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# NATIONAL BUREAU OF STANDARDS REPORT

9937



FINAL REPORT ON EVALUATION OF THE WEATHERING CHARACTERISTICS OF THE TYPE 2 ALUMINIZED STEELS



U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

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# FINAL REPORT ON EVALUATION OF THE WEATHERING CHARACTERISTICS OF THE TYPE 2 ALUMINIZED STEELS

by Joseph W. Pitts

Materials Durability and Analysis Section Building Research Division Institute for Applied Technology

to

Office of the Chief of Engineers, U.S. Army Directorate of Civil Engineering, U.S. Air Force Naval Facilities Engineering Command, U.S. Navy

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U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

## FINAL REPORT ON EVALUATION OF THE WEATHERING CHARACTERISTICS OF THE TYPE 2 ALUMINIZED STEELS

by

Joseph W. Pitts

#### I. INTRODUCTION

Aluminized or aluminum-coated steel is a steel product that is hot-dip coated on both sides with a layer of aluminum or an aluminum-silicon alloy. Aluminized steel is produced in much the same manner as hot-dipped galvanized sheet steel is produced; e.g., by passing the sheet through a bath of the molten coating metal. The continuous hot-dipping process of coating steel with aluminum was developed in 1939 and the producer designated the products as either Type 1 or Type 2 Aluminized Steel, depending upon the composition and weight of the coating.

Type 1 has a coating of aluminum alloyed with 5 to 10% silicon. The amount of the coating material is controlled during processing so that the total weight of the coating on both sides of the sheet is approximately  $0.5 \text{ oz/ft}^2$ , or in terms of thickness, about 0.001 inch (1 mil) of coating per side. Type 1 aluminized steel is used primarily to resist high temperature corrosion in applications such as automobile mufflers, furnaces, and home appliances. Type 1 is not normally recommended for weather exposure, so it was not included in this study.

The composition of the coating on Type 2 is different from that on Type 1 in that the coating material is commercially pure aluminum, without silicon. Also, the total weight of coating on Type 2 is about twice that on Type 1, or approximately 1.0 oz/ft<sup>2</sup>, which is equivalent to 0.002 in. (2 mils) thickness per side. Type 2 is used in applications where superior atmospheric corrosion resistance is required. Type 2 aluminized steel was initially exposed to outdoor corrosion testing in 1939 and because of the outstanding resistance to corrosion displayed during the first few years of testing, the developer of the material began producing it as a commercial product in 1952. Soon thereafter, a second steel company started producing continuous hot-dipped aluminum-coated steel sheets and designated the products as Types 1 and 2 Aluminum-Coated Steels. а С

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This later Type 1 has essentially the same composition and thickness as the original Type 1, but the later Type 2 is different from the original Type 2. The original Type 2 Aluminized Steel, as mentioned previously, has a 1 oz/ft<sup>2</sup> coating of commercially-pure aluminum, whereas the later Type 2 Aluminum-Coated Steel has the same composition as Type 1 (aluminum plus silicon) but applied at about twice the thickness of Type 1.

This repetitive usage of the term "Type 2" to designate two different coatings has led to some confusion; therefore, to recap for the reader a description of the two coated steels of concern in this report: both are designated "Type 2", both have approximately the same thickness and weight of coating, but one is coated with commercially-pure aluminum, the other with an aluminum-silicon alloy.

Based on their extensive outdoor exposure testing and actual field experience, both producers freely espouse the superior atmospheric corrosion resistance of Type 2 aluminized steel over galvanized steel. One producer claims that its Type 2 outlasts unpainted commercial galvanized coatings on sheets by more than four to one, and the company attributes this superior corrosion resistance to the unalloyed aluminum coating on the sheet. The other producer stresses the importance of silicon in the aluminum coating on the behavior of its Type 2 sheets. It emphasizes the fact (a fact which is corroborated by independent investigators) that silicon alloyed with aluminum reduces the thickness and brittleness of the aluminum-iron alloy layer that forms at the interface during hot-dipping. The thinner, more ductile alloy layer is said to improve coating adherence and enhance formability. The aluminumsilicon alloy coating has a duller, darker appearance than the pure aluminum coating, but the protective quality of the coating is said to be unimpaired by the silicon addition.

The attractive feature of the Type 2 aluminized steels is that they economically combine the surface characteristics of aluminum with the strength and rigidity of steel. The material is gaining increasingly wider acceptance for roofing and siding and other outdoor applications. Both producers seem to have complete confidence in their Type 2 and there is no known technical reason to doubt the validity of their confidence and claims. The writer visited the exposure testing sites of both producers and observed test panels of the steels that have been exposed to the weather for many years, yet still appear to be in good condition. Nevertheless, there is no independent evaluation of the material and no truly unbiased comparison of the aluminum versus the aluminumsilicon coating. The building industry needs information of this

nature and it needs an unbiased assessment of the performance characteristics of this material compared with other betterknown coated materials, such as galvanized steel. The current project is an attempt to provide an unbiased evaluation of the two different compositions of Type 2 aluminized steels and to compare the behavior of these steels with galvanized steels.

It was decided in the beginning to divide the project into two parts: a short-range program consisting of laboratory tests on specimens of aluminized steel sheets and a long-range program of exposing specimens of both aluminized and galvanized steel to weathering on outdoor testing racks at several locations. The laboratory tests included in the program are: salt spray, accelerated weathering (Weather-Ometer), abrasion resistance, sulfur dioxide, bend, hardness, and determinations of the weight, thickness, and uniformity of each of the coatings.

Industry representatives were questioned regarding these tests and the possibility of including other laboratory tests, but the consensus of opinion was that there is no known short-time test that will give meaningful results for predicting long-time service performance in outdoor environments. However, some authorities felt that the laboratory tests are useful and will be of great value if later a correlation is found between such tests and weathering tests. The outdoor exposure tests were planned to be conducted according to current ASTM practices and specimens were to be exposed at the six testing sites available to NBS.

This report includes the final results of all of the laboratory tests and a description of the first phase (preparation and mounting of specimens) of the long-range weathering tests.

#### II. MATERIALS

The specific steels included in the program are Type 2 aluminized steel, coated with commercially-pure aluminum (Al-coated); Type 2 aluminum-coated steel, coated with an aluminum-8% silicon alloy (Al-Si-coated); and two coating weights of galvanized steel (1.25 and 2.25  $oz/ft^2$ ). It was specified that the steel be 22 gage sheet stock, chemically treated, and in both flat and corrugated shapes. The tolerance set for the weight of coating on the aluminized steels was 1  $oz/ft^2$ , plus or minus 10%. The corrugated material was to have standard corrugations, i.e., 2 1/2 in. by 1/2 in. Figure 1 shows photographs of flat sheets of the aluminized steels. The average thickness of these sheets, as measured with a micrometer, is 0.036 in. for the Al-coated steel and 0.033 in. for the Al-Si-coated steel.

Due to a misunderstanding, the Al-Si-coated steel was not chemicallytreated at the mill by the supplier, as had been requested, and this fact did not become known until after the tests were nearly completed. Also, the heavier of the two coating weights of zinc on the corrugated galvanized material was 2.0 oz/ft<sup>2</sup> instead of the 2.25 oz/ft<sup>2</sup> as originally planned.

#### III. LABORATORY TESTS AND MEASUREMENTS

1. Coating Weight Measurements

The coating weights of the two aluminized steels were determined by measuring the loss of weight of specimens after stripping the coating in hot sodium hydroxide solution, in accordance with directions contained in Military Specification MIL-S-4174A, 7 January 1959, "Steel Sheet and Strip, Flat, Aluminum Coated, Low Carbon" and ASTM Test Method A 428, "Weight of Coating on Aluminum-Coated Iron or Steel Articles". The coating weight measurements of three specimens of each material in ounces per square foot of sheet are as follows:

Alu	minum Coating	Aluminum-silicon Coatin	g
	oz/ft <sup>2</sup>	oz/ft <sup>2</sup>	
	1.16	1.12	
	1.10	1.13	
	1.13	1.22	
AVERAGE	1.12	1.16	

The average weight of each coating is slightly greater than the tolerance limit that had been set, but the excess is approximately the same for each coating; furthermore, the weight differences between the two coatings is considered too small to have any significant effect on other test results.

## 2. Coating Thickness Measurements

Metallographic sections of the two aluminized steels were prepared and from these, microscopic measurements of coating thicknesses were made. Ten measurements, equally spaced, were made along each side of each of the one-inch-long mounted specimens. The twenty measurements of each specimen were averaged and the averages are shown below together with the maximum and minimum values:

			Aluminum-Silicon Alloy Coating	Commercially-pure Aluminum Coating
Average	Thickness,	mils	2.8	2.4
Maximum	Thickness,	mils	3.6	3.1
Minimum	Thickness,	mils	1.3	1.9



#### 3. Coating Uniformity

During the course of making coating thickness measurements from metallographic sections, it was noted that there is a very significant difference in coating uniformity between the Al-coated and the Al-Si-coated materials. Figures 2 and 3 show photomicrographs of metallographic sections mounted vertically and at a 7° taper, respectively. It is obvious that the thickness of the aluminum coating is more uniform than that of the aluminumsilicon coating. Also, the base metal of the Al-coated steel is relatively smooth, while the base metal of the Al-Si-coated steel is rough; this roughness of the base metal probably accounts for the non-uniformity of thickness of the Al-Si-coating.

While it was not the intent of this study to evaluate the effects of differences in manufacturing variables, but rather the effects of differences in coating composition, it is felt that the physical character of the coating may have a significant effect on its performance and is therefore an important consideration. The probable effects of coating thickness variations on certain test results will be discussed later.

#### 4. Abrasion Resistance

Measurements of the abrasion resistance of the two aluminized steels were made with the Roberts Jet Abrader. 1,2,3/ This instrument was originally developed to measure the abrasion resistance of organic coatings but was later found to be quite suitable for measuring the abrasion resistance of metallic and ceramic coatings as well.

The Roberts Jet Abrader measures the abrasion resistance of coatings in terms of the time required for a closely controlled jet of fine abrasive particles to penetrate the coating. The end-point, which is determined visually by the operator, is a change in appearance of the abraded spot that occurs when the substrate material becomes exposed. The substrate is distinguished by a change in color or reflectivity and usually first appears as a small spot in the center of the abraded area of the coating (approximately 1/8 in. in diameter). Figure 4 shows examples of the abraded areas and the distinguishing end-point spots. Although the end-point determinations were quite distinct for both the aluminum and the aluminum-silicon alloy coatings when the steel substrates became exposed, we were not able to distinguish an end-point between the outer coating and the intermediate layer of either the aluminumiron alloy or the aluminum-silicon-iron alloy.

- 1/ "Abrasive Jet Method for Measuring Abrasion Resistance of Organic Coatings", A.G. Roberts, W.A. Crouse, and R.S. Pizer, <u>ASTM</u> <u>Bulletin</u>, No. 208, Sept. 1955, pp 36-41.
- 2/ "Improved NBS Abrasive Jet Method for Measuring Abrasion Resistance of Coatings", A.G. Roberts, <u>ASTM Bulletin</u>, No. 244, Feb. 1960, pp 48-51.
- 3/ Bulletin 1064, Kameras Instruments, Garrett Park, Maryland, 1965.

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Twenty measurements, randomly scattered over both sides of a 3-inch by 12-inch specimen, were made of each of the coating materials. The average, maximum, and minimum abrasion resistance values in terms of time required to abrade through the coating are as follows:

		Aluminum-Silicon	Commercially-pure
		Alloy Coating	Aluminum Coating
Average Time,	Seconds	<b>1</b> 4 。5	22.9
Maximum Time,	Seconds	33.5	30.4
Minimum Time,	Seconds	6.2	14.4

The end-point break-through to the substrate normally occurs in the center of the abraded area, because the abrasive jet is most intense at the center and tapers off toward the perifery, but the end-point spot for the Al-Si-alloy coating frequently appeared off-center, rather than at the center of the abraded area as would be expected for a uniform coating on a smooth base. Figure 4 (left) shows the substrate spot slightly off-center; in other cases the eccentricity was more pronounced.

On an uneven substrate it is statistically probable that some point on the substrate below the abraded area, other than the center point, would be closest to the surface and thus would become exposed first when the coating was abraded away. The fact that the aluminum-silicon coating was non-uniformly thick on a rough substrate undoubtedly accounts for the eccentricity of the end-point. Whether or not this condition also accounts for the lower abrasion resistance values is another question. It probably has an effect, but one must also consider that the two coatings have different compositions and that the alloy layers have different thicknesses and are much harder than the basic coating materials.

#### 5. Bend Test

Specimens of the aluminized steel sheets were bent 180° over a diameter equal to two times the thickness of the sheets in accordance with Military Specification MIL-S-4174A. Bending was accomplished in two stages: first, the 3 in.<sup>2</sup> specimens were bent in a sheet metal brake on a 1/8 in. radius to form an angle of 135°. Then, two pieces of the coated sheet were placed in the acute angle of the partially bent specimen and the 180° bend was completed by flattening the specimen in a hydraulic press. Since the Al-coated material is about 0.003 in. thicker than the Al-Si-coated material, the former was used for shims to insure that a bend of equal radius would result in both materials. X

Both coatings sustained some damage along the bent edges where the coating was placed in tension, but suprisingly the aluminum coating appeared to withstand the bending better than the aluminum-silicon coating. The former developed very few actual cracks, but showed a general rippled pattern characteristic of non-uniform plastic flow. On the other hand the aluminumsilicon coating had developed numerous rather wide cracks, indicating brittle fracture of the coating. Figure 5 shows photographs of the bent edges of the specimens. No flaking or peeling of either coating was observed, therefore, it is assumed that they both meet the bending requirements of MIL-S-4174A.

## 6. Base Metal Hardness

Rockwell hardness measurements of the base metals were made on specimens after stripping off the coatings. The base metal hardness of the Al-Si-coated sheet was measured to be Rockwell "B" 45, while that of the Al-coated sheet was Rockwell "B" 57; both are well below the maximum of Rockwell "B" 80 authorized by MIL-S-4174A.

# 7. Salt Spray Test

Specimens for salt spray testing were prepared by shearing the flat sheet material into 1 ft<sup>2</sup> panels. A 90° bend on a 1/16 in. radius was made along one edge of each specimen, 1/2 in. from the edge. Also, each specimen was deformed in two spots by pressing a 1-in. diameter hardened steel ball, under 500-1b load, onto the specimen, which was backed up by a shallow cup die, 0.156 in. deep, and 1 1/8 in. diameter. One deformation was made on the front side and one on the back side of each specimen, so that both a concave and a convex deformation would be exposed to the corrosive environment. The galvanized steels in both coating weights were included in the salt spray test. Although all materials were received from the suppliers in the oiled condition, in order to insure that all specimens would be uniform in this respect, they were first thoroughly cleaned in tri-chloroethylene and then re-oiled.

Three specimens of each material were exposed to the salt spray in accordance with ASTM B117 Salt Spray (Fog) Testing which calls for a 5% sodium chloride solution at 95°F. The duration of the test was 624 hours (26 days). The specimens were observed periodically during exposure for signs of corrosion. Rusting began to appear along the exposed, sheared edges of the Type 2 specimens soon after the test started, but did not seem to progress



to a significant degree thereafter. After 528 hours, rust staining was observed on the faces of the 1.25 oz/ft<sup>2</sup> galvanized specimens. At 624 hours, rust stains began to appear on the face of one of the 2.25 oz/ft<sup>2</sup> galvanized specimens. There was still no indication of rusting on the faces of the aluminized steel panels; therefore, the test was terminated at 624 hours. It should be pointed out, however, that the white corrosion product of aluminum,  $Al_2O_3$ , if present would not be observable because of the accumulation of salt caked on the specimens. It is only when the underlying steel begins to rust that corrosion would be noticeable.

After removal from the salt spray cabinet, the specimens were cleaned by scrubbing with a stiff bristle brush in hot water to remove the layer of accumulated salt. Then, after drying, the specimens were visually evaluated as follows:

- a. Neither the deformations nor the bends had any apparent deleterious effect on the corrosion resistance of any of the materials.
- b. The 1.25 oz/ft<sup>2</sup> galvanized specimens had severe rust spots and streaks covering about one-half of their surfaces.
- c. <sup>T</sup>he 2.25 oz/ft<sup>2</sup> galvanized specimens had developed a few spots, exposing what appeared to be the base metal, with rust just beginning to form.
- d. The Al-Si-coated panels had turned a dark, dull gray except for numerous white splotches and streaks scattered over their surfaces. The fact that these white splotches were not dissolved by the hot water cleaning treatment indicates that they are a corrosion product of aluminum.
- e. The Al-coated panels had turned somewhat darker, but still retained a metallic look and had not developed the white splotching as had the Al-Si-coated panels.
- f. Both the aluminum-coated and, to a lesser extent, the aluminum-silicon coated panels had corroded considerably more at the exposed edges than was evident during the test. The coating was intermittently affected in an area extending in from the edges up to a maximum of about 1/2 inch.

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Photographs of the aluminized steel panels are shown in Figure 6. The 90° bend that was made near one edge of each specimen is on the left side in the photographs and was in the verticle position during the test. The sheared edge seen at the top of the photographs was also at the top during the test and was covered with adhesive plastic tape. The right hand and bottom sheared edges were unprotected and, as can be seen, the right hand edge (which was in the verticle position during the test) corroded considerably more than the bottom edge.

## 8. Accelerated Weathering Test

Specimens for accelerated weather testing were sheared from flat sheets into panels 6 in. by 12 in. Two 45° bends on 1/16 in. radii were made on each specimen, 3/4 in. from the two opposite long edges. (This configuration was convenient for mounting specimens in the Weather-Ometer). Concave and convex deformations were made in each specimen just as was done for the salt spray specimens. Also, specimens were cleaned and re-oiled as before.

Specimens in the Weather-Ometer were subjected to an environment of continuous carbon arc radiation and intermittent spray of demineralized water at 80°F. The panels were sprayed for 9 minutes every hour, then during the 51-minute drying cycle the carbon arc caused the panels to warm to about 130°F. Two specimens of each material including the galvanized steels were exposed for 540 hours, then removed for examination.

In general, the Weather-Ometer exposure appeared to have very little effect. Specifically, the following changes were noted:

- a. The galvanized steels, both coating weights, showed no deterioration other than tarnishing which made them noticeably duller and darker than originally.
- b. The Al-Si-coated steel was slightly darker, less reflective, and had developed a faint pebbly or water-spotted pattern.
- c. The Al-coated steel was less glossy, but otherwise appeared just as bright as originally.
- d. On close examination it could be seen that the aluminized steels (both compositions) had developed a fine hairline of rust along the cut edges.

Specimens of Al-coated and Al-Si-coated steel sheets were subjected to an accelerated weathering-simulation test in which the ambient atmosphere contained controlled amounts of sulfur dioxide and in which moisture was alternately condensed onto and evaporated from specimens during 15-minute cycles4/. The results are summarized as follows:

- a. With 1 ppm SO<sub>2</sub> in the atmosphere, no change could be detected on either material after 24 hours' exposure.
- b. When the SO<sub>2</sub> concentration was increased to about 400 ppm and after 24 hours' exposure, the Al-Si-coated specimen had developed about 12 pinhole, reddish-brown rust spots over the 1-1/2 in. x 3/4 in. exposed surface. The Al-coated specimen showed no signs of iron rust, but the surface had a slightly whitish appearance indicating oxidation of the aluminum.
- c. With 100 ppm SO<sub>2</sub> and an exposure time of 3 days, rust spots again appeared on the A1-Si coating and also some white areas developed, indicating aluminum oxide. The A1 coating again showed no signs of iron rust, but the appearance of the white aluminum oxide was more pronounced than in the previous test and was more extensive than occurred on the A1-Si coating.
- d. The last test was for 7 days in 150 ppm SO<sub>2</sub>. Massive coating corrosion occurred on both materials. There was some evidence of iron rust on the A1-Si coating, but it was either less than previously observed or was partially masked by the voluminous amount of white corrosion product.
- e. Typical results of conditions b. c. and d. above are shown in Figures 7, 8, and 9 respectively.

4/ "Apparatus for Studying the Effects of Atmospheric Pollution and Cyclic Dew Formation on the Deterioration of Materials", J. W. Pitts and D. G. Moore, <u>Materials Research & Standards</u>, Vol. 6, No. 7, July 1966, pp. 328-333.

In 1960 ASTM Committee A-5 on Corrosion of Iron and Steel initiated outdoor exposure testing of the Type 2 aluminumcoated steels; specimens of both galvanized and aluminized steels were put out on exposure at five scattered sites in the United States. This test, however, was oriented primarily toward distinguishing differences in galvanizing processes and coating weights of zinc rather than evaluating the performance characteristics of the two compositions of Type 2 aluminized steel. The two specimens of Type 2 included in the test are, unfortunately, of such great difference in coating weight (0.92  $oz/ft^2$  for the Al-Si alloy coating vs 1.39  $oz/ft^2$  for the Al coating) that the results may be of limited value. Very recently, however, and since the NBS project was started, ASTM Committee G-1 on Corrosion of Metals has initiated planning of a new program of outdoor exposure testing of the Type 2 aluminum-coated steels.

At about the time the NBS program was initiated, the Building Research Division of NBS was completing arrangements for establishing outdoor materials-testing exposure sites at six locations in the United States. Five of the six sites were provided by the Department of Defense and are located on installations of the three military services. The sixth site is on the grounds of the NBS in Gaithersburg, Maryland. The six sites together with the types of climate and/or environments represented are listed as follows:

- 1. NBS, Gaithersburg, Maryland---Rural
- 2. Fort Holabird, Baltimore, Maryland---Industrial
- 3. U.S. Naval Station, Roosevelt Roads, Puerto Rico---Tropic, Coastal
- 4. Nellis Air Force Base, Las Vegas, Nevada---Desert
- 5. Fort Lewis, Tacoma, Washington---Temperate, Heavy Rainfall
- 6. Fort Greely, Fairbanks, Alaska---Sub-arctic

During the period of October 1967 to June 1968, specimens of both of the aluminum-coated steels and two coating weights of galvanized steels were put out on exposure at all of the sites except Fort Greely, Alaska where there was a delay in installing the racks. The angle and direction of exposure at all sites conform with the practice followed by ASTM committees concerned with metal corrosion



testing; specifically, the specimens are tilted at an angle of 30° to the horizontal and face true south. The specimens consist of two 2 X 3 ft. corrugated panels, one overlapping the 2° other, of each of the four different steels. Also, ten 1 ft. 2° specimens of the flat sheet stock (two of each of the galvanized coating weights and three of the aluminum-coated steels) are mounted singly. There is a 90° bend on a 1/16-inch radius on the upper edge of each of the 1 ft. 2° sheets and on the lower edge of most. The lower bent edge projects upward from some specimens and downward from others. Just as in the case of the salt-spray specimens, there are concave and convex deformations on these specimens. The materials for this test occupy one of the 5 1/2 ft. X 12 ft. specimen-holding racks at each site. Placement of the specimens on the racks is illustrated in Figure 10.

A program of periodic visits to the test sites and inspection of the materials will be initiated and reports will be issued as often as is warranted. Distribution of these reports will be made to all known interested parties.

#### V. DISCUSSIONS AND CONCLUSIONS

The stated objective of this project was to evaluate the weathering characteristics of two commercial sheet steels, one coated with aluminum and the other coated with an aluminum-silicon alloy. Although these two steels were produced by different companies, there was a widespread belief that the only essential difference between the two products was the composition of the coating (including those related conditions, such as alloy layer thickness, that are known to vary with coating composition). Therefore, when the project was started, the author tacitly assumed that the evaluation would be exclusively concerned with the relative performance of aluminum versus aluminum-silicon as a coating material. Later, however, when the results of various measurements became available, it was obvious that coating composition was not the only difference between the two steels and perhaps was not even the most significant difference. For example, it was found that the surface contour (roughness) of the base metals was different and this fact in turn affected the uniformity of the coating thickness. Also, as indicated by the abrasion tests, non-uniformity of coating had an effect on the measured abrasion resistance values. In addition, it should be mentioned again that the Al-Si coating had not been chemically treated prior to testing as had the Al coating, although it is doubted that this difference had any appreciable effect on the results of the laboratory tests.

Therefore, the reader of this report should understand that the results reported here apply to two commercial products that vary not only in composition and pre-treatment of coating but also vary in roughness of base metal, in uniformity of coating, and possibly in other aspects that were beyond the scope of this investigation to determine.

In addition to the adverse effect that the non-uniformity of the aluminum-silicon coating had on its abrasion resistance measurements, there is some evidence that non-uniformity may have had an effect on initial corrosion behavior. It is possible that the small rust spots that appeared on the Al-Si-coated steel in the SiO<sub>2</sub> test developed at undetected discontinuities that may occur in the coating where it is extremely thin or where there is an abrupt change in coating thickness. Nevertheless, these tiny blemishes appeared to become self-arresting with time in the laboratory tests, just as they have been observed to do in the field.

With regard to the potential weatherability of the two coating compositions, these tests gave no indication that either coating, the pure aluminum or the aluminum-silicon, would be superior to the other in long-time protective quality. The blemishes that developed on the aluminum-silicon coating are not believed to be an inherent characteristic of aluminum-silicon coatings in general, but rather are believed to be due to coating imperfections resulting from a particular manufacturing technique.

Visually the two coated steels, as received, are distinctively different--the aluminum-silicon coating is slightly darker and duller than the pure aluminum coating. On the other hand the Al-Si coating presents a more uniform, homogeneous surface texture than the Al coating. The latter has a dappled or mottled appearance consisting of shiny blotches in a duller matrix (see Figures 1 and 7a). But again, this difference is probably a function of the processing procedure rather than an inherent characteristic of the coating composition.

The overall results of the laboratory tests are obviously inconclusive in leading to a prediction of long-time weathering behavior. These tests, however, will have served a useful purpose if they have brought to light previously undisclosed differences between the aluminum-coated steels; i.e., differences resulting from processing variables. Any correlation (or lack of it) between the results of the laboratory tests and service performance can not, of course, be firmly established until the results of the weathering tests are known.

Figure 1. Photographs of flat surfaces of the Al-Si-coated steel (left) and the Al-coated steel (right). The splotches on the latter are actually smooth, uniform areas that appear dark in the photograph because of specular reflection of the oblique illumination. Magnification: 1X



Figure 2. Photomicrographs of polished metallographic cross sections of the Al-Si-coated steel (left) and the Al-coated steel (right). The dark bands between steel and coating are the alloy layers that etched preferentially. Note that the alloy layer between the Al-Si coating and steel is thinner than that between the Al coating and steel. Magnification: 35X



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Figure 3. Photomicrographs of polished metallographic taper sections of the Al-Si-coated steel (upper) and the Al-coated steel (lower). The specimens were mounted at an angle of 7° from the horizontal which has the effect of extending the coating thickness about 8 times.

Magnification: 35X



Figure 4. Photograph showing an abraded spot on a specimen of the Al-Si-coated steel (left) and an abraded spot on a specimen of the Al-coated steel (right). Magnification: 8X



Figure 5. Photograph showing specimens of the Al-Sicoated steel (left) and the Al-coated steel (right), each bent 180° on two thicknesses of itself. The longitudinal center line of each specimen is the line of maximum tensile stress. The darker bands along the center lines are caused by the oblique lighting coming from both sides. Magnification: 7X





Figure 6. Photographs of 1 ft<sup>2</sup> specimens of the Al-Sicoated steel (left) and the Al-coated steel (right), after 26 days in the salt spray test. The top edges of both specimens were covered with plastic tape during the test. The 90° bends are on the left hand edges while the right-hand and bottom edges are sheared, unprotected edges. The concave and convex deformations are barely discernable in the lower quarter of each specimen. Reduction: about  $\frac{1}{4}$  size



Figure 7. Photographs of specimens of Al-Si-coated steel (left) and Al-coated steel (right), before (a) and after (b) 24 hours of alternate wetting and drying in air containing about 400 ppm SO<sub>2</sub>.

Magnification: 2.4X



Figure 8. Photographs of specimens of Al-Si-coated steel (left) and Al-coated steel (right) after 72 hours of alternate wetting and drying in air containing about 100 ppm SO<sub>2</sub>.

Magnification: 2.4X



Figure 9. Photographs of specimens of Al-Si-coated steel (left) and Al-coated steel (right) after 7 days of alternate wetting and drying in air containing about 150 ppm SO<sub>2</sub>. Magnification: 2X

Below: Same specimens. Magnification: 7.6X









aluminum-coated and sheet specimens with are two corrugated are shorter the 2 02/ to right and panels the left stee] 0f There each material: from galvanized corrugated each lat H O Layout of specimens on exposure racks. three each of the galvanized steels. the I -Si-coated include 02 far right are 0 the Al These stee overlapping the other -coated that At bends. Note the others. °06 panels, one overla Al-Si-coated steel steels and two of steel. indentations and galvanized wider than Figure 10.

