FIELD STUDY OF FENCING MATERIALS IN A MARINE-ATMOSPHERIC ENVIRONMENT - RESULTS OF UP TO THREE YEARS OF ATMOSPHERIC EXPOSURE AND CORROSION RATE DETERMINATION

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by

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ABSTRACT

Fifteen different corrosion-resistant chain-link fencing systems were installed at the Naval Civil Engineering Laboratory, Port Hueneme to evaluate their performance in a marine-atmospheric environment. These included metallic, plastic-coated, and alloy wire fencing. The test fences were inspected and evaluated periodically for their performance, and the corrosion rates were determined during and up to three years of their exposure. A salt-spray test was also run on some of the samples.

As of this date, the evaluation indicates that the vinyl-clad galvanized chain-link fence and accessories are performing better than other corrosion-resistance chain-link fence being investigated. Although cost of the vinyl-clad fencing was slightly more (11%) than the galvanized chain-link fence, the extra cost of the vinyl-clad fencing appears economically well justified because of its outstanding corrosion resistance, longer service life, and other benefits provided by the vinyl coating.

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INTRODUCTION AND BACKGROUND

The Naval Facilities Engineering Command (NAVFAC) is responsible for the operation and maintenance of the many structures throughout the Naval Shore Establishment. Each Naval Shore Facility has some type of security fencing to protect Government property within its boundary. The fences themselves are subject to corrosion and deterioration from the natural environment.

The most commonly used security fence in the Naval Shore Establishment is a galvanized chain-link fence which is very susceptible to corrosion from the sea spray. However, there are newer types of chain-link fencing available which are more corrosion-resistant and require less maintenance in such corrosive environments, but their performance data is lacking. Hence, a study was undertaken by the Naval Civil Engineering Laboratory (NCEL) to investigate the performance of various types of corrosion-resistant chain-link fencing in a corrosive marine-atmospheric environment, and to obtain information regarding the initial material and installation cost, length of satisfactory service, and the cost of maintenance per year of service.

In-place test sections, consisting of 15 different systems of corrosion-resistant chain-link fence, were installed as an integral part of the NCEL security fence. Two of these test sections were installed two years later than the others. All sections are being inspected, rated, and photographed regularly. The same chain-link fence wires were also subjected to 4 months of the salt-spray test procedure described in ASTM Method B117-64.[1] Technical Note N-1043[2] describes in detail the first 13 experimental chain-link fencing materials used, their installation costs, the conditions of the test sections after 12 months of exposure, and the results of the 4 months salt-spray test.

Short segments of the same fencing materials were placed on an exposure rack in the same environment a year after the initial fencing installation to determine their corrosion rates.

This note describes the condition of each chain-link fence exposed up to 3 years, the corrosion rates of the fence wires during the first 2 years of exposure, and the results of the 4 months salt-spray test of the last two fencing materials installed.

DESCRIPTION OF CHAIN-LINK FENCING MATERIAL USED

Thirteen systems of experimental chain-link fence, installed earlier for a corrosion-resistance study, were described in detail in reference 2. Following the installation of the test fence sections at NCEL, the new interim Federal Specification, RR-F-191e (GSA-FSS) was issued. The old classifications and their corresponding revised classifications were reported in reference 2. Thus, only the description of the last two sections which were installed 2 years later are given here. Table 1 summarizes all fencing materials currently undergoing the exposure test with the appropriate new classification number.

System 14. Polyvinyl Chloride-coated Steel Chain-link Fabric:

This chain-link fabric is specified in Federal Specification RR-F-191e as Class 4, Coating G. The surface of the core wire is treated by grid blasting. Before weaving, the steel wire with the bonding agent is then bonded with vinyl covering by the thermal fusion process. Measurement showed that the thickness of the vinyl-covering was approximately 10 mils.

System 15. Welded-aluminum Coated Steel Chain-link Fabric:

This chain-link fabric is not classified in Federal Specification RR-F-191e. The fabric is coated with a very thick pure aluminum over the wire applied by a welding process. The Laboratory test showed that the aluminum coating was approximately 10 mils thick. This is considerably thicker than the 2.5 mils of Class 3, Coating E, of Federal Specification RR-F-191e.

Post and Accessories:

Polyvinyl chloride cover posts, ties, and other accessories were used for all experimental chain-link fence sections to eliminate electrical contact between the different types of fencing materials. The vinyl-coated post and accessories are classified as Class 7 in Federal Specification RR-F-191e. Some of the accessories were coated over galvanized steel and some were coated over steel. Zinc-coated posts, ties, and other accessories were used for the remaining security fencing and will be examined for relative performance. The zinc-coated post and accessories are classified as Class 6 in Federal Specification RR-F-191e. The entire security fence, including the test sections, is topped with three lines of vinyl-coated barbed wire.

COST ANALYSIS

Costs of 13 previously installed sections (System 1 through 13) are given in Table 2. The costs of System 1 through 13 were quoted in 1967. The fabrics for System 14 (vinyl-coated on steel wire by thermal fusion process) and for System 15 (wleded-aluminum coating on steel) were quoted at $3.06 and $3.56 per lineal feet, respectively, by a local supplier in 1969. Systems 14 and 15 were installed by Laboratory personnel and the quotation does not include posts and installation cost. A cost analysis for each complete section of the chain-link fence is given in Table 2. Up-dated costs of the chain-link fence are also presented in Table 2 for a comparisonal purpose. The computations of updated costs were made based on references 3 and 4. It is too soon to make a comparison of maintenance costs.

ATMOSPHERIC EXPOSURE TEST

Test Site

All fifteen in-place test sections were installed as an integral part of the security fence along portions of the perimeter of NCEL (Naval Civil Engineering Laboratory), located at Port Hueneme, California. Atmospheric conditions at the test site were described in detail in reference 2.

Visual Examination

The test sections were inspected and photographed immediately after the installation and after 4, 12, 18, 24 and 36 months. The test sections were evaluated in a subjective and comparative manner to describe their initial and weathered condition, as described in reference 2. Any corrosion products or appearance of rust on the surface was noted. Quantitative estimates of the extent of corrosion were made wherever applicable. The overall condition of each fence system was rated and summarized in Table 3.

CORROSION RATE DETERMINATION

Because the test sections are an integral part of the security fence, the quantitative determination of corrosion rates was made as follows.

The sample wires were cut from surplus chain-link fencing and exposed on a test rack adjacent to the chain-link fence undergoing atmospheric-exposure test at the location shown in Figure 1. The test wires were approximately 12 inches long and were weighed to the nearest 0.001 gram. A few wires from each group were scribed to expose the base metal of the wire. The weighed sample wires were carefully suspended on taut horizontal nylon cords of the atmospheric-exposure rack so as to preclude contact between the samples as shown in Figure 2.

Three wires from each system were removed from the exposure rack after 1, 4, 12, 18, and 24 months of exposure. The samples were inspected and photographed when they were removed. The corrosion rates of removed wires were determined by either a weight loss or weight gain method, depending on the nature of the sample, as described in detail in reference 2 for salt-spray (fog) test.

SALT SPRAY (FOG) TEST

Fencing wires of Systems 14 and 15 were subjected to the salt-spray (fog) test by the procedure described in ASTM Method B117--64.[1] The results of other systems previously tested were reported in reference 2. The sample wires were obtained from the surplus of the chain-link fencing used for the atmospheric exposure test.

The sample wires were cut to a length of approximately 12 inches and were weighed to the nearest 0.001 gram. A few wires from each group were scribed to expose the base metal of the wire. The weighed sample wires were carefully suspended in the salt-spray chamber to preclude contact between samples and also arranged so as to prevent corrosion products from one specimen dropping onto any other sample. The temperature of the salt-spray chamber was maintained at 95 ± 3°F throughout the experiment. The salt-spray solution was 5% by weight of sodium chloride dissolved in demineralized water.

Three wires from each system were removed from the salt-spray chamber after one week, one, two and four months of continuous salt-spray exposure. The samples were inspected and photographed when they were removed. The corrosion rates of aluminum-coated and vinyl-coated wires were determined by a weight loss and weight gain method, respectively, as described in reference 2.

RESULTS

Atmospheric Exposures

Systems 1 and 2 - Light and Heavy Zinc-coated Fabrics: The surface of the zinc-coated fabrics exhibited a bright metallic appearance when inspected at the time of installation (Figure 3). At the time of the fifth inspection (2 years after installation), the surface of both fabrics were nearly completely covered with a white corrosion product, a blend of fine air-borne sand and dirt that formed a rough surface on the fence wire. Very faint speckles of rust stains, in the form of pin-hole rust, appeared on the surfaces of the wire. Some of the rust stains were superficial and were probably caused by iron contaminated air-borne sand and dirt. The air-borne sand and dirt accumulated on the windward side more than the leeward side of the wire.

At the sixth inspection (3 years after installation), the zinc coating on the wire seemed to have disappeared, and only a dark gray zinc-iron alloy remained under the white corrosion product. Speckled rust stains were more apparent compared to the previous inspection and were distributed uniformly over about 5% of the zinc-coated surface (Figure 4). A little more of the rust stains were observed on wires located near the water than on those located away from water. The zinc-coated wires tarnished and corroded much faster than they normally would in a non-maritime environment. This was readily evident when comparing the test fence against a similar fence at a public school which was located 10 miles inland from the shore. After five years of atmospheric exposure, the school yard fence had tarnished to only a gray color and there was no accumulation of the white coarse corrosion product (Figure 5).

Although the corrosion products had accumulated and covered the entire wire surface of both systems, the performance of the zinc-coated wire for the first 3 years was rated fair because there was no significant amount of red rust formed on the base metal. Overall ratings are summarized in Table 3.

Systems 3 and 4 - Light and Heavy Aluminum-coated Fabrics: The bright metallic appearance of the aluminum-coated wires (Figure 6) diminished rapidly as the exposure test continued, and the surface of the wire was rapidly covered with white corrosion products. The corrosion products were coarse and consisted of white loosely-adhering crystals, which crumbled easily when rubbed between the fingers.

At the fifth inspection (2 years of exposure), the faint pin-hole rust stains were obscured by the heavy accumulation of corrosion products. Fine air-borne dust and sand also continued to accumulate on the corrosion-roughened wire surface.

At the time of the sixth inspection (3 years of exposure), corrosion attack on the base metal was apparent. Faint yellow-rust stains had become red-rust stains which covered approximately 15% of the corrosion roughened surface (Figure 7). Sample wires located away from the shore were covered with somewhat less red-rust stains than the wires located near the shore.

The overall performance of the aluminum-coated fences was rated fair because the corrosion attack on the base metal was not extensive enough to necessitate the removal of wires.

Systems 5 and 6 - Vinyl-clad Galvanized Steel Fabric: After the 3 years of exposure there was no evidence of cracking, color-fading, or any other visible form of deterioration in the polyvinyl chloride covering. Accumulations of air-borne sand and dirt on the wires were quickly washed away after each rainfall and the appearance of the fabric was as good as when installed (Figures 8 & 9). The white corrosion product observed at the cut-end is considered normal for this type of fencing and it did not corrode any further nor cause any rust stains.

The performance of the vinyl-clad galvanized steel fabrics was rated excellent during the first 3 years of exposure.

System 7 - Vinyl-clad Steel Wire Fabric: The condition of this fabric was generally the same as that of Systems 5 and 6. The cut ends were covered with red rust, but without noticeable staining of the vinyl covering. Such rust is expected for this type of material and not likely to affect the overall performance of the fence. Heavy rusting was observed in the portions of wire fabric exposed by mechanical damage (Figure 10).

Except where the plastic covering had been mechanically damaged, the overall performance of the fabric was rated excellent for the first 3 years of exposure.

System 8 - Aluminum Alloy Fabric: During the three years of exposure, the bright metallic appearance of the aluminum alloy wire (Figure 11) was gradually lost by the accumulation of white corrosion product (Figure 12). The accumulation rate of the whitish corrosion product was slightly slower than that of the aluminum-coated wires, Systems 3 and 4.

The overall performance of the aluminum alloy fabric is rated good during the three years of atmospheric exposure.

System 9 - Stainless Steel Fabric: The stainless steel fabric maintained its bright metallic appearance (Figures 13 & 14) throughout the three years of exposure. However, some of the accumulated sand and dust on the fabrics were not washed away easily following each rainfall and gave a rusty appearance.

The overall performance of the stainless steel fabrics was rated excellent.

Systems 10, 11, 12 and 13 - Fence Fabrics with Slats: After 3 years of exposure, none of the anodized aluminum slats in System 10 showed any sign of corrosion (Figures 15 & 16). The redwood pickets in System 11 showed no sign of deterioration for the first three years of exposure except a slight fading of color (Figure 17). The condition of the zinc-coated fabrics with anodized aluminum and redwood slats (Systems 10 & 11) was slightly better than that of the zinc-coated fabric without the slats (System 2). The wires accumulated less white corrosion product, fine sand, and dirt. This is probably due to the shielding effect of the slats. Contact between the aluminum slats and zinc-coated wire did not appreciably affect the corrosion process.

Within 2 weeks following the installation, the aluminum slats of Systems 12 and 13 were damaged by vandalism as reported in reference 2. The damaged and dislodged slats were later replaced by spring-tempered aluminum alloy slats coated with baked enamel. The new slats were not identical to those installed originally. After three years of exposure, small blisters were found on the newly-replaced slats of System 12. Most of the blisters formed at the edges of slats where they contacted each other (Figure 18). The corrosion was accelerated at those contact points because of the entrapment of sand and hygroscopic dirt which in turn retain moisture for a prolonged time and set up a local concentration cell.

In less than 12 months of exposure, small blisters appeared on the new slats of System 13. As the exposure continued, the blisters became quite numerous and large. At the time of the last inspection (after 3 years of exposure) some of the blisters were broken and exposed a white corrosion product under the coat (Figure 19).

Although the slats are identical in both cases (System 12 and 13), their performances were considerably different. The slats in System 13 were well insulated from other electrical contacts because the only contact was the vinyl-coated fabric. The results were, however, more extensive blistering than the slats on System 12, which had a direct contact with the aluminum-coated wires.

Vinyl-covered and Zinc-coated Posts and Accessories: Except where the vinyl covering had been mechanically damaged by some external factor other than weathering, most of the vinyl-coated posts and accessories were in excellent condition. Some of the vinyl-coated posts and accessories were coated over steel and others were coated over galvanized steel.

When the vinyl coating was mechanically damaged it resulted in adverse effects on the post and accessories. Blistering and corrosion took place rapidly in the damaged areas (Figure 20). However, the post and accessories in which galvanized steel was under the vinyl coating, were protected from corrosion attack where the covering was damaged by mechanical forces (Figure 21).

System 14 - PVC-bonded Chain-link Fabric: The vinyl coating is applied to the prime steel by the thermal fusion method, which bonds the vinyl coat to the underlying wire. The advantage of the fused vinyl coating over the vinyl coating which is extruded on the wires as in Systems 5, 6 and 7, is the protection against moisture penetration under the vinyl coating. If the bonded coating is broken at some point, there is less possibility of moisture or other corrosion-inducting material getting under the coating. Corrosion is therefore limited to the localized area.

During the 12 months of atmospheric exposure, the fabric showed no evidence of cracking, color fading, or any other form of visible deterioration in the vinyl-coating (Figure 22). However, rust and blisters appeared in the areas where the fabric was damaged by an external mechanical force.

Except for the damaged areas, the performance of the vinyl-coated fabrics were rated excellent during the first 12 months of exposure.

System 15 - Aluminum-welded Chain-link Fabric: Although this material is somewhat similar to the aluminum-clad fabrics, (Systems 3 & 4), the resistivity to corrosion of this fabric appears to be much superior than the two forementioned fabrics. After 12 months of exposure, the accumulation of corrosion products on System 15 were much less (Figure 23) than that of Systems 3 and 4 which were completely covered with a white corrosion product (Figure 24). Approximately 40% of System 15's surface, mostly on the windward side of the fabric, was covered with the white corrosion product. There were no visible red rust stains on the wires.

The performance of the aluminum-welded fabric was rated good for the first 12 months of exposure.

Corrosion Rates of Chain-link Fabrics

Three short fence wire segments corresponding to each of the fence systems were removed from the exposure rack after 1, 4, 12, 18 and 24 months of exposure, and they were inspected and photographed. Their corrosion rates were determined as described in an earlier section of this report. Quantitative data on the coating weight and thickness of metal and plastic coats are listed in Table 4, and the corrosion rates for the metal and plastic-coated wires are listed in Tables 5 and 6 respectively.

Zinc-coated Chain-link wires, Systems 1 and 2: Federal Specification RR-F-191e requires that Systems 1 and 2 (Class 1 - Coating A and C) have a minimum coating of 1.2 ounces and 2.0 ounces of zinc per square foot of uncoated wire surface respectively. The laboratory test revealed that the zinc coatings of Systems 1 and 2 were 1.06 ounces and 2.23 ounces per square foot on uncoated wire surface respectively. Thicknesses of the zinc coat of Systems 1 and 2 were 1.78 and 3.75 mils respectively, as listed in Table 4.

After 12 months of atmospheric exposure, 75% of the surfaces of both systems were rough due to the formation of a white corrosion product and accumulation of air-borne sand and dirt. After removing the corrosion product with a cleaning solution, the remaining amount of zinc coating was determined. System 1 lost an average of 1 mil or 61.4% of zinc coating, while system 2 lost 1.2 mil or 30.9% of zinc coating (Table 5).

After 24 months of exposure, both systems were completely covered with a white corrosion product and air-borne sand and dirt. Approximately 15% of the surface was covered with red-rust stain, mostly concentrated near the cut end of the wires (Figure 25). System 1 lost an average of 1.4 mils or 77.5%, and System 2 lost 1.7 mils or 47.3% of the zinc coating as indicated in Table 5.

The zinc coating that remained on the wires after 24 months of exposure appeared to be mostly of a dark gray zinc-iron alloy, which had formed between the zinc coating and the base metal during the hot-dip process. This dark zinc-iron alloy is apparently more resistant to corrosion attacks than the zinc coating itself. Although a large percent of the zinc coating was lost, there was protection from rusting in a large area of the base metal (Figure 26).

A graphical illustration of the corrosion attack on metal-coated and alloy wires in the atmospheric environment is shown in Figure 27. During the initial four months, the graph shows that the wires lost their zinc coating slowly, and during the next few months, they lost the coating very rapidly. After 12 months of exposure, the corrosion rate of the zinc coating decreased with time.

Aluminum-coated wires. System 3, 4, and 15: Federal Specification RR-F-191e requires that Systems 3 and 4 (Class 3 - Coatings D and E), are coated with a minimum of 0.35 ounce of aluminum alloy per square foot of uncoated 11 gauge wire surface, and 0.40 ounce of aluminum alloy per square foot of uncoated 6 or 9 gauge wire surface, respectively.

The laboratory test revealed that the aluminum alloy coating of Systems 3 and 4 were 0.50 and 0.58 ounce per square foot on uncoated wire surface, respectively. The coating of System 15 was 2.46 ounces of pure aluminum per square foot on the uncoated wire surface as listed in Table 4. The thickness of the aluminum coating in Systems 3, 4, and 15 was 2.18, 2.51 and 10.72 mils, respectively.

After 12 months of atmospheric exposure, the segment samples of Systems 3 and 4 were completely covered with a white corrosion product and air-borne sand and dirt. System 3 lost an average of 1.0 mils or 38%, and System 4 lost an average of 1.1 mils or 43% of the aluminum coating as indicated in Table 5.

However, after 12 months of exposure, only 45% of the surface of System 15 was covered with a white corrosion product. System 15 lost 0.2 mils or 1.4% of the aluminum coating; this was far less than the loss of coating in Systems 3 and 4 with a comparable length of exposure (Figure 28).

After 24 months of exposure, numerous pin-hole rust stains appeared on the surface of Systems 3 and 4 (Figure 29). System 3 lost an average of 1.8 mils or 61.9% and System 4 lost an average of 2.3 mils or 65.1% of the aluminum coating.

Despite the remaining aluminum coating on wires (Figure 30), the underlying steel core of fence wires was pitted extensively after 24 months of exposure by corrosion attack. The aluminum-coated and zinc-coated wires were stripped of their coatings after 24 months of atmospheric exposure as shown in Figure 31. Figure 31 indicates that the zinc coating protects the underlying steel core until all of the zinc is sacrifically used up, and that the aluminum coating is not as effective in providing sacrificial protection as the zinc coating to protect the underlying steel core. As a result, the underlying steel core was attacked and pitted by corrosion while some of the aluminum coating still remained on the surface of the wire.

The graph in Figure 27 shows that the wires of Systems 3 and 4 steadily lost their aluminum coating.

<u>Aluminum Alloy Wire, System 8</u>: After 24 months of exposure, the surface was completely covered with a white corrosion product and air-borne sand and dirt (Figure 32). Aluminum alloy wires lost an average of 0.5% and 1.2% of its weight after 12 and 24 months of atmospheric exposure, respectively.

Most of the corrosion of the aluminum alloy wires was in the form of pin-hole pitting. Thus, depth of penetration was deep, although the amount of metal lost was very light. The corrosion rate obtained by the amount of weight loss in metals as shown in Table 4 is therefore misleading because the corrosion rate so obtained will be much less than the actual penetration of pin-hole pitting. Although the amount of metal weight lost was small, the penetration of some of the pin-hole pittings were as deep as 2 mils or more when examined under a microscope.

<u>Stainless Steel Wire, System 9</u>: During the 24 months of exposure air-borne sand and dirt accumulated on the stainless steel wire and gave it a rusty appearance. However, the sand and dirt were easily wiped off and the wire revealed a metallic appearance underneath. The wires demonstrated no other sign of corrosion (Figure 32). The corrosion rate was very small as shown in Table 5, and it could not be illustrated graphically in Figure 27.

Vinyl-clad wires, Systems 5, 6, 7 and 14: Federal Specification RR-F-191e requires that the vinyl-coating thickness of Systems 5, 6 and 14 (Class 4 - Coatings F and G) be a minimum of 18, 18, and 7 mils respectively. The laboratory test indicated that the thickness of vinyl-coating for Systems 5, 6 and 14 were 32, 32, and 10 mils respectively, as shown in Table 4. The vinyl-coating of System 7, which is not classified in RR-F-191e, was 28 mils.

The corrosion rate of the vinyl-coated wires was determined by the weight gain method as described in an earlier section of the report. The results are listed in Table 6. A graphical illustration of the corrosion rate of vinyl-coated wires during the 24 months of atmospheric exposure is shown in Figure 33. Although visual inspection of the test fence did not reveal the condition of core wire, the graph shows that System 5 is the most corrosion-resistant system compared to Systems 7 and 14. System 7 appeared to be corroding faster than the other two systems. System 5 gained 7.1 mg while Systems 7 and 14 gained 76.2 and 31.6 mg of the corrosion product, respectively, during the 12 months of exposure. There was no apparent red-rust accumulation in the inter-space between the vinyl-coating and the core wire of System 5, except for the white corrosion product found near the cut end and scribed area, when the underlying core wire was examined after removing the vinyl coating (Figure 34). Most of the core wires of Systems 7 and 14 were also well protected from corrosion and maintained the original metallic appearance, except near the cut-ends and scribed areas (Figures 28 and 34).

Salt-spray (Fog) Test

Thermal-fused Vinyl-coated Wires, System 14: Shortly after the salt-spray test began, rust appeared on the cut ends and the scribed areas of the wires. After 4 months of exposure, tubercles of rust formed both on cut-ends and in the scribed areas (Figure 35). The vinyl covering near the cut ends and scribed areas was stained by rust but otherwise appeared to be unaffected by the salt-spray exposure.

After 4 months of salt-spray exposure, the wire was stripped of its vinyl covering for inspection. Except near the cut ends and scribed areas, the underlying core wires maintained their metallic appearance without any sign of corrosion attack.

Reliable measurements of rust formation rate could not be made by the weight-gain method on this test because the rust formed was constantly washed out and lost during the salt-spray exposure test.

Aluminum-welded wire, System 15: After 4 months of salt-spray exposure, approximately 25% of the surface was covered with a white corrosion product (Figure 35). Except for a small amount of red rust at the cut ends and scribed areas, there was no other red rust on the wires. System 15 was very corrosion-resistant and lost very little of the aluminum coating in comparison with the aluminum-coated wire (System 4) which received extensive pitting corrosion during the comparable length of salt-spray test (Figure 36 vs 37).

System 15 is weld-coated with pure aluminum and lost 0.008 mils or 0.08% of its coating after 16 weeks of the salt-spray test, whereas the aluminum-coated wires (System 4) lost 0.1 mils or 0.18% of their coating. These data are given in Table 7.

FINDINGS

All vinyl-coated fabrics under investigation are performing their required function very well, combining outstanding corrosion resistance, a good appearance, and proper security. The polyvinyl chloride covering showed very good weather resistance with no color fading during the 3 years of atmospheric exposure. While all other metal-coated and alloy fence exhibited a buildup of corrosion products or air-borne dirt, the vinyl-coated wires were cleansed by each rainfall. Treasure Island Naval Station has informed the Laboratory that their vinyl-clad over galvanized chain-link fence (similar to System 5) is performing very well and has provided a maintenance free service for the past 7 years. Zinc-coated and aluminum alloy chain-link fences did not provide a long useful service in the past because of the severe marine environment there.

Vinyl coated fabrics, posts, and their accessories are often subjected to abuse and mechanical damage by careless handling. Vinyl-coated galvanized steel is, therefore, preferred to vinyl-coated prime steel in providing double protection against corrosion induced by natural and exterior mechanical damages.

Although the zinc-coated chain-link fabrics are subjected to rapid corrosion attack in a marine atmospheric environment, they should perform satisfactorily in a non-maritime environment providing that there is no serious industrial atmospheric pollution within the vicinity.

Zinc is anodic to iron and has the characteristic of a sacrificial coating. The core wire of the fence was protected from corrosion until all of the zinc coating was cathodically expended. Since the corrosion rates of the heavy and light zinc-coated fabrics were similar, the service life of the zinc-coated chain-link fence is a function of zinc-coating thickness.

The aluminum-coatings of Systems 3 and 4, in contrast, were not as effective or sacrificial as the zinc coatings in protecting steel against rusting in a marine atmospheric environment. The core wire was badly pitted after 2 years of exposure while a considerable amount of aluminum coating still remained on the wires. Although aluminum has the ability to self-passivate to make it a quite stable material, the accumulation of air-borne fine sand and dirt on the wire sets up a condition vulnerable to the development of concentration cell, causing a considerable pitting corrosion of the core wire. Free access to the oxygen supply is essential in maintaining passivity of the aluminum coating, and the presence of sand or dirt on the wire prevents this in localized areas.

The aluminum-welded wire (System 15) had much less white corrosion products than that of the aluminum-clad (Systems 3 & 4) or the aluminum alloy (System 8). The corrosion resistance of aluminum depends very much on the purity of the metal. Resistivity against corrosion exhibited by System 15 is probably due to the purity of the aluminum and the coating thickness used.

Although air-borne sand and dirt accumulated on the wire, the stainless steel fabric was the only exposed metal fencing material which maintained its bright metallic appearance without visible corrosion throughout the 3 years of the atmospheric corrosion test. The corrosion rate was too small to be determined accurately by the method described in this report, as shown in Table 5. If the service life of stainless steel fencing proves to be at least two and a half times that of zinc-coated fencing, then the higher initial cost of the stainless steel fabric would be economically justified.

The shielding of areas from public view can be effectively achieved by inserting anodized aluminum slats into chain-link fencing or by installing a chain-link fabric that has redwood pickets already inserted. However, the aluminum slats were not found to be as durable as the redwood pickets. Within two weeks after installation, the aluminum slats were damaged by vandalism, as indicated in reference 2. Figure 38 illustrates a similar consequence at a nearby Naval installation.

RECOMMENDATION

As of this date, the investigation of various corrosion-resistant chain-link fencing materials in a marine atmospheric environment indicates that the vinyl-clad galvanized chain-link fence and accessories should be used at all Naval Shore facilities where the corrosion abatement of the chain-link fence is a problem. Cost of the vinyl-clad fencing ($3.51 per linear ft) was approximately 11% more than that of the zinc-coated fencing ($3.17 per linear ft). However, the extra cost of the vinyl-clad fencing appears economically well justified because of its outstanding corrosion resistance, longer service life, and other benefits provided by the vinyl coating. It is believed that in a non-marine atmosphere, zinc-coated chain-link fencing will be quite satisfactory.

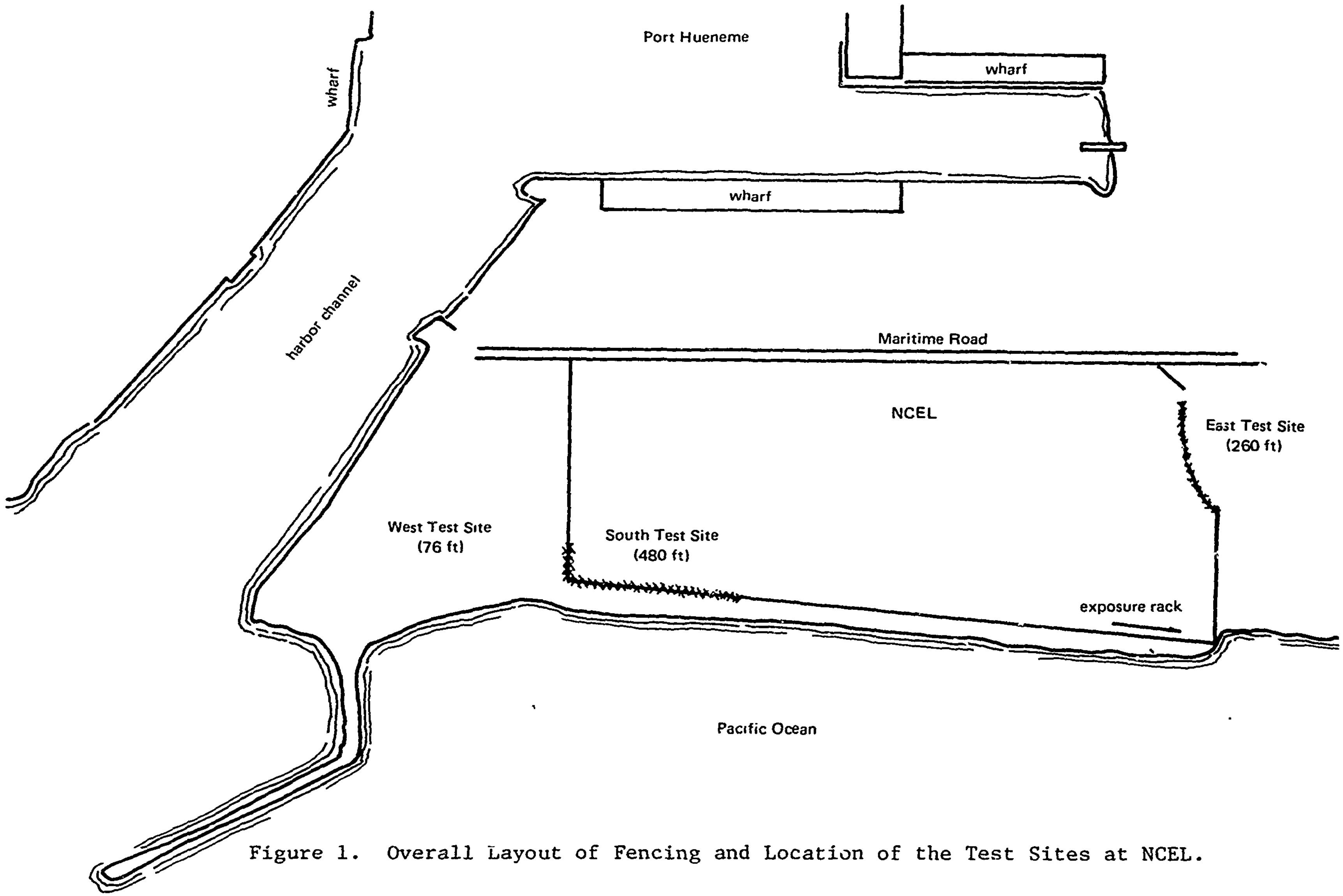

Figure 1. Overall Layout of Fencing and Location of the Test Sites at NCEL.

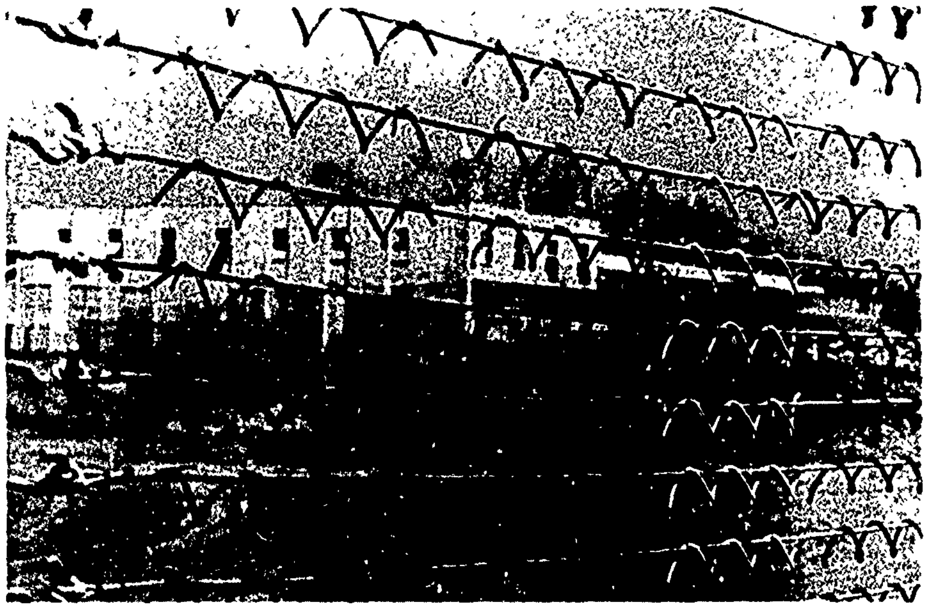

Figure 2. Atmospheric exposure rack for corrosion rate determination.

Figure 3. System 1. Newly installed zinc-coated steel.

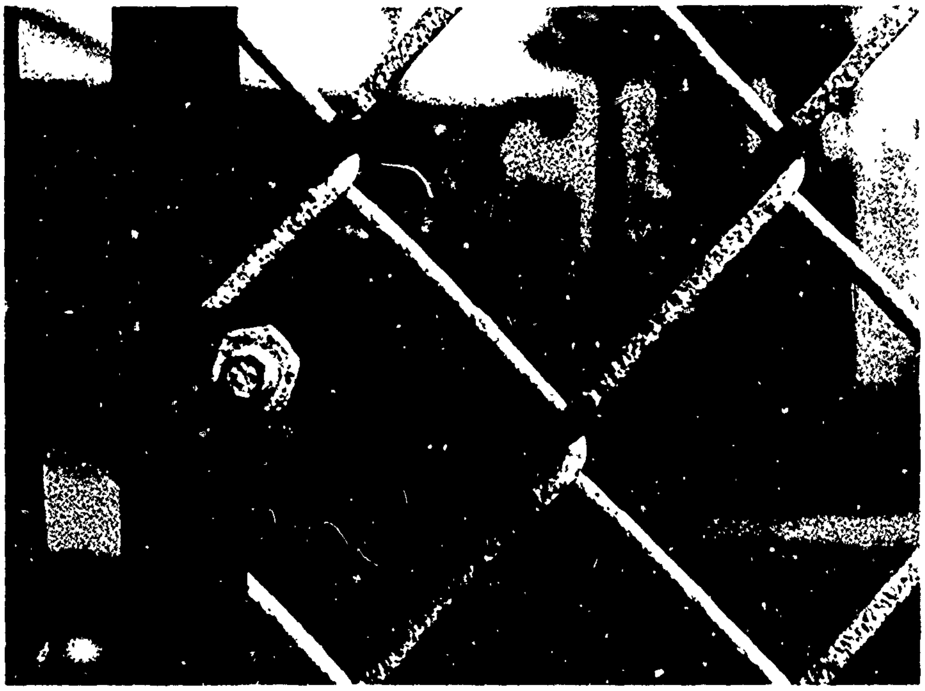

Figure 4. System 1. Zinc-coated steel - after 3 years of exposure.

Figure 5. Zinc-coated steel - after 5 years - located 10 miles inland from shore.

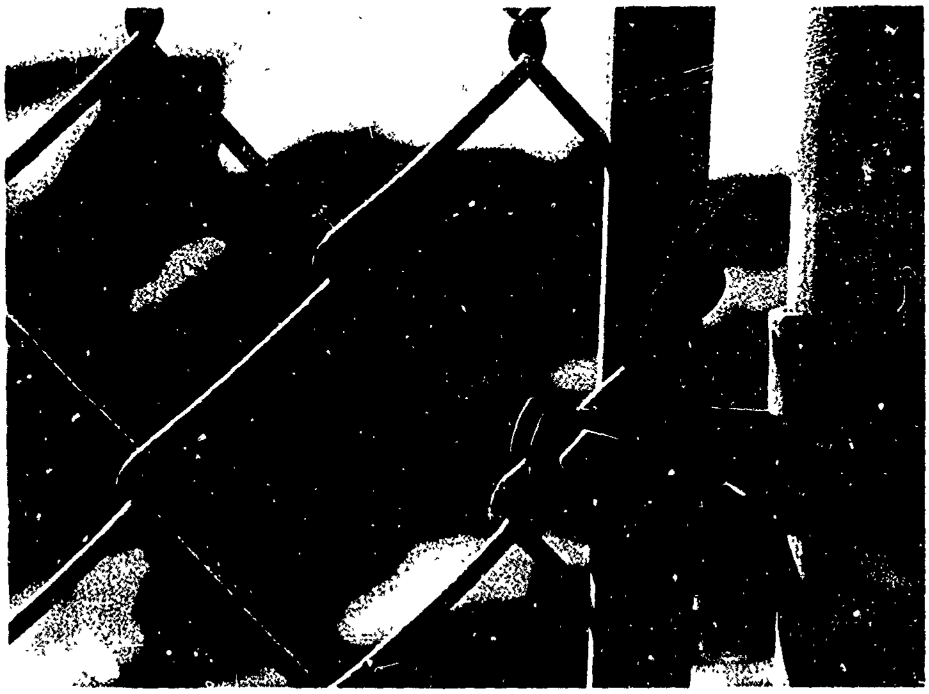

Figure 6. System 3. Newly installed aluminum-coated steel.

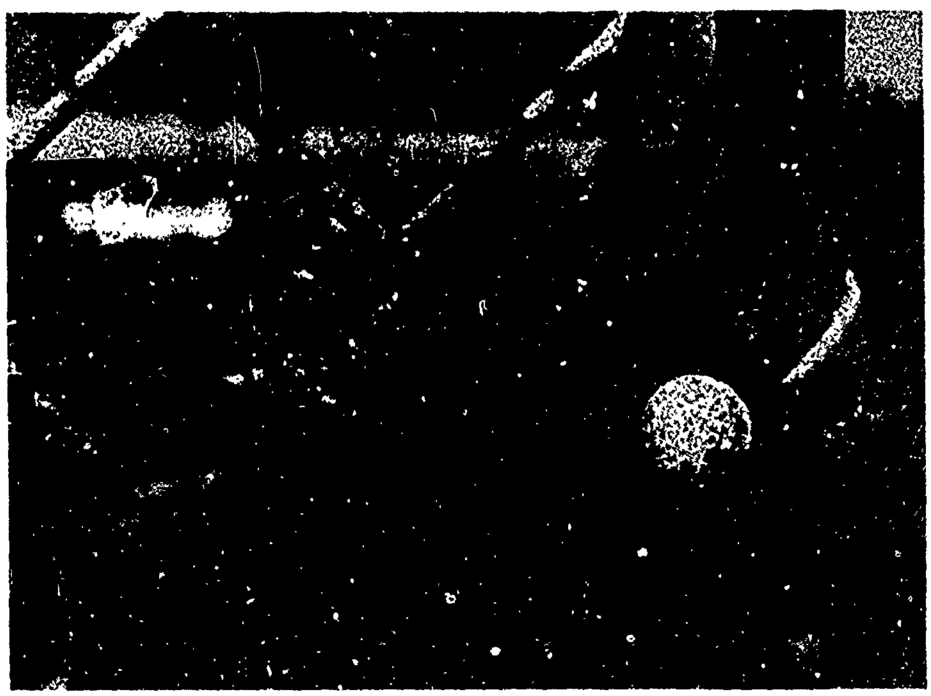

Figure 7. System 3. Aluminum-coated steel - after 3 years of exposure.

Figure 8. System 5. Newly installed vinyl-clad galvanized steel.

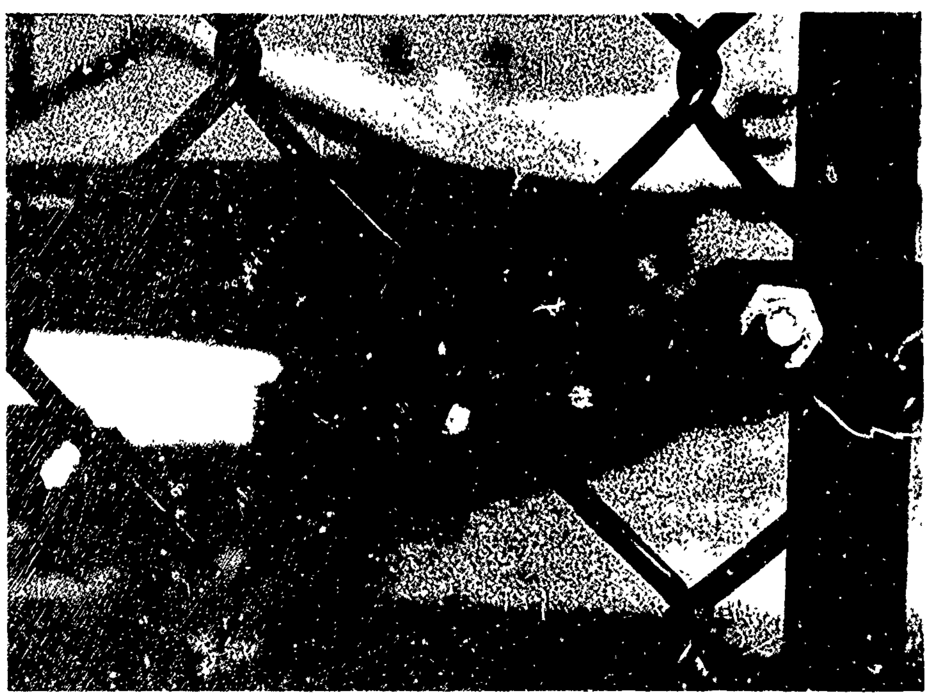

Figure 9. System 5. Vinyl-clad galvanized steel - after 3 years of exposure.

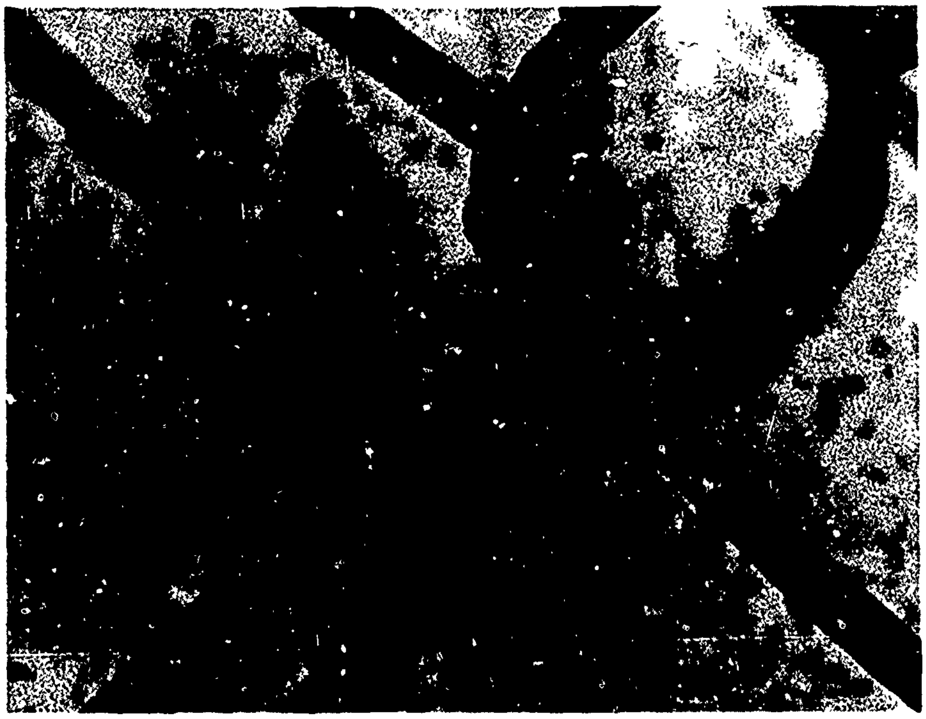

Figure 10. System 7. Vinyl-clad prime steel - rusting mechanically damaged area.

Figure 11. System 8. Newly installed aluminum alloy fence wire.

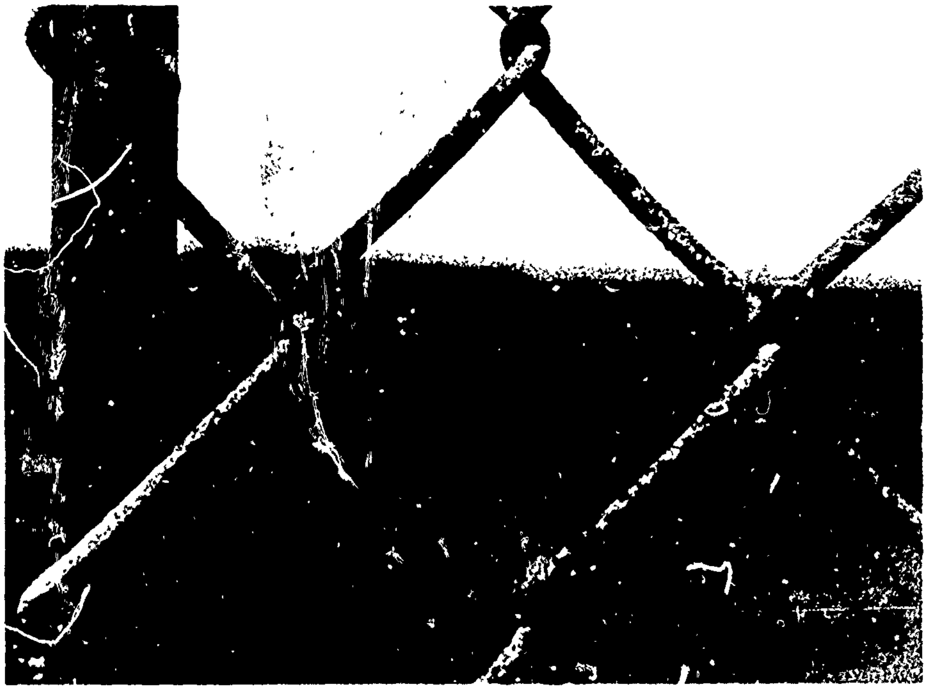

Figure 12. System 8. Aluminum alloy after 3 years of exposure.

Figure 13. System 9. Newly installed stainless steel.

Figure 14. System 9. Stainless steel after 3 years of exposure.

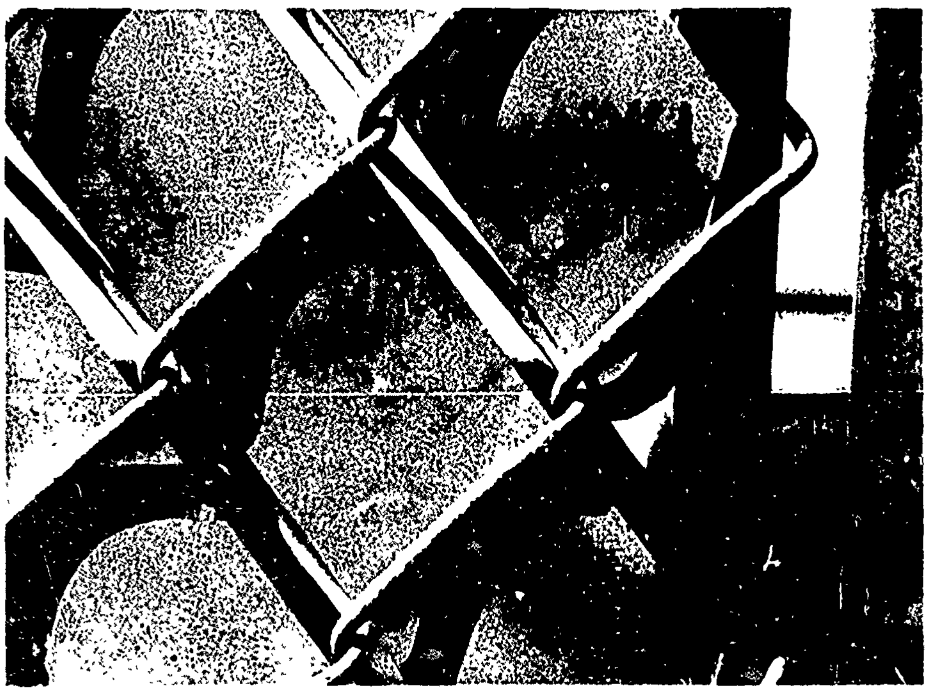

Figure 15. Newly installed anodized aluminum slats on zinc-coated wire.

Figure 16. System 10. Anodized slats and zinc-coated wire after 3 years of exposure.

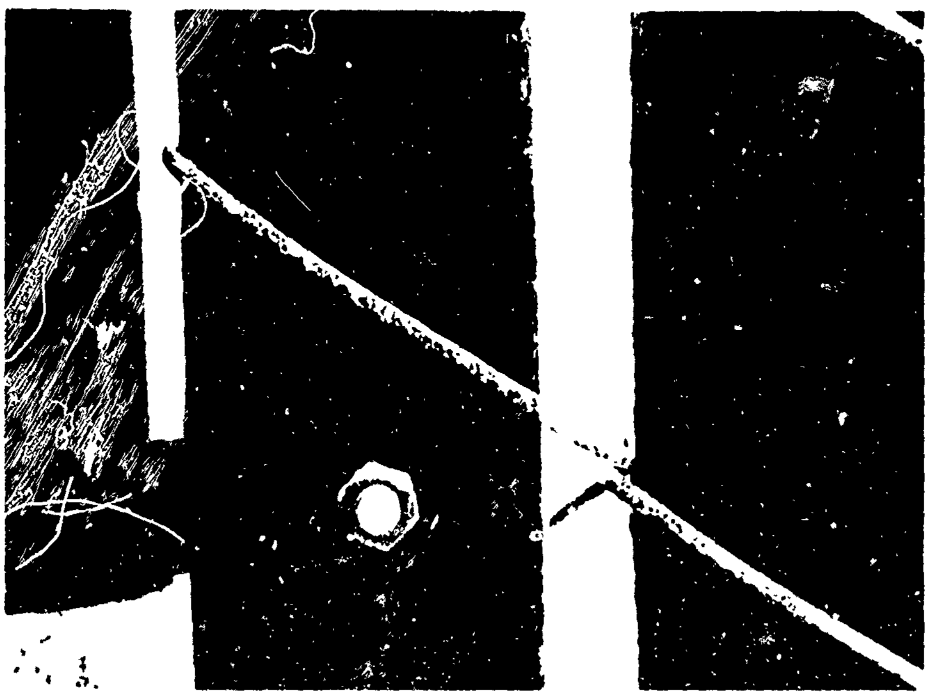

Figure 17. System 11. Redwood slats with zinc-coated wire after 3 years of exposure.

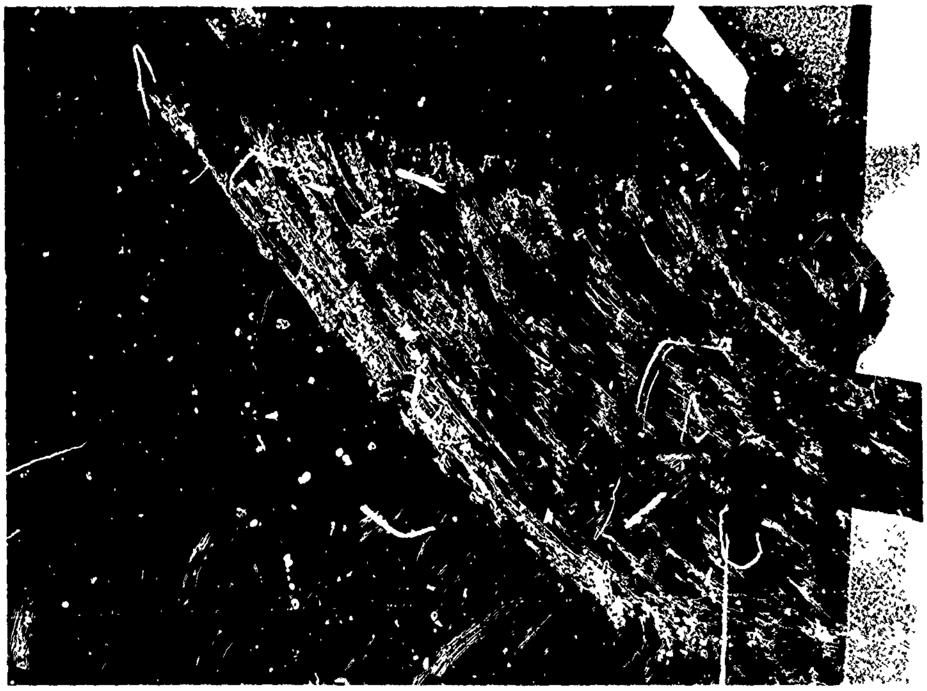

Figure 18. System 12. Aluminum slats with aluminum-coated wire after 3 years of exposure.

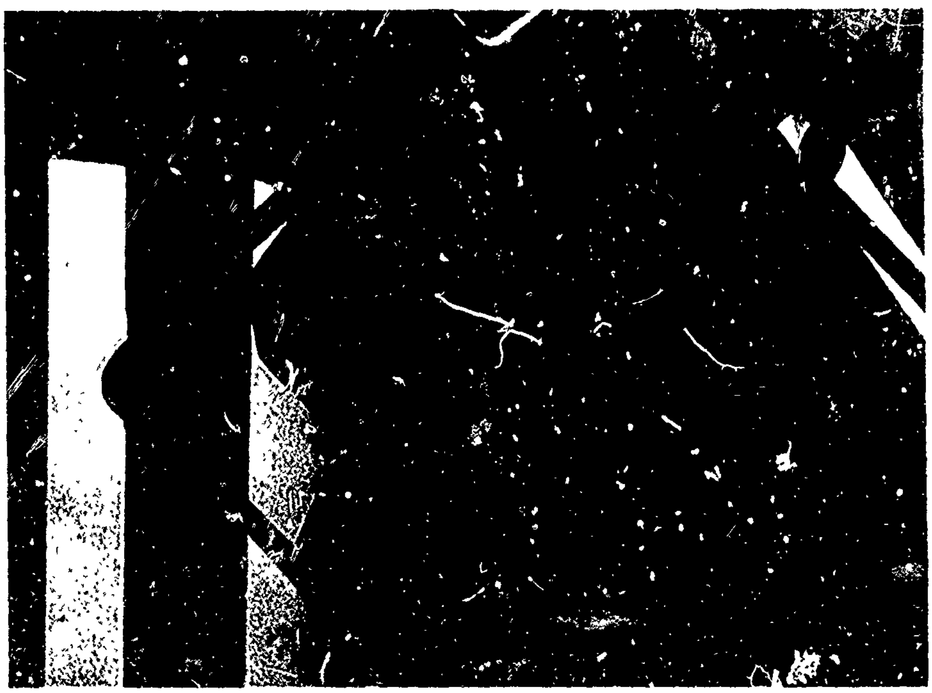

Figure 19. System 13. Blisters on aluminum slats with vinyl-clad wire after 3 years of exposure.

Figure 20. Blister formation on mechanically abraded area.

Figure 21. Coating damage of vinyl-clad galvanized stretch bar.

Figure 22. System 14. Blister formation around damaged area - after 12 months of exposure.

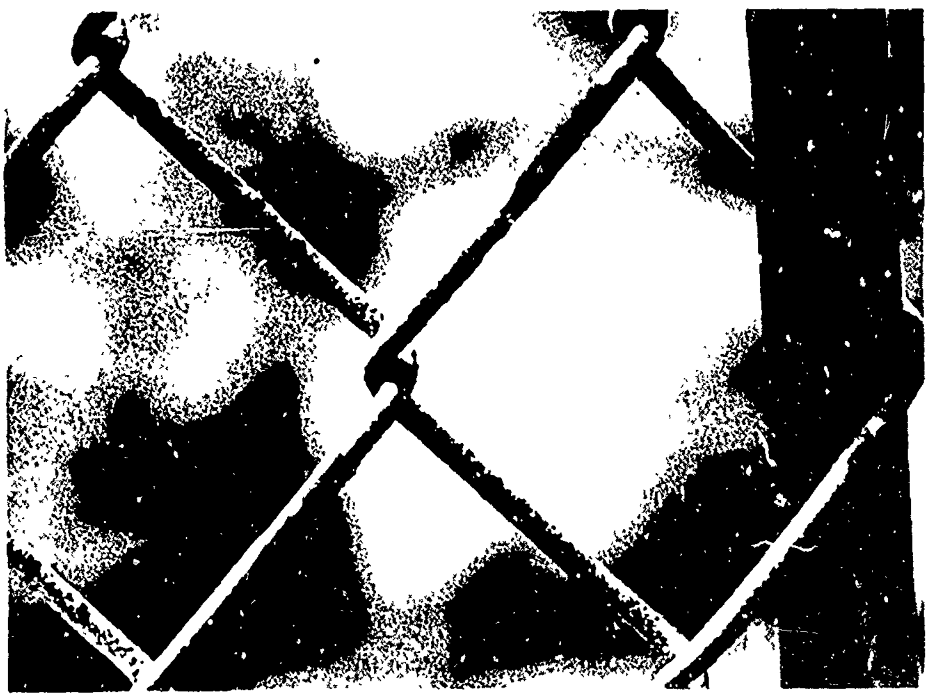

Figure 23. System 15. Aluminum-welded steel - after 12 months of exposure.

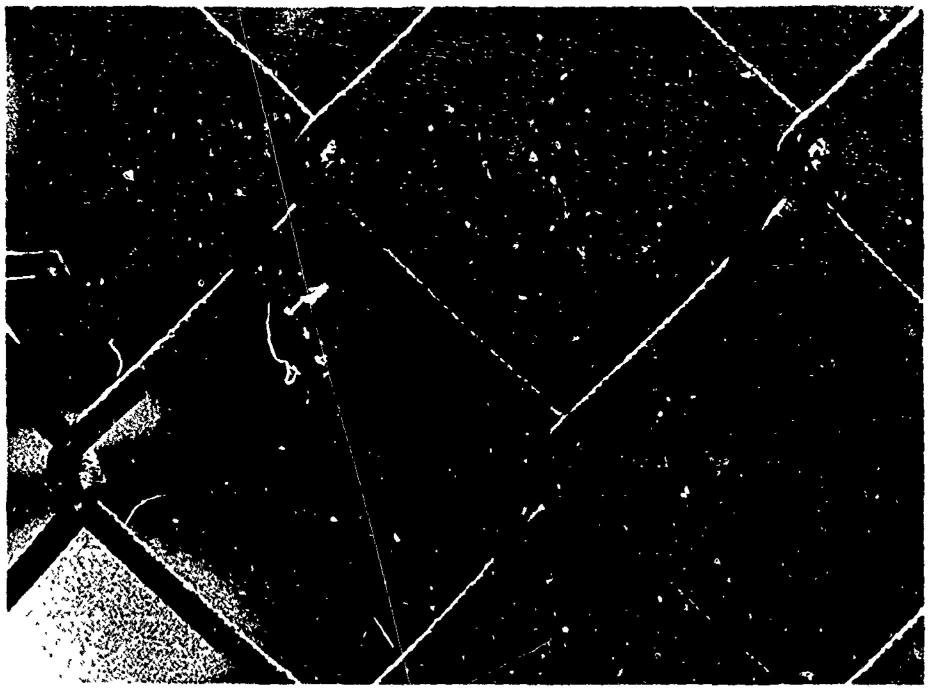

Figure 24. System 3. Aluminum-coated steel - after 12 months of exposure.

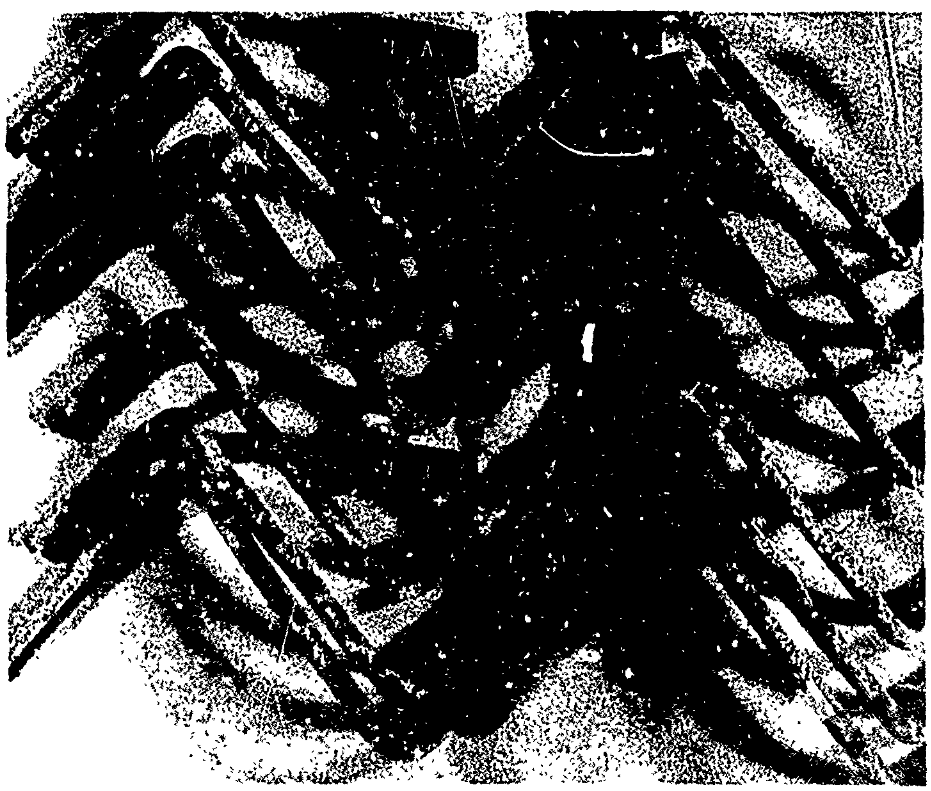

Figure 25. Systems 1 & 2. Zinc-coated steel - after 24 months of exposure.

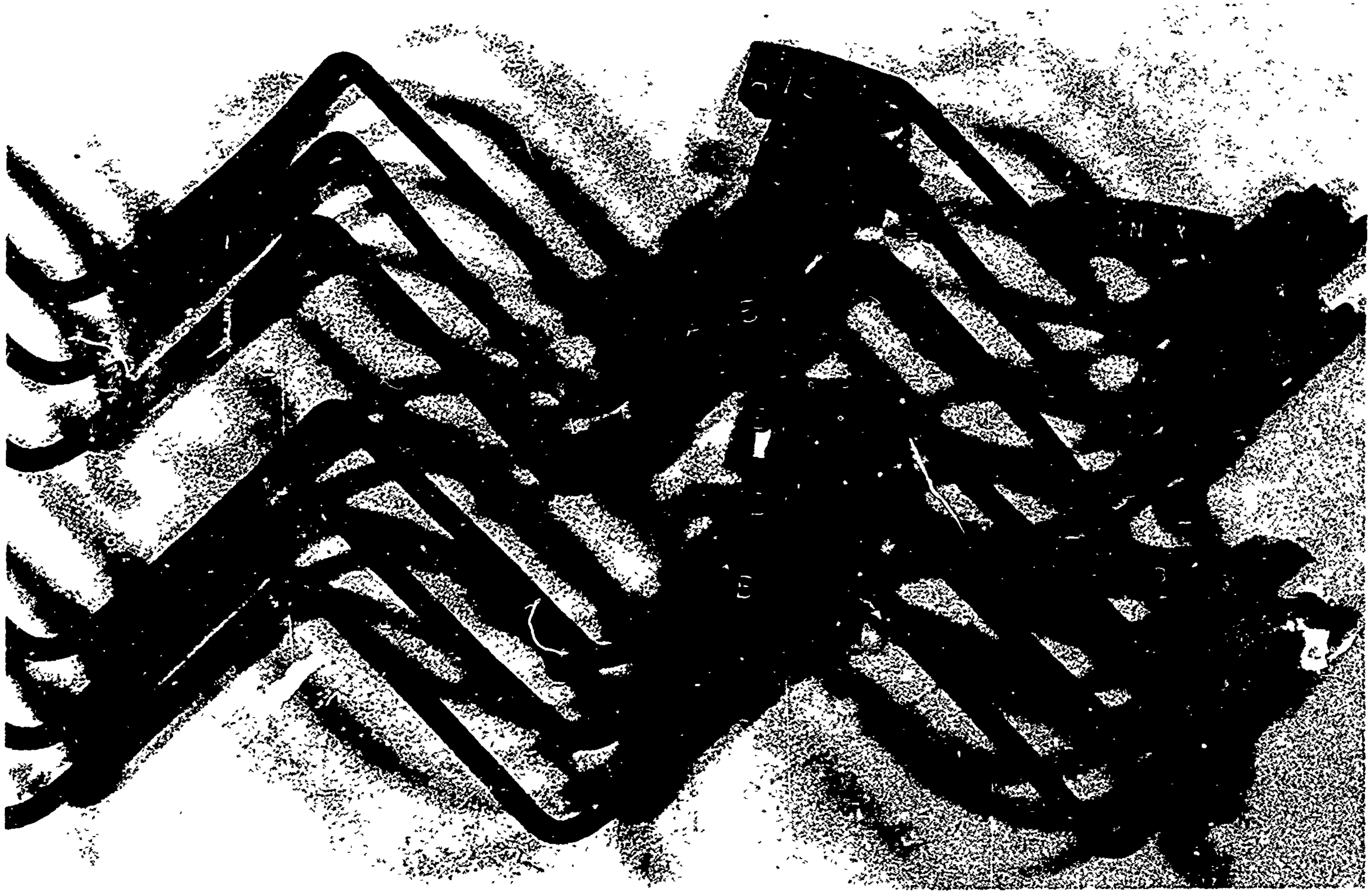

Figure 26. Systems 1 & 2. Remaining zinc coat after corrosion product was removed - after 24 months of exposure.

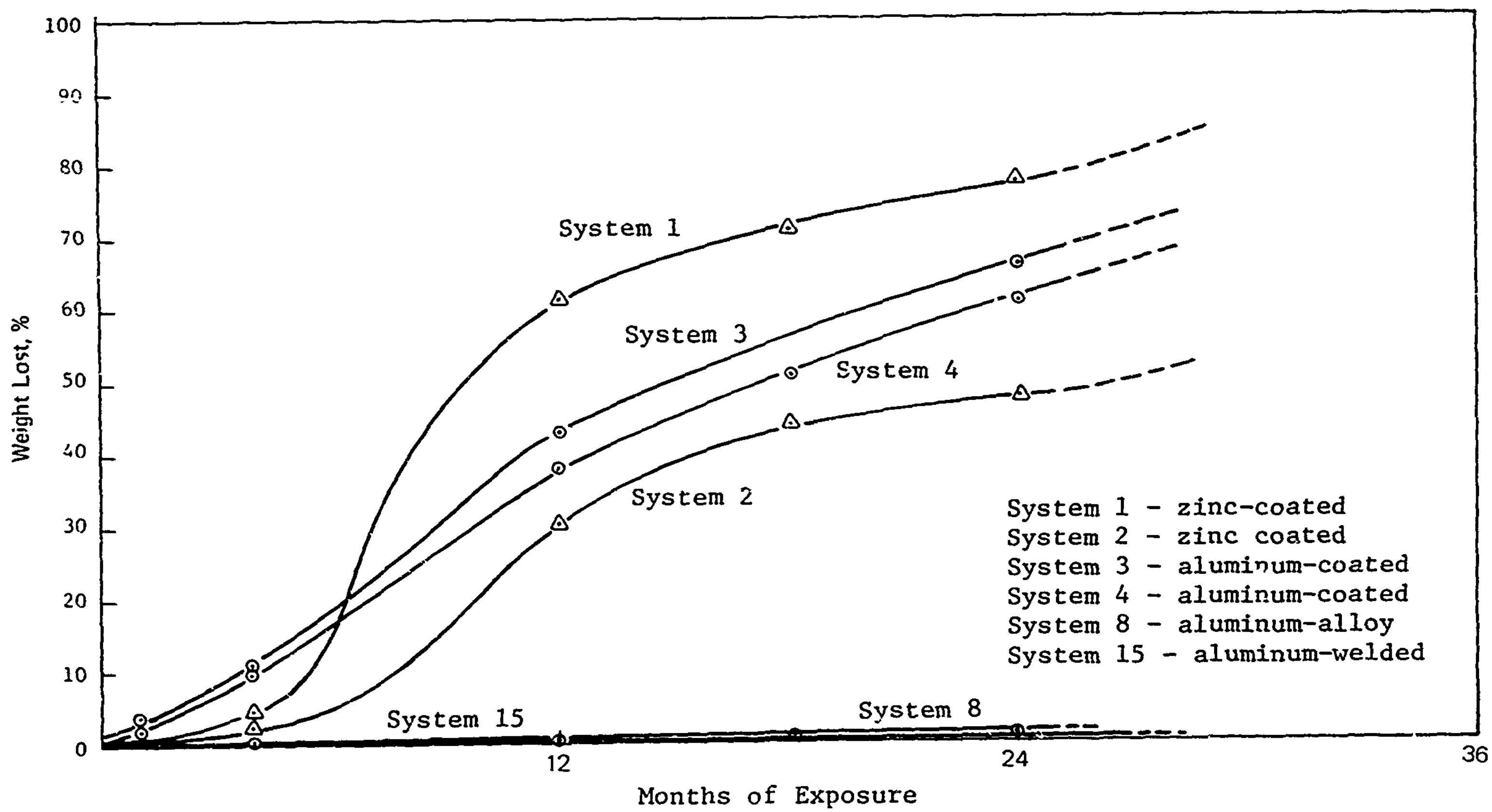

Figure 27. Corrosion patterns of metal-coated and alloy fence wires in marine atmospheric environment.

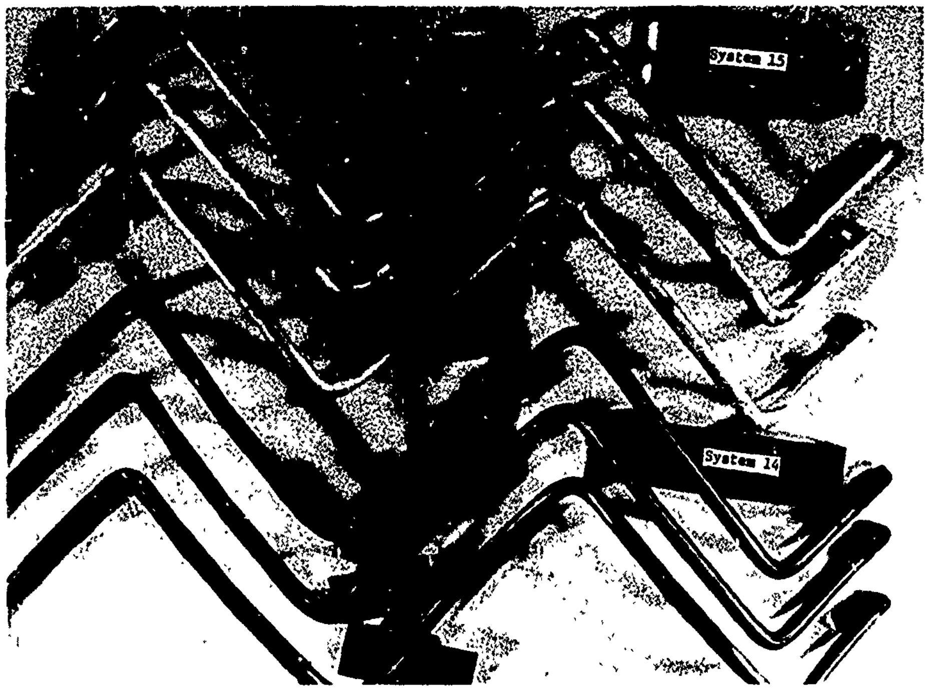

Figure 28. Systems 14 & 15. Remaining aluminum coat and condition of core wire after 12 months of exposure.

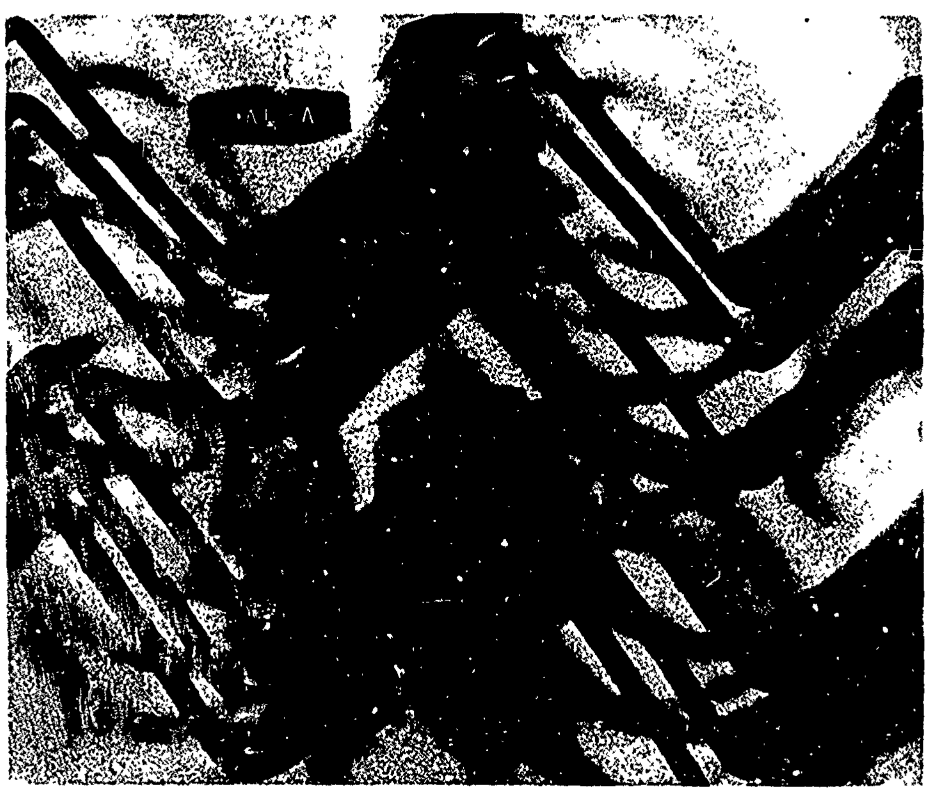

Figure 29. Systems 3 & 4. Aluminum-coated steel - after 24 months of exposure.

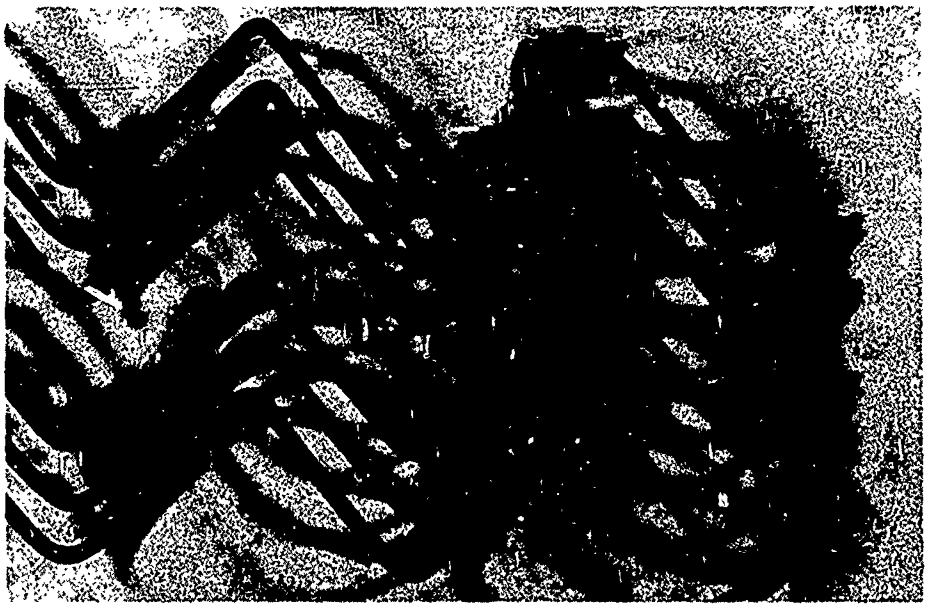

Figure 30. Systems 3 & 4. Remaining aluminum coating after corrosion product removed - after 24 months of exposure.

Figure 31. Systems 1 & 3. Remaining core wires of zinc and aluminum coated wires - after 24 months of exposure.

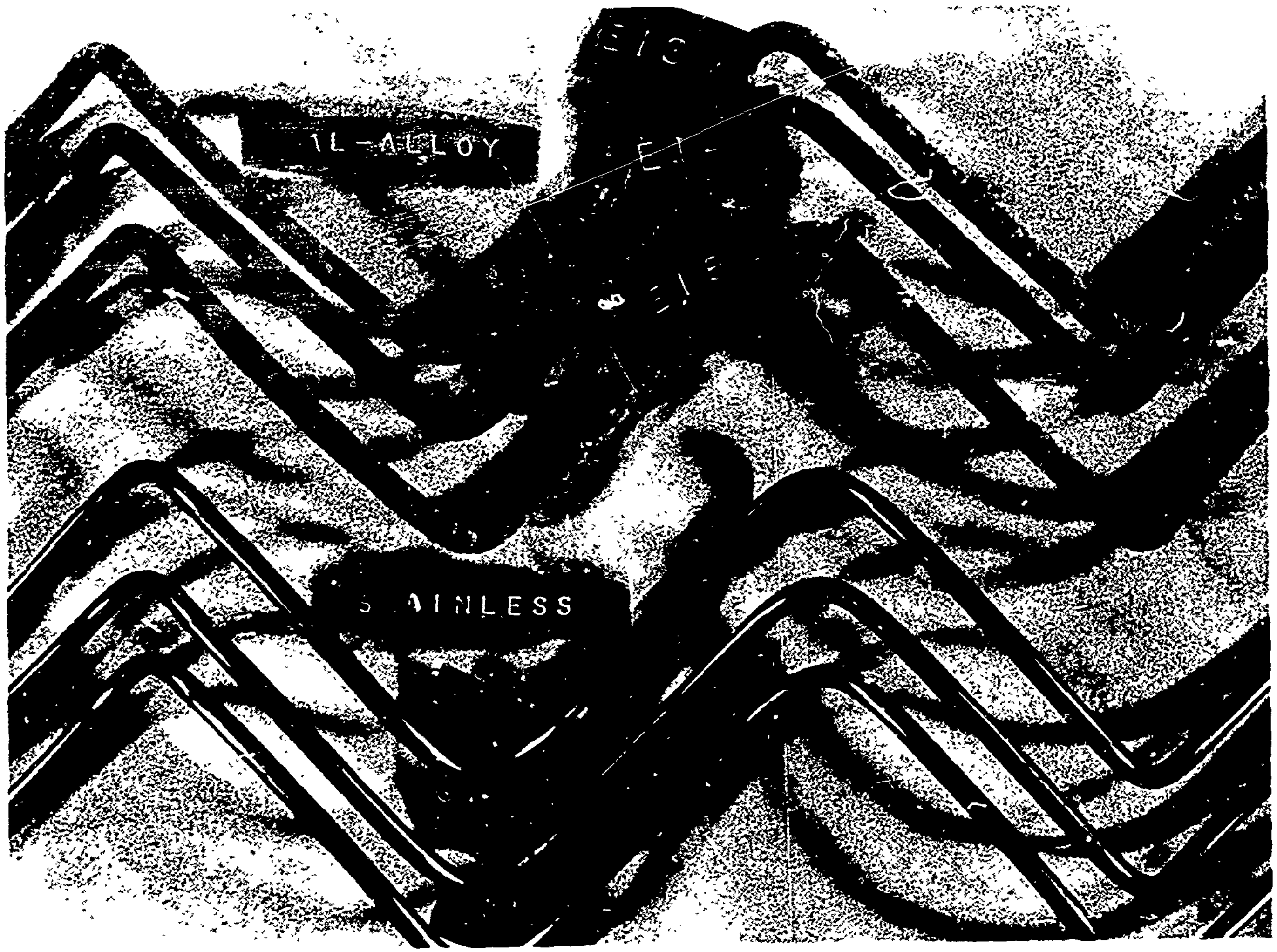

Figure 32. Systems 8 & 9. Aluminum alloy and stainless steel wires - after 24 months of exposure.

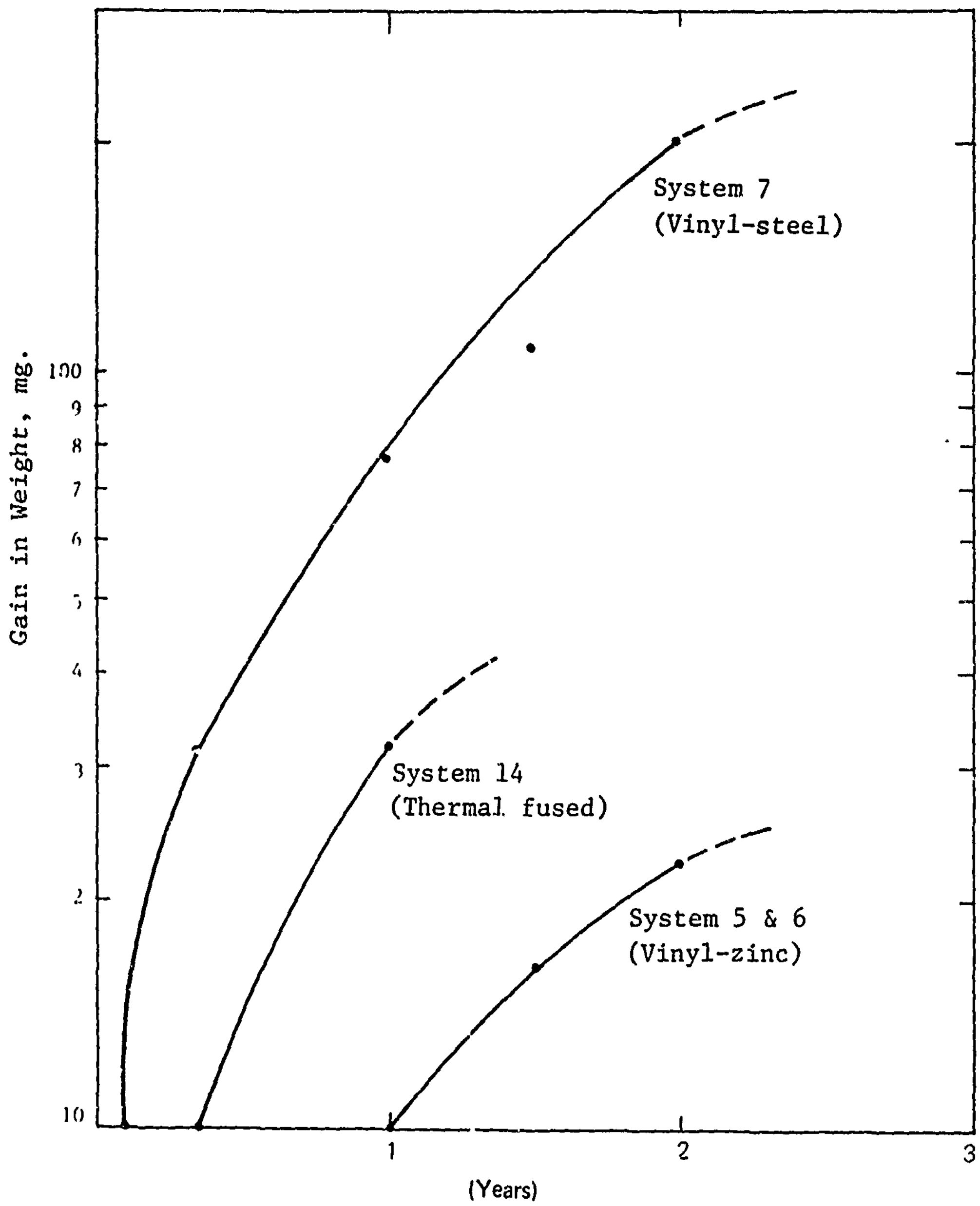

Figure 33. Corrosion patterns of vinyl-coated fence wires in atmosphere.

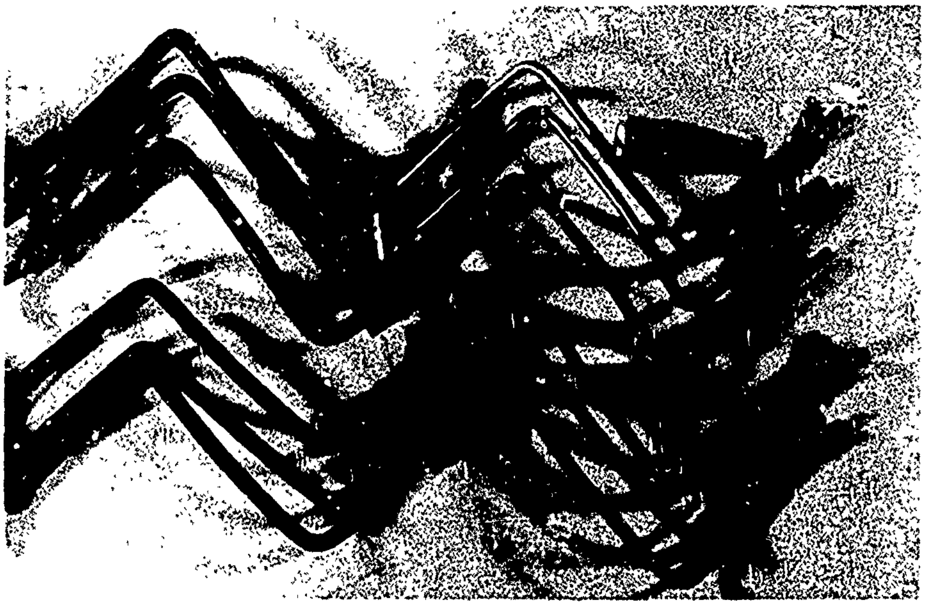

Figure 34. Systems 5 & 7. Condition of core wire after 24 months of exposure.

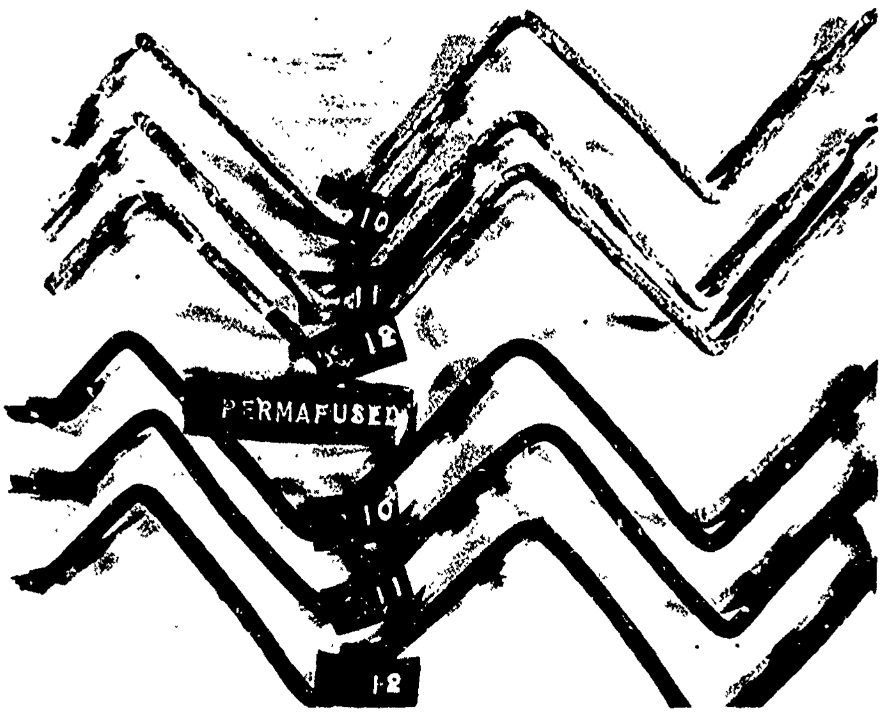

Figure 35. Systems 14 & 15 - after 4 months of salt-spray test.

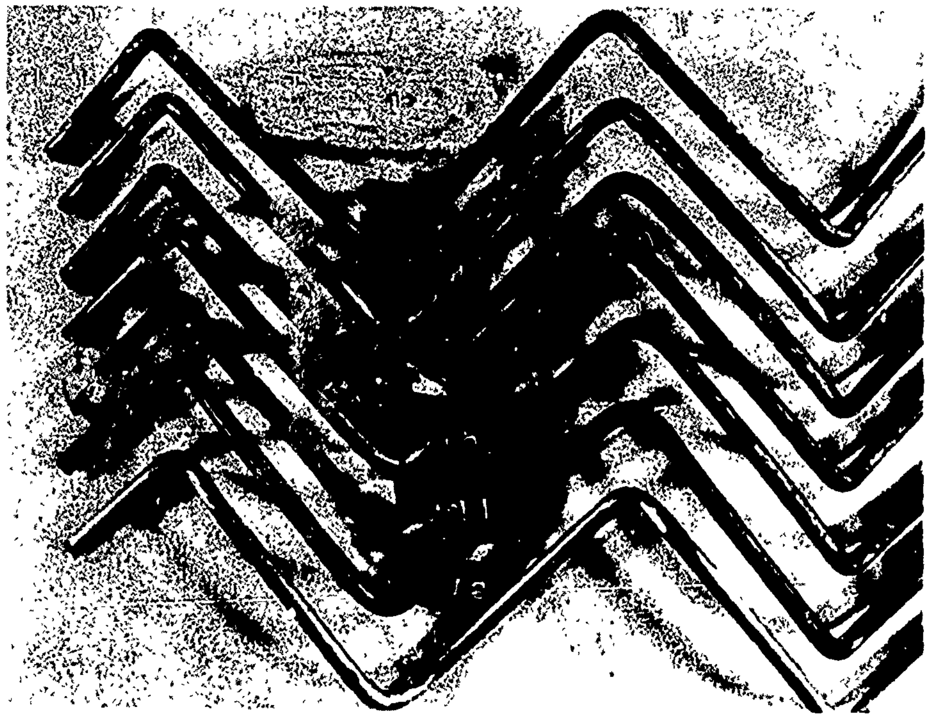

Figure 36. System 15. Corrosion product removed after 2 to 4 months of salt-spray test.

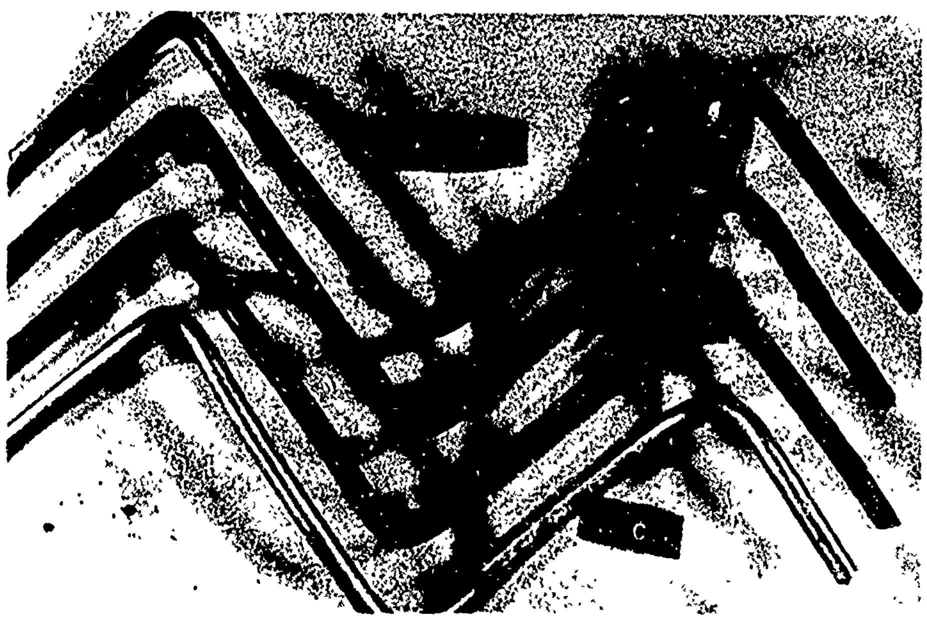

Figure 37. System 4. Corrosion product removed after 4 months of salt-spray test.

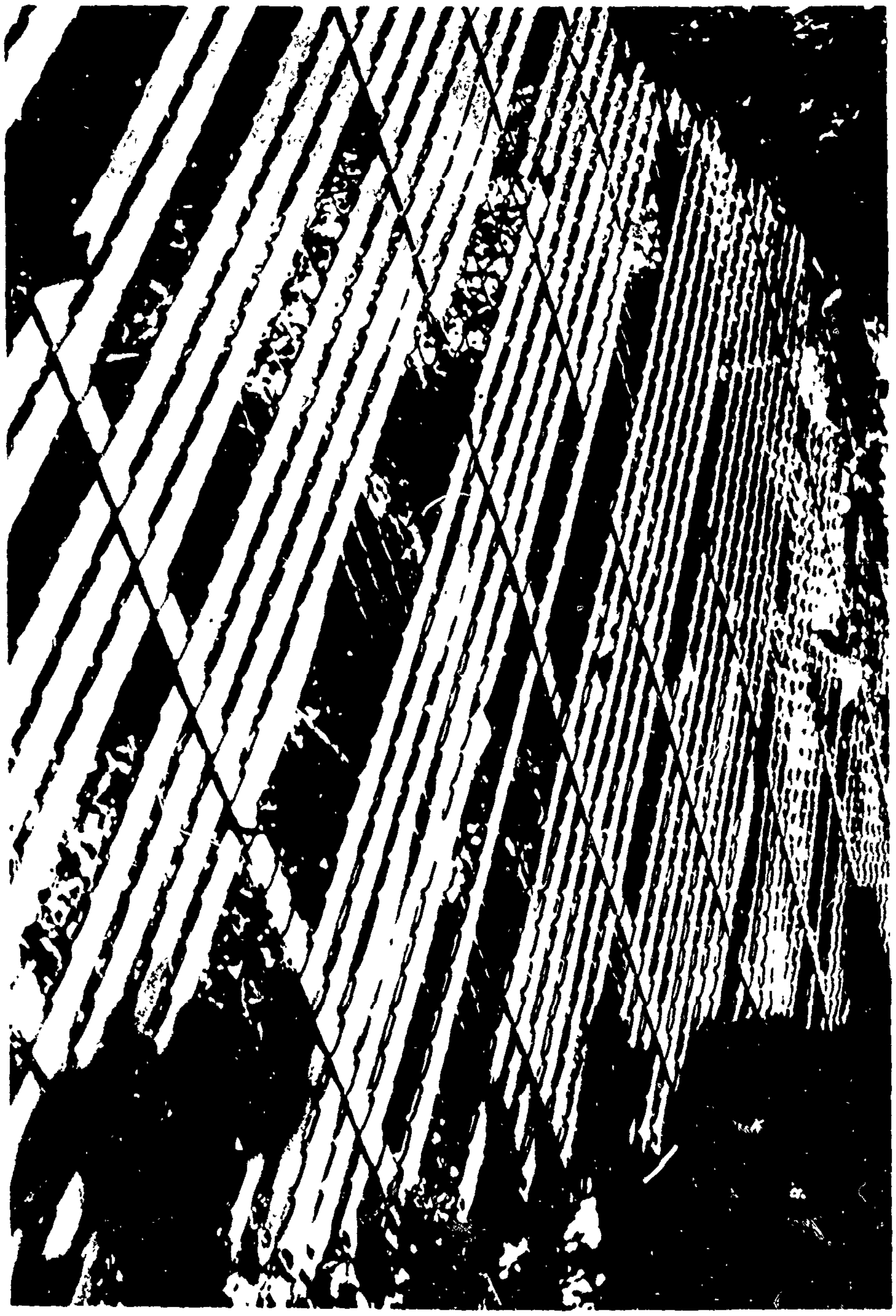

Figure 38. Aluminum slats damaged and dislodged by vandalism at nearby Naval base.

Table 1. Description of Chain-link Fencing Materials Under Test

Material Description	Specification
Zinc-coated Chain-link Fabric:	RR-F-191e
System 1. Light zinc-coated steel (1.2 oz/ft^2)	Class 1, Coating A
System 2. Heavier zinc-coated steel (2.0 oz/ft^2)	Class 1, Coating C
Aluminum-coated Chain-link Fabric:	
System 3. Light aluminum-coated steel (0.35 oz/ft^2)	Class 3, Coating D
System 4. Heavier aluminum-coated steel (0.04 oz/ft^2)	Class 3, Coating E
Vinyl-clad Chain-link Fabric:	
System 5. Green vinyl-clad galvanized steel	Class 4, Coating F
System 6. Blue and white colored vinyl-clad galvanized steel	Class 4, Coating F
System 7. Vinyl-clad prime steel	NA 1/
Aluminum Alloy Chain-link Fabric:	
System 8. Aluminum alloy, 6061	Class 5
Stainless Steel Chain-link Fabric:	
System 9. Stainless steel, AISI, Type 304	NA 1/
Chain-link Fabric with Slats:	
System 10. Heavier zinc-coated steel with aluminum slats	Class 1, Coating C with slats
System 11. Heavier zinc-coated steel with redwood slats	NA 1/
System 12. Heavier aluminum-coated steel with aluminum slats	Class 3, Coating E with slats
System 13. Vinyl-clad galvanized steel with aluminum slats	Class 4, Coating F with slats
Vinyl-coated and Aluminum-welded Chain-link Fabric:	
System 14. Thermal fused vinyl-coated steel	Class 4, Coating G
System 15. Welded-aluminum coated steel	NA 1/

1/ Not applicable

Table 2. Cost Data on Chain-Link Fence

System No.	Material	Material Cost (per linear ft) 1/		Labor Cost (per linear ft) 2/		Total Cost (per linear ft)	
		Original	1971 Est.	Original	1971 Est.	Original	1971 Est.
1	Light Zinc-coated steel	$2.36	$3.20	$0.71	$0.95	$3.07	$4.15
2	Heavier zinc-coated steel	2.45	3.30	0.71	0.95	3.17	4.30
3	Light aluminum-coated steel	2.42	3.25	0.71	0.95	3.13	4.25
4	Heavier aluminum-coated steel	2.68	3.60	0.71	0.95	3.39	4.60
5	Green vinyl-clad galvanized steel	2.80 3/	3.80	0.71	0.95	3.51	4.75
6	Blue and white colored vinyl-clad galvanized steel	2.92	3.95	0.71	0.95	3.63	4.90
7	Vinyl-clad prime steel	2.75	3.70	0.71	0.95	3.46	4.60
8	Aluminum alloy	3.11	4.20	0.71	0.95	3.82	5.20
9	Stainless steel, AISI Type 304	6.59	8.90	0.71	0.95	7.30	9.85
10	Heavier zinc-coated steel with aluminum slats	3.91 4/	5.30	1.01 5/	1.35	4.62	6.25
11	Heavier zinc-coated steel redwood slats	3.66	4.95	0.71	0.95	4.37	5.90
12	Heavier aluminum-coated steel with aluminum slats	3.13 4/	4.25	1.01 5/	1.35	4.84	6.55
13	Vinyl-clad galvanized steel with aluminum slats	4.07 4/	5.50	1.01 5/	1.35	5.08	6.85
14	Thermal fused vinyl-coated steel	3.34	3.90	0.71	0.95	5.02	4.70
15	Welded-aluminum coated steel	3.56	4.15	0.71	0.95	4.52	4.95

1/ Cost includes 3-strand vinyl-clad barbed wire, vinyl-coated posts and accessories, per linear foot.

2/ Labor costs include removal of old fence and minor eathwork required for installation of new fence (estimated at $0.29 per linear foot).

3/ Zinc-coated post and accessories were used in this section.

4/ Includes material cost of $1.15 per linear foot for aluminum slats.

5/ Includes labor cost of $0.30 per linear foot for inserting aluminum slats.

Table 3. Overall Rating of Fencing Material in Atmospheric Exposure and Salt-spray (Fog) Test

System No.	Description	Overall Racing			
		Atmospheric Exposure			Salt Spray Exposure
		12 months 1/	24 months	36 months	(16 weeks)
1	Light zinc-coated steel	Fair	Fair	Fair (PHR-5%) 2/	Poor
2	Heavier zinc-coated steel	Fair	Fair	Fair (PHR-5%)	Poor
3	Light aluminum-coated steel	Fair	Fair	Fair (PHR-20%)	Fair
4	Heavier aluminum-coated steel	Fair	Fair	Fair (PHR-15%)	Good
5	Green vinyl-clad galvanized steel	Excellent	Excellent	Excellent	Excellent
6	Blue and white colored vinyl-clad galvanized steel	Excellent	Excellent	Excellent	NA 3/
7	Vinyl-clad prime steel	Excellent	Excellent	Excellent	Good
8	Aluminum alloy	Good	Good	Fair	Good
9	Stainless steel	Excellent	Excellent	Excellent	Excellent
10	Heavier zinc-coated steel with aluminum slats	Fair (Excellent) 4/	Fair (Excellent) 4/	Fair (Excellent) 4/	NA (Excellent) 4/
11	Heavier zinc-coated steel with redwood slats	Good (Excellent) 5/	Good (Excellent) 5/	Fair (Good) 5/	NA
12	Heavier aluminum-coated steel with aluminum slats	Fair (Excellent) 6/	Fair (Good) 6/	Fair (Fair) 6/	NA
13	Vinyl-clad galvanized steel with aluminum slats	Excellent (Fair 5%-b) 7/	Excellent (Fair 10%-b) 7/	Excellent (Fair 20%-b) 7/	NA
14	Thermal fused PVC-coated steel	Excellent	-- 8/	--	Good
15	Welded-aluminum coated steel	Good	--	--	Good

Continued

Table 3. (Cont'd)

1/ Copied from reference 1 for continuity
2/ Pin-hole rust stained area in percentage
3/ NA - not applicable
4/ Anodized slats only
5/ Redwood slats only
6/ Replaced aluminum alloy slats only
7/ Blistered area in percentage
8/ Not due for test

Table 4. Coating Weight and Thickness of Metal and Plastic Coating

System Number	1	2	3	4	15	5	6	7	14
Coating Material	Zinc	Zinc	Al	Al	Al	PVC	PVC	PVC	PVC
Coating Weight (oz/ft^2)	1.06	2.23	0.50	0.58	2.46	-	-	-	-
Thickness (mil)	1.78	3.75	2.18	2.51	10.72	32	32	28	10
RR-F-191e requirement (oz/ft^2)	1.2	2.0	0.35	0.40	-	-	-	-	-
(mils)	-	-	-	-	-	18	18	-	7

Al - aluminum
PAV - Polyvinyl chloride
oz/ft^2 - ounces per square foot

Table 5. Corrosion Rates of Metallic-coated and Metal Alloy Fencing in the Marine Atmospheric Exposure

System No.	Material Description	Exposed (months)	Corrosion Loss (mil)	Corrosion Loss (% by wt)	Corrosion Loss (MPY)
1	Light zinc-coated steel (1.2 oz/ft^2)	1	0.06	2.98	0.69
		4	0.08	4.67	0.25
		12	1.04	61.42	1.04
		18	1.18	70.67	0.78
		24	1.43	77.49	0.71
2	Heavier zinc-coated steel (2.0 oz/ft^2)	1	0.07	1.78	0.83
		4	0.10	2.56	0.29
		12	1.19	30.93	1.19
		18	1.57	44.37	1.05
		24	1.74	47.26	0.87
3	Light aluminum-coated steel (0.35 oz/ft^2)	1	0.07	3.25	0.81
		4	0.23	10.79	0.70
		12	0.95	38.05	0.96
		18	0.88	43.35	0.59
		24	1.86	61.93	0.91
4	Heavier aluminum-coated steel (0.40 oz/ft^2)	1	0.06	2.45	0.70
		4	0.24	10.34	0.73
		12	1.14	43.36	1.16
		18	1.42	50.88	0.96
		24	2.33	65.13	1.26
8	Aluminum alloy	1	0.00005	0.13	0.0006
		4	0.00009	0.25	0.0003
		12	0.00019	0.51	0.0002
		18	0.00023	0.63	0.0002
		24	0.00046	1.24	0.0002
9	Stainless Steel	1	nil	nil	nil
		4	nil	nil	nil
		12	nil	0.03	nil
		18	nil	0.06	nil
		24	nil	0.08	nil
15	Welded-aluminum coated steel	1	0.08	0.78	0.93
		4	0.14	1.31	0.66
		12	0.16	1.44	
		18	-	-	-
		24	-	-	-

- Not due for test

Table 6. Gain in Weight of Vinyl-coated Wires Exposed in the Marine Atmospheric Environment

System No.	Material Description	Exposed (months)	Weight Gain Unscribed (gm)	Weight Gain Scribed (gm)
5	Vinyl-clad galvanized steel	1	0.0004	0.0010
		4	0.0011	0.0031
		12	0.0077	0.0232
		18	0.0162	0.0375
		24	0.0227	0.0387
7	Vinyl-clad prime steel	1	0.0089	0.0093
		4	0.0319	0.0589
		12	0.0762	0.1137
		18	0.1067	0.2803
		24	0.2004	0.2866
14	Thermal fused PVC-coated steel	1	nil	0.0001
		4	0.0102	0.0141
		12	0.0316	0.1171
		18	-	-
		24	-	-

- Not due for test

REFERENCES

1. "Salt Spray (Fog) Testing," ASTM Designation B 117-64 in 1968 book of ASTM Standard, Part 21. American Society for Testing and Materials, Philadelphia, Pa., 1968, pp. 1-9.

2. Naval Civil Engineering Laboratory. Technical Note N-1043: Field Study of Fencing Materials in a Marine-Atmospheric Environment - Results of 12 Months of Atmospheric Exposure and 4 Months of Salt Spray Tests, by E. S. Matsui, Port Hueneme, California, August 1969.

3. "Building Construction Cost Data 1970," 28th Annual Edition, published by Robert Snow, Means Company, Incorporated.

4. CNO letter to Distribution, OP-422G, Serial 2206P44 of 1 April 1970.