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THE BASICS OF 55% Al-Zn COATED SHEET'S LEGENDARY PERFORMANCE

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The Basics of 55% Al-Zn Coated sheet's Legendary Performance

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Abstract

The excellent long term performance of 55% al-Zn coated sheet is well acknowledged around the world. The product has now been in commercial production for over 25 years. It's superior corrosion resistance is primarily due to the coating's low rate of dissolution resulting from its composition and unique microstructure. The composition provides the optimum combination of galvanic and barrier protection to the steel substrate; the microstructure restricts oxidation of the highly reactive zinc phase which is virtually "locked" in the coating's interdendritic areas and is activated only when required.

The 55% Al-Zn coating's rate of dissolution, its microstructure and corrosion performance on buildings will be discussed.

Introduction

The superior long term corrosion performance of 55% Al-Zn coated sheet steel is well established. This reputation is based on the product's continuing excellent performance after more than 25 years of commercial production. In the U.S., many buildings with near flat roofs and side walls, made from 55% Al-Zn coated sheet, continue to demonstrate excellent performance after more than 20 years. This is based on an inspection of buildings in the heavy industrial and acid rain areas in the north eastern United States. Additionally, pilot-line prepared test samples have shown excellent performance in a variety of environments after more than 30 years exposure. These tests are still continuing.

Results of the more than 20-year old roofs on buildings show that the metal coating is still intact and protecting the steel substrate against corrosion. This excellent performance of 55% Al-Zn coated sheet on roofs is particularly important in the U.S. and other markets where the product is offered with a 20 year warranty against perforation. During its initial 20 year service life, no major maintenance was required. Thus, the product has performed beyond its warranty period and reaffirmed the confidence that enabled the producers to offer this unique warranty. Based on the inspection results, the product is expected to provide at least another 10-15 years of maintenance-free life. This superior field performance is further complemented by more than 30 years outdoor exposure testing of pilot-line produced material in various atmospheric environments.

Such long term corrosion resistance is dependent on one over-riding factor, i.e. the rate at which the metal coating "corrodes" or "dissolves" while protecting the underlying steel substrate.

This basic factor provides the characteristic superior performance to 55% Al-Zn coated sheet, both in the unpainted and prepainted condition. With the additional paint film on the sheet steel, discussion about the performance and warranty issues can become unclear. In this case, attention is distracted from the primary issue of corrosion resistance. The reason for this confusion is that paint systems are sold with long term warranties, in some cases, up to 40 years. It must be realized that the paint film warranties are only for paint film integrity and do not cover corrosion resistance. As an extreme example, the paint film warranty may be technically valid, even after it delaminates from the steel substrate but retains its film integrity, color, chalk, and fade characteristics, within the limits defined by the paint manufacturer.

It must be remembered that most paint films are semi permeable; corrosents can be transported through the film to the metal coating-paint film interface where corrosion of the metal occurs. The perforation resistance, i.e. the actual service life of the product is thus dependent on the corrosion resistance of the metal coating and not on the paint film. The main function of the paint film is aesthetics.

Background of 55% Al-Zn Coated Sheet Development

In 1964, a series of aluminum-zinc (Al-Zn) alloy coatings were applied to sheet steel on a laboratory continuous pilot hot-dip coating line. This program was designed to combine in one product, the long-term durability of aluminum coatings with the galvanic property of zinc coatings. The coated sheets were exposed in outdoor corrosion tests in severe marine, moderate marine, rural and industrial environments. Following eight years of outdoor exposure testing, the 55% Al-Zn composition was selected as the optimum composition because it combined excellent long term durability with the ability to provide cut edge protection to the steel substrate. After more than 30 years of continuing outdoor exposure testing, results show conclusively that the 55% Al-Zn alloy coating lasts two to six times longer than ordinary zinc coating of equal thickness (20 μm).

Commercial production commenced in 1972. After a quarter century of commercial production, the product finds widespread application principally in construction applications around the world. A recent inspection of up to 22 year old buildings with near flat roofs made of 55% Al-Zn coated sheet, confirmed earlier conclusions that the product would easily surpass its unique 20 year warranted service life.

Coating Dissolution

It is well known that zinc "corrodes" or "dissolves" at a significantly higher rate in the atmosphere than aluminum. Interestingly, this high reactivity of zinc results in its excellent galvanic or sacrificial protection property. However, this protective property also results in shorter service life when used as a coating on steel. Consequently, for longer service life, higher coating thickness must be used. By comparison, the corrosion rate for aluminum is 2 to 7 times lower than zinc⁽¹⁾, and consequently, is responsible for the long term barrier protection property of aluminum coatings. Obviously, this rate of dissolution is dependent on the exposure environment.

The same dissolution rate trends hold true when the relative dissolution of zinc and zinc alloy coatings on the one hand, and aluminum and aluminum alloy coatings on the other, are compared. Such long term atmospheric exposure data in different environments around the world have been published. Bethlehem Steel reported the results of an extensive study where the corrosion loss on the skyward- and groundward-facing surfaces of 55% Al-Zn coated and galvanized sheet was calculated. In this study, 0.53 mm thick panels of commercially produced, zinc coated sheet with 275 g/m² coating and 55% Al-Zn alloy coated sheet with 165 g/m² coating, were used. (Coating thickness in both cases is 20 μm .)

The study concluded that "..... 55% Al-Zn will have four to 19 times the life of an equal thickness galvanized coating. On average, 55% Al-Zn coated sheet will outlast galvanized by a factor of nine"⁽²⁾. Similarly, the Swedish Corrosion Institute has reported that "55%

Al-Zn coated sheet outperforms galvanized sheet of equal thickness three to seven times in marine and industrial atmospheres in Sweden”⁽²⁾.

Earlier, Bethlehem Steel had published the ratio of average corrosion rates for galvanized and 55% Al-Zn coated sheet after long term atmospheric exposure in a variety of environments. Based on that ratio, 55% Al-Zn coated sheet demonstrated 2 to 6 times lower corrosion loss than galvanized (Table 1). Similar corrosion loss as a function of time was extrapolated from the coating loss data presented by Stoneman and Schuhmacher at Intergalva 97.⁽³⁾ Based on that data, the ratio of average corrosion rates for galvanized and Galfan coatings is essentially similar (Table 2). Moreover, the corrosion rate versus time curve for 55% Al-Zn coated sheet shows two distinct stages, a steady initial rate followed by a slowing down stage in coating weight loss curve; by comparison, the corrosion rate versus time curve for zinc coatings is linear (Figure 1). This means that the zinc coating will be consumed at a steady rate which is higher than that of 55% Al-Zn coatings. The data presented at Intergalva shows a linear relationship between coating thickness loss and time for both galvanized and Galfan coatings (Figure 2).

In summary, this lower rate at which the 55% Al-Zn coating corrodes is the key to its long term service life, and thus its worldwide acceptance as a superior corrosion resistance product.

Results of 30 year outdoor exposure testing

As mentioned above, various aluminum-zinc alloy coating compositions were applied to low carbon strip steel on a pilot-scale, continuous hot dip coating line.⁽⁴⁾ In this laboratory facility, full-hard cold rolled steel sheet coils were uncoiled, scrubbed in the alkaline cleaner and rinsed. The sheet was then annealed in a gas-fired Sels type furnace, cooled in hydrogen gas, and dipped in a coating bath. Coating thickness was controlled between 20 and 25 μm by use of coating rolls as the strip was withdrawn from the bath. The coating was solidified by forced air cooling. In addition to other tests, samples of the various coating compositions were exposed in the atmosphere at different sites⁽²⁾. These test panels were inspected regularly to determine the time to first red rust, defined as the number of years until red rust has developed on about 2% of the coated surface. Commercially produced 275 g/m^2 zinc coated (galvanized) and Type 2 Al-coated sheet, were used as controls. The coating thickness of the zinc and zinc alloy coatings was about 20 μm whereas that of Al-coated was 50 μm .

Figures 3 through 6 show the time to first red rust after thirty years exposures at the various sites. At the severe marine site, 50 meters from the surf, red rust was first observed on 55% Al-Zn coated sheet after 15 years, as compared to only five years for the galvanized control; a three fold improvement (Figure 3). At the other sites, the 55% Al-Zn composition is still free of rust after more than 30 years of exposure. By comparison, the time for red rust on galvanized samples ranged from 10 to 15 years (Figure 4-6).

The corrosion potential, with reference to saturated calomel electrode, was also determined for these test panels. Typically, after 30 years exposure in the atmosphere, the corrosion potential for 55% Al-Zn coated sheet ranged between -0.92 to -0.95 V_{SCE} (Table 3). To further elaborate the point, bare steel, prior to any exposure, has a corrosion potential of -0.45 V_{SCE} and that for 55% Al-Zn coated sheet is -1.0 V_{SCE} which is similar to that of pure zinc. Thus after 30 years' exposure, the 55% Al-Zn coating is still galvanically active and protective towards the steel substrate. By comparison, the zinc coating at these exposure sites was fully consumed over a period ranging from about 5 to 15 years (Figures 3-6).

Corrosion Protection Mechanism

55% Al-Zn alloy coatings, as previously stated, were designed to combine the galvanic protection of zinc coatings and the barrier protection of aluminum coatings. It is important to understand the microstructure of 55% Al-Zn coating to better understand its unique corrosion resistance (Figure 7). The coating consists of an alloy of nominally 55% aluminum, 1.5% silicon, the balance being zinc, by weight. On a volume basis, the aluminum content of the coating is 80%. The coating microstructure consists of a zinc rich interdendritic network in an aluminum-rich matrix.

In simple words, in 55% Al-Zn alloy coating, the zinc is 'locked' in tiny pockets within the aluminum-rich matrix and is available to protect the steel on an 'as needed' basis. At the steel coating interface is a thin intermetallic or alloy layer. During the initial stages of exposure, the zinc-rich phase in the interdendritic areas near the sheared edge, or areas where the steel is exposed, provides galvanic protection and is consumed. The zinc rich interdendritic areas are filled with insoluble corrosion product and are thus plugged. The 'adjacent pockets' of the zinc-rich phase, which are in electrical contact with the steel, are then activated to provide continued galvanic protection. However, the 'zinc' in the zinc-rich phase is not as readily soluble; it thus provides long term protection to the substrate while maintaining a low rate of dissolution. The aluminum in the coating further complements the corrosion resistance process by providing barrier protection.

Building Inspection Results

Before discussing the results of the building inspections, it is important to understand that roofs, especially flat roofs, are the most demanding application for metal panels used in construction. Because most unpainted roofs are virtually flat, they are subjected to debris collection, exposure to sunshine (heat), rain water running over the panels, snow, etc. In industrial or polluted environments, atmospheric contaminants can be dissolved in the precipitation and further aggravate the exposure environment. On the roof panel itself, the drip edge is the most severe location, because in addition to the environmental considerations described above, the substrate steel is exposed at the edge and a galvanic

cell is thus activated. Water running off the roof into the gutter hangs along this edge and accelerates the corrosion process. Consequently, the building inspection results presented below will focus mainly on the condition of the drip edge; performance along formed and flat areas on building panels will also be described.

Of the 82 buildings inspected under this program described above, 21 were more than twenty years old. The main objective of this inspection was to document the performance of near flat roofs made from unpainted 55% Al-Zn coated sheet after the expiration of the 20-year warranted life. Figures 8 and 9 show the excellent condition of the roof panels after 22 and 21 years respectively.

Another inspection of prepainted 55% Al-Zn coated and G-90 galvanized (275 to 285 g/m² zinc coating) was conducted in the U.S. The age of buildings in this inspection ranged between 8 and 20 years and included buildings painted with silicon modified polyester (SMP) and plastisol paint systems. Figure 10 shows the performance of drip edge on prepainted 55% Al-Zn coated and galvanized roof panels on a 15 year old building painted with an SMP paint system. While the 55% Al-Zn coated sheet panel shows evidence of blistering along the drip edge in Figure 10, there is no evidence of red rust. By comparison, a similar building made from G-90 galvanized sheet has extensive red rust along this edge.

A similar comparison of 16 year old 55% Al-Zn coated and 14 year old G-90 galvanized buildings painted with SMP paint system is shown in Figure 11. Again, the 55% Al-Zn coated panels are free of red rust while the galvanized panels exhibit red rust along the drip edge and bends. Figure 12 shows widespread general corrosion on another 15 year old galvanized building painted with a SMP paint system. Such widespread general corrosion has not been observed on similarly prepared 55% Al-Zn coated sheet panels.

Plastisol paint systems are applied at heavier thicknesses, typically 200 to 300 µm. For comparison, the typical paint film thickness for SMP, polyester, and fluorocarbon systems is 25 µm. Consequently, plastisol coated sheet is significantly more expensive than the other paint systems. Figure 13 shows the performance of 8 year old 55% Al-Zn coated sheet buildings and an 11 year old G-90 galvanized building, both prepainted with plastisol paint system. Although the plastisol coated galvanized panel drip edge is superior to that of a SMP coated galvanized panel, it does not match the performance of plastisol coated 55% Al-Zn coated panel. The galvanized panel has developed red rust under the paint film while the 55% Al-Zn panel is free from red rust after 8 years.

As already stated, the main purpose of the paint film on the steel sheet is aesthetics; most paint films are semi-permeable and allow the transport of corrosive species through to the paint-metal coating interface. Once the corrosives reach this interface, the sheet's corrosion performance then depends on the inherent corrosion resistance of the metal coating. The rate of coating dissolution thus becomes the critical factor.

Coating Loss over Time

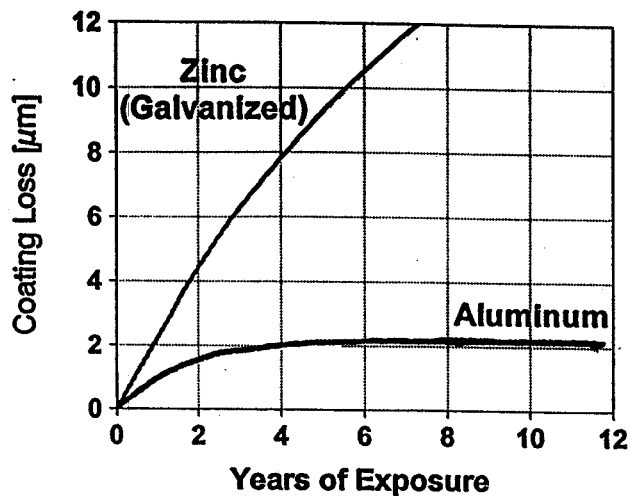


FIGURE 1
Loss of thickness of zinc and aluminum coatings as a function of time

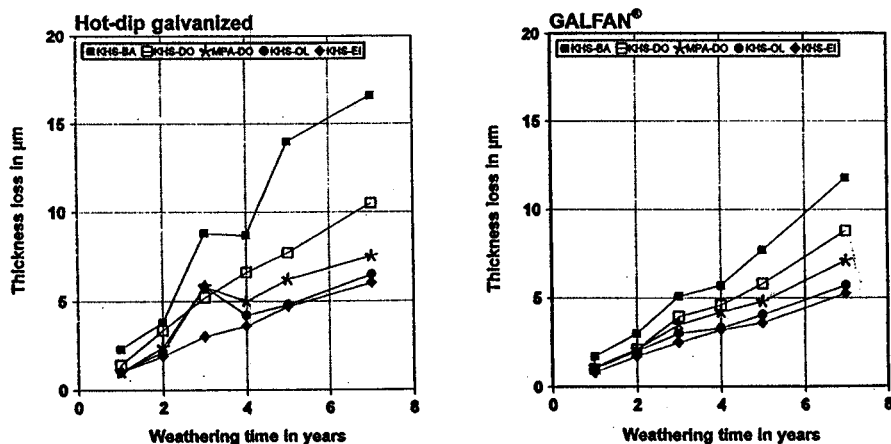


FIGURE 2*
Influence of weathering duration on coating thickness loss for hot dip galvanized sheet (Z-275) and GALFAN® (ZA-255) at varying weathering locations.

*Reference: Stoneman, A.M., (GALFAN Technology Center) and Schuhmacher (Krupp Hoesch Stahl), "Update on GALFAN Market Activity and Performance Data", Proc. InterGalva 97, Birmingham, UK, June 1997.

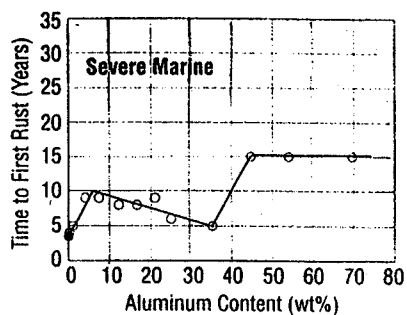


Figure 3
Effect of Aluminum content on coating life in a severe marine environment. Open circles: pilot line product. Solid circles: commercial product.

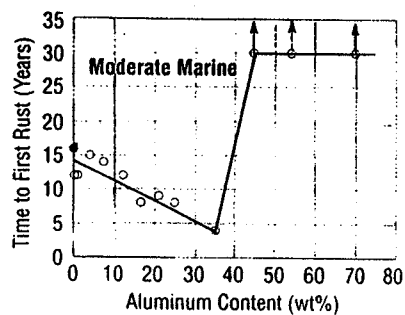


Figure 4
Effect of Aluminum content on coating life in a moderate marine environment. Open circles: pilot line product. Solid circles: commercial product.

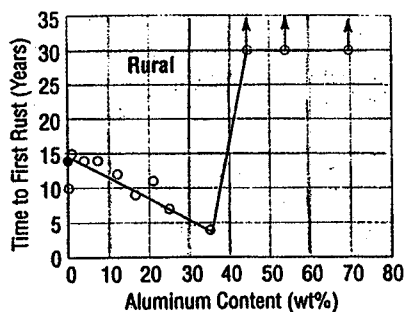


Figure 5
Effect of Aluminum content on coating life in a rural environment. Open circles: pilot line product. Solid circles: commercial product.

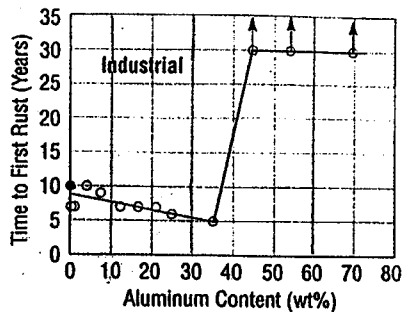


Figure 6
Effect of Aluminum content on coating life in an industrial environment. Open circles: pilot line product. Solid circles: commercial product.

TABLE 1
Ratios of Average Corrosion Rates of 55% Al-Zn Coated and Conventional Galvanized Sheet

<u>Site</u>	<u>Ratio of Average Corrosion Rates</u> <u>55% Al-Zn Coated: Galvanized</u>
Kure Beach, NC, 25-m lot (Severe marine)	4.2
Kure Beach, NC, 250-m lot (Moderate marine)	2.3
Bethlehem, PA (Industrial)	6.2
Saylorsburg, PA (Rural)	3.4

TABLE 2*
Ratios of Average Corrosion Rates of Galfan and Galvanized Sheet

<u>Location</u>	<u>Code</u>	<u>Environment</u>	<u>Ratio:</u> <u>Galfan:Galvanized</u>
North Sea Island	KHS-BA	Marine	1.4
KHS-Dortmund Works	KHS-DO	Industrial	1.2
Materialprüfungsamat Dortmund	MPA-DO	Urban or Moderate Industrial	1.0
Olpe	KHS-OL	Urban	1.1
KHS-Eichen Works	KHS-EI	Urban	1.2

*Extrapolated from Figure 2 (Stoneman, A.M., (GALFAN Technology Center) and Schuhmacher (Krupp Hoesch Stahl), "Update on GALFAN Market Activity and Performance Data", Proc. InterGalva 97, Birmingham, UK, June 1997.

TABLE 3⁽²⁾
Corrosion Potentials of 54% Al-Zn Coated Sheet After 30-Year Exposure**

<u>Site</u>	<u>Corrosion Potential (Vsce)</u>
Unexposed	-1.00
Moderate marine, 30 y	-0.92
Rural, 30 y	-0.95
Industrial, 30 y	-0.95
Bare steel, unexposed	-0.45
Pure Zn, unexposed	-1.00

**Actual composition produced during pilot line trials.

This effect is especially highlighted when the corrosion resistance in sheltered or 'unwashed' areas is considered. Unwashed area is defined as the area under eaves, overhangs or the groundward facing surface of the sheet which is not washed by rain. Corrodents can accumulate on the surface, permeate through the paint film and corrode the substrate. It is under such conditions that the permeable nature of the paint film becomes clear and the superior corrosion resistance of the metal coating is highlighted.

Figure 14 and 15 clearly demonstrate that unwashed areas, both vertical and horizontal exposures in the flat and formed conditions are susceptible to this corrosion phenomenon. Figure 15 is the underside of identical gutters made from prepainted galvanized and 55% Al-Zn coated sheet after three years' exposure in a severe marine environment. Figure 16 shows the relative performance of both substrates on a wall section under an overhang after 7 years exposure. In each of the above figures, the 55% Al-Zn coated sheet performed significantly better than G-90 galvanized material.

Concluding Comments

The overall corrosion resistance of metal coated sheet steel products is primarily dependent on the metal coating's dissolution characteristics. If the metal coating is galvanically active, like zinc coatings, it will protect the steel against corrosion for the relatively short term, and in doing so, will itself corrode at a higher rate. Consequently, the total service life of this product will be lower.

The excellent long term corrosion resistance of 55% Al-Zn coated sheet depends on the coating's lower overall rate of dissolution which is due to the unique blend of zinc and aluminum coatings. Thus this coating behaves more like an aluminum coating reinforced with the galvanic protection of zinc.

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 2. Townsend, H.E., and Borzillo, A.R., "55% Al-Zn Alloy Coated Sheet Steel: The Versatile, Long Lasting Building Panel Steel", Intergalva 97, Birmingham.
 3. Stoneman, A M, and Schuhmacher, B, "Update on Galfan Market Activity and Performance Data", Intergalva 97, Birmingham, England.
 4. Townsend, H.E., and Borzillo, A.R., "Thirty-Year Atmospheric Corrosion Performance of 55% Aluminum-Zinc Alloy-Coated Sheet Steel", Galvatech '95, Chicago, IL, USA.
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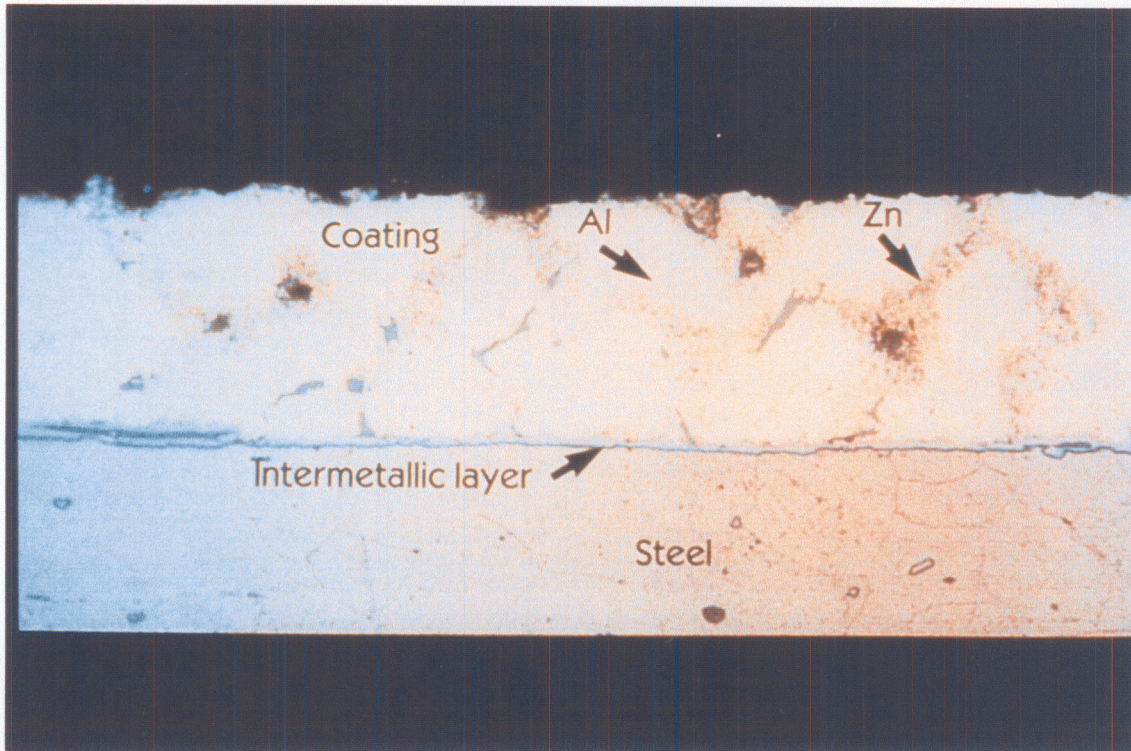


Figure 7
Typical cross-sectional photomicrograph of 55% Al-Zn coating.

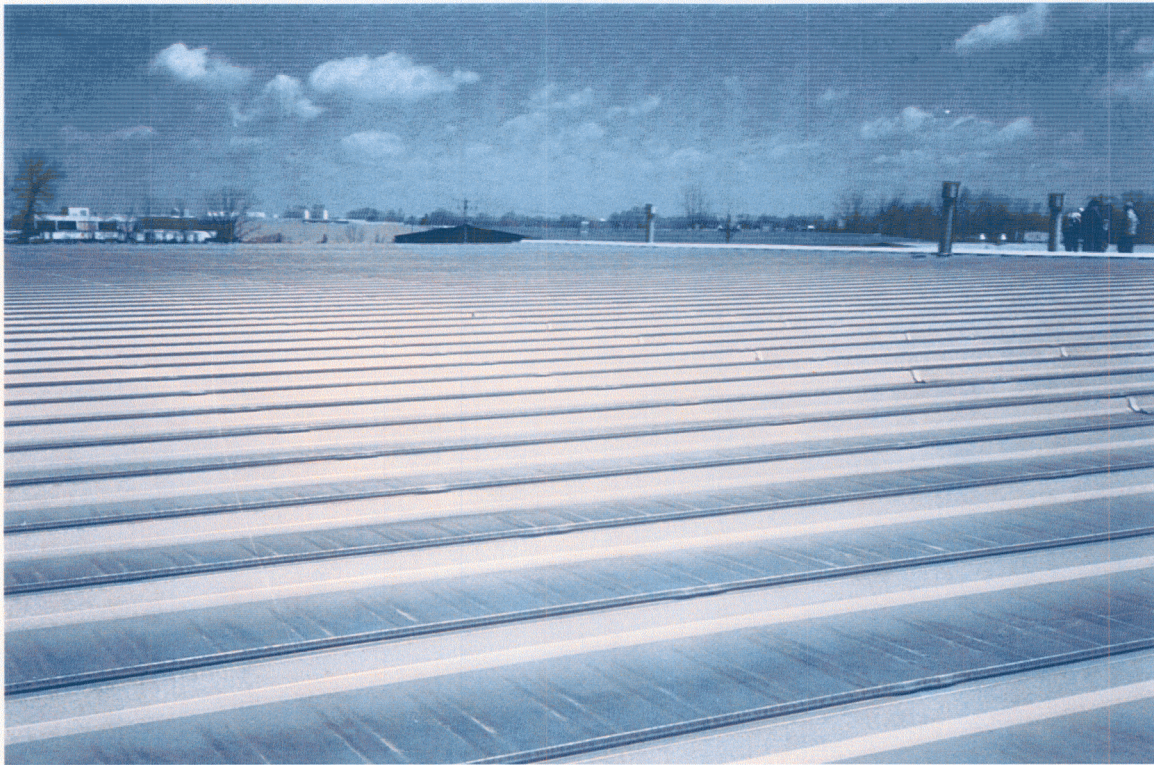


Figure 8

Located in an area of paper mills, this 20-year old, $\frac{1}{4}$:12 slope Galvalume SSR was covered with dirt. The Al-Zn coating was intact and protecting the steel base. Galvanized roof ancillaries were completely rusted. The life of the roof is projected to be 30 to 40 years.



Figure 9

Located in Davenport, IA, this Galvalume SSR has already given 20 years of maintenance free service and is on its way to a 30-year life.

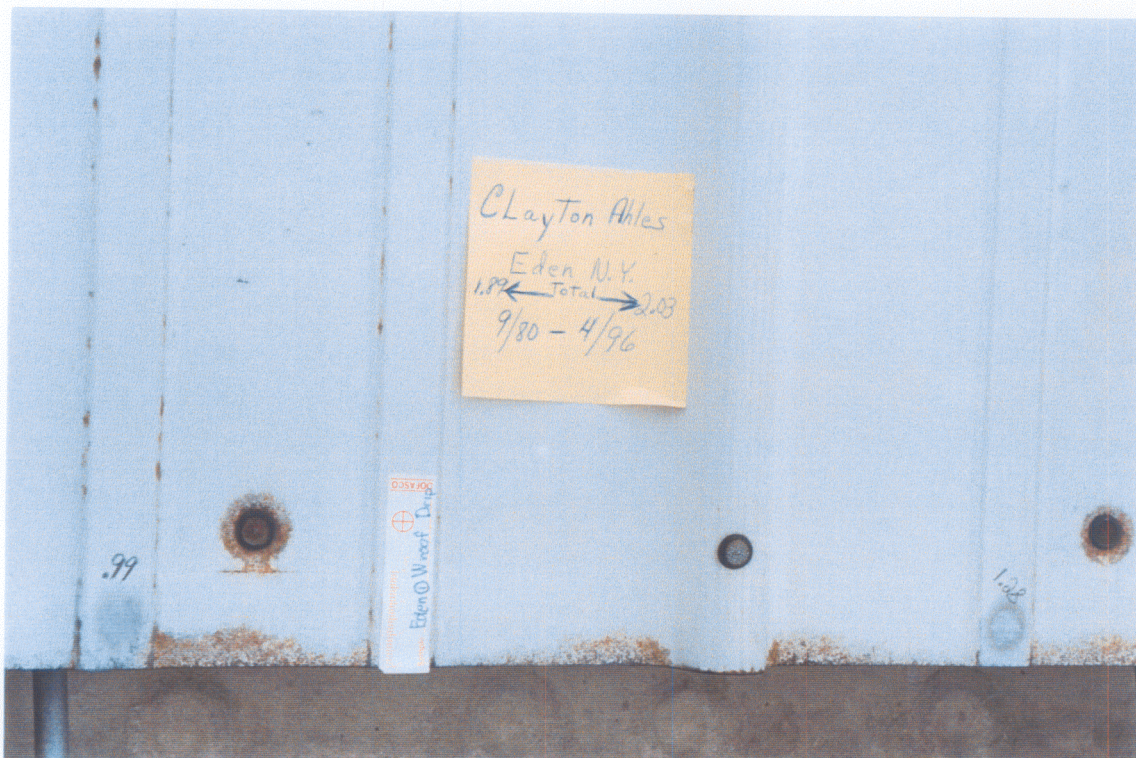


Figure 10a. 55% Al-Zn Coated, SMP, Chromate Pretreatment

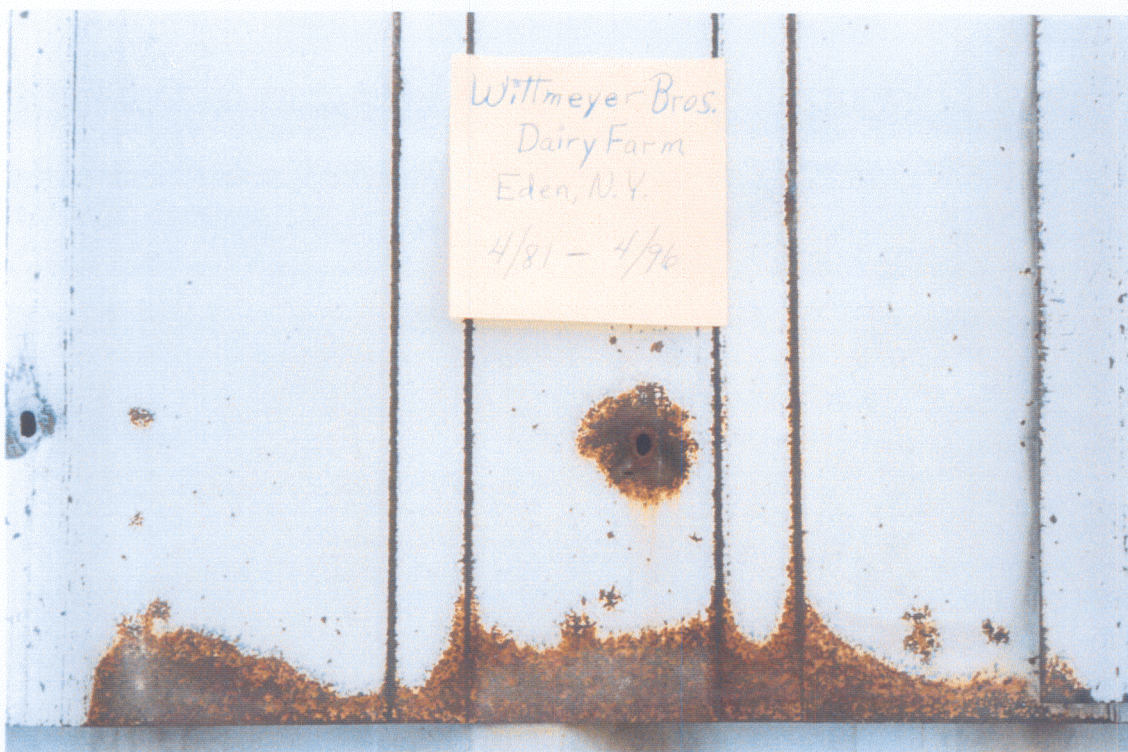


Figure 10b. G-90 Galvanized, SMP, Zinc Phosphate Pretreatment

Figure 10
Drip edge and bend performance of 15 year old Prepainted 55% Al-Zn and G-90 Galvanized Sheet Buildings; Silicon Modified Polyester (SMP) Paint System



Figure 11a. 16 year old Prepainted 55% Al-Zn Coated Sheet buildings, SMP, Chromate Pretreatment

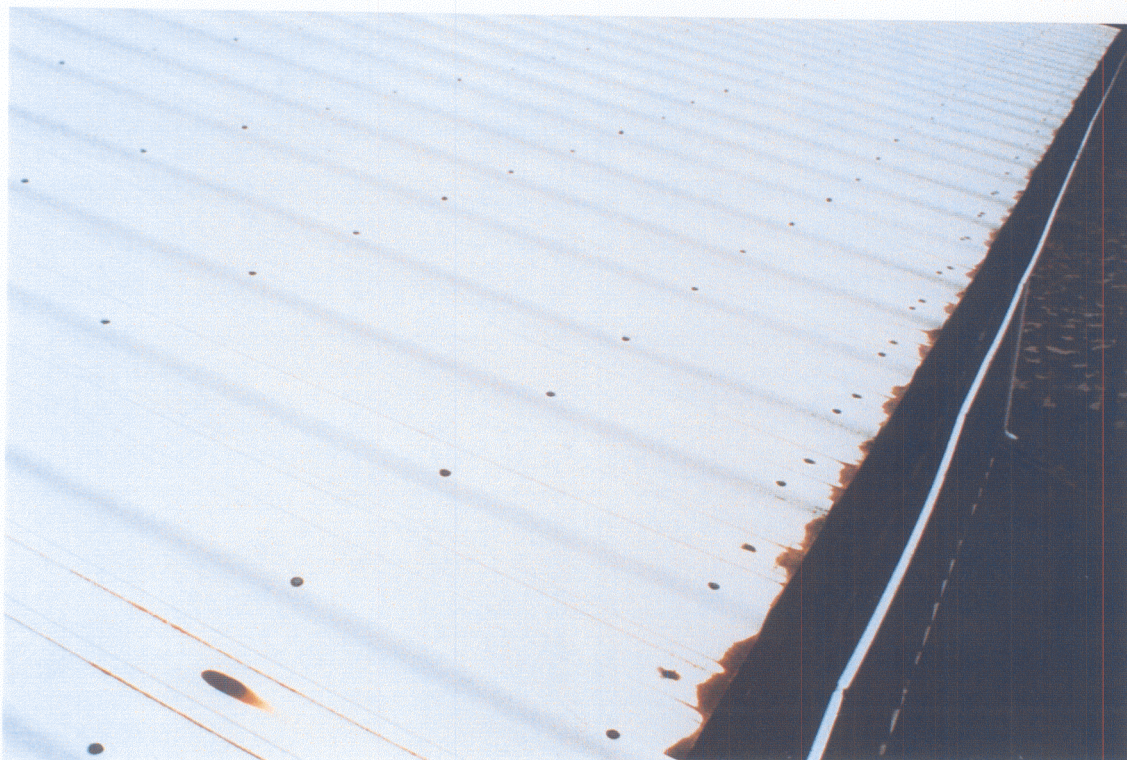


Figure 11b. 14 year old Prepainted G-90 Galvanized building, SMP, Zinc Phosphate Pretreatment

Figure 11
Drip edge and bend performance of Prepainted 55% Al-Zn and galvanized buildings; Silicon Modified Polyester (SMP) Paint System

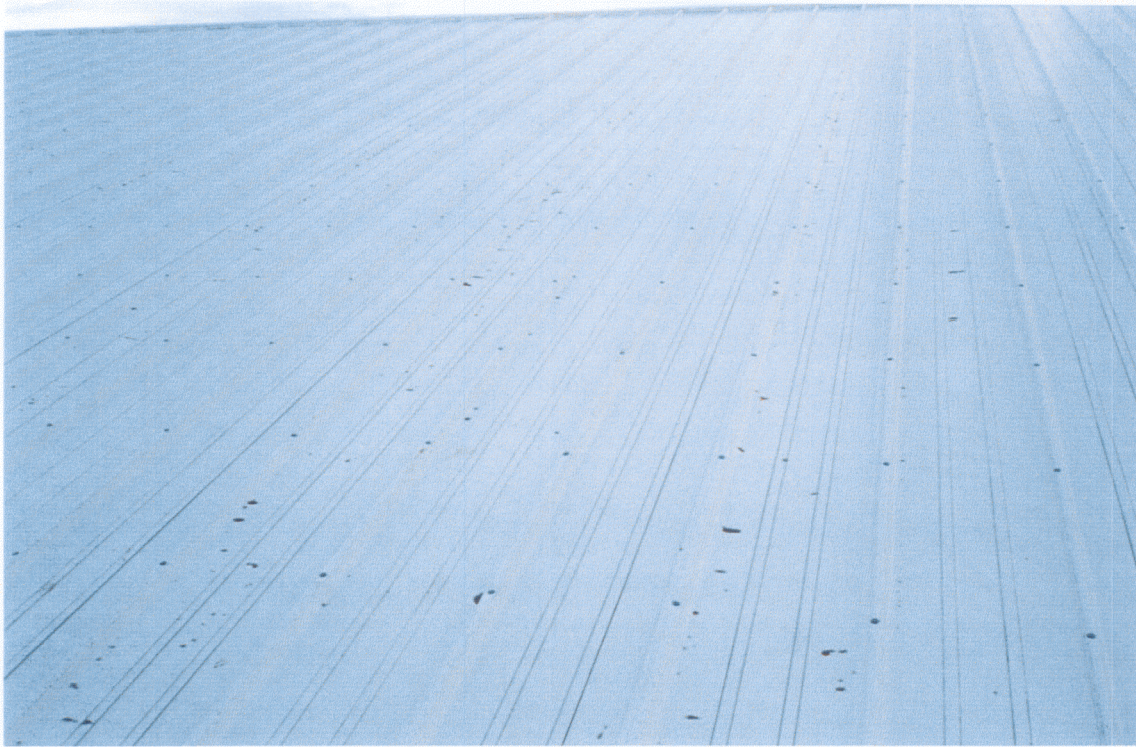


Figure 12
General corrosion on a 15 year old G-90 Galvanized Sheet roof

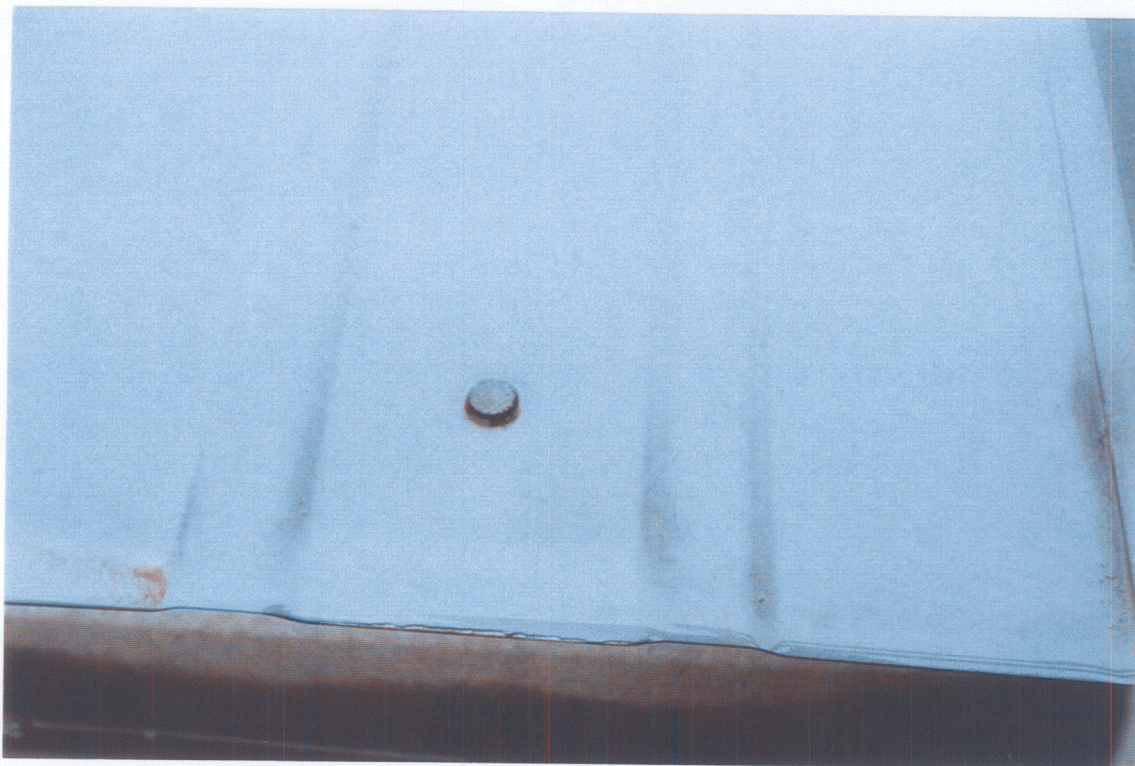


Figure 13a. 8 year old, 55% Al-Zn Coated Sheet, Plastisol Paint System, Chromate Pretreatment



Figure 13b. 11 year old, G-90 Galvanized, Plastisol Paint System, Complex Oxide Pretreatment

Figure 13
Relative performance of Plastisol Coated 55% Al-Zn Coated and G-90 Galvanized buildings

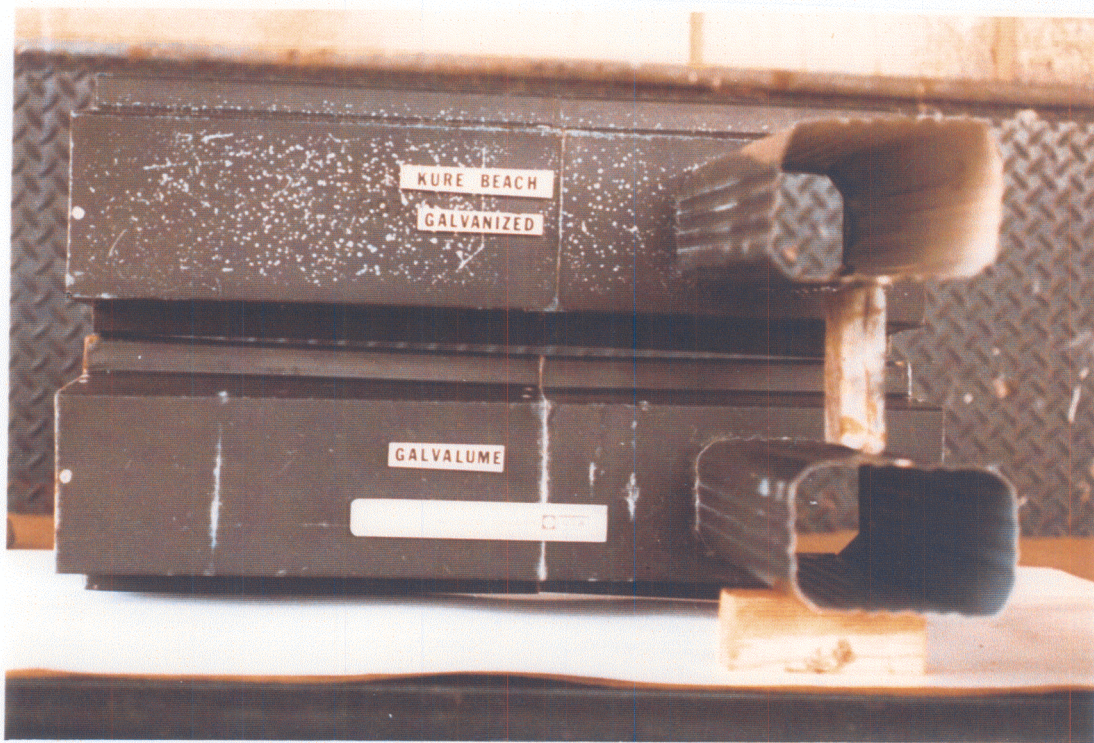


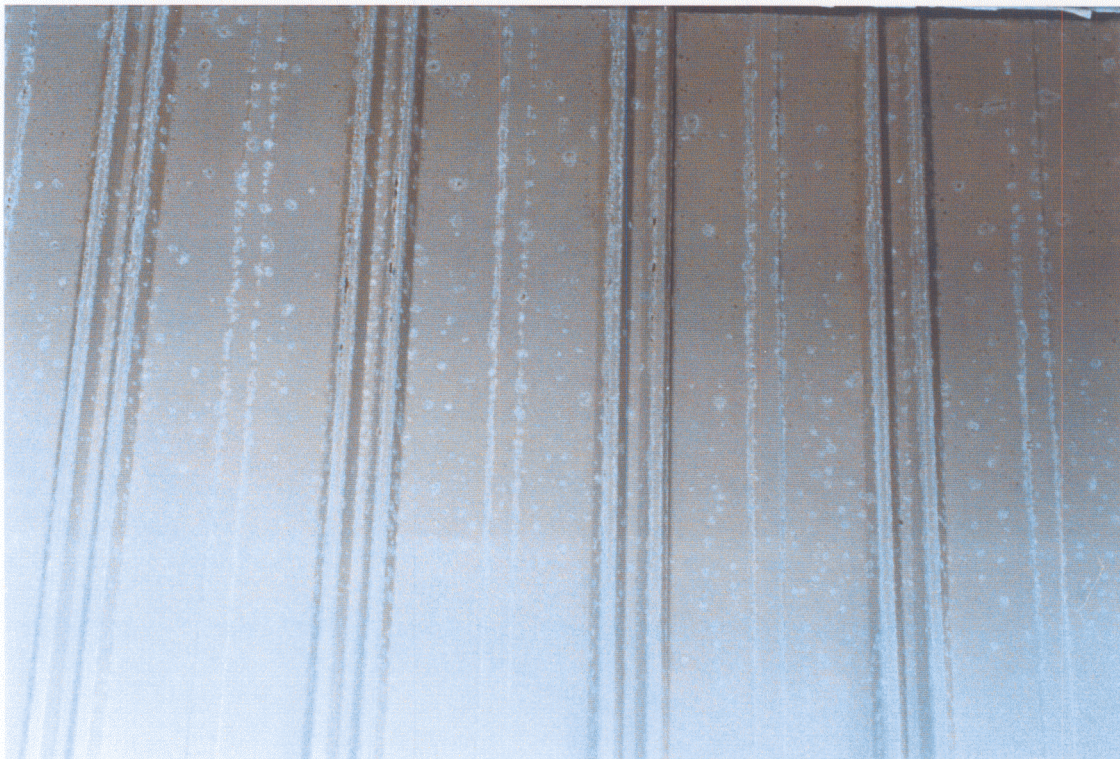
Figure 14

Relative performance of unwashed areas on galvanized and GALVALUME sheet after 3 years exposure in a marine environment.

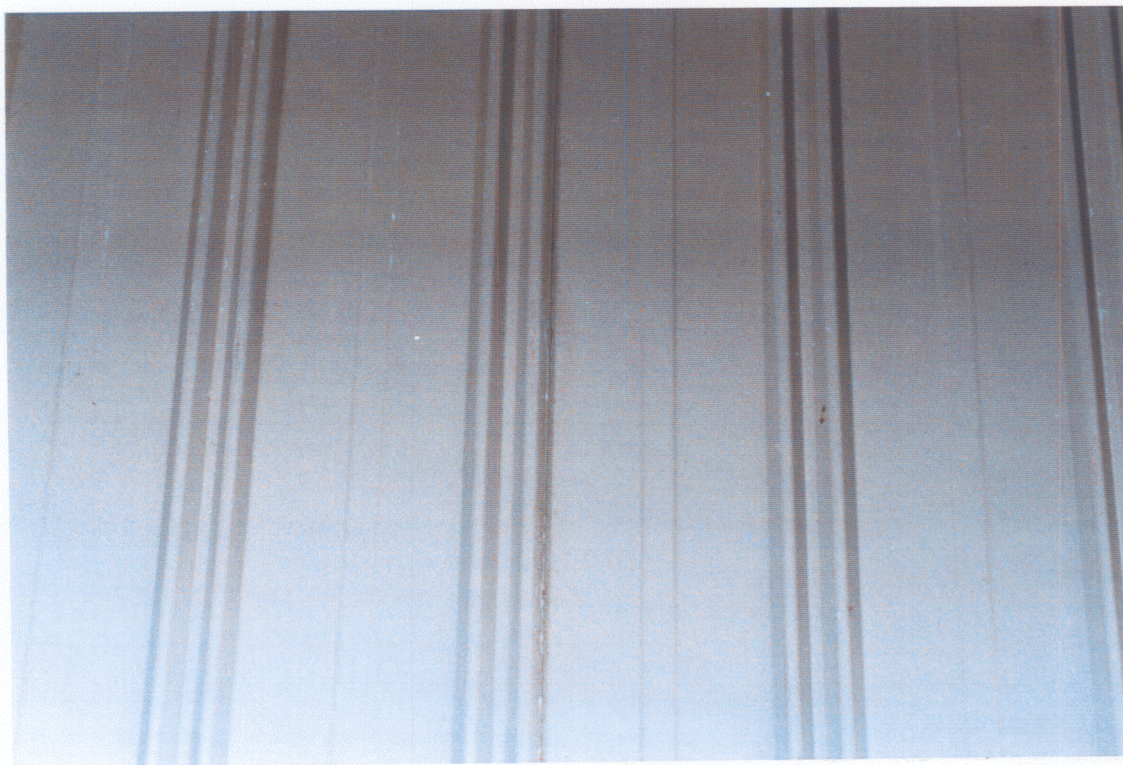


Figure 15

Relative performance of galvanized and GALVALUME sheet on formed areas after 3 years in a marine environment.



Galvanized



ZINCALUME

Figure 16
Relative performance of galvanized sheet and ZINCALUME sheet, vertical wall section in unwashed area after 7 years in marine environment.