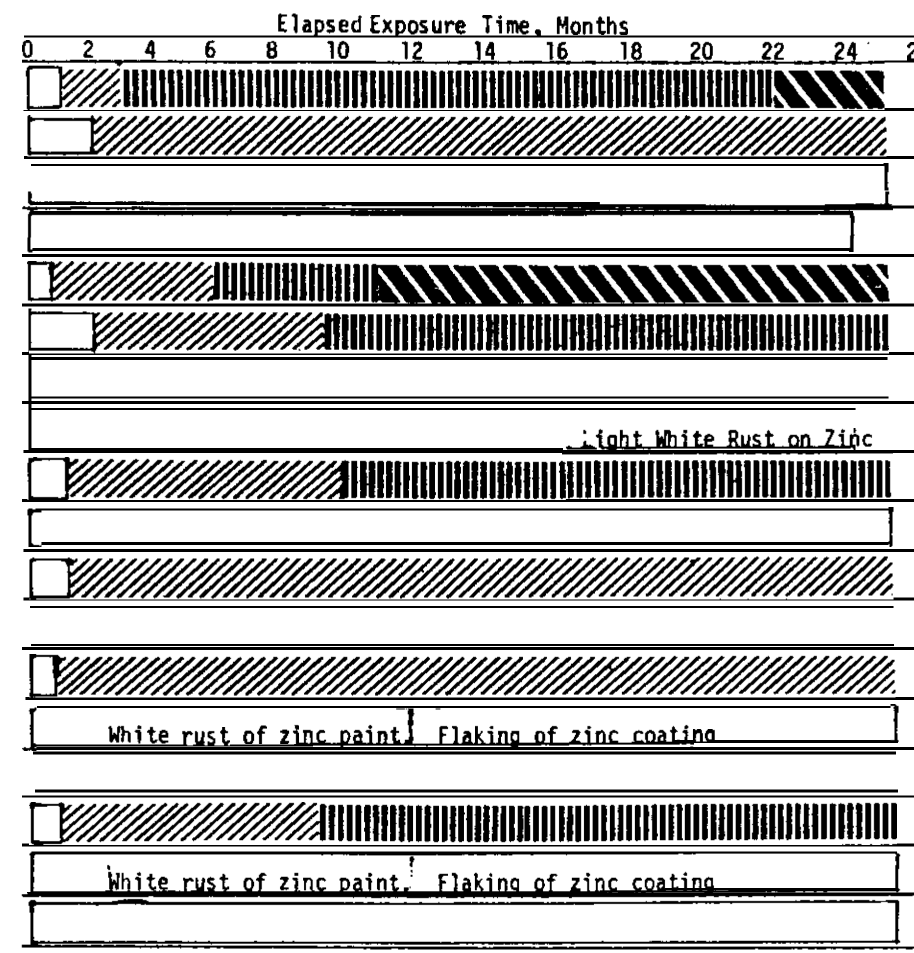


Figure 2 (Continued)

Sample Code	Test Specimens	Treatment	Exposure
4-1	Stainless Tubing Assembly	None	Exposed
4-2	Stainless Tubing Assembly	Polyethylene Tape	Exposed
4-3	Stainless Tubing Assembly	Organic Zinc	Exposed
4-4	Stainless Tubing Assembly	MIL-L-46010	Exposed
4-5	Stainless Tubing Assembly	MIL-C-16173-2	Exposed
4-6	Stainless Tubing Assembly	None	Sheltered
4-7	Stainless Tubing Assembly	Polyethylene Tape	Sheltered
4-8	Stainless Tubing Assembly	Organic Zinc	Sheltered
4-9	Stainless Tubing Assembly	MIL-L-46010	Sheltered
4-10	Stainless Tubing Assembly	MIL-C-16173-2	Sheltered
5-1	Stainless Flange Bolts	None	Exposed
5-2	Stainless Flange Bolts	Organic Zinc	Exposed
5-3	Stainless Flange Bolts	MIL-C-16173-2	Exposed
5-4	Stainless Flange Bolts	None	Sheltered
5-5	Stainless Flange Bolts	Organic Zinc	Sheltered
5-6	Stainless Flange Bolts	MIL-C-16173-2	Sheltered

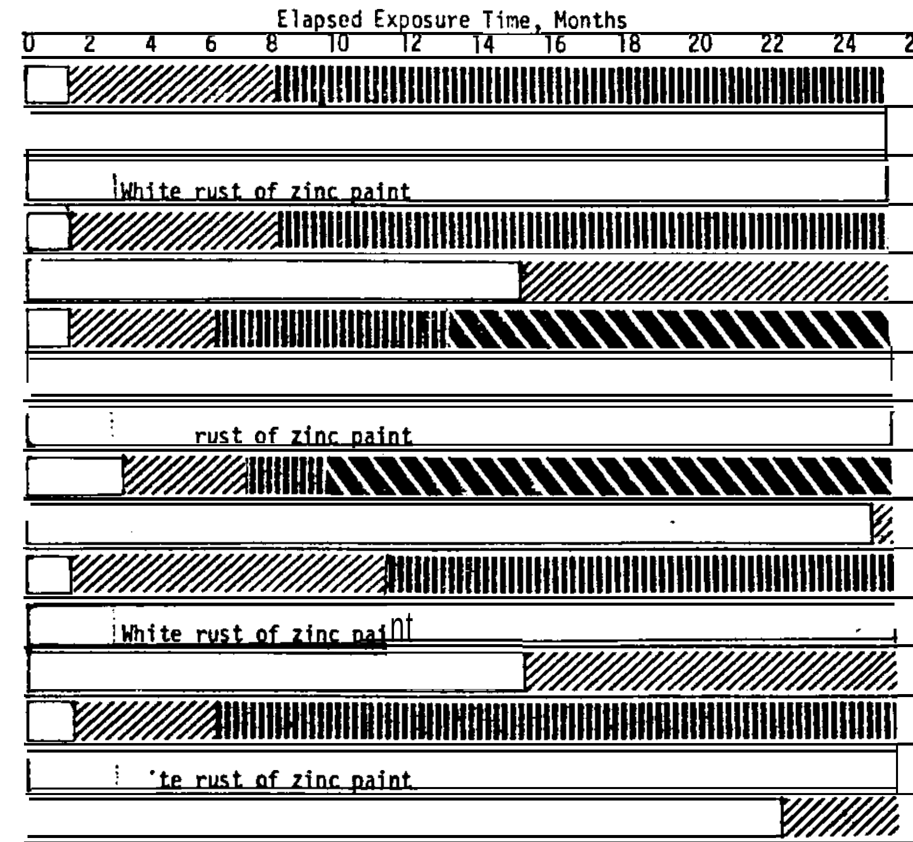
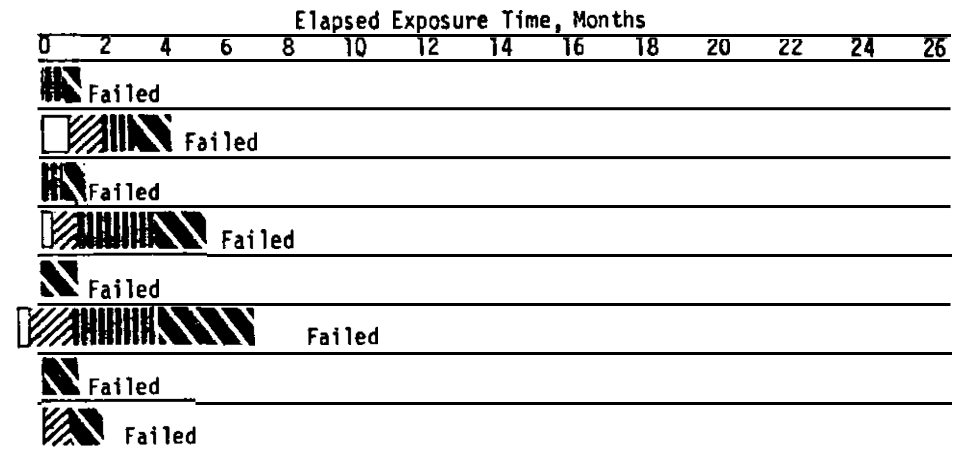


Figure 2 (Continued)

Sample Code	Test Specimens	Treatment	Exposure	Elapsed Exposure Time, Months (0 2 4 6 8 10 12 14 16 18 20 22 24 26)
6-1	Steel Cables	None	Exposed	Failed
6-2	Steel Cables	MIL-C-16173-4	Exposed	Failed
6-3	Steel Cables	MIL-G-81322	Exposed	
6-4	Steel Cables	None	Sheltered	Failed
6-5	Steel Cables	MIL-C-16173-4	Sheltered	Failed
6-6	Steel Cables	MIL-G-81322	Sheltered	
7-1	Piano Hinge	None	Exposed	Failed
7-2	Piano Hinge	MIL-C-16173-3	Exposed	Failed
7-3	Piano Hinge	LPS-1	Exposed	Failed
7-4	Piano Hinge	None	Sheltered	Failed
7-5	Piano Hinge	MIL-C-16173-3	Sheltered	Failed
7-6	Piano Hinge	LPS-1	Sheltered	Failed
8-1	Turnbuckles	None	Exposed	White rust of galvanizing
8-2	Turnbuckles	MIL-C-11796	Exposed	White rust of galvanizing
8-3	Turnbuckles	MIL-C-16173-2	Exposed	White rust of galvanizing
8-4	Turnbuckles	MIL-T-5544	Exposed	White rust of galvanizing
8-5	Turnbuckles	None	Sheltered	White rust of galvanizing
8-6	Turnbuckles	MIL-C-11796	Sheltered	e rust of galvanizing
8-7	Turnbuckles	MIL-C-16173-2	Sheltered	ust of galvanizing
8-8	Turnbuckles	MIL-T-5544	Sheltered	White rust of galvanizing

Figure 2 (Continued)

Sample Code	Test Specimens	Treatment	Exposure
9-1	Carbon Steel Rods	None	Exposed
9-2	Carbon Steel Rods	MIL-C-16173-2	Exposed
9-3	Carbon Steel Rods	LPS-1	Exposed
9-4	Carbon Steel Rods	MIL-L-46010	Exposed
9-5	Carbon Steel Rods	None	Sheltered
9-6	Carbon Steel Rods	MIL-C-16173-2	Sheltered
9-7	Carbon Steel Rods	LPS-1	Sheltered
9-8	Carbon Steel Rods	MIL-L-46010	Sheltered



LEGEND

A. No corrosion.

B. Corrosion initiation; early stage of pitting or general corrosion.

C. Extensive corrosion - advanced stage of B.

D. Severe corrosion - part still marginally serviceable.

E. Failed Corroded to extent that part is no longer serviceable.

F. White rust Corrosion of zinc coating, but no corrosion of ferrous base metal.

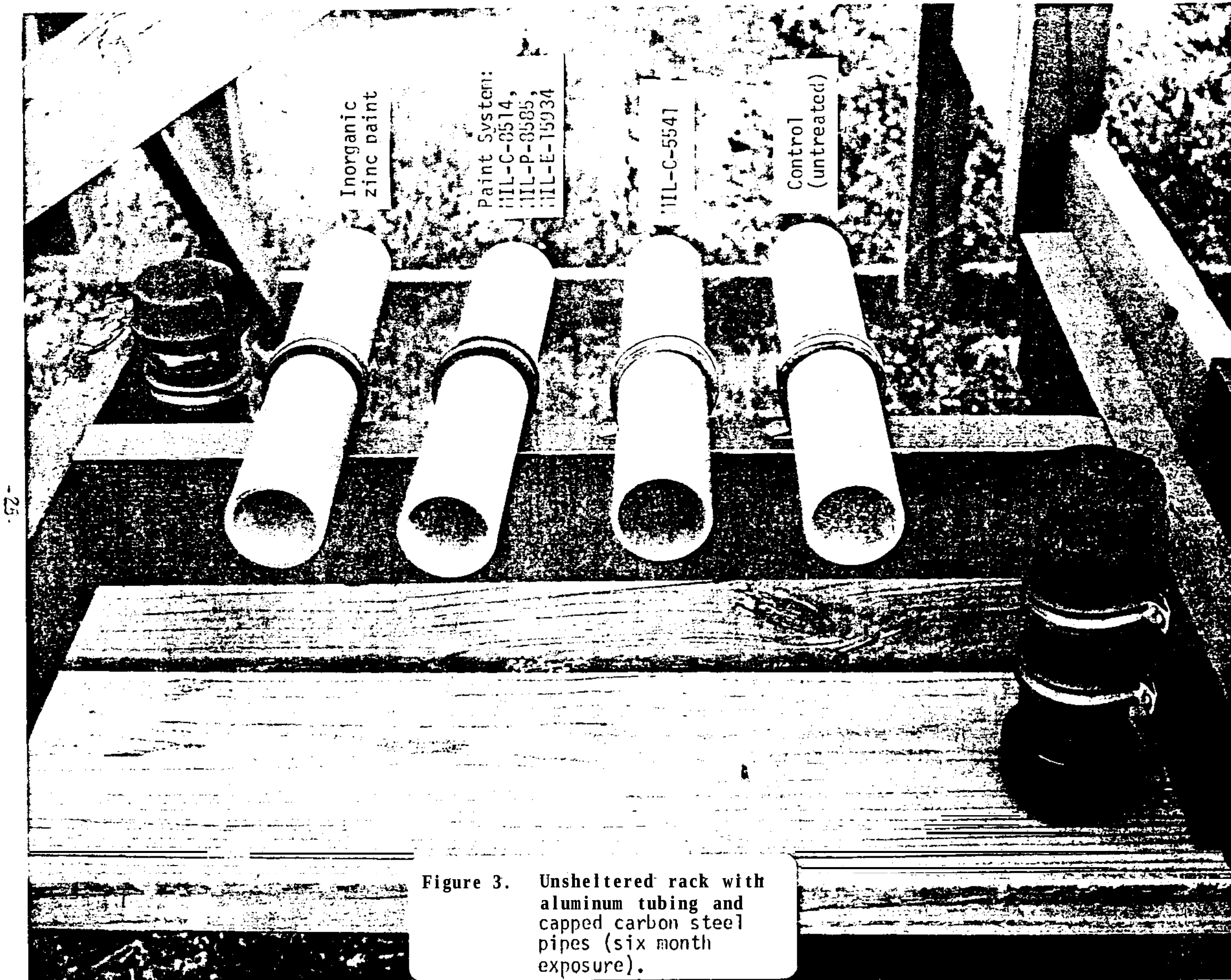


Figure 3. **Unsheltered rack with aluminum tubing and** capped carbon steel pipes (six month exposure).

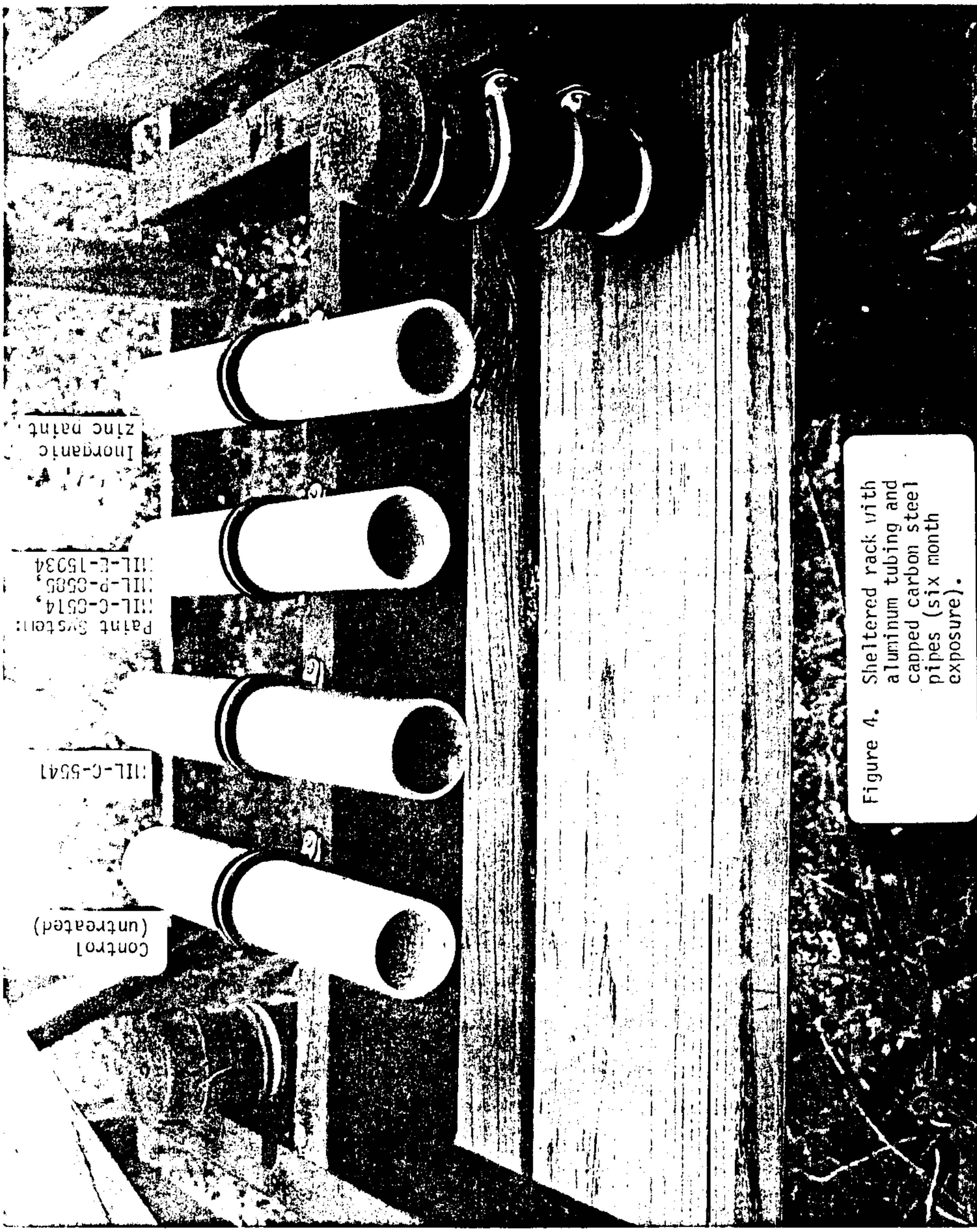


Figure 4. Sheltered rack with aluminum tubing and capped carbon steel pipes (six month exposure).

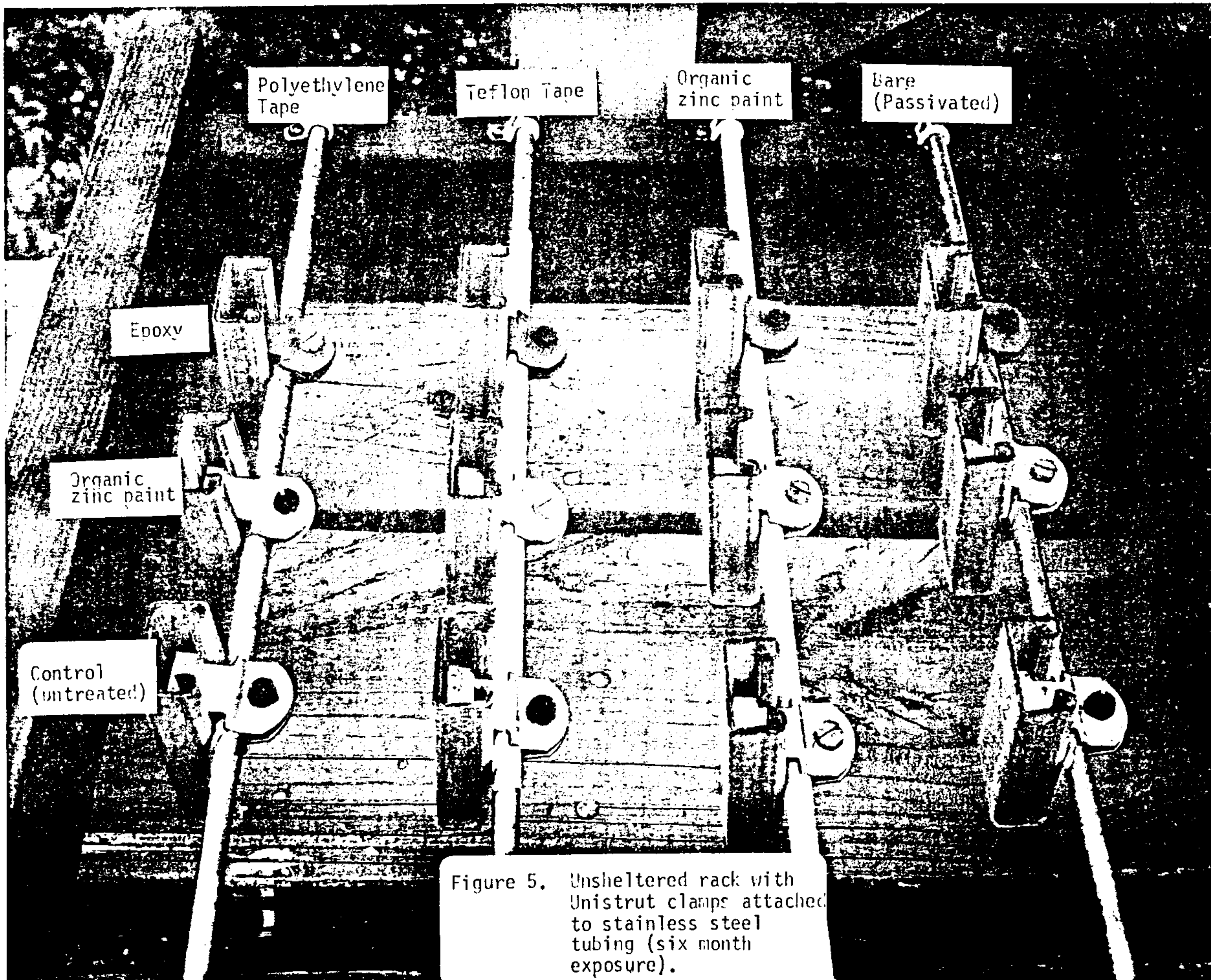


Figure 5. Unsheltered rack with Unistrut clamps attached to stainless steel tubing (six month exposure).

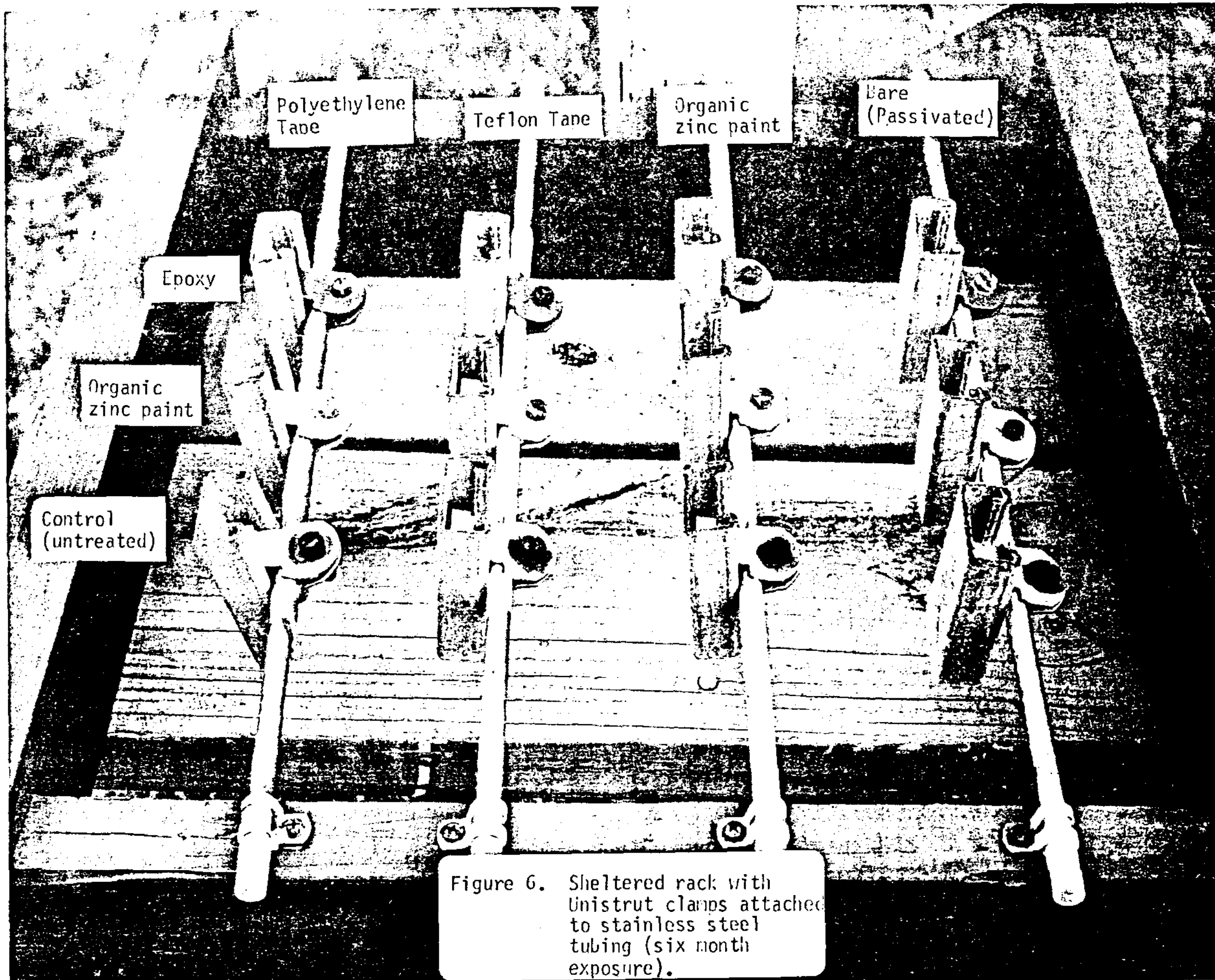


Figure 6. Sheltered rack with Unistrut clamps attached to stainless steel tubing (six month exposure).

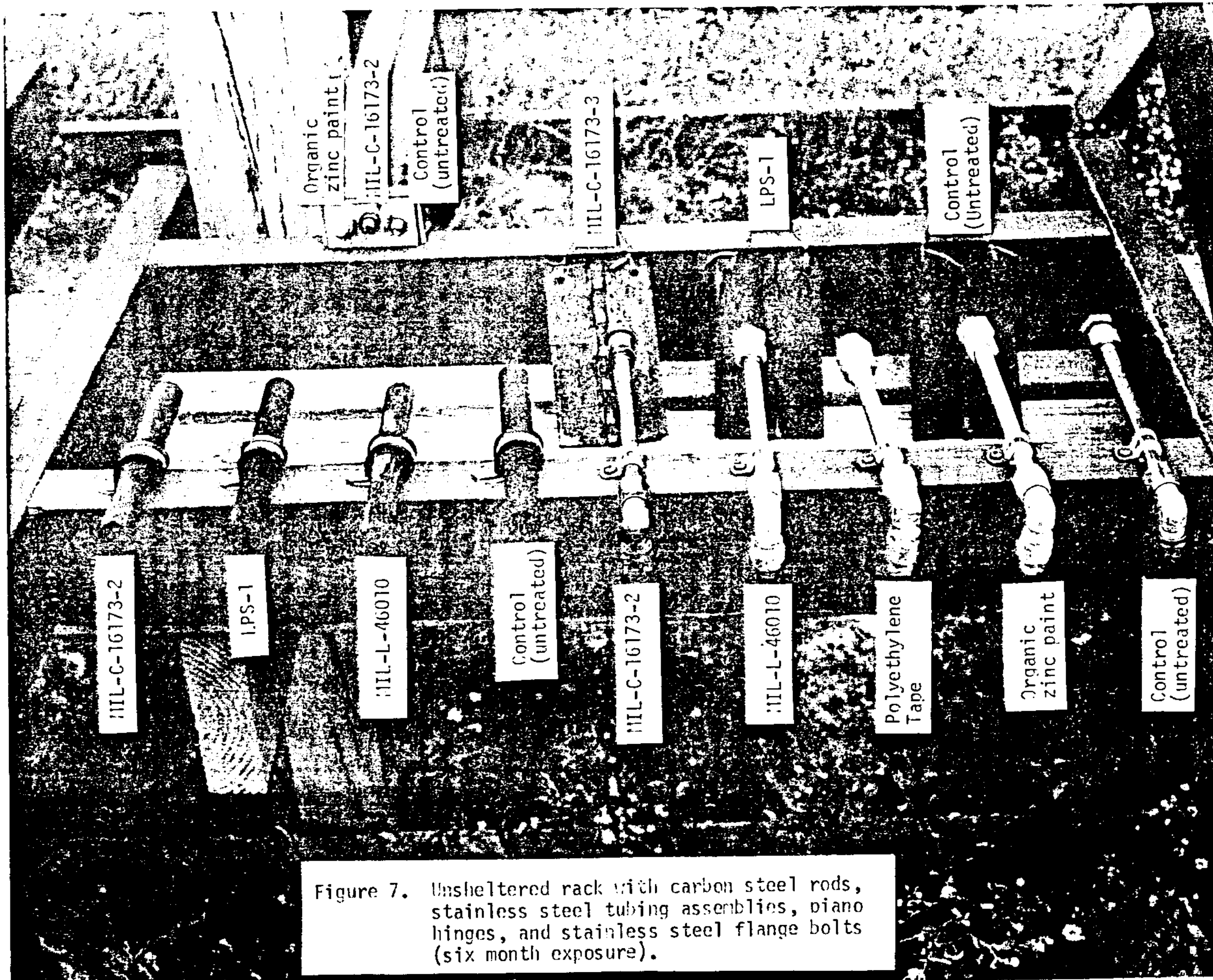


Figure 7. Unsheltered rack with carbon steel rods, stainless steel tubing assemblies, piano hinges, and stainless steel flange bolts (six month exposure).

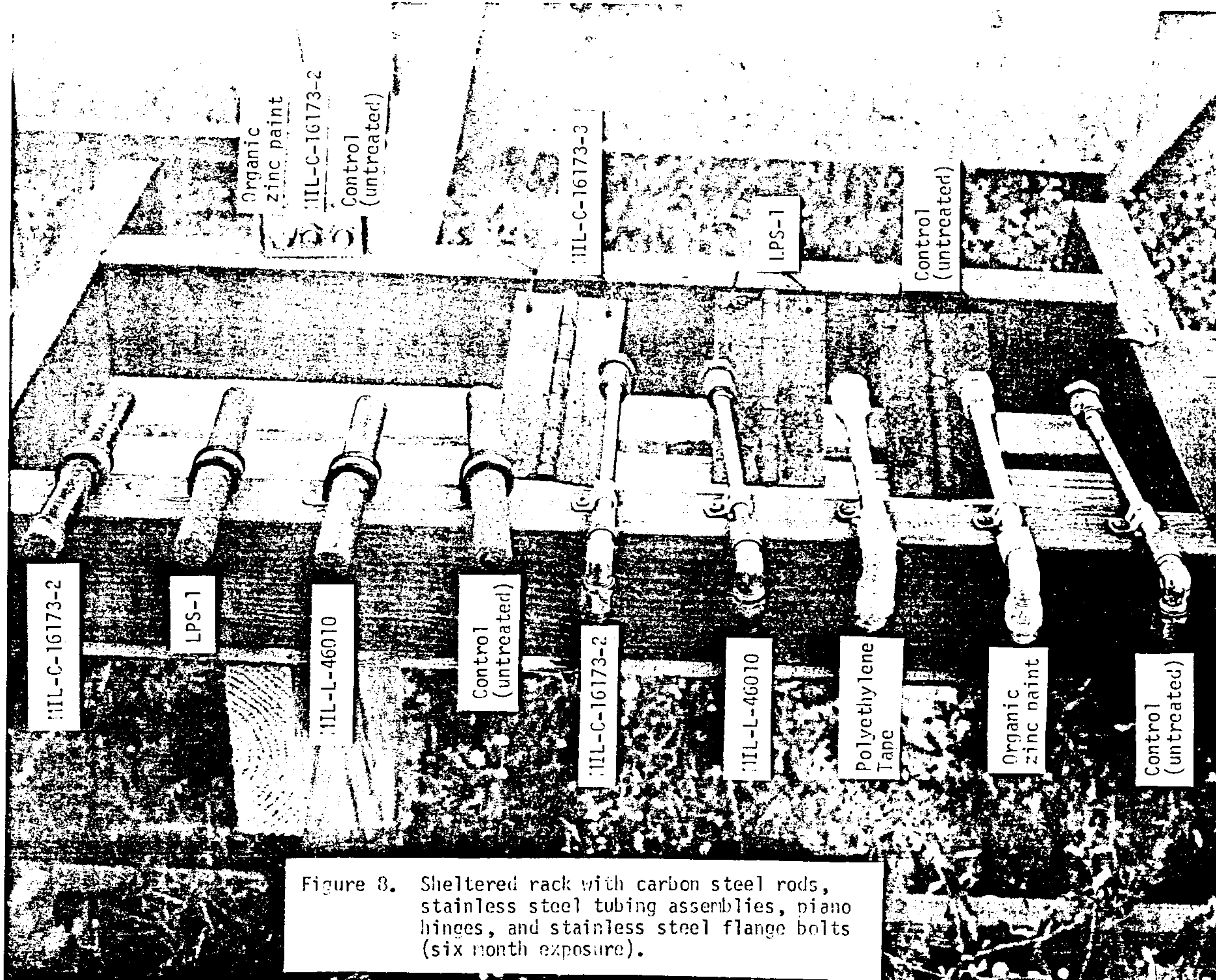


Figure 8. Sheltered rack with carbon steel rods, stainless steel tubing assemblies, piano hinges, and stainless steel flange bolts (six month exposure).

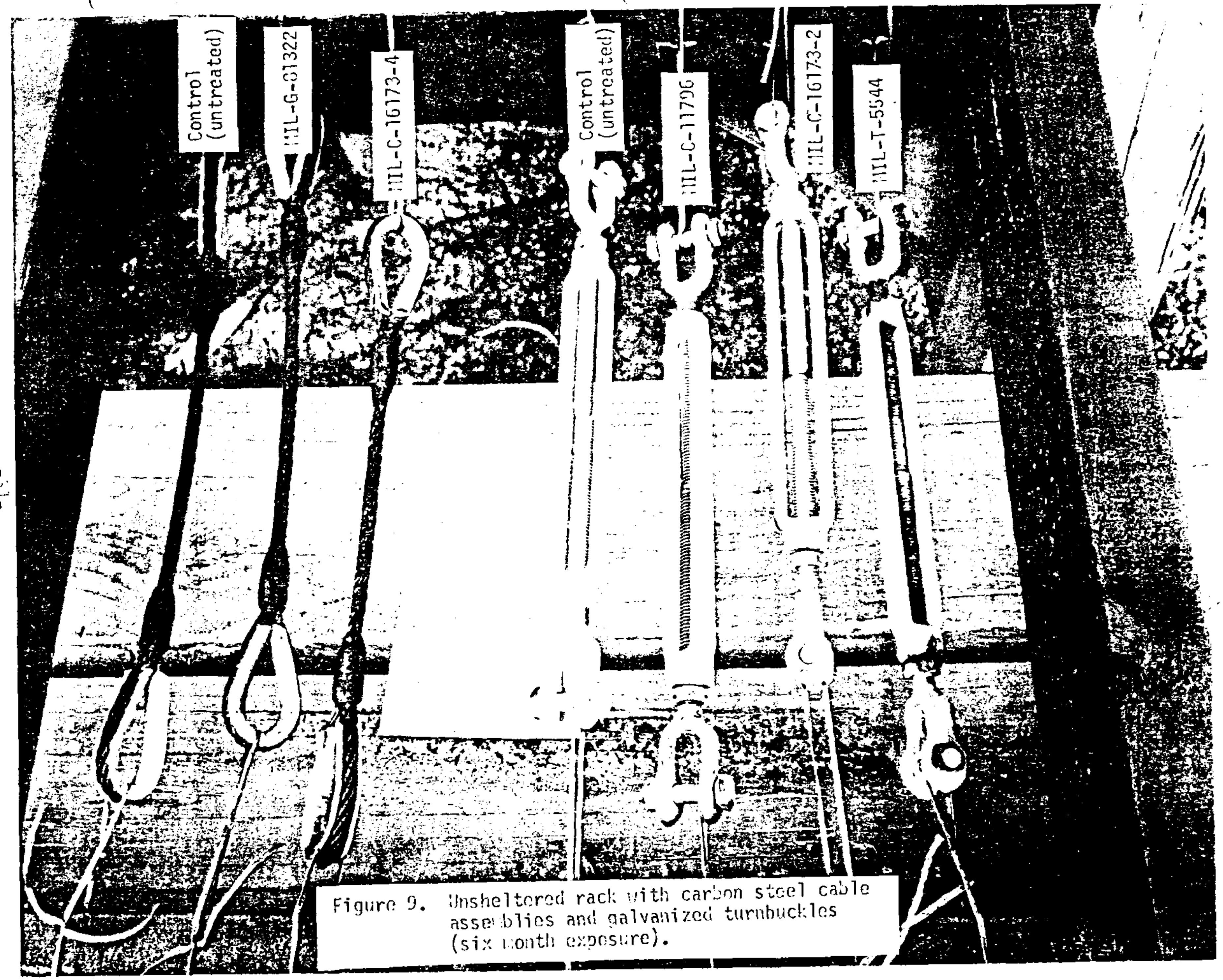


Figure 9. Unsheltered rack with carbon steel cable assemblies and galvanized turnbuckles (six month exposure).

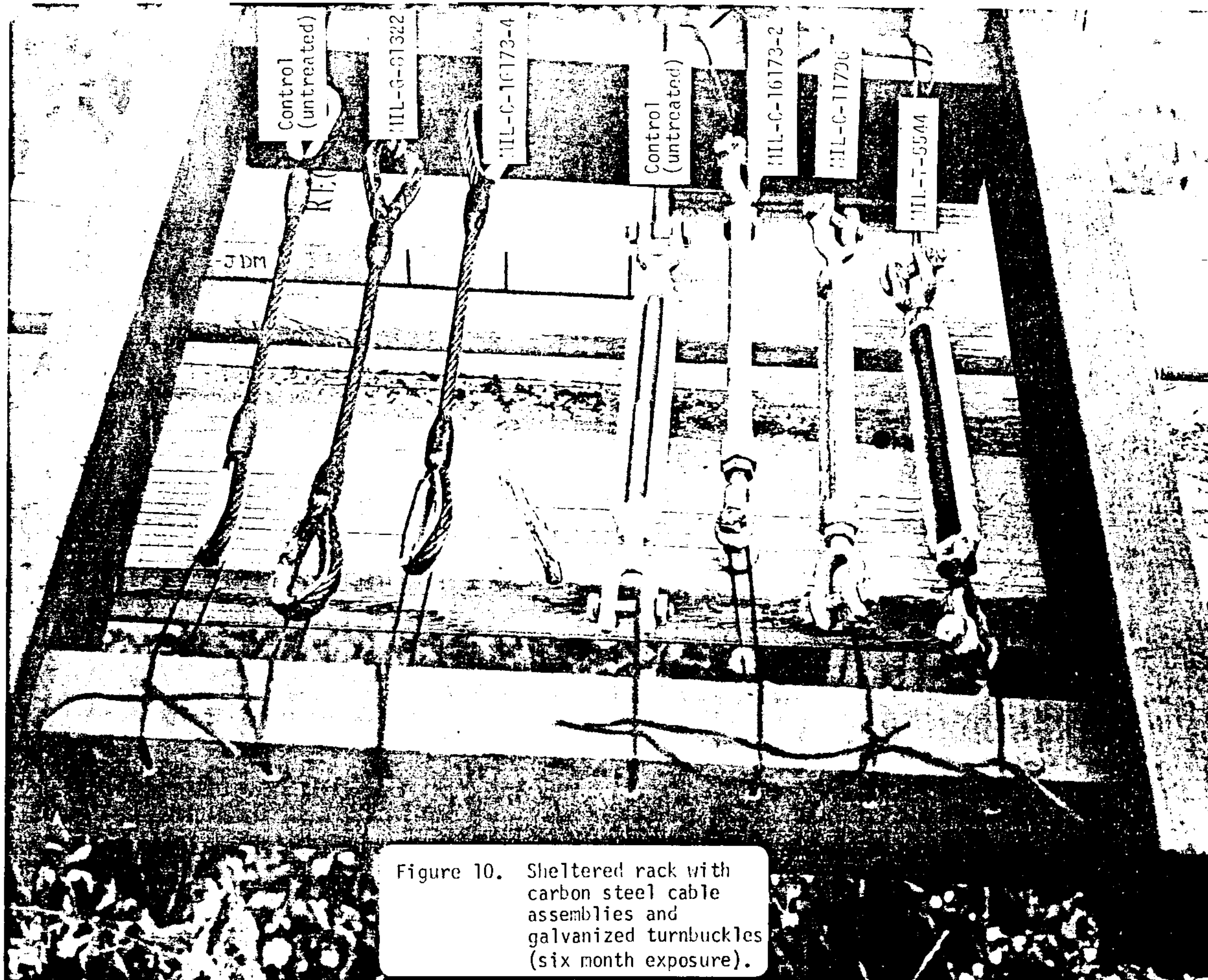
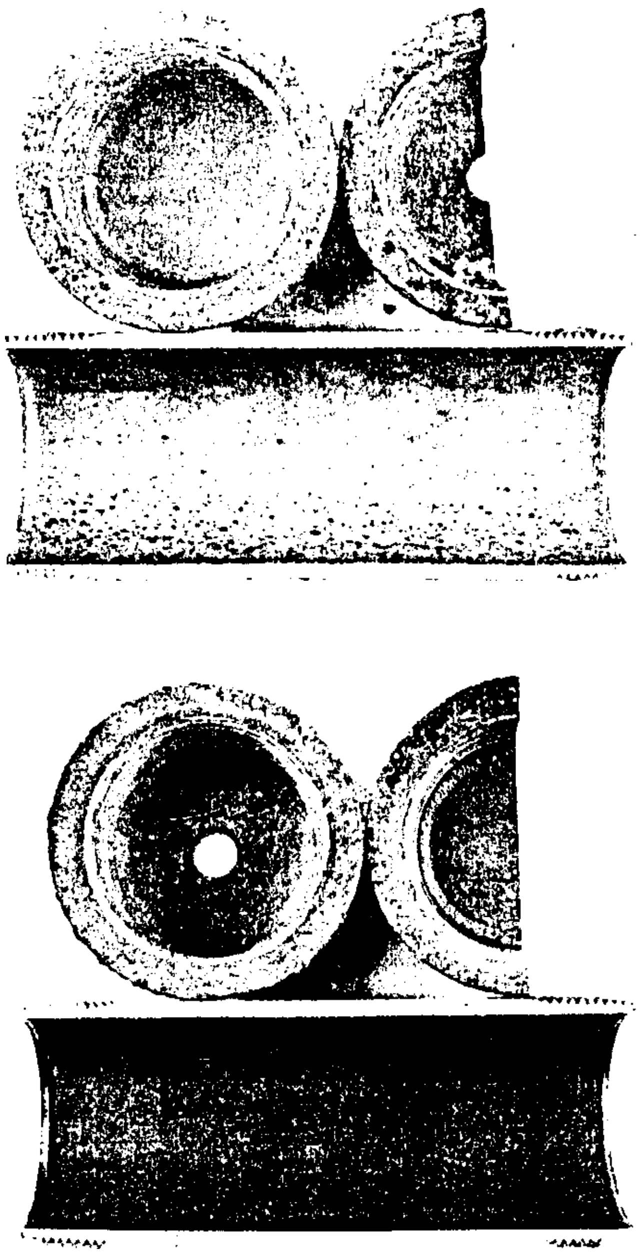


Figure 10. Sheltered rack with carbon steel cable assemblies and galvanized turnbuckles (six month exposure).



Control
(untreated)

MIL-L-46002

Figure 11. Interior surfaces of capped carbon steel pipe assemblies from sheltered rack (two year exposure)

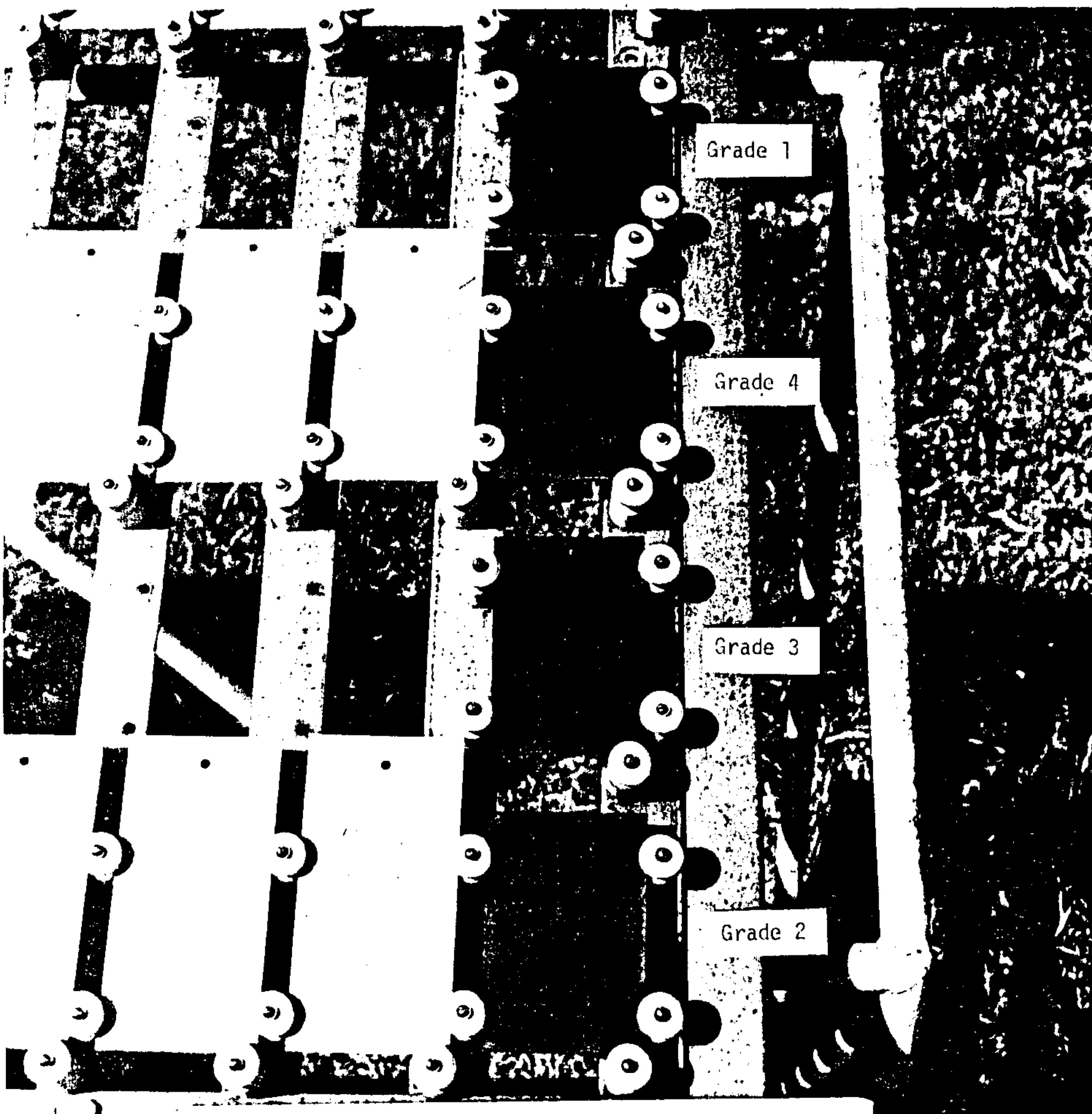


Figure 12. Unsheltered carbon steel panels coated with four grades of compound MIL-C-16173; after beach exposure for approximately six months.

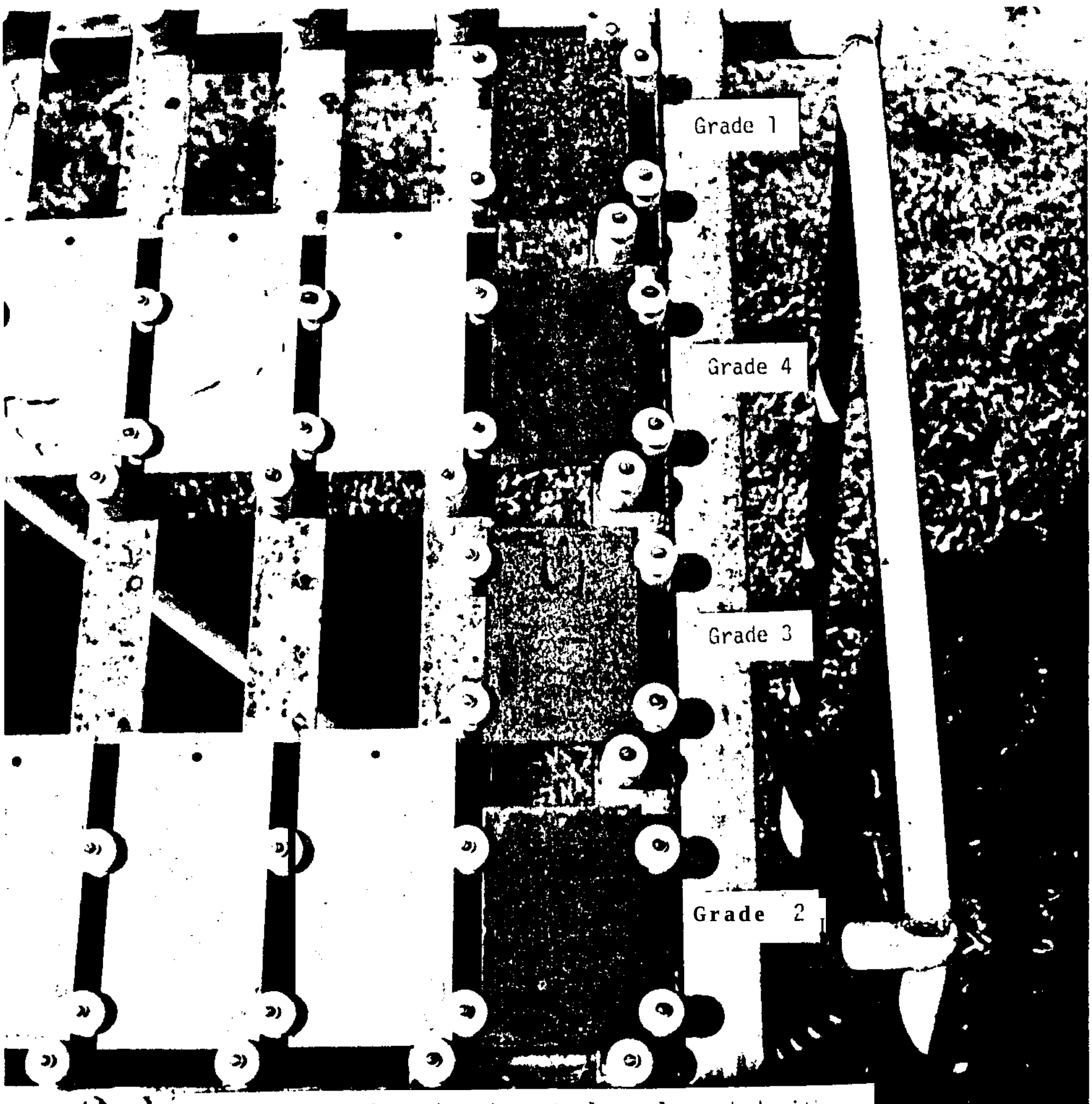


Figure 13. Sheltered carbon steel panels coated with four grades of Compound MIL-C-16173; after beach exposure for approximately six months.

Figure 14. Carbon steel and stainless steel panels coated with Goodrich Aerocoat AR-7, after approximately six months beach exposure.