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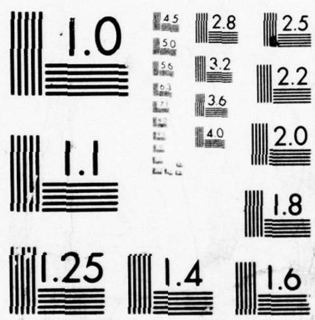
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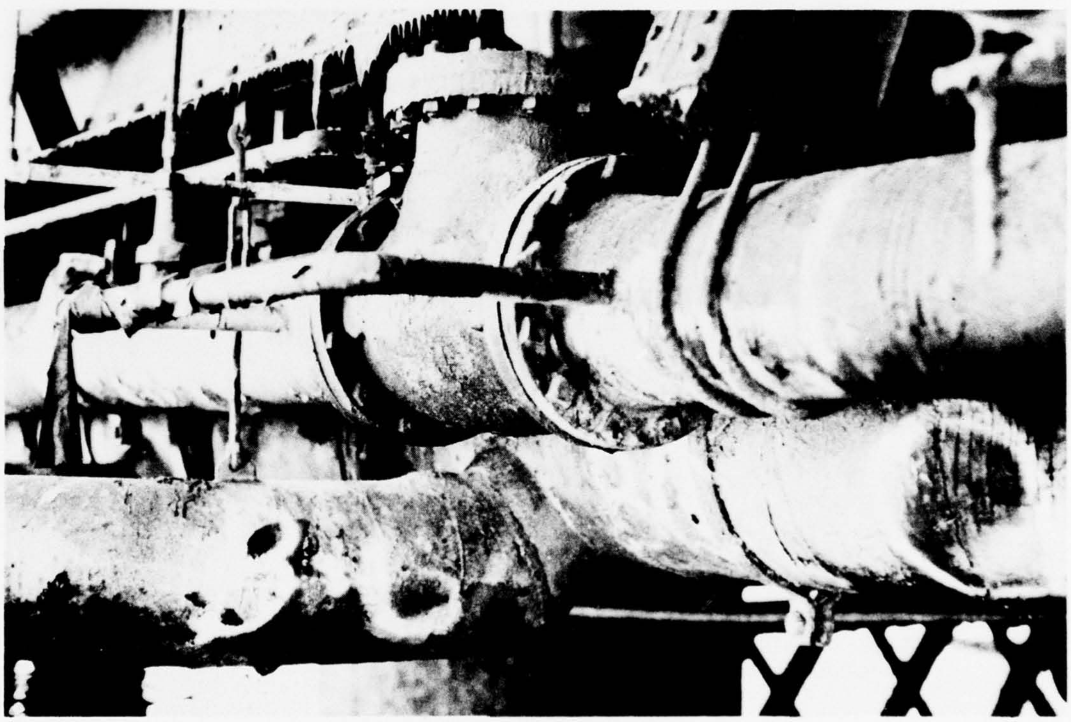

CORROSION PROTECTION OF EXISTING UTILITY LINES UNDER PIERS AND WHARVES - RESULTS OF 3 YEARS OF MARINE ATMOSPHERIC EXPOSURE

by E. S. Matsui

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Most utility lines under piers and wharves are made of iron or galvanized steel which become badly corroded when exposed to severe marine environment. The problem is compounded because of the difficulty of preparing good surfaces of these lines before coating because of their location and shape. CEL is investigating new and improved coating systems that can tolerate minimum surface preparation, extend the service life, and reduce

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1. Utility lines 2. Corrosion protection I. YF54.593.012.01.003

Most utility lines under piers and wharves are made of iron or galvanized steel which become badly corroded when exposed to severe marine environment. The problem is compounded because of the difficulty of preparing good surfaces of these lines before coating because of their location and shape. CEL is investigating new and improved coating systems that can tolerate minimum surface preparation, extend the service life, and reduce the maintenance cost. Various coating systems were subjected to 3 yr of in-service and atmospheric exposure tests. Of these systems, the grease-impregnated tape, Denso tape, was found to provide the best protection against corrosion attack under piers.

CONTENTS

INTRODUCTION AND BACKGROUND

Most utility lines under piers and wharves are made of steel or galvanized steel. These underpier lines are not only subjected to high humidity and salt spray but are intermittently submerged in saltwater at high tide in many areas. They soon become badly corroded, resulting in high maintenance or replacement costs. Maintenance problems are compounded because of the difficulty of preparing a good surface before recoating. In many cases, the maze of pipe lines (Figure 1) makes the area inaccessible for sandblasting; in addition, the area is accessible only during low tide.

A coal-tar felt-wrapped coating system (NAVFAC specification TS-15057, formerly 34Y) is normally specified for the protection of pipelines under piers at Navy installations. However, the Navy has experienced many corrosion problems that have required costly maintenance on the coal-tar felt-wrapped fuel lines under piers. The weathered and deteriorated felt wrappings retain moisture and corrosive elements that promote rather than protect the fuel lines from corrosion. The felt cover also hides the condition of the pipe, often necessitating replacement of the whole pipe by the time deterioration is detected. The coal-tar felt-wrapping system is formulated for shop application. It is extremely difficult to apply this type of coating system on existing utility lines under piers; the felt wrapping must be applied under constant tension, with a machine, and at a specified temperature to provide a smooth, uniform, and securely bonded wrapper without air pockets. The coating specification requires that the quality of the resulting protection must be equal to that produced in the shop, although applied in the field. Such a requirement is extremely difficult to meet under most field conditions. The Civil Engineering Laboratory (CEL) has received many calls requesting assistance regarding use of some alternative protective coating.

Previously, CEL conducted a field experiment on performance of various coating systems for protection of existing fuel lines under piers at the Point Loma Annex, San Diego, Calif. Inplace test sections of 14 different coating systems were installed, and their performances were evaluated.* The surface was sandblasted, but during the coating application it was noted that obtaining a good surface prior to the recoating operation was difficult. Flush rust appeared soon after the sandblasting because of seawater spray; thus, the sandblasted surface was generally less than satisfactory for recoating. The poor surface preparation appeared to cause premature failure of some of the coatings tested. The difficulty of obtaining good surface preparation under piers seems to be a problem common to many Naval facilities.

To remedy these coating problems, CEL had initiated an investigation of new and improved coating systems that can tolerate minimum surface

*Civil Engineering Laboratory. Technical Report R-832: Protection of Existing Fuel Lines Under Pier at Point Loma Annex, by E. S. Matsui. Port Hueneme, Calif., Dec 1975.

preparation, extend the service life of utility lines, and reduce the maintenance cost significantly.

This report describes the coating materials investigated, test procedures, and the results of 3 yr of marine atmospheric exposure and field experiments.

COATING MATERIALS INVESTIGATED

Coating systems were selected for this investigation based on certain criteria. These coatings presumably would perform well: (1) without requiring a sandblasted surface; (2) if applied to wire-brushed rusty surfaces, preferably in one application; and (3) under extremely corrosive underpier marine atmospheric environments. The goal of this project was to find a coating that would extend the average life of utility lines under piers and wharves by about 20%.

A number of coating manufacturers were contacted for information about protective coatings which might meet the above criteria. Most of them were reluctant or declined to recommend any of their coatings, stating that coatings applied under the above conditions would have no more than cosmetic value or that the service life of a coating would be severely reduced under such conditions. Very few manufacturers were willing to participate in the experiment. Coating descriptions and minimum surface preparations according to the manufacturers of those systems submitted for testing are given below and summarized in Table 1, which also includes the names and addresses of the suppliers.

<u>Astrol RP Extra:</u> This coating is a metallo-organic complex combined with a rust inhibitor, petroleum waxes, and volatile solvents. It meets the requirements of Military Specification MIL-C-83933, Grade 1, for corrosion preventive compound. Special preparation of a surface is not required aside from removing all loose foreign material. Neither sandblasting nor steam-cleaning the surface before application is necessary. It may be applied to a wet surface and directly on top of tightly adhering rust. A wet film of 5 to 6 mils (127 to 152 μm) total thickness is recommended for proper dry-film thickness.

<u>Carbomastic X2256-138:</u> This coating is an aluminum-filled, coal-tar epoxy. Special preparation of the surface is not required aside from removing all loose rust, barnacles, and other foreign matter with a wire brush. A primer is not required, and the coating can be applied on the surface above or below the waterline. A wet film of 10- to 120-mil (254- to 3,175-μm) thickness is applied as the environment may require.

<u>Rust-Ban EX6692:</u> This polyamide-cured, coal-tar epoxy coating does not require a primer. Surface preparation by power tool is acceptable for most cases, but sandblasting is required for immersion service. A wet-film thickness of 10 to 14 mils (254 to 355 μm) minimum is required in order to achieve the recommended dry-film thickness of 5 to 7 mils (127 to 177 μm).

<u>MIL-P-24441:</u> This government specification coating was included in this study as a control standard. It was developed by the Mare Island Paint Laboratory for long-term corrosion protection of exterior and interior ship surfaces. This epoxy-polyamide coating system, consisting of a primer and two topcoats, has excellent wetting ability, and is tolerant to cold, damp, and difficult-to-clean surfaces. Recommended total dry-film thickness is 7 to 9 mils (177 to 228 μm).

Table 1. Descriptions of Coatings, Their Sources, and Thickness

Coating	Generic Type	Number of Coats	Finished Coat Thickness [mils (μm)]	Sources
Astro RP Extra	Petroleum wax	2	5-8 (127-203)	Imperial Oil & Grease Co. 6505 Wilshire Blvd Los Angeles, CA 90048
Carbomastic X2256-138	Aluminum coal-tar epoxy	1	10-30 (254-762)	Carboline Company 328 Hanley Industrial Ct St. Louis, MO 63144
Rust-Ban EX6692	Coal-tar epoxy	1	7-15 (177-381)	Enjay Chemical Company 8230 Stedman St Houston, TX 77029
MIL-P-24441	Epoxy-polyamide			Pro-Line Paint Company 2646 Main St San Diego, CA 92113
F-150 primer		1	2 (50)	
F-151 finish		1	2-3 (50-76)	
F-154 finish		2	4-5 (101-127)	
		4	8-10 (203-254)	
Denso Tape	Fabric reinforced petrolatum tape			Unico Engineering, Inc. P. O. Box 12125 El Paso, TX 79912
Primer paste		1	5-10 (127-254)	
Tape		1	40-50 (1016-1270)	
		2	45-60 (1143-1524)	
Plicoflex Tape	Butyl rubber-laminated PVC tape			Plicoflex, Inc. 2425 Mowery Road P. O. Box 45829 Houston, TX 77045
Adhesive primer		1	5-10 (127-254)	
PVC tape		1	30 (762)	
		2	35-40 (889-1016)	
Poly-mastic #455	Synthetic rubber	1	10-20 (254-508)	Plicoflex, Inc. 2425 Mowery Road P. O. Box 45829 Houston, TX 77045

Denso Tape: This product differs from other coatings in that it is a fabric-reinforced petrolatum-impregnated tape. The fabric is woven cotton or synthetic fibers. The petrolatum used is a green jelly obtained from the refining of certain nonasphaltic crude oils and compounded with inert siliceous fillers and corrosion inhibitors. A typical thickness of a petrolatum-coated tape is 45 mils (1,143 μm). A petrolatum primer (Denso Paste) is recommended to insure complete bonding of the tape, particularly where the tape is being applied to an irregular surface. The tape is hand-applied. With a special technique, pipes can be wrapped under water with this tape. No special surface preparation is required; wire brushing is adequate in most cases.

Plicoflex Tape: This material is a butyl rubber-laminated poly(vinyl chloride) (PVC) wrapping tape. The wrapping tape is available in various thicknesses with a minimum of 7 mils (177 μm) of butyl rubber plus the thickness of PVC tape - 8 mils (203 μm) and above. This product is not pressure-sensitive and requires an adhesive primer to assure good bonding between the metal and the tape. The primer contains rust and fungus inhibitors. A bright metal surface is not necessary before application, and the tape can be applied with a wrapping machine or by handwrapping. Firm tension must be maintained during application in order to obtain best results. Because the PVC tape is not soft or flexible enough to conform to the irregular surface, the same manufacturer supplied Poly-mastic #455 coating for fittings and other odd-shaped items, such as flanges and bolt heads. The Poly-mastic #455 consists of synthetic rubber, selected asphaltum, cumar resins, inert fibers, and corrosion inhibitor; it can be applied on moist or damp wire-brushed steel surfaces.

TEST CONDITIONS

In-Place Field Exposure at Pearl Harbor, Hawaii

Experimental Site. The field experiment with the coatings was conducted at the V-4 fuel pier, Pearl Harbor Naval Base. The V-4 fuel pier is located at the south end of the Pearl City peninsula where it extends into Pearl Harbor. The fuel lines under the V-4 pier were located approximately 3 ft (0.9 m) above the waterline at low tide (Figure 2) and were constantly receiving salt-spray carried by the prevailing east-northeast wind. The fuel lines are frequently submerged during high tides or under large waves created by passing ships in the harbor. Base personnel considered the V-4 fuel pier the most corrosion prone and difficult to maintain among all the fuel piers located at Pearl Harbor.

Surface Preparation. Prior to the coating application, the surface of the old and corroded 10-in.-OD (25.4-cm) fuel lines were wire-brushed to remove loose rust and scale. The workers labored under difficult working conditions and were required to use a small raft under the pier to perform their work. The small 3 x 10-ft (0.91 x 3.05-m) raft provided extremely poor footing during surface preparation and painting because of constant swaying caused by the choppy waves. Also, the low ceiling prevented the workers from standing. Wire-brushing of the bottom side of the pipes was particularly difficult under such working conditions. The resulting surface preparation was, therefore, much less than desirable for a normal coating application.

Coating Application. Five coatings (MIL-P-24441, Astrol RP Extra, Rust-Ban EX6692, Carbomastic X2256, and Poly-mastic #455) and two tapes (Denso and Plicoflex) were applied on the wire-brushed fuel lines. All coatings and tapes were applied on the designated areas according to the direction given by each supplier. Each coating or tape was applied on 20-ft (6.1-m) sections of the pipelines (Figure 2). All paints were applied without much difficulty.

Wrapping of the pipe with Plicoflex tape while applying constant tension, to avoid wrinkling or trapping of air under the tape, was difficult under the field working conditions. The wrinkles or air pockets, once formed, could not be eliminated by hand pressure and necessitated unwrapping and rewrapping of the pipe to correct these conditions. The adhesive primer, applied prior to application of the Plicoflex Tape, dried too quickly (sometimes before the wrapping was completed); often a second primer application was required to assure bonding of the plastic tape to the steel pipes.

In comparison, the inexperienced workers found the grease-impregnated tape (Denso tape) was much easier to apply on the wire-brushed pipes than was the plastic-laminated tape (Plicoflex). Trapped air pockets or wrinkles could be removed easily by hand pressure alone.

After coating was completed, each coated section was photographed.

Marine Atmospheric Exposures at Three CEL Exposure Sites

CEL Exposure Sites. The coated short pipe specimens, prepared as described later, were exposed to the marine atmospheric environments at three geographical locations: Port Hueneme, California; Kaneohe, Hawaii; and Kwajalein, Marshall Islands. Each location presents different combinations of weathering factors (such as rainfall, temperature, humidity, solar radiation, wind, and sea-spray) in varying intensities and duration; thus, they provide an opportunity for simultaneous exposure studies of identical coatings under differing conditions at the three different geographical locations.

1. Kwajalein - Kwajalein is located near the center of the tropical zone at lat. 8°44" N. The exposure racks are about 50 ft (15.2 m) from the surfline at high tide and hold the pipe specimens at a 35-deg angle to the horizontal, facing east-northeast (Figure 3). The prevailing east-northeast wind carries large amounts of sea-spray to the specimens. Rainfall is plentiful, averaging over 10 in. (24.5 cm)/mo. during 8 mo. of the year. Total annual rainfall is about 105 in. (266.7 cm)/yr. The annual average temperature range is 81F to 83F, and wind velocity is about 8 to 21 mph (34 kph).

2. Kaneohe - The exposure racks at Kaneohe face east-northeast into the prevailing wind and are about 100 ft (30.4 m) from the surf at high tide and up a knoll about 15 ft (4.6 m) above sea level. The pipe specimens were placed at a 45-deg angle to the horizontal. The wind often carries small amounts of fine sand, bringing a slight abrasive action to the coating surfaces. This test area is at lat. 21°21" N near the northern edge of the tropical zone (the Tropic of Cancer is lat. 23°27" N). The Kaneohe test site has a slightly greater variation in temperature than does Kwajalein with the average annual temperature ranging between 73F and 79F. The monthly rainfall varies from 1 to 9 in. (2.54 to 22.9 cm); the annual total averages about 43 in. (109 cm).

3. Port Hueneme - The corrosion dock is located in Port Hueneme harbor. Port Hueneme is at lat. 34°7" N (10°40" N of the Tropic of Cancer). The annual average rainfall is about 13 in. (33 cm) and arrives during 5 mo. in the winter. The average annual temperature is from 51F to 65F. One of the duplicate pipe specimens was suspended from the corrosion dock above the high-tide level so that it would not be submerged but always subjected to splashing of seawater. The other duplicate specimen was suspended below the high-tide level so that it would be alternately exposed to the atmosphere during low tide and submerged in seawater during high tide (Figure 4).

Sample Preparation. For the marine atmospheric exposure at three CEL test sites, short steel pipe - 4-in. (10.2-cm) OD - with flange joints, bolts, caps, and split-ring hinged pipe hangers were assembled, simulating utility pipe under piers. Before coating, these pipe specimens were soaked in seawater once a day (Figure 5) and exposed to the air. This pre-rusting procedure was repeated every day for 2 wk to obtain a uniform rusting of the pipe specimens. Half of each pipe specimen was then sandblasted, and the other half was wire-brushed. Each coating or tape was then applied on both sandblasted and wire-brushed surfaces according to the instruction provided for each coating system.

The coated pipe specimens in duplicate were either placed on exposure racks at the three CEL atmospheric test sites or suspended from the corrosion dock at Port Hueneme as described.

Inspection

The in-place test sections at Pearl Harbor and test specimens at the three CEL exposure sites were photographed immediately after installation. The first visual inspection was conducted after 6 mo. of exposure. Thereafter, annual inspections were made during the 3 yr of exposure. The coated test sections or specimens were evaluated subjectively and comparatively to describe their initial and weathered conditions. Rust, blisters, and any other corrosion products on the surface, as well as conditions of the coatings, were noted. Corrosion and deterioration of a coating rarely occurs uniformly over an entire coated surface; therefore, the overall condition of each coating system was rated subjectively as excellent (in essentially the same condition as when first placed in service); good (very minor deterioration); fair (a significant amount of coating deterioration but still in serviceable condition); or poor (rusting and coating deterioration serious enough to lead to early removal or recoating). The overall condition of each coating system was rated; Table 2 summarizes the results.

RESULTS

Astro RP Extra

Pearl Harbor. The coating was relatively easily applied (Figure 6) and was protecting the fuel line under the V-4 pier satisfactorily during the first 12 mo of exposure except for some of the localized rusting at the bottom of the fuel line where moisture and sea-spray condensed daily. However, the coating deteriorated rapidly thereafter. Approximately 70% of the pipe surface was covered with red rust after 2 yr of exposure. The coating was in such poor condition (Figure 7) that the pipeline was recoated with other paint to prevent undue damage to the fuel line before the 3 yr of exposure was completed. Overall

Table 2. Tape and Coating System Performance at Pearl Harbor, Kwajalein, Kaneohe, and Port Hueneme During 3 Years of Exposure Testing

Site	Month	Performance Ratings for Following Coatings –						
		Astro RP Extra	Carbomastic X2256-138	Rust-Ban EX6692	MIL-P-24441	Denso Tape	Plicoflex Tape	Poly-Mastic #455
Pearl Harbor	6	Good	Excellent	Good	Excellent	Excellent	Excellent	Fair
	12	Fair	Good	Fair	Good to Excellent	Good to Excellent	Excellent	Fair to Poor
	24	Poor	Good	Fair	Good	Good to Excellent	Fair	Fair to Poor
	36	Poor	Fair	Fair	Fair to Good	Good to Excellent	Fair	Poor
Kwajalein	6	Poor	Good to Fair	Good	Good	Excellent	Good	Fair
	12	Poor	Fair	Fair to Good	Fair to Good	Excellent	Fair to Good	Poor
	24	Poor	Fair	Fair	Fair	Excellent	Fair	Poor
	36	Poor	Fair to Poor	Fair to Poor	Fair to Poor	Excellent	Fair	Poor
Kaneohe	6	Poor	Good	Good to Excellent	Good	Excellent	Excellent	Fair
	12	Poor	Good to Fair	Good	Fair to Good	Excellent	Good	Poor
	24	Poor	Fair	Fair	Fair	Excellent	Fair	Poor
	36	Poor	Fair	Fair	Fair	Excellent	Fair	Poor
Port Hueneme[a]	1	Good / Fair	Excellent / Good	Good / Good	Excellent / Excellent	Excellent / Excellent	Excellent / Excellent	Fair / Fair
	6	Good / Fair	Excellent / Good	Good / Good	Good / Excellent	Excellent / Excellent	Good / Fair	Poor / Poor
	12	Fair / Poor	Good to Excellent / Fair to Poor	Fair to Good / Fair	Good / Good to Excellent	Excellent / Good	Fair / Fair	Poor / Poor
	24	Poor / Poor	Good / Poor	Fair / Fair	Good / Good to Excellent	Excellent / Fair to Good	Fair / Fair	Poor / Poor
	36	Poor / Poor	Good to Fair / Poor	Good to Fair / <Fair	Fair to Good / Good to Excellent	Excellent / Fair	Fair / Fair	Poor / Poor

[a] Two ratings at Port Hueneme represent performances of specimens suspended above and below high tide water level, respectively.

performance of the Astro RP Extra was rated poor during the 3 yr of field tests at Pearl Harbor.

Kwajalein. The original coating on the pipe specimens (Figure 8) was completely gone after 6 mo of atmospheric exposure at Kwajalein (Figure 9). The specimens continued to corrode for the remaining 3 yr of exposure, and the coating offered very little protection. Overall performance of the Astro RP Extra was rated poor during the 3 yr of exposure at Kwajalein.

Port Hueneme. The coated pipe specimen suspended from the corrosion dock above the high-tide water level lost its glossy appearance after 6 mo of exposure. Thereafter, the coating rapidly eroded; rust was very much apparent after 12 mo of exposure. By the end of 3 yr of exposure, the coating was completely eroded, and the exposed metal surface was rusted and heavily pitted (Figure 10).

The coating on the specimen suspended within the intertidal zone discolored to a milky color during the first month of exposure because of the seawater absorbed by the coating during submersion. No barnacle growth appeared on the specimen during the first month of exposure, but approximately 25% of the coated surface was covered with red rust. By the end of 12 mo of exposure, the specimen was completely covered with red rust and barnacles (Figure 11). The coating offered very little protection against corrosion, and the condition of the specimen worsened throughout the remaining 3 yr of exposure. Overall performance of the Astro RP Extra was rated poor, both above and below the high-tide zone, after 3 yr of exposure at Port Hueneme.

Carbomastic X2256-138

Pearl Harbor. Carbomastic X2256-138 was a thick, viscous coating, and its application resulted in a dry coating thickness ranging from 8 to 30 mils (203 to 762 μm) (Figure 12). It provided excellent protection during the first 6 mo of exposure. After 12 mo, however, small rust spots began to appear where the coating was thin or where it had been applied over incompletely removed rust scales. Frequency of the rust spots gradually increased during the 3-yr exposure (Figure 13), particularly at the bottom of the pipe. Overall performance of this coating was rated fair after 3 yr of field exposure at Pearl Harbor.

Kwajalein. The Carbomastic X2256-138-coated specimens (Figure 14) began to show rust at irregular surfaces such as bolt heads, nuts, threaded areas, flange joint, and pipe hangers after 6 mo of exposure (Figure 15). The pipe hangers appeared to be particularly vulnerable to the corrosion attack because of the difficulty in obtaining a uniform coating thickness during the coating. Many blisters were found at the flange joint area after 2 yr of exposure. By the end of 3 yr, approximately 50% of the total surface was covered with rust and blisters (Figure 16). The coating showed very little difference in protection between the sandblasted and wire-brushed surfaces. Overall performance of the Carbomastic was rated fair to poor after 3 yr of exposure at Kwajalein.

Kaneohe. The rust began to appear first on irregular surfaces of the pipe specimens in the same pattern as that at Kwajalein, except less severely. The pipe hangers were again very vulnerable to corrosion attack because of the irregular surface. After 3 yr of exposure, approximately 30% of the surface was covered with blisters and rust (Figure 17). Overall performance of the Carbomastic coating was rated fair after 3 yr of exposure at Kaneohe.

Port Hueneme. No corrosion was noticeable on the coated pipe specimens suspended from the corrosion dock above the tidal zone during the first 12 mo of exposure. The pipe hangers were slightly stained with rust. Approximately 20% of the surface was corroded after 3 yr of exposure; most of the corrosion was limited to the pipe hangers and flange joint. Overall performance of the Carbomastic coating was rated good to fair after 3 yr of exposure above the high-tide zone at Port Hueneme.

The pipe specimen suspended below the high-tide zone was discolored to brown after 1 mo of exposure, but no rust was noticeable. Barnacles began to grow on it after 6 mo and covered nearly 80% of the surface after 12 mo of exposure. The barnacles continued to grow heavily and damaged and peeled the coating in some areas (Figure 18). Overall performance of this coating was rated poor after 3 yr of exposure below the high-tide zone at Port Hueneme.

Rust-Ban EX6692

Pearl Harbor. The pipe section coated with Rust-Ban (Figure 19) was protected well during the first 6 mo of exposure. Rust began to appear along the bottom side of the pipeline after 12 mo of exposure. Corrosion along the bottom side of the pipelines appear to be a common problem under piers due to daily condensation of moisture and sea-spray. Upper portions of the coated pipe, however, appeared to be well-protected during 3 yr of exposure (Figure 20). Overall performance of Rust-Ban was rated fair after 3 yr of exposure at Pearl Harbor.

Kwajalein. Pipe specimens with Rust-Ban (Figure 21) were protected well but quickly lost their original glossy appearance during the first 6 mo of exposure. Rust began to appear on the pipe hangers, and small localized blisters appeared at the flange joints during 12 mo of exposure. The blisters and rust continued to spread at the flange joints and pipe hangers during the remaining exposure (Figure 22). The wire-brushed area was protected nearly as well as that of the sandblasted area. Overall performance of Rust-Ban was rated fair to poor during the 3 yr of exposure at Kwajalein.

Kaneohe. Rust-Ban provided excellent protection during the first 6 mo of exposure. Blistering and rusting became quite noticeable at the flanges and hangers after 12 mo of exposure. The coating over the sandblasted areas was providing better protection than that coated over the wire-brushed areas after 3 yr of exposure. Overall performance of Rust-Ban was rated fair after 3 yr of exposure at Kaneohe.

Port Hueneme. Except for slight corrosion at the flange and hangers, the specimen suspended above the tidal zone was well-protected for the first 12 mo of exposure. Rust at the flange joints, hangers, and threaded areas became noticeable, but otherwise most of the parts were protected fairly well during the 3 yr of exposure (Figure 23). Slightly more rust showed on the wire-brushed area than the sandblasted area. Overall performance of the Rust-Ban suspended above the tidal zone was rated good to fair after 3 yr of exposure.

Very few barnacles grew on the specimen suspended below the tidal zone during the first 6 mo of exposure. By the end of 12 mo of exposure, approximately 25% of the surface (mostly at irregular surface areas such as bolt heads, flange joints, and hangers) was covered with barnacle growth. The irregular surface appeared to give better footing compared to the smooth surfaces, for the barnacles to grow (Figure 24). By the end of 3 yr of exposure, however, the entire surface was covered by the barnacles, and the extent of damage to the coating was difficult to determine. Overall performance of the Rust-Ban suspended below the high-tide zone was rated less than fair after 3 yr of exposure at Port Hueneme.

MIL-P-24441

Pearl Harbor. MIL-P-24441, used as a control standard, required a primer and two topcoats (Figure 25). Small localized rust appeared after 12 mo of exposure. Most of the rust appeared where loose rust scales had been incompletely removed or where heavily pitted surfaces prevented even coating. The rust along the bottom of the pipelines due to the daily condensation of moisture and sea-spray was noticed after 2 yr of exposure. However, this coating was providing better protection than other paints undergoing the exposure test (Figure 26). Overall performance of MIL-P-24441 was rated fair to good after 3 yr of exposure at Pearl Harbor.

Kwajalein. MIL-P-24441 coated pipes (Figure 27) soon lost their glossiness after 6 mo of exposure. After 12 mo rust appeared at the usual irregular surfaces and sharp corners, flange joints, pipe hangers, threaded areas, and bolt and nut heads. The coated specimens continued to corrode and approximately 30% to 40% of the surface was covered with rust after 3 yr of exposure (Figure 28). In contrast to other coatings being investigated, MIL-P-24441 appeared to have protected the wire-brushed rusted surface better than the sandblasted surface. Overall performance of the MIL-P-24441 was rated fair to poor after 3 yr of exposure at Kwajalein.

Kaneohe. First sign of the rust appeared at the usual irregular surfaces and sharp corners (flange joints, bolt and nut heads, pipe hangers, and threaded areas) within a year of exposure. Corrosion was much less than for specimens exposed at Kwajalein during the 3 yr of exposure. Overall performance of the MIL-P-24441 was rated fair after 3 yr of exposure at Kaneohe.

Port Hueneme. This coating maintained its glossy appearance fairly well (for 12 mo) compared to other coatings. There was a slight rusting at flange joints and coated threaded areas of the specimen suspended above the high-tide zone for 12 mo. The rusting at the flange joints gradually increased during the remaining years (Figure 29). Overall performance of MIL-P-24441 exposed above the tidal zone for 3 yr was rated fair to good.

The specimen suspended below the high-tide zone was covered with algae and a slight growth of barnacles after 12 mo of exposure (Figure 30), but there was no noticeable rust. The specimen became heavily covered with barnacles after 2 yr of exposure, but the coating was providing good protection against corrosion. The coating continued to provide good protection for the remaining 3 yr of exposure except where the coating was mechanically abraded during the exposure (Figure 31). Contrary to other coatings being tested, this coating system appears to provide better protection against corrosion for systems under water than for specimens suspended above the waterline. Overall performance of MIL-P-24441 in the intertidal zone was good to excellent after 3 yr of exposure at Port Hueneme.

Denso Tape

Pearl Harbor. Application of the Denso tape by inexperienced workers appeared to be easier than application of other types of coatings on the pipes. The finished wrapping contained 25% overlap (Figure 32); normally, 50% overlap (double wrapping) is recommended for a marine environment. The tape was adhering well to the pipe, and no loose or detached tape was noticed during the first 12 mo of exposure. A cut was made on the tape to examine the condition of the pipe under the Denso tape. The pipe appeared to be well-protected by the tape system, and no fresh red rust had appeared underneath the tape since its application.

The Denso tape continued to adhere well to the pipe and provided good protection throughout the 3 yr of exposure. Cuts were made on the tape each time the inspection was made, and no fresh rust was found under the Denso tape (Figure 33). It was interesting to note that the pipe section coated with Denso paste (primer) alone without the Denso tape was providing protection as good as or better than other paints being investigated (Figure 34). The rust found at the bottom of the pipe appeared to be due to incompletely removed loose rust scale at the time of the paste application and the daily condensation of moisture and salt-spray, which gradually eroded and penetrated the paste. Overall performance of the Denso tape system was rated good to excellent after 3 yr of exposure at Pearl Harbor.

Kwajalein. Denso tape specimens (Figure 35) gradually discolored to a darker color and displayed a somewhat dry appearance. However, closer examination indicated that the tape was dried only superficially and was retaining its softness and wettability and adhered to the metal substrate during the 3 yr of atmospheric exposure. The tape was cut and the condition under the tape was examined each time the inspection was made. Inspection revealed that the Denso tape was providing excellent protection against corrosion and showed no fresh red rust on either the sandblasted or wire-brushed surfaces (Figure 36) throughout 3 yr of atmospheric exposure. Only unwrapped pipe hangers suffered severe corrosion. Overall performance of the Denso tape was rated excellent after 3 yr of exposure at Kwajalein.

Kaneohe. The specimens in Kaneohe were discolored and exhibited a dried appearance, as did those specimens exposed at Kwajalein, but the Denso tape provided excellent protection against corrosion throughout 3 yr of atmospheric exposure. When examined each time the inspection was made, no fresh rust had appeared under the tape on either sandblasted or wire-brushed surfaces. Overall performance of the Denso tape was rated excellent at Kaneohe after 3 yr of exposure.

Port Hueneme. The Denso tape wrapped specimen suspended above the tidal zone exhibited excellent protection against corrosion. No rust was evident either on the sandblasted or the wire-brushed surfaces when a cut was made and the pipe inspected underneath the tape. Even the most difficult areas, such as at joints and bolt heads, were well protected by the Denso tape while all other coatings failed to protect (Figure 37).

During the first 6 mo of exposure, no significant change was noted on the Denso tape wrapped specimen suspended below the high-tide zone. However, the tape became soggy and appeared whitish after 12 mo of exposure. Many small barnacles began to grow on the Denso tape. The barnacles continued to grow, and the specimen was heavily covered with them after 2 yr of exposure. The grease from the tape appeared to have leached out from the tape and was soggy. The tape was loose and sagging because of the weight of the attached barnacles. Seawater was obviously penetrating through the tape to the metal underneath it. However, the metal surface appeared black and did not appear to be seriously corroded. The absence of the red rust is probably due to the lack of oxygen to support corrosion under the tape during the immersion. Slight red rust began to appear on the wire-brushed surface under the tape after 3 yr of exposure (Figure 38). Overall performance of the Denso tape was rated excellent above the tidal zone and fair below the high-tide zone after 3 yr of exposure at Port Hueneme.

Plicoflex Tape and Poly-mastic #455

Pearl Harbor. Wrapping with the Plicoflex tape (Figure 39) was much more difficult than wrapping with the Denso tape under similar working conditions. The tape (PVC) was flexible but tough and was not as easily manipulated as the Denso tape. The tape, highly resistant to moisture and sea-spray, retained its glossiness and flexibility well and showed no sign of deterioration during the 3 yr of exposure. However, red rust was found underneath the tape when the tape was cut and inspected after 18 mo of exposure (Figure 40).

The section coated with Poly-mastic (Figure 41) began to deteriorate rather quickly. Within 6 mo of exposure a considerable amount of red rust appeared at the bottom of the pipeline. The deterioration continued rapidly; more than 60% of the surface was covered with the red rust before 3 yr of exposure was over (Figure 42). Overall performance of the Plicoflex tape was rated fair and Poly-mastic paint was rated poor after 3 yr of exposure at Pearl Harbor.

Kwajalein. Plicoflex taped specimens (Figure 43) lost their glossy appearance slightly during the 3 yr of atmospheric exposure. The sandblasted metal surface was protected well during the first 12 mo but began to show slight red rust after 18 mo of exposure (Figure 44). Red rust was found also at the wire-brushed area, indicating that the corrosion was not completely contained by the Plicoflex tape. After the inspection, the cut area was patched with manufacturer-supplied adhesive and tape, but the patching tape soon discolored to white and showed signs of lifting 12 mo after the application (Figure 45). The wrapped tape also shrank considerably during the 3 yr of exposure as illustrated in Figure 46.

Poly-mastic #455 on the flange joints, hangers, and end-cups rapidly deteriorated within 6 mo and provided very little or no protection throughout 3 yr of exposure (Figure 45). Overall performance of Plicoflex tape was rated fair, and Poly-mastic paint was rated poor after 3 yr of exposure at Kwajalein.

Kaneohe. Plicoflex tape at Kaneohe also lost its glossiness somewhat during the exposure but retained its flexibility. When the tape was cut and examined after 12 mo of exposure, considerable red rust was discovered on the wire-brushed area, indicating that the corrosion was unchecked under the tape (Figure 47). The sandblasted area appeared to be well-protected, and no rust surfaced during the first 12 mo of exposure. However, traces of rust began to appear on the sandblasted area also after 3 yr of exposure. The tape also contracted considerably during the 3 yr of atmospheric exposure, as it did at Kwajalein.

Poly-mastic #455 on the flange joints, hangers, and end-caps deteriorated rapidly and provided very little protection against corrosion throughout the 3 yr of exposure.

Overall performance of the Plicoflex tape was rated fair and Poly-mastic paint was rated poor after 3 yr of exposure at Kaneohe.

Port Hueneme. After 12 mo of exposure above the tidal zone, contraction of the Plicoflex tape appeared to have caused wrinkles on the surface. The plastic tape was cut and examined underneath the tape. Red rust was found under the air pocket created by the wrinkle (Figure 48). The cut area was patched with adhesive and tape after the inspection, but the patch came loose after 6 mo of exposure. The sandblasted and wire-brushed areas were both found to be rusting when the tape was cut and the substrate examined after 3 yr of exposure.

Neither sandblasted nor wire-brushed sections showed rust when cuts were made on the specimen suspended below the high tidal zone for 12 mo and the specimen inspected (Figure 49). The cuts were patched-up with adhesive and tape, which came loose within 6 mo of exposure. Although the surface of the PVC tape was smooth, it did not prevent the growth of barnacles on its surface during the 3 yr of exposure (Figure 50). During this time, the tape end became detached, and the weight of the attached barnacles caused the tape to dangle from the pipe specimen. Although seawater had obviously intruded through the tape to the metal substrate, no red rust appeared, only black iron oxide (Figure 51). This was probably due to lack of oxygen required for further corrosion under the PVC tape. Overall performance of the Plicoflex tape suspended below the high tidal zone was rated fair after 3 yr of exposure at Port Hueneme.

Poly-mastic #455 paint offered no protection against the corrosion, either above or below the high tidal zone, and was rated poor after 3 yr of exposure at Port Hueneme.

DISCUSSION

During 3 yr of exposure under the pier at Pearl Harbor, all five paints coated over wire-brushed old surfaces showed varying degrees of rusting. The bottom part of the pipelines appear to be particularly susceptible to corrosion attack. Some of the reasons for the corrosion attack there are the difficulty in removing rust scale at the bottom of the pipes, an inaccessible area, and the restricted view during surface preparation under piers. Any incompletely removed rust scale will immediately set up corrosion couples (corrosion cell) between the scale and metal. Also, the bottom areas painted too thinly or totally missed may easily escape detection during the painting. Daily condensation of moisture and sea-spray at the bottom of the pipe can eventually penetrate the paint and aggravate the condition in a relatively short time. The bottom of many of the existing pipes were heavily pitted from previous corrosion. Removing rust from those deep pits by wire-brushing is another difficulty, in addition to the difficulty of painting the pitted surfaces. The deep pits trap air and form air pockets during paint application and eventually form pinholes on the paint surface. All of these factors invite corrosion and early paint failure.

Although the pipe specimens were carefully coated, the atmospheric exposure tests revealed quite clearly that irregular surfaces (such as flange joints, bolt and nut heads, threaded areas, and pipe hangers) are very susceptible to corrosion attack. It is difficult to build up a coating to the desired thickness at sharp corners and edges of irregular surfaces. Unless the paint film on these sharp corners and edges are built up, moisture and corrosive elements eventually penetrate through the thin film and attack the metal under it. The results indicate that if pipelines were joined by welding instead of joining them with bolts and nuts, the corrosion problem areas could be reduced considerably and could lead to a reduction of overall maintenance costs.

Government specification paint MIL-P-24441 protected steel pipes better than the other four paints (Astro RP Extra, Carbomastic, Rust-Ban, and Plicomastic) at all test sites. This coating provided better protection on the wire-brushed surfaces than the sandblasted surfaces while other paints protected the surfaces in reverse manner. Less rust appeared on the coated pipe specimens suspended below the tidal zone than on those suspended above the tidal zone. The barnacle growth on the MIL-P-24441 coated specimens in the intertidal area appeared to be slightly less compared to those on other painted specimens exposed under the same condition.

When compared to the performance of the five paints and the Plicoflex tape, Denso tape performed best. It provided the best protection against corrosion attack under the pier at Pearl Harbor as well as at all three CEL exposure sites. Denso tape was easy to apply and easily conformed to the irregular surfaces of any configuration, whereas Plicoflex (PVC) tape was too tough to manipulate to conform to the irregular surfaces to be taped. Denso tape was the only system which kept the sandblasted and wire-brushed areas, as well as irregular surfaces, from rusting (see Figures 33, 36, 37). Judging from the conditions illustrated, the Denso tape should continue to provide effective protection for 10 or more years in the same environment.

Another advantage of using the Denso tape is that the condition of substrate under the tape can be inspected without destroying the tape. The applied Denso tape can be cut with a knife (Figure 52) and peeled back for inspection of the substrate (Figure 36). The tape can be pushed back over the substrate and restored to the original condition (Figure 53) without additional repairing materials. No other coating can be inspected in this manner without destroying the original coating, which then requires re-application for repair.

However, grease in the Denso tape will gradually leach out, and the tape will become soggy after prolonged immersion in seawater. In the tests, the grease did not prevent barnacle growth, and the weight of the attached barnacles caused the tape to detach and sag from the pipe. Although the Denso tape provided excellent protection against corrosion above water, the results of the experiments indicated that the Denso tape should not be used to protect utility lines under seawater.*

*In January 1977, CEL was informed by the supplier that an antifouling Denso tape has been introduced on the market and is said to be successful.

Leaking fuel oil can pose another problem by dissolving the petrolatum grease of the Denso tape, and thus lead to early tape failure.* Therefore, any oil leaks should be repaired prior to application of Denso tape.

Rapidly changing labor and material costs make it impossible to give exact costs of coating applications. The application cost is also dependent on the configuration of and ease of access to the piping involved. The following investigated material and labor costs were based on coating 100 linear feet of 10-in.-diameter pipe line under a pier during 1977. Estimated materials and labor costs of applying the petrolatum system (Denso tape and paste) were calculated to be $1.86/sq ft ($20.01/sq m), which includes $1.52/sq ft for materials and $0.34/sq ft for labor. Estimated materials and labor costs for painting a similar pipe line was calculated to be $1.81/sq ft ($19.48/sq m), which includes $1.50/sq ft for sandblasting to white metal, $0.21/sq ft for three coats of paint, and $0.10/sq ft for labor.

FINDINGS AND CONCLUSIONS

1. Of the five coatings and two wrapping tapes used in underpier exposures at Pearl Harbor and in marine atmospheric exposures at three CEL test sites for 3 yr, Denso tape gave the best performance. The government specification coating system MIL-P-24441 was second best.

2. The Denso tape system, which can be applied by relatively inexperienced personnel, provided excellent protection to the wire-brushed, rusty, test surfaces and shows promise of exceeding the goal to extend coating service life by about 20%. No additional rusting was evident when the underlying steel pipe was examined after 3 yr of exposure. It was the only system which protected irregular and difficult-to-paint surfaces (joints with bolts and nuts or pipe hangers) from rusting during the 3 yr of exposure.

3. Some disadvantages in using Denso tape do exist. The petrolatum grease can gradually leach out from the Denso tape under water, and the tape becomes soggy and loosens. Also, the petrolatum grease does not prevent barnacle growth under water. It is also likely that floating oil from a spill can dissolve the petrolatum grease and damage the Denso tape. All indications are that the Denso tape should not be used under water.

4. If significant numbers of difficult-to-coat areas (e.g., flange joint with bolts and nuts) could be eliminated from pipe systems, it is likely that a considerable saving in maintenance costs could be realized. All joints, therefore, should be welded instead of joining them with bolts and nuts wherever possible.

RECOMMENDATIONS

Denso tape is recommended for existing utility lines under piers where good surface preparation is difficult to obtain or where rusty pipe surfaces exist. Any oil leaks should be repaired prior to the application of Denso tape. Use of Denso tape on constantly submerged pipes is not recommended because it does not prevent barnacle growth and the impregnated grease will eventually leach out from the tape under water. For constantly submerged utility lines, MIL-P-24441 is recommended only if good surface preparation can be accomplished by sandblasting prior to coating.

*Civil Engineering Laboratory. Technical Report R-832: Protection of Existing Fuel Lines Under Pier at Point Loma Annex, by E. S. Matsui. Port Hueneme, Calif., Dec 1975.

ACKNOWLEDGMENTS

The author expresses his appreciation to the personnel of the Fuel Department, Naval Supply Center, Honolulu; the Public Works Department, Marine Corps Air Station, Kaneohe Bay; and the Construction and Utilities Division, Headquarters, Kwajalein Missile Range for their cooperation, assistance, and interest in long-term marine atmospheric exposure tests being conducted in the Pacific area.

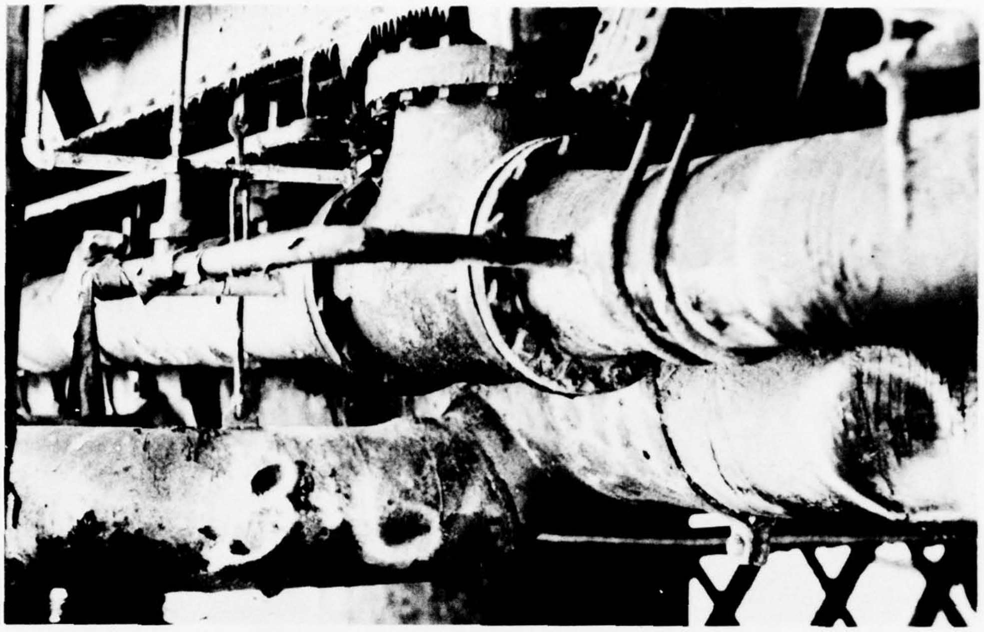

Figure 1. Typical fuel lines under a fuel pier.

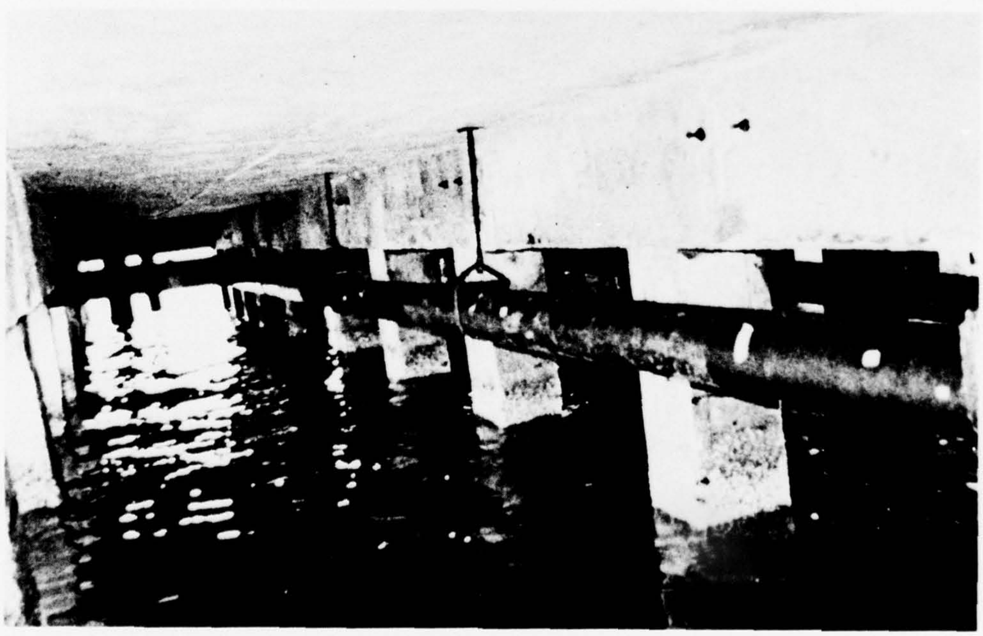

Figure 2. Coated fuel lines undergoing field testing at Pearl Harbor.

Figure 3. Marine atmospheric exposure site at Kwajalein, Marshall Islands.

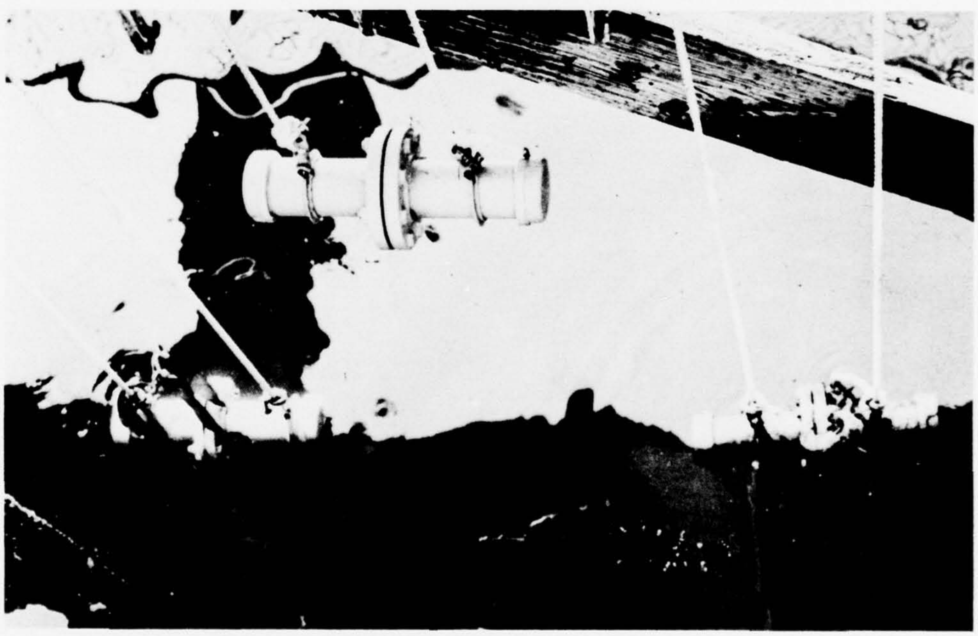

Figure 4. Test pipes suspended from a dock to above and below the tidal zone.

Figure 5. Pre-rusting of a pipe specimen with seawater.

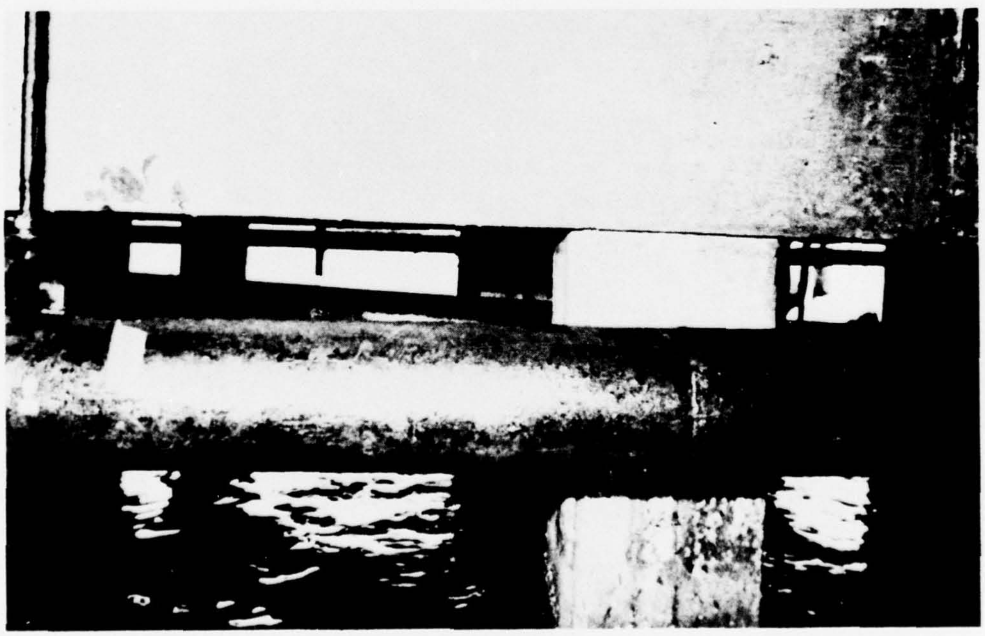

Figure 6. Fuel line under V-4 fuel pier newly coated with Astro RP Extra at Pearl Harbor.

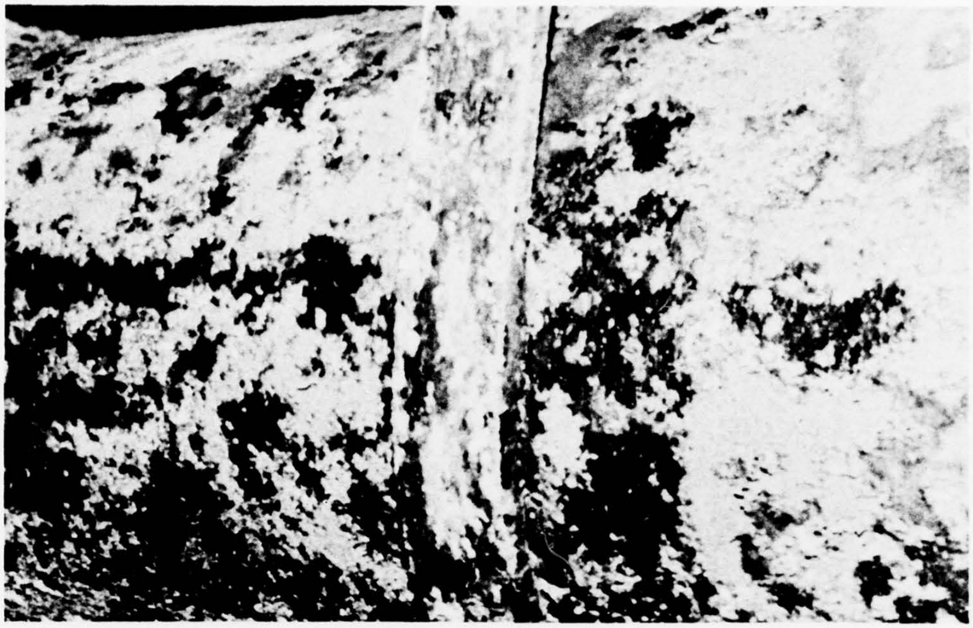

Figure 7. Astro RP Extra coated fuel line after 2-1/2 yr of exposure at Pearl Harbor.

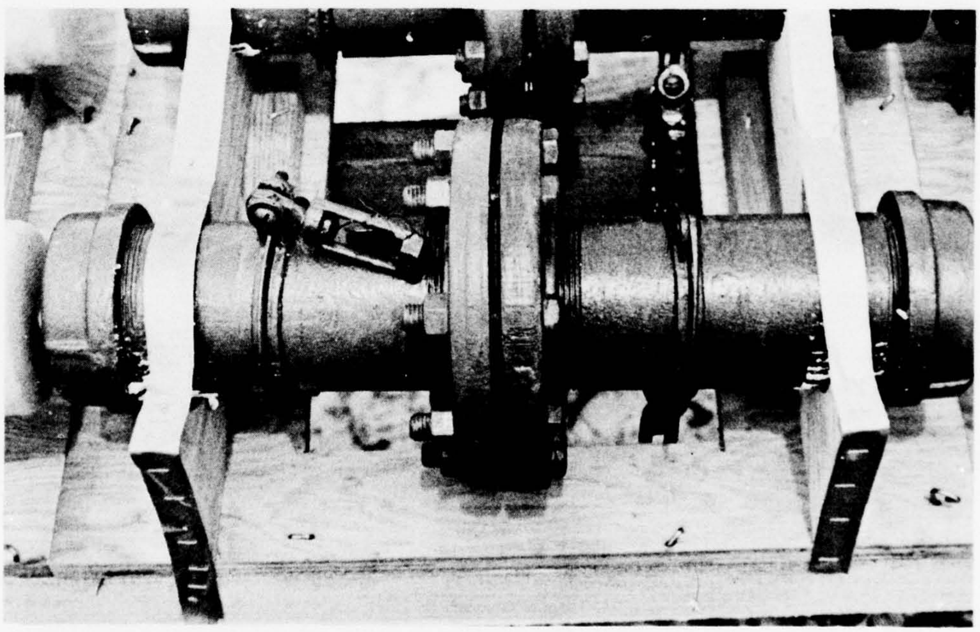

Figure 8. Initial condition of pipe specimen coated with Astro RP Extra at Kwajalein.

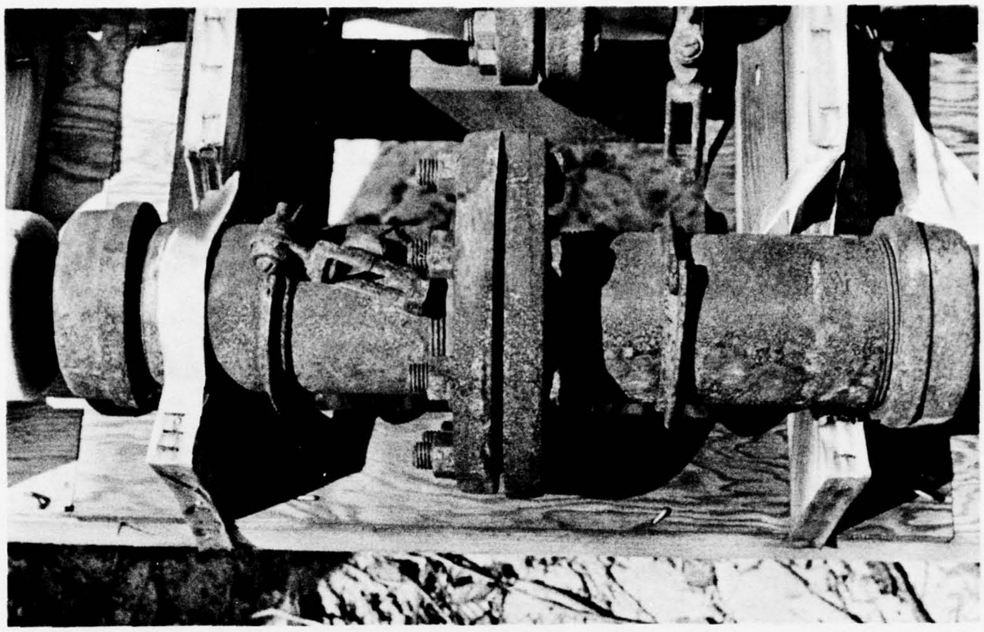

Figure 9. Astro RP Extra coated pipe specimen after 6 mo of exposure at Kwajalein.

Figure 10. Rusted and heavily pitted pipe specimen coated with Astro RP Extra after 3 yr of exposure above the tidal zone.

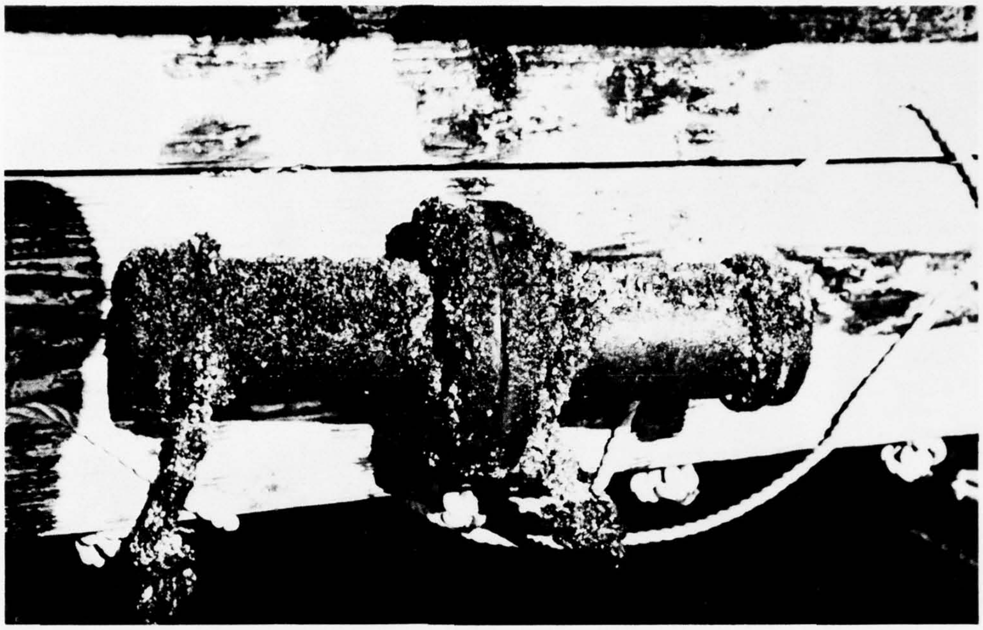

Figure 11. Rust and barnacles on a pipe specimen coated with Astro RP Extra after 12 mo of exposure below tidal zone.

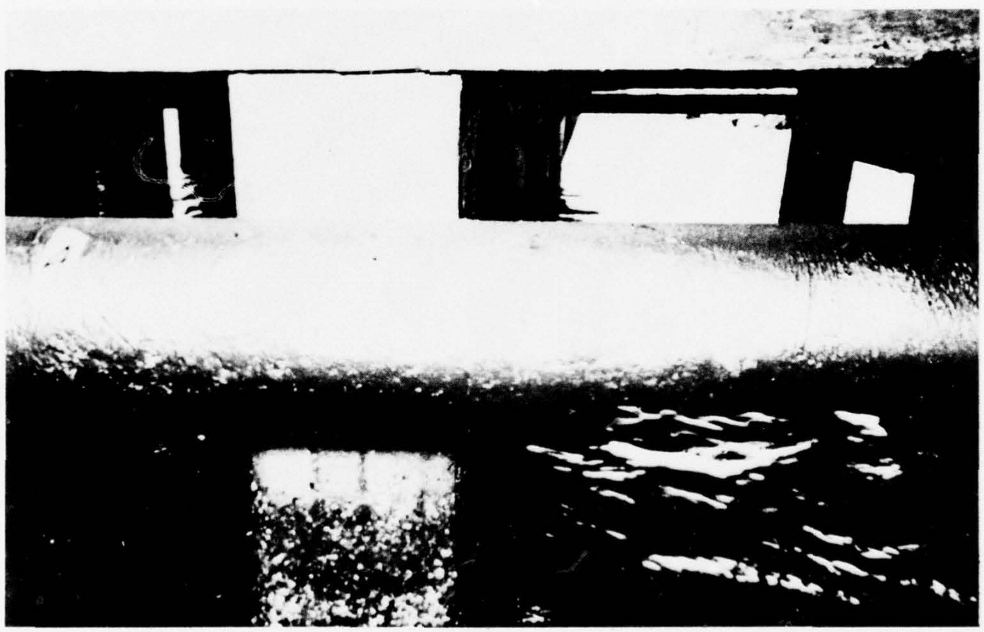

Figure 12. Fuel line coated with Carbomastic X2256-138 at Pearl Harbor.

Figure 13. Carbomastic X2256-138 coated fuel line after 3 yr of exposure at Pearl Harbor.

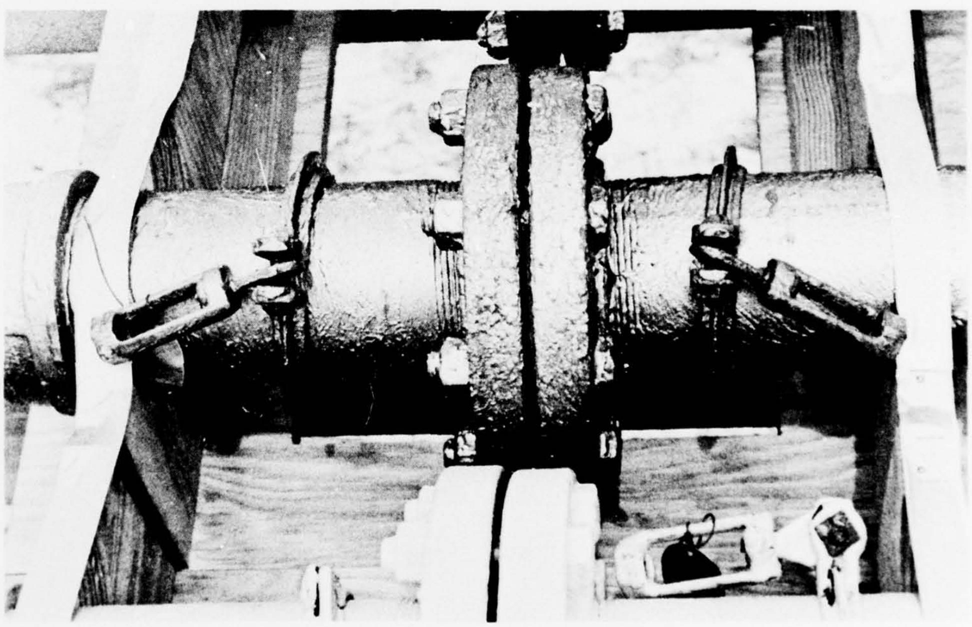

Figure 14. Initial condition of Carbomastic X2256 coated pipe specimen at Kwajalein.

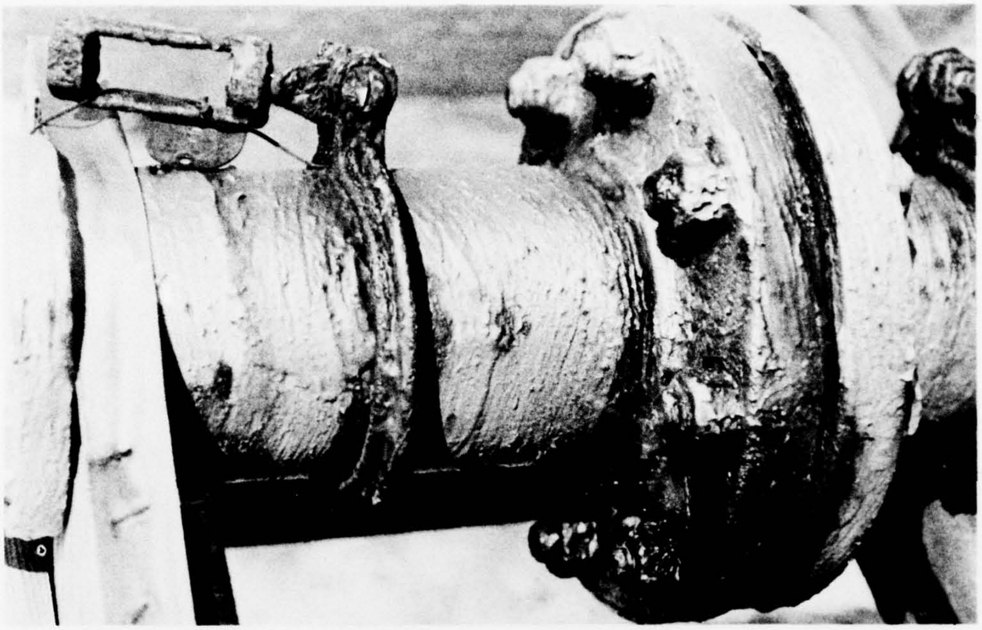

Figure 15. Carbomastic X2256 coated pipe specimen after 6 mo of atmospheric exposure at Kwajalein.

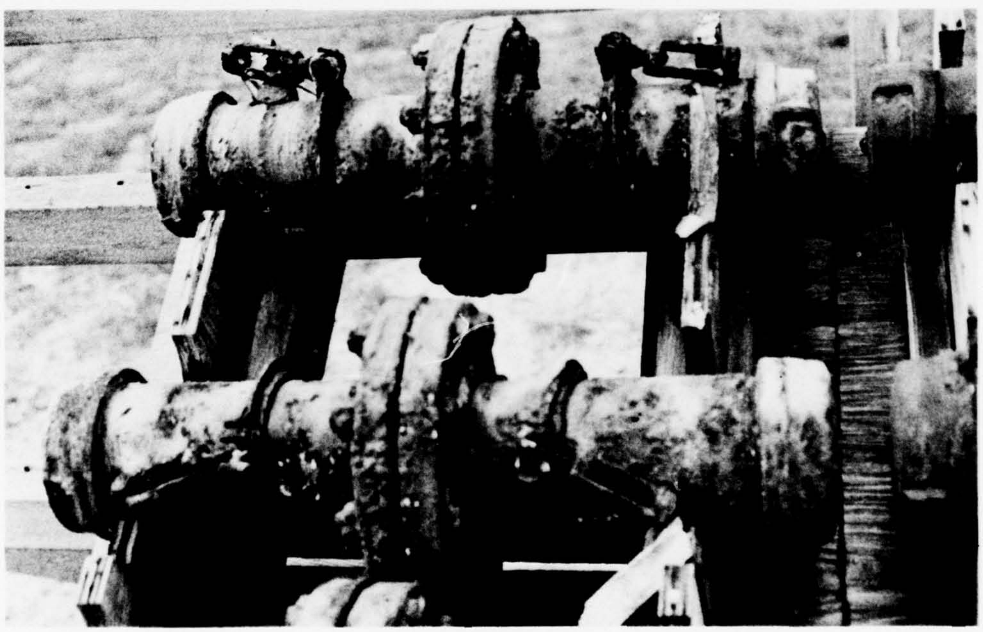

Figure 16. Carbomastic X2256 coated specimens after 3 yr of atmospheric exposure at Kwajalein.

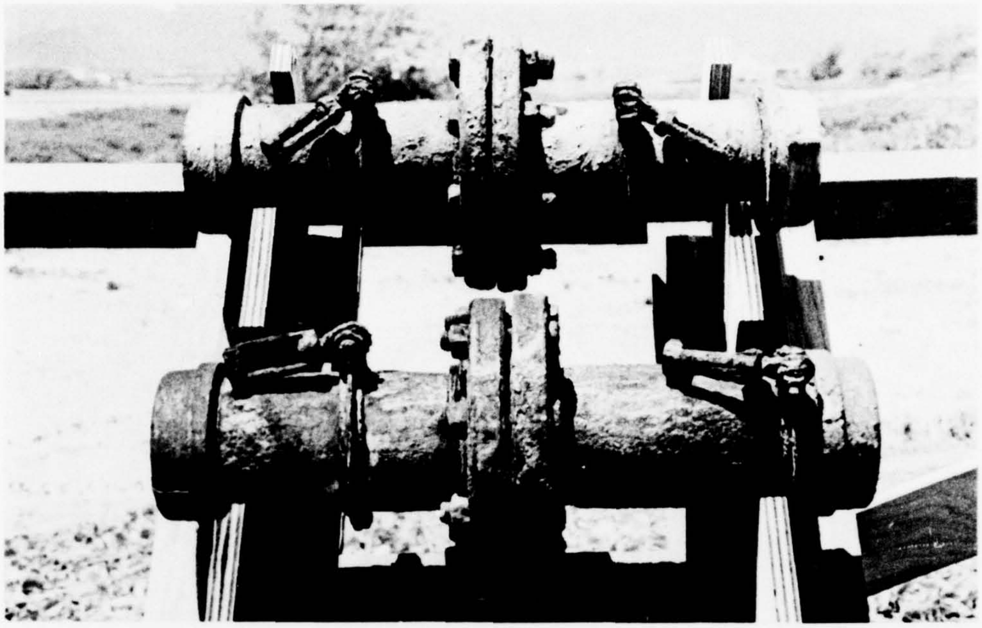

Figure 17. Carbomastic (above) and Astro RP (below) coated pipe specimens after 3 yr of exposure at Kaneohe.

Figure 18. Carbomastic coating damaged by barnacle growth after 2-1/2 yr of exposure below tidal zone at Port Hueneme.

Figure 19. Fuel line under pier newly coated with Rust-Ban at Pearl Harbor.

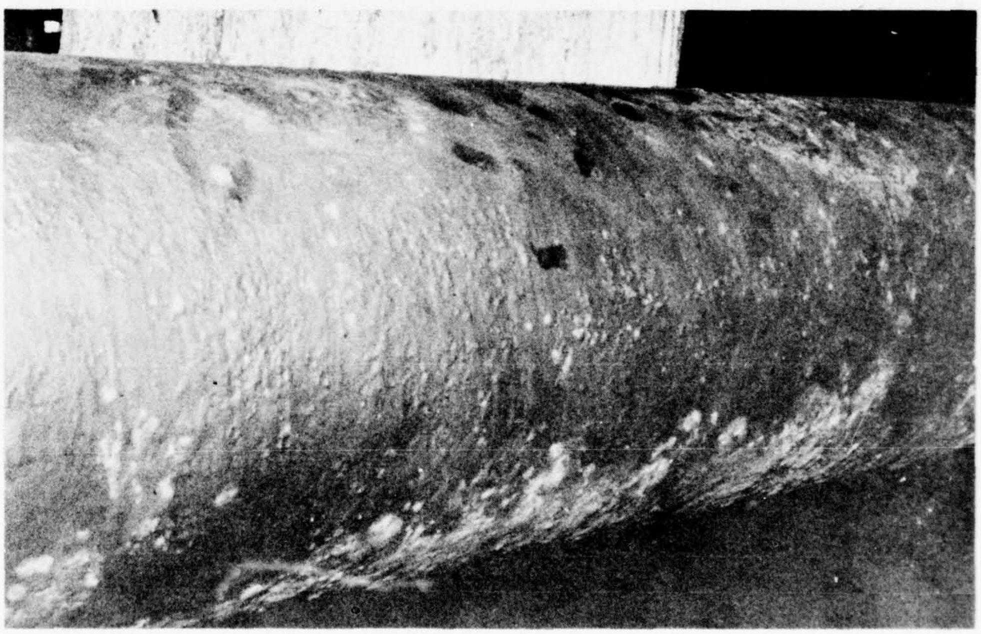

Figure 20. Rust-Ban after 3 yr of exposure at Pearl Harbor.

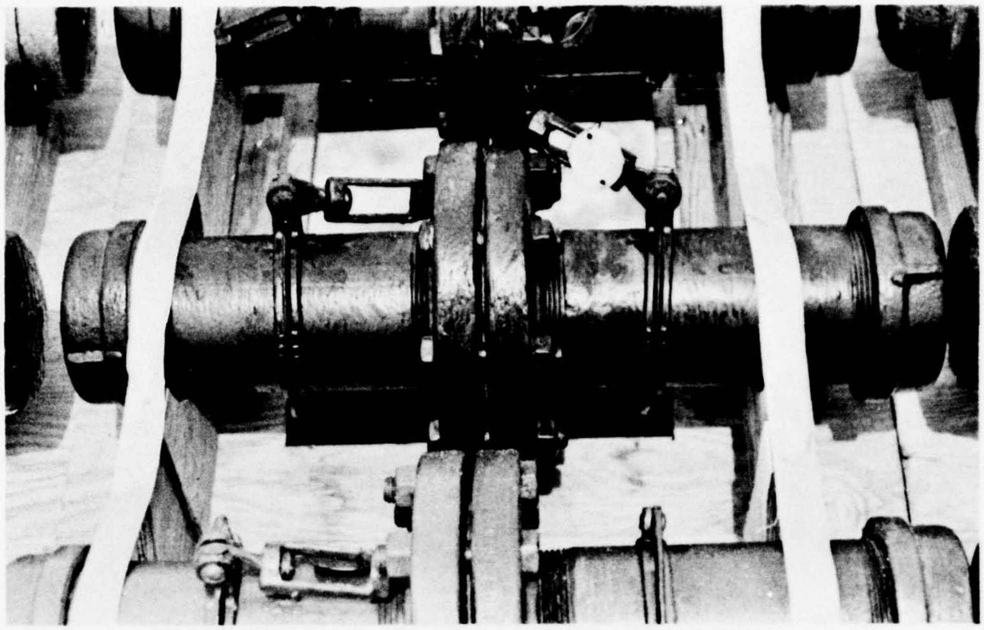

Figure 21. Initial condition of pipe specimens coated with Rust-Ban at Kwajalein.

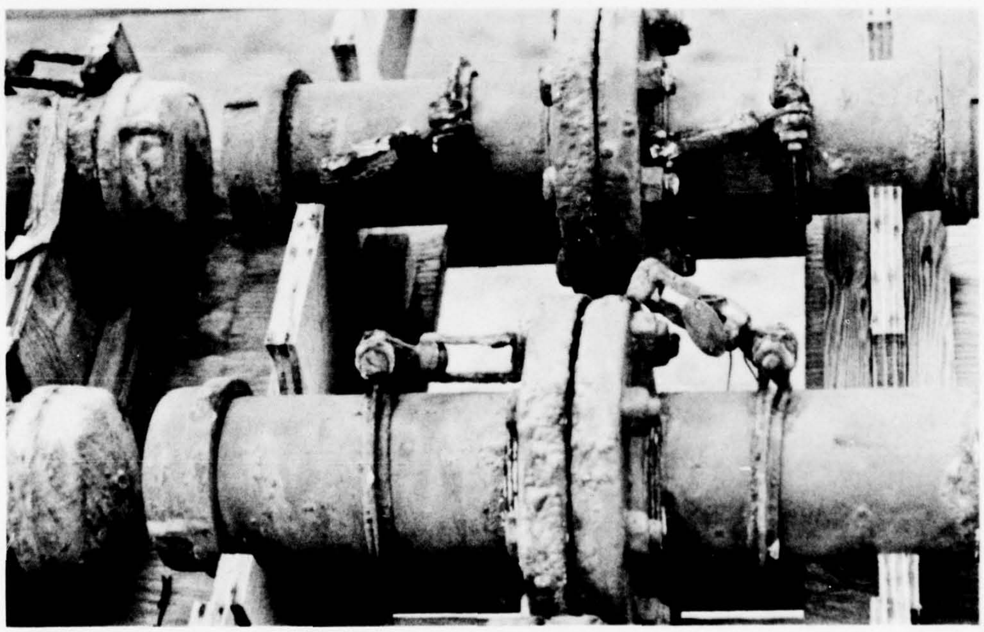

Figure 22. Pipes coated with Rust-Ban exposed for 3 yr at Kwajalein.

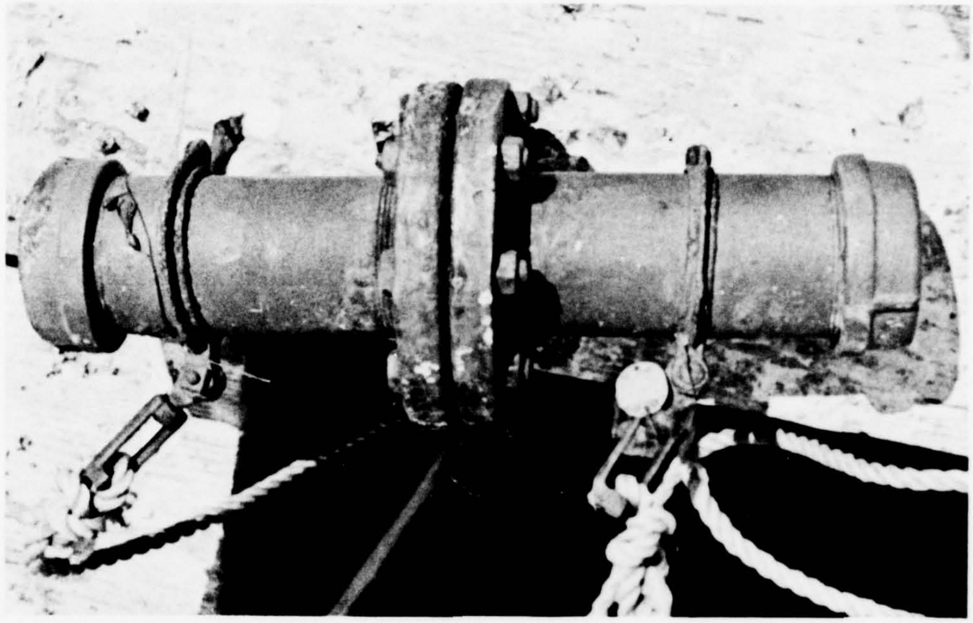

Figure 23. Rust-Ban coated pipe specimen exposed above tidal zone for 3 yr at Port Hueneme.

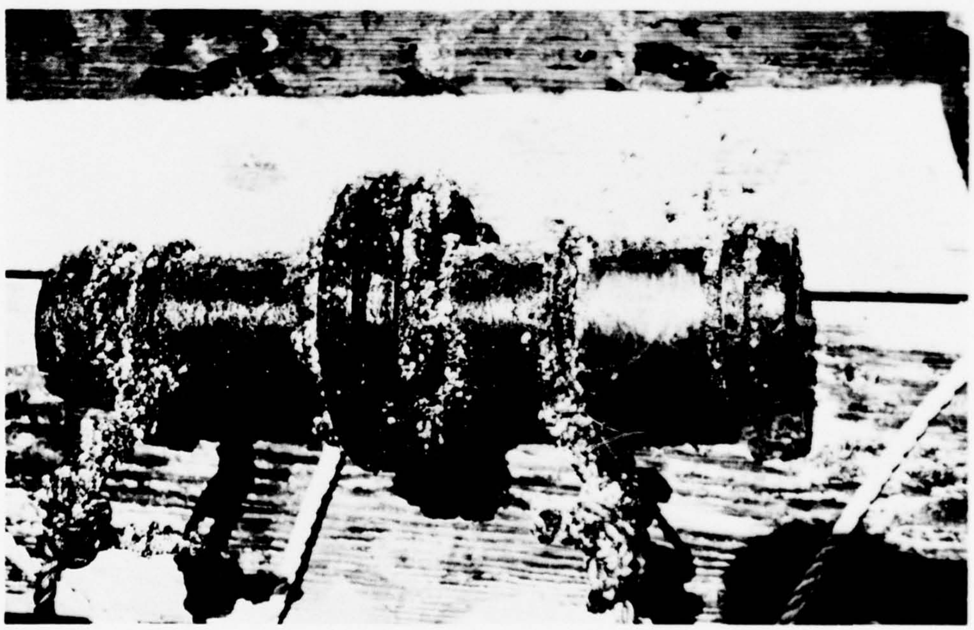

Figure 24. Rust-Ban coated pipe specimen exposed below tidal zone for 12 mo at Port Hueneme.

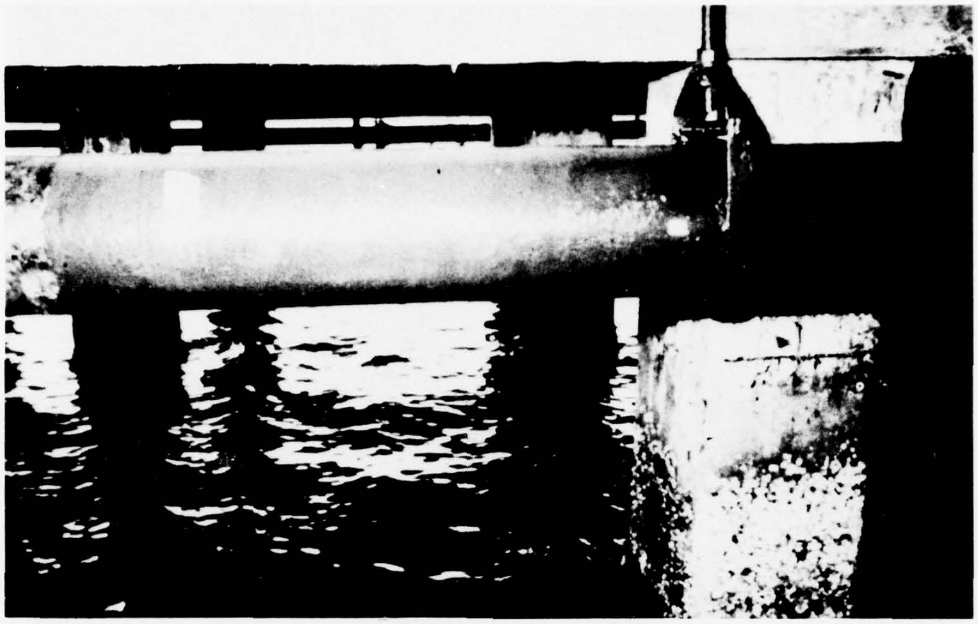

Figure 25. Fuel line under pier newly coated with MIL-P-24441 at Pearl Harbor.

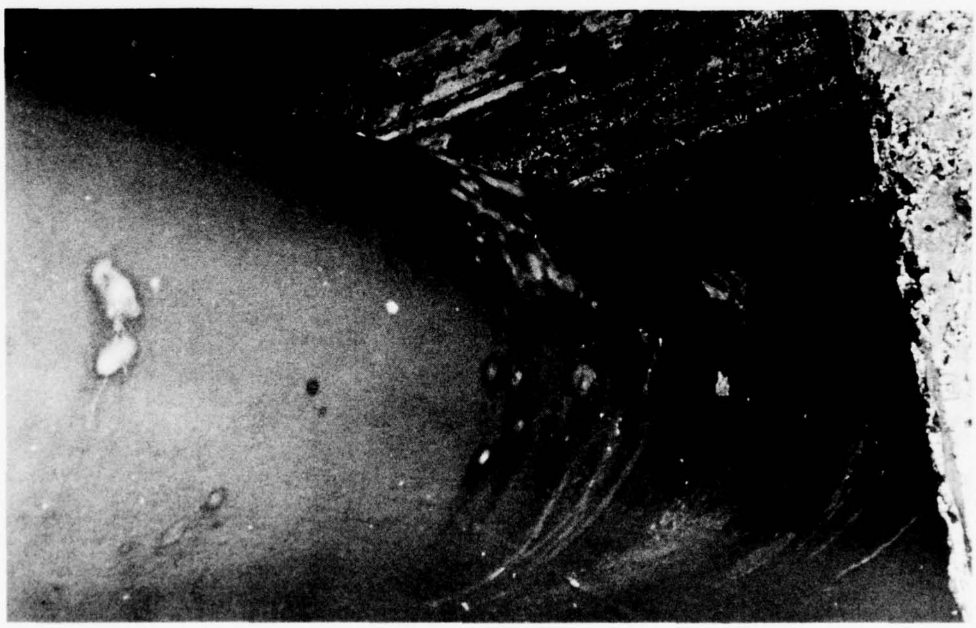

Figure 26. MIL-P-24441 coated fuel line after 3 yr of exposure at Pearl Harbor.

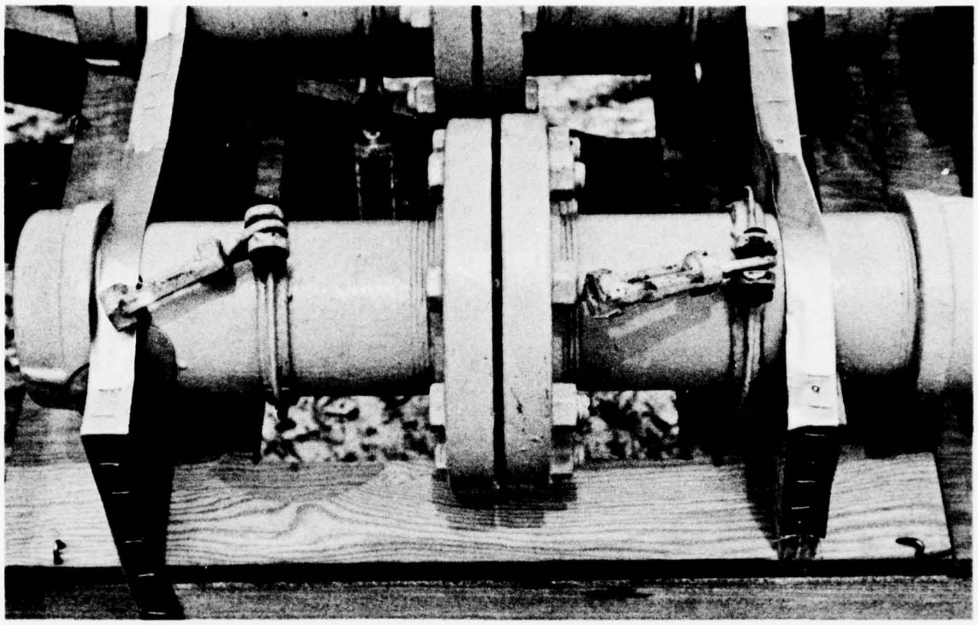

Figure 27. Initial condition of MIL-P-24441 coated pipe specimen at Kwajalein.

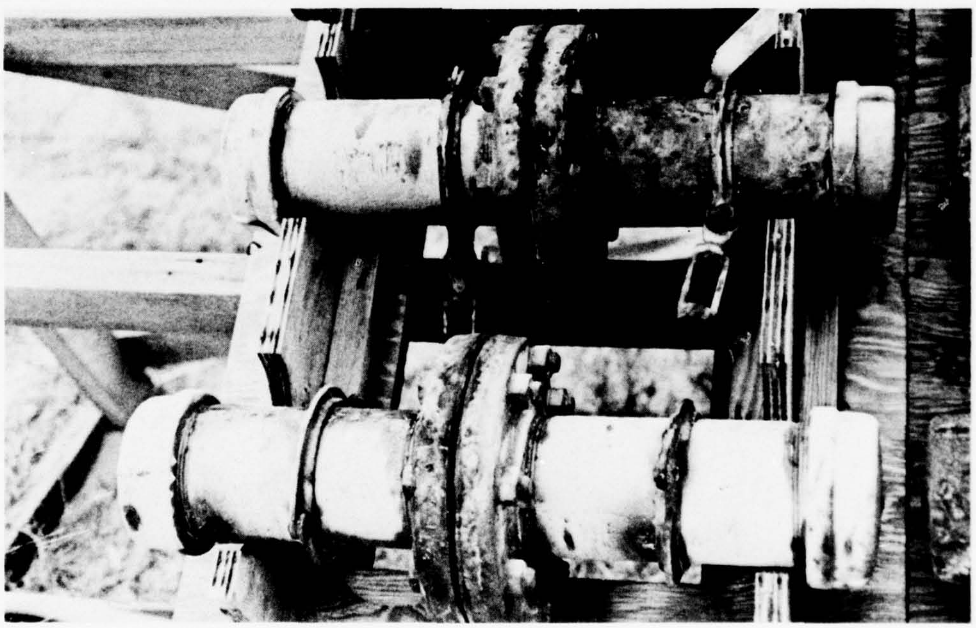

Figure 28. MIL-P-24441 coated pipe samples after 3 yr of exposure at Kwajalein (the pipes on the nut end of the flanges were wire-brushed).

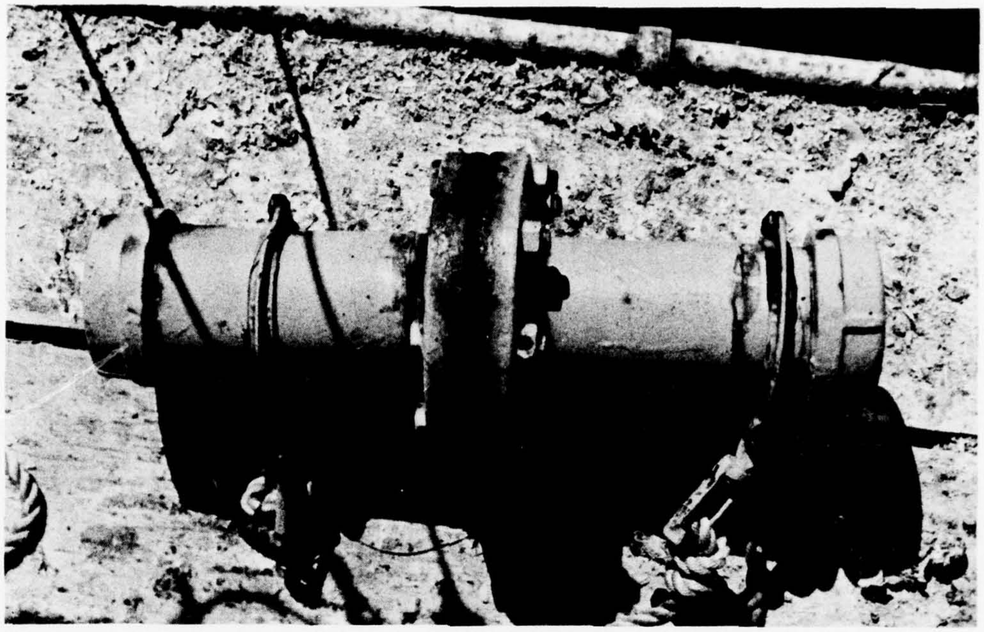

Figure 29. MIL-P-24441 coated pipe exposed for 3 yr above tidal zone at Port Hueneme.

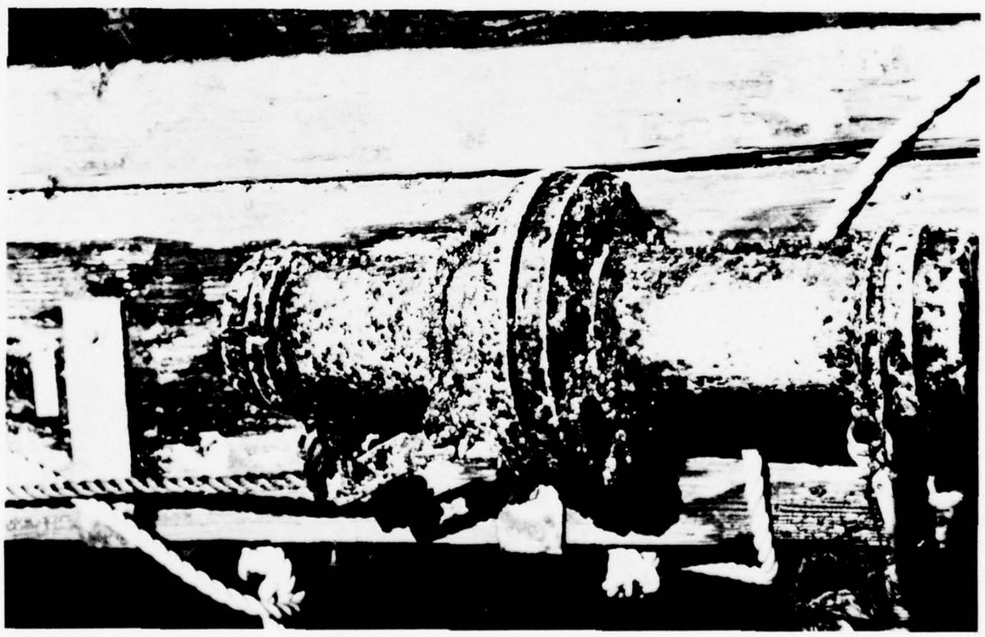

Figure 30. MIL-P-24441 coated pipe covered with algae and a few barnacles after 12 mo below tidal zone at Port Hueneme.

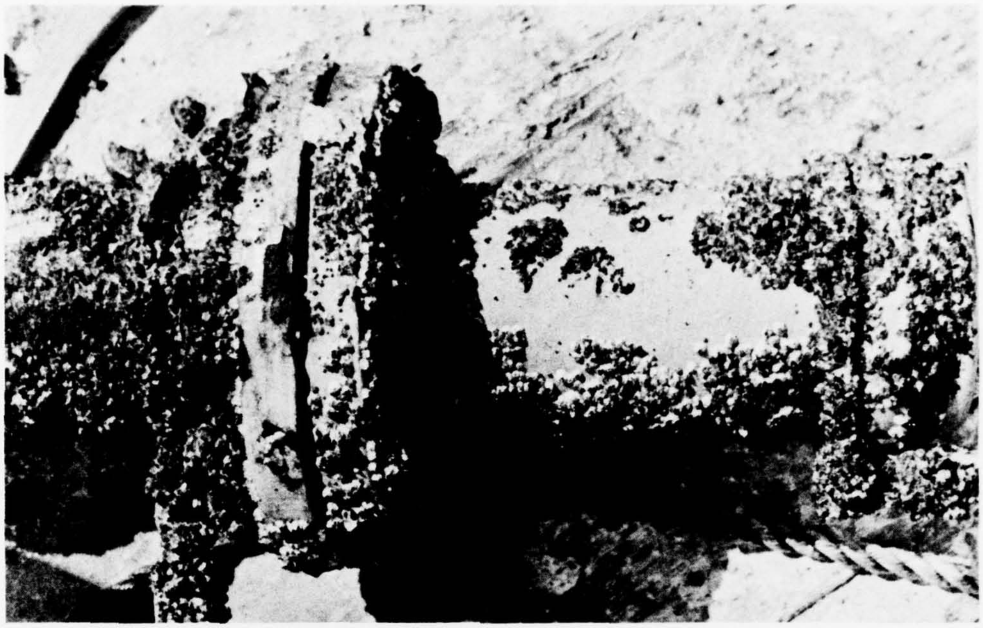

Figure 31. MIL-P-24441 coated specimen exposed for 3 yr below tidal zone at Port Hueneme.

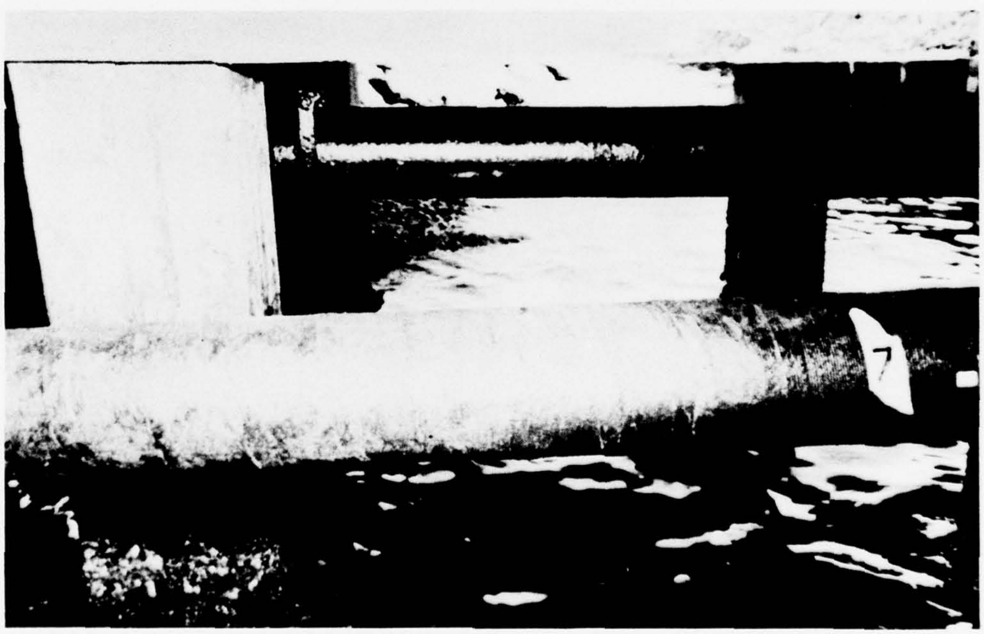

Figure 32. Fuel line under pier with Denso tape applied at Pearl Harbor.

Figure 33. No fresh rust formed under Denso tape after 3 yr of in-field exposure at Pearl Harbor.

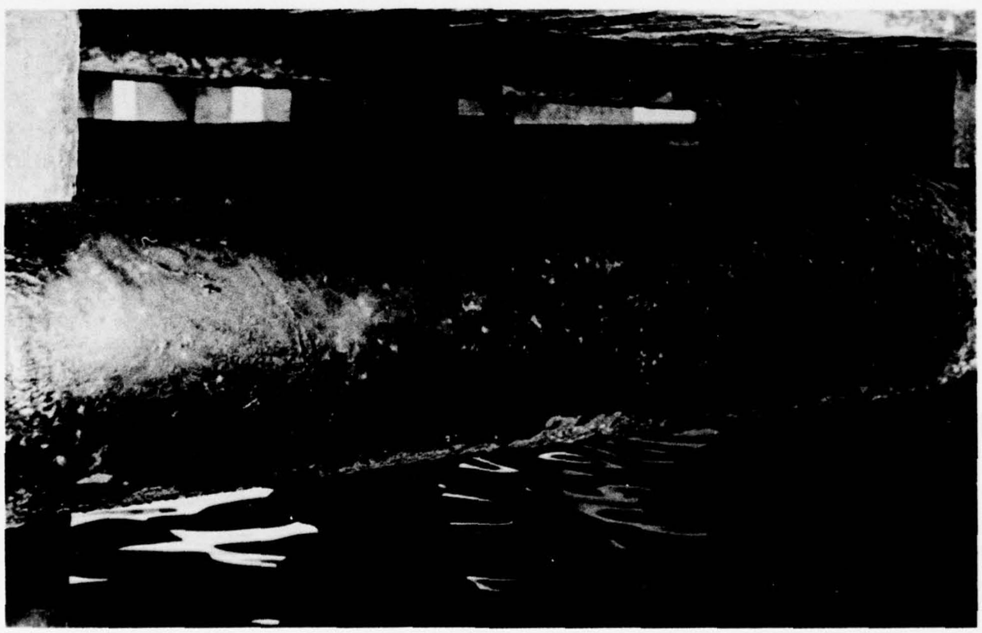

Figure 34. Fuel pipe coated with Denso paste without Denso tape exposed for 3 yr at Pearl Harbor.

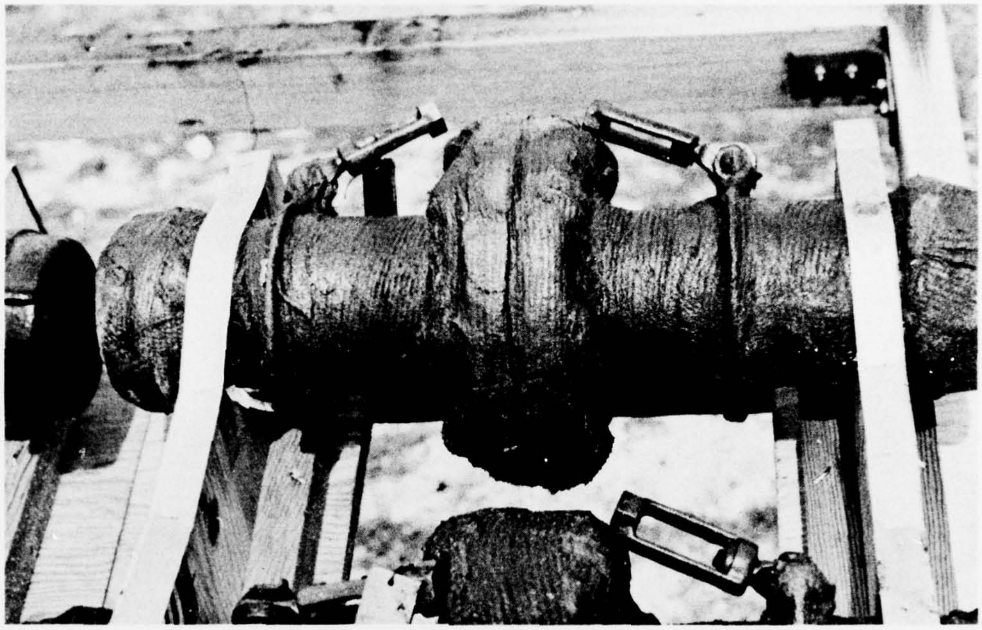

Figure 35. Initial condition of Denso tape wrapped pipe at Kwajalein.

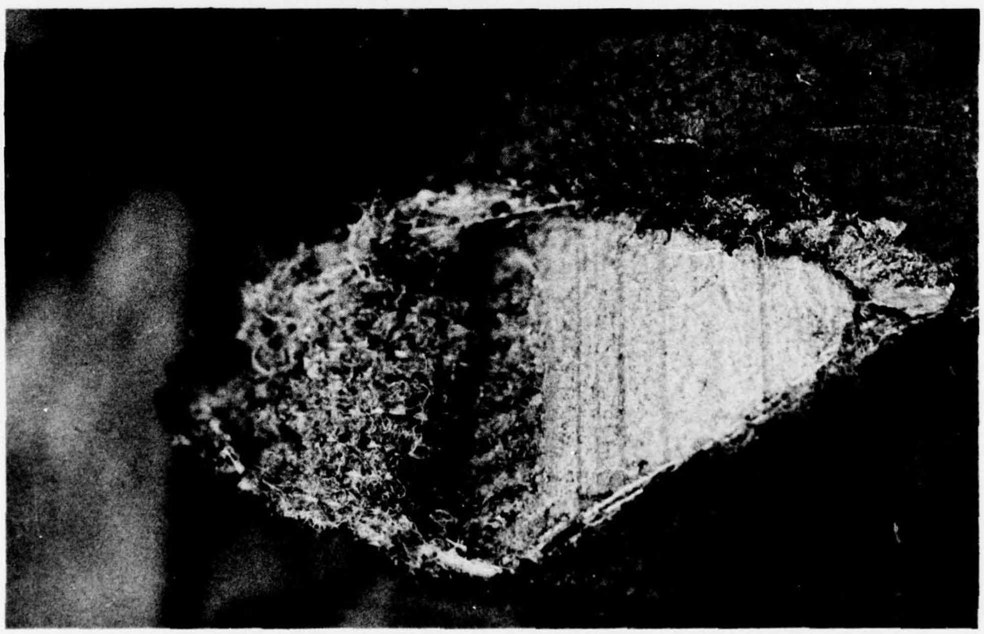

Figure 36. No rust on sandblasted surface under Denso tape after 3 yr of atmospheric exposure at Kwajalein.

Figure 37. Well-protected flange joint wrapped with Denso tape exposed for 3 yr above tidal zone at Port Hueneme.

Figure 38. Slight red rust under the Denso tape after 3 yr of exposure below high tide zone at Port Hueneme.

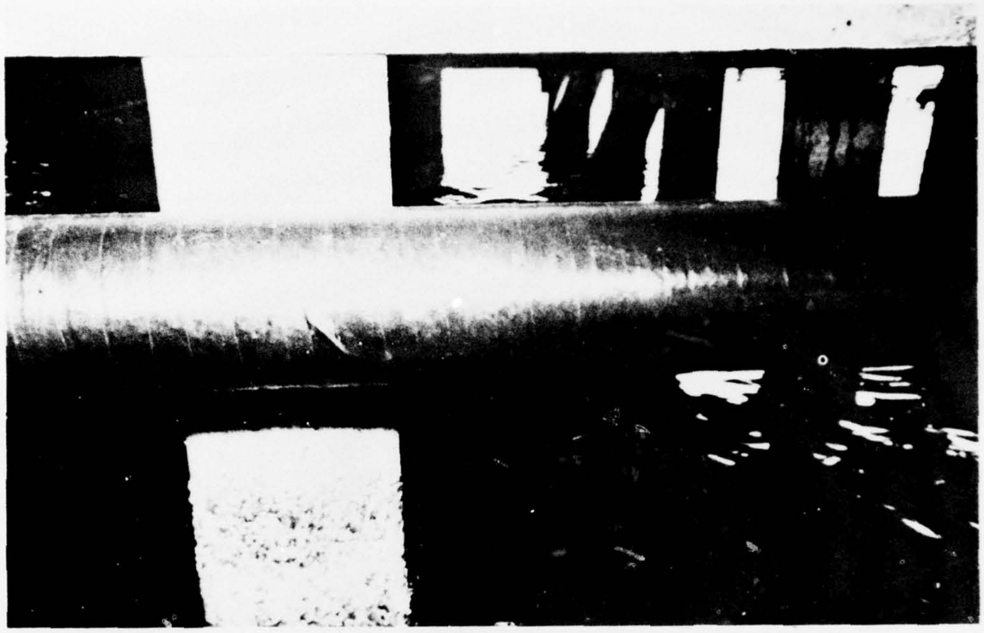

Figure 39. Fuel line newly wrapped with Plicoflex tape at Pearl Harbor.

Figure 40. Red rust underneath the Plicoflex tape after 18 mo of exposure at Pearl Harbor.

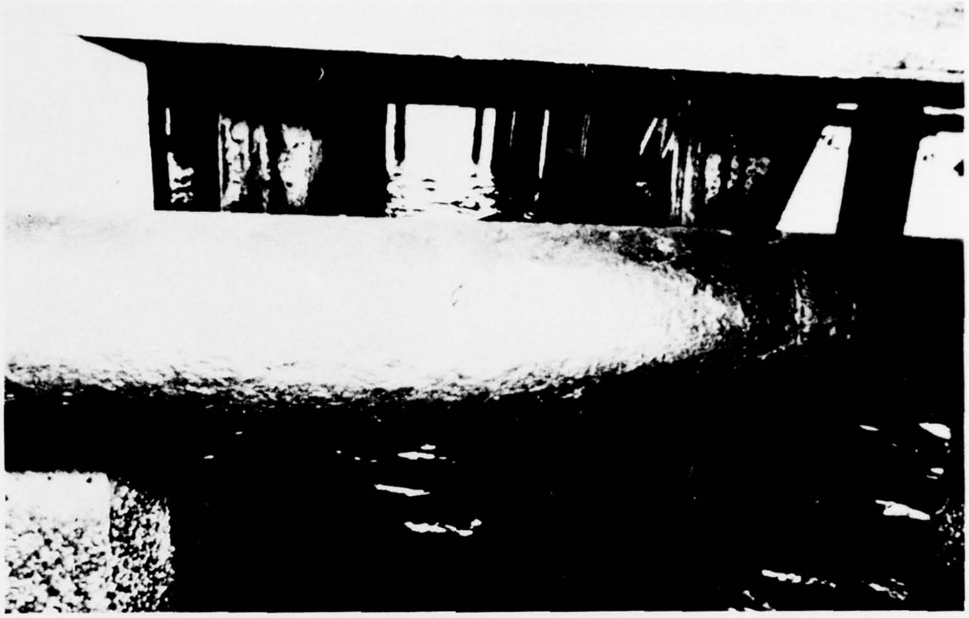

Figure 41. Fuel line newly coated with Poly-mastic #455.

Figure 42. Poly-mastic #455 coated pipe after 3 yr of exposure under pier at Pearl Harbor.

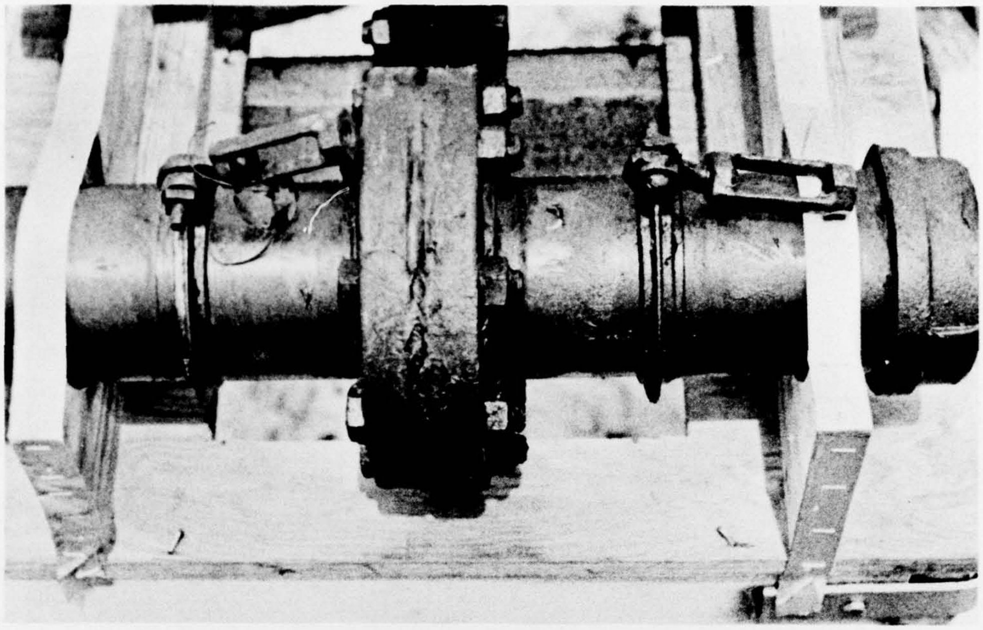

Figure 43. Initial condition of Plicoflex tape wrapped pipe at Kwajalein.

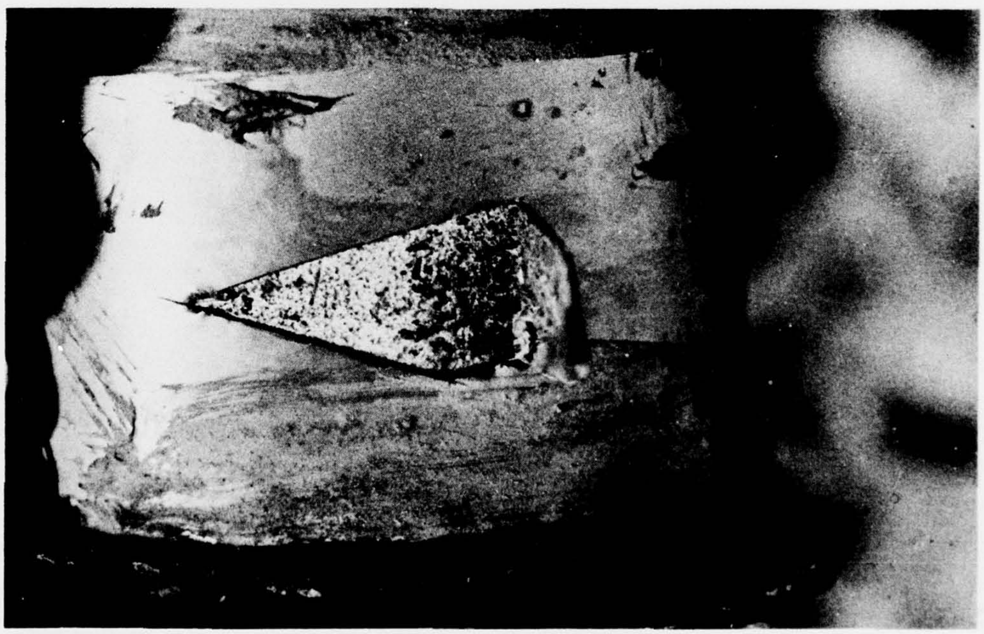

Figure 44. Slight red rust under Plicoflex tape after 18 mo of exposure at Kwajalein.

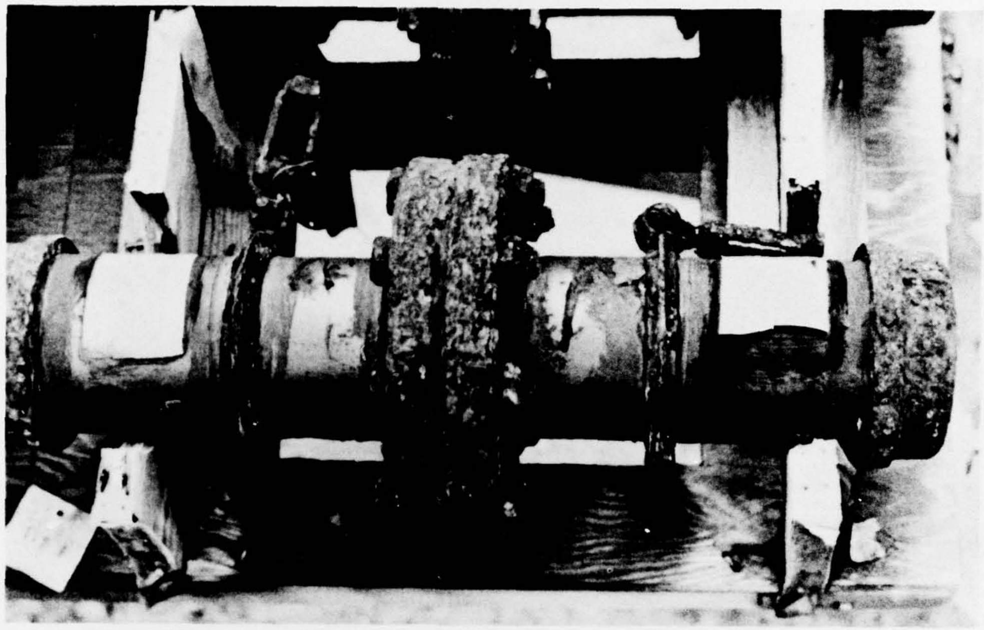

Figure 45. Discoloration and lifting at patched areas after 12 mo of exposure at Kwajalein.

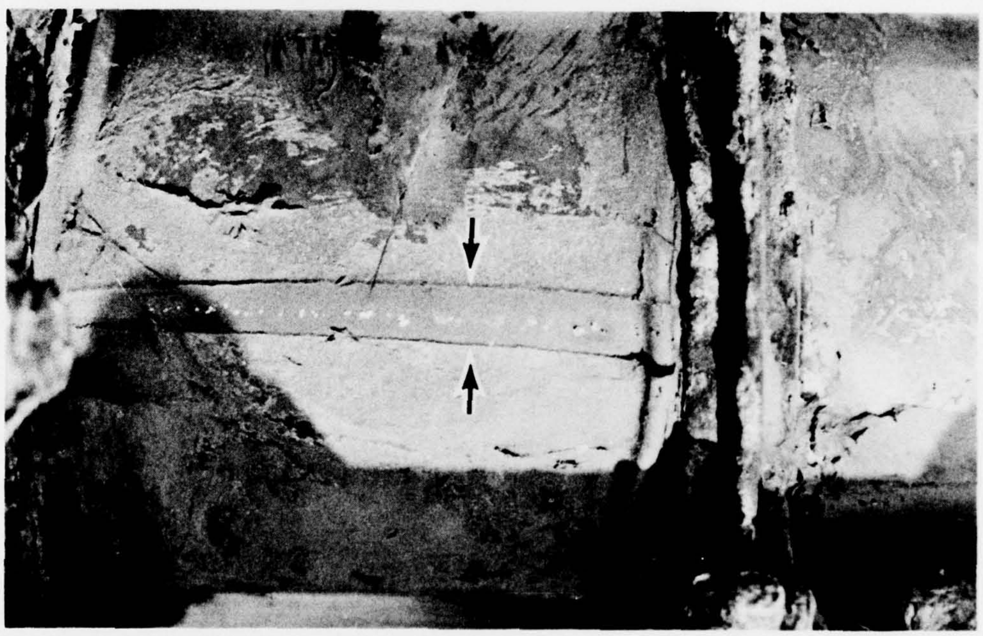

Figure 46. Shrinkage of Plicoflex tape during atmospheric exposure at Kwajalein.

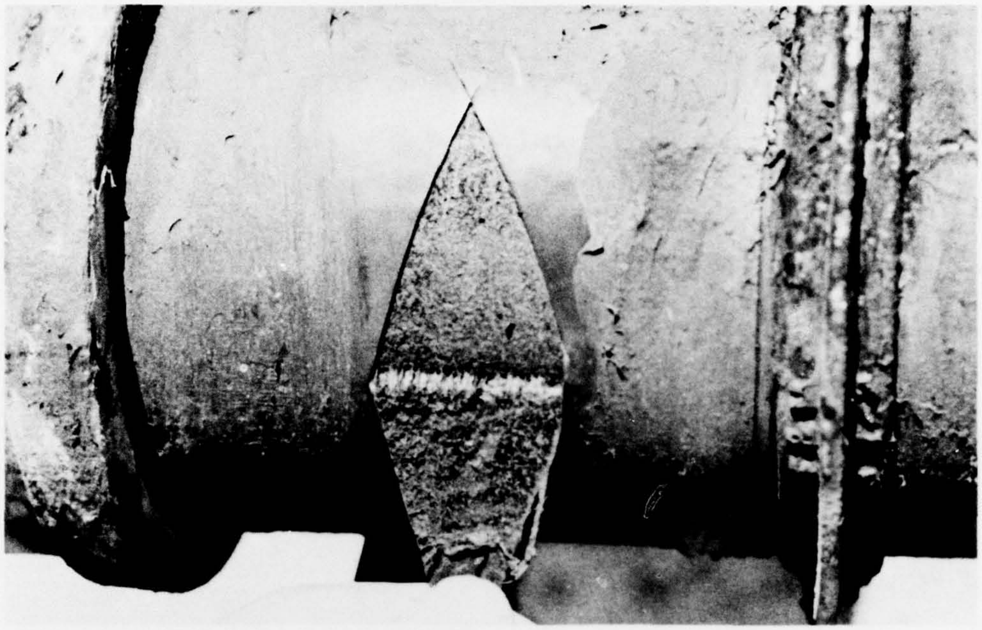

Figure 47. Rust under Plicoflex tape after 12 mo of exposure at Kaneohe.

Figure 48. Red rust under wrinkled Plicoflex tape after 12 mo of exposure above tidal zone at Port Hueneme.

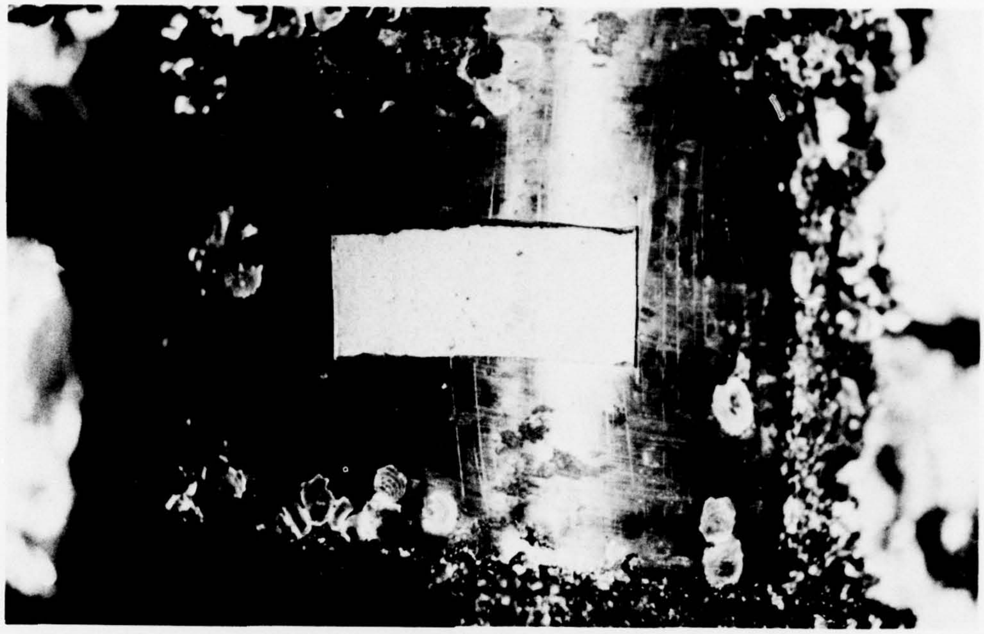

Figure 49. No red rust under Plicoflex tape during the first 12 mo of exposure below tidal zone at Port Hueneme.

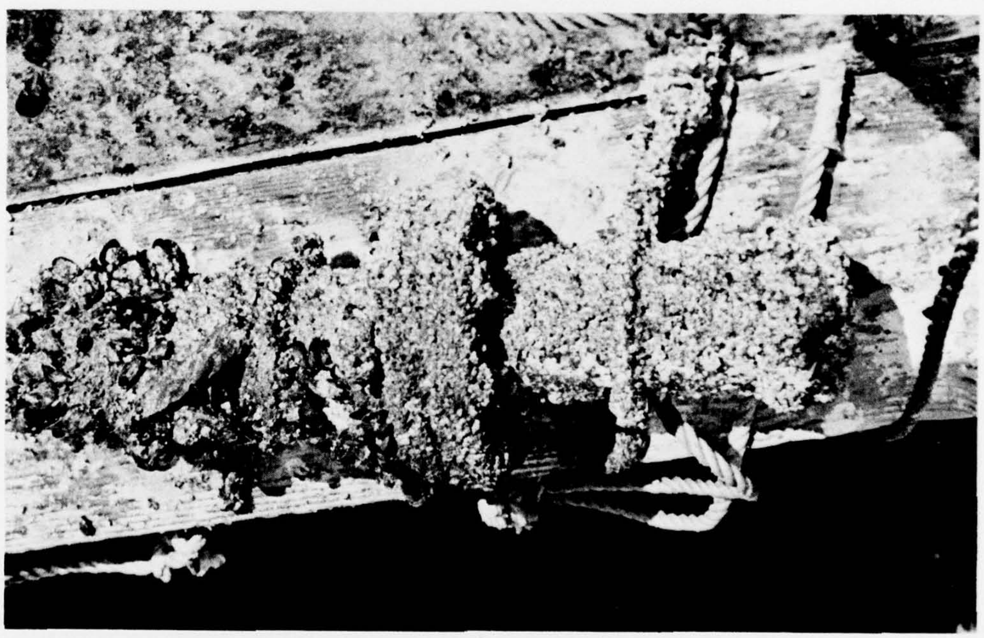

Figure 50. Barnacle growth on PVC tape after 3 yr of exposure below tidal zone at Port Hueneme.

Figure 51. Black oxide under Plicoflex tape exposed for 3 yr below tidal zone at Port Hueneme.

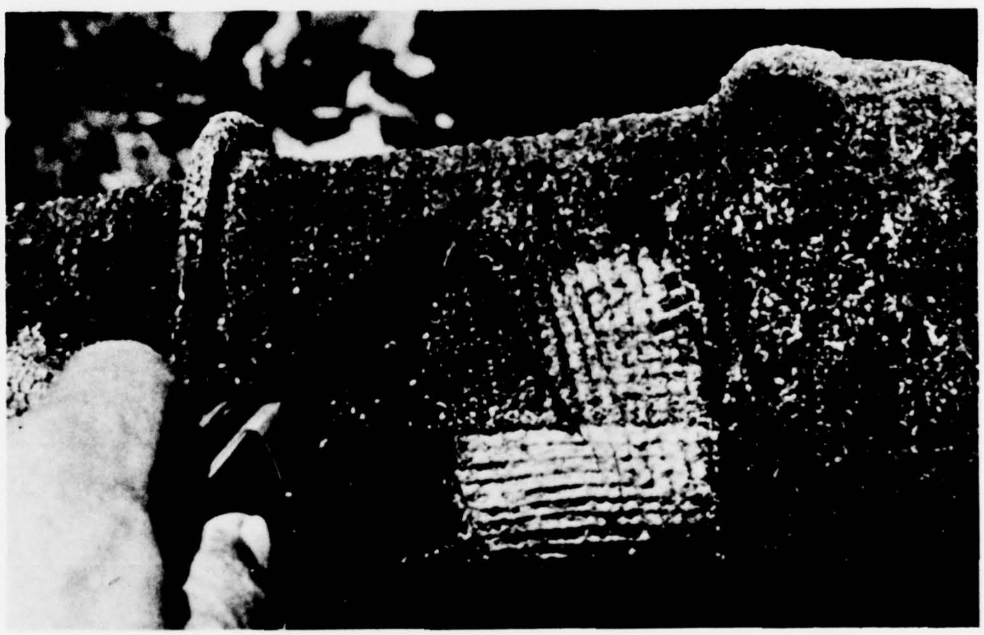

Figure 52. Cut being made through Denso tape for inspection.

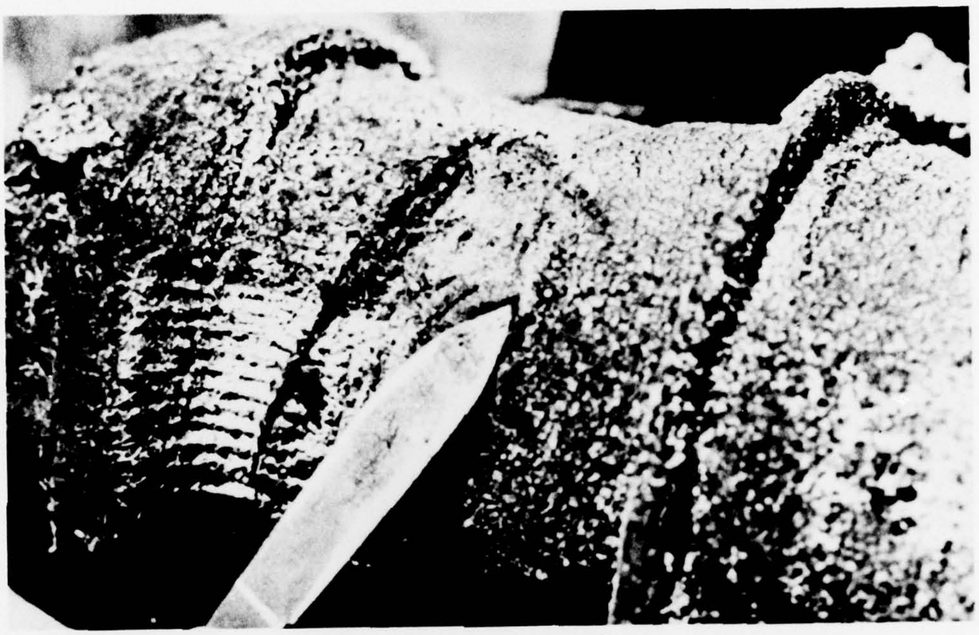

Figure 53. Cut repaired by merely pressing back the peeled tape.

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