論　文

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55% Al-Zn-Alloy-Coated Sheet Steel*

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Synopsis:
Based on extensive studies of 1 to 70% Al-Zn alloy coatings on sheet steel, the 55% Al-Zn alloy coating was found to have the optimum combination of corrosion resistance, heat resistance and galvanic protection of sheared edges of sheet. This paper reviews the corrosion and heat resistance of this new coated sheet product under various service conditions, as well as paintability, formability and weldability. This new coated sheet product is in commercial production now in the United States and Australia (John Lysaght, Ltd, Inc) and will be produced soon in Sweden (Svengt Stal). The various commercial applications for this product are described.

Introduction

In June 1972 the Bethlehem Steel Corporation announced the commercial availability of a new hot-dip-coated sheet steel product, which we have called Galvalume. The coating is an alloy of 55% Al, 1.6% Si, balance Zn. This new product is significantly more corrosion-resistant than a zinc coating, is oxidation-resistant, and is more galvanic toward steel than an aluminum coating[1].

The research program which led to the 55% Al-Zn alloy coating began in 1962. Various Al-Zn alloys containing 1 to 70% Al were prepared in Bethlehem's laboratories as hot-dip coatings on sheet for studies to determine the optimum composition. The optimum composition turned out to be the 55% Al-Zn alloy, which was several times more corrosion-resistant than zinc coatings of the same thickness and about as corrosion-resistant as aluminum coatings. In addition, the new coating provided better galvanic protection to steel than aluminum and much better high-temperature oxidation resistance than zinc and about the same as that provided by aluminum. As demonstrated by extensive testing since that time, the 55% Al-Zn alloy coating combines the best properties of zinc or aluminum coatings.

Among the topics covered in this article are: physical metallurgy of the Al-Zn alloy system, corrosion resistance and galvanic properties of 1 to 70% Al alloys, properties and corrosion resistance of the 55% Al-Zn alloy, and, finally, commercial applications and production characteristics.

Physical Metallurgy of Al-Zn Alloy System

A review of the Al-Zn equilibrium phase diagram is helpful in understanding the corrosion behavior of Al-Zn alloys. Currently, the diagram (Fig. 1) from PRESNYAKOV et al[2] and GOLDAK and PARR[3] is most widely accepted, although some areas are not yet reliably established. Here are some of the features of the equilibrium diagram:

(1) There is a eutectic at 5% Al.

(2) There is very limited solid state solubility of Al in the betazinc terminal phase.

(3) The terminal alpha-aluminum phase is very extensive at intermediate temperatures ranging from 100% to 30% Al. The solubility of beta-zinc in alpha-aluminum decreases from 30% to 5% on cooling from 525 F to room temperature.

(4) There is believed to be a peritectic transformation at about 28% Al in which the gamma phase is formed, which in turn undergoes a eutectoid transformation at 22% Al on further cooling.

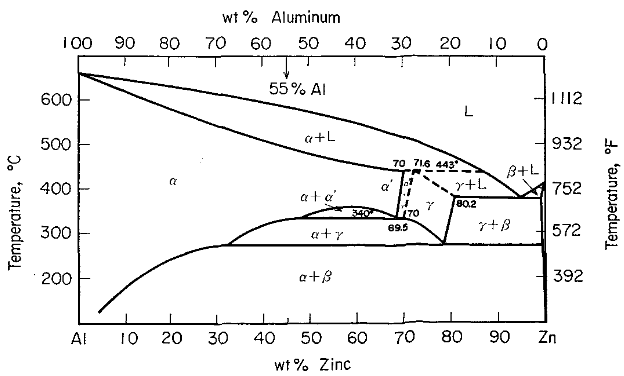

Fig. 1. Phase diagram of Al-Zn system.

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(5) At room temperatures the equilibrium structure comprises alpha-aluminum and beta-zinc. There are no intermetallic compounds or ordering reactions in the Al-Zn alloy system. An intermetallic layer is formed actively between molten Al-Zn and a steel surface. Small additions of silicon are added to the Al-Zn melt to control this reaction.

Liquid 55% Al-Zn alloy cooled very slowly under near-equilibrium conditions has a microstructure of alpha-aluminum matrix with a dispersed spherodized beta-zinc phase, as shown in Photo. 1 for furnace-cooled 55% Al-Zn alloy. More rapid air-cooling conditions typical of the commercial hot-dip coating (Photo. 2) result in microstructures that are nonequilibrium and more complex. The first solid formed is alpha-aluminum at about 80% Al leading to a cored dendritic structure in which the final liquid to solidify is substantially lower in aluminum content (zinc-rich) and whose microstructure is quite fine and not well defined.

As the aluminum content of the Al-Zn alloy increases to 70% Al, the dark-etching zinc-rich phase decreases in volume and disappears at 60-70% Al.

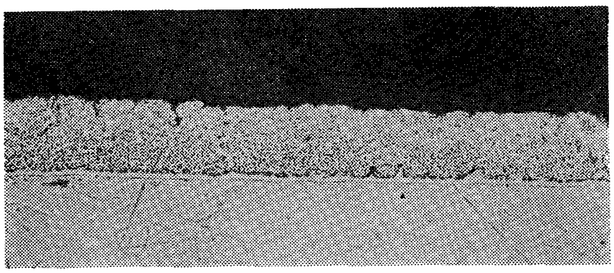


Photo. 1. Near-equilibrium structure of 55% Al-Zn coating (×500×33/56, amyl-nital etch) furnace-cooled from 400°C.

Thus the structure of these alloy coatings and consequently their corrosion behavior are a function of the aluminum content and to some extent the freezing and subsequent cooling rate of the coating. As explained in the following discussion, the optimum corrosion resistance with adequate galvanic protection is obtained with the forced-air-cooled 55% Al-Zn alloy, which gives a coating of mostly alpha-aluminum phase with an interdendritic zinc-rich phase.

Summary of Testing of 1 to 70% Al-Zn Alloy Coatings that led to the Selection of 55% Al-Zn

In the earlier stages of the program that eventually culminated in the selection of 55% Al-Zn, Al-Zn alloy compositions from 1-70% Al were prepared with 3% silicon additions by weight of the aluminum content. These alloys were applied as hot-dip coatings at about 0.8 to 1.0 mil (20 to 25 microns) average thickness to 0.018″ (0.46 mm) steel sheet. These were then corrosion-tested in the atmosphere to determine the optimum aluminum content based on corrosion resistance and the galvanic protection of sheared edges.

Fig. 2 shows the atmospheric corrosion losses after a five year exposure at one rural, two marine, and two industrial test sites. Because the density of the various alloys varies with aluminum content, the corrosion weight losses have been converted by calculation to average loss of thickness using the density of the Al-Zn alloy for up to 21% Al coatings and the density of 22% Al-Zn alloy for 25-70% Al-Zn alloy coatings. The corrosion rate compared to that of galvanized steel decreases with increasing aluminum content to about 4-7% Al, then rises to a maximum at 21% Al, near the eutectoid composition, then decreases

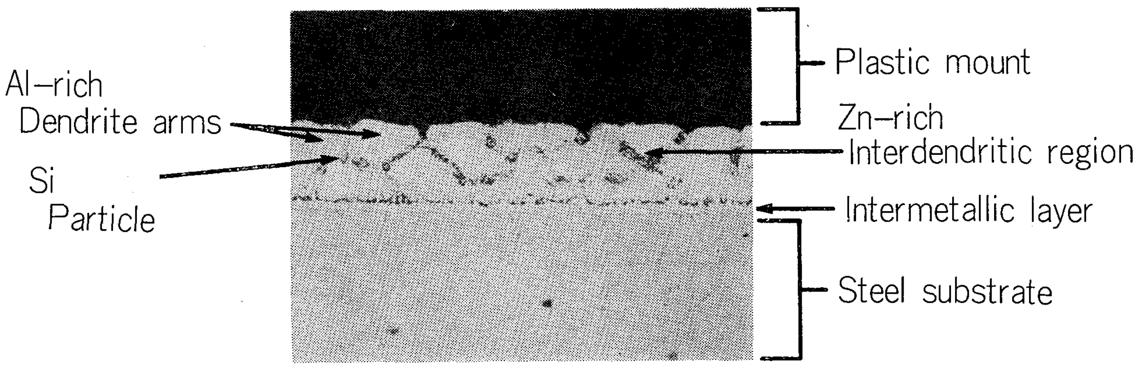


Photo. 2. Random cross section of a 55% Al-Zn coating (×500×33/38, amyl-nital etch)

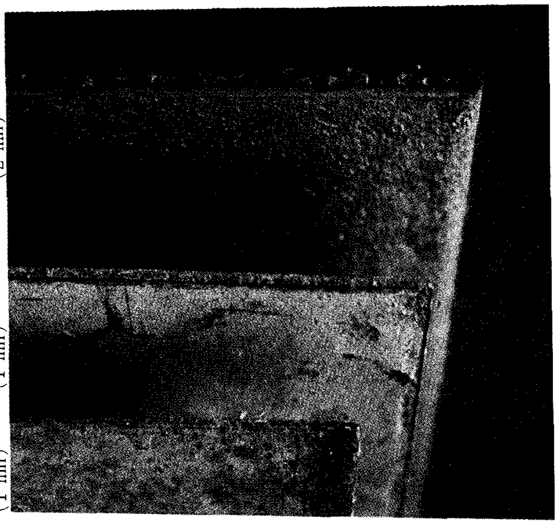


Photo. 4.
Condition of sheared edges of thin sheets after 6 years' exposure at Saylorsburg (Rural) ($\times\frac{1}{2}$).

Photo. 3.
Condition of sheared edges of thin sheets after 6 years' exposure at Bethlehem (Industrial) ($\times\frac{1}{2}$).

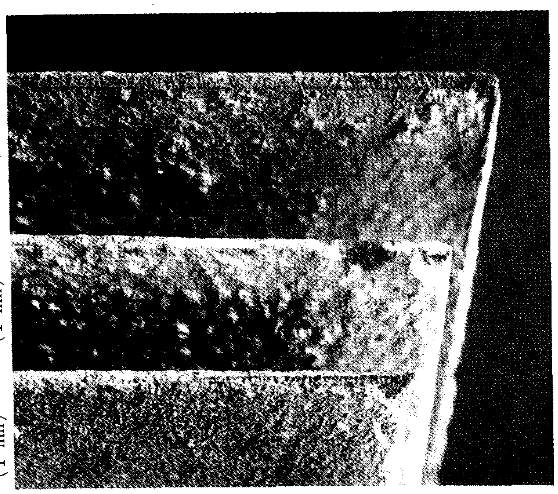


Photo. 5. Condition of sheared edges of thin sheets after 5.5 years' exposure at 80-Foot Lot, Kure Beach (Marine) ($\times\frac{9}{20}$).

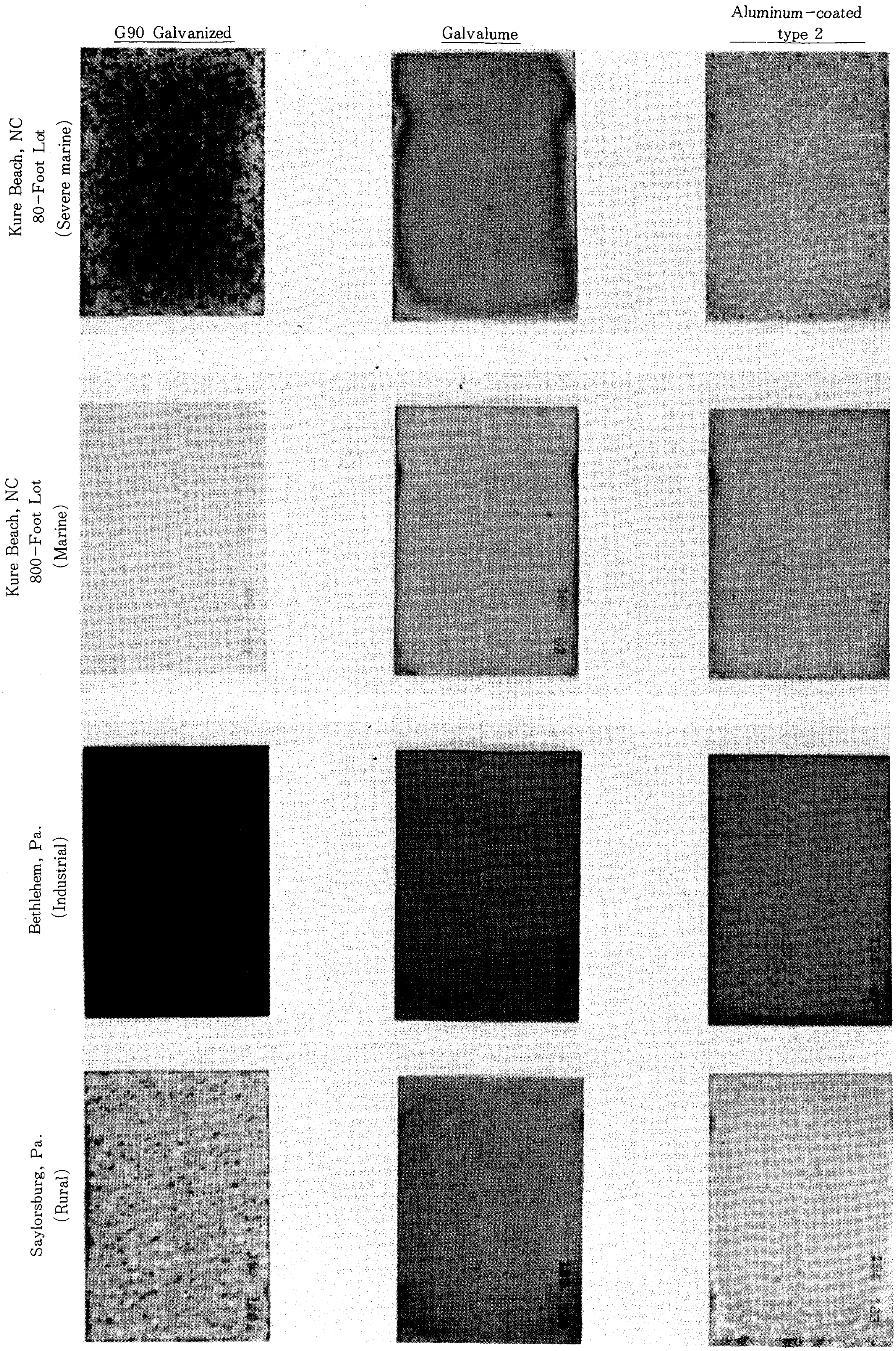
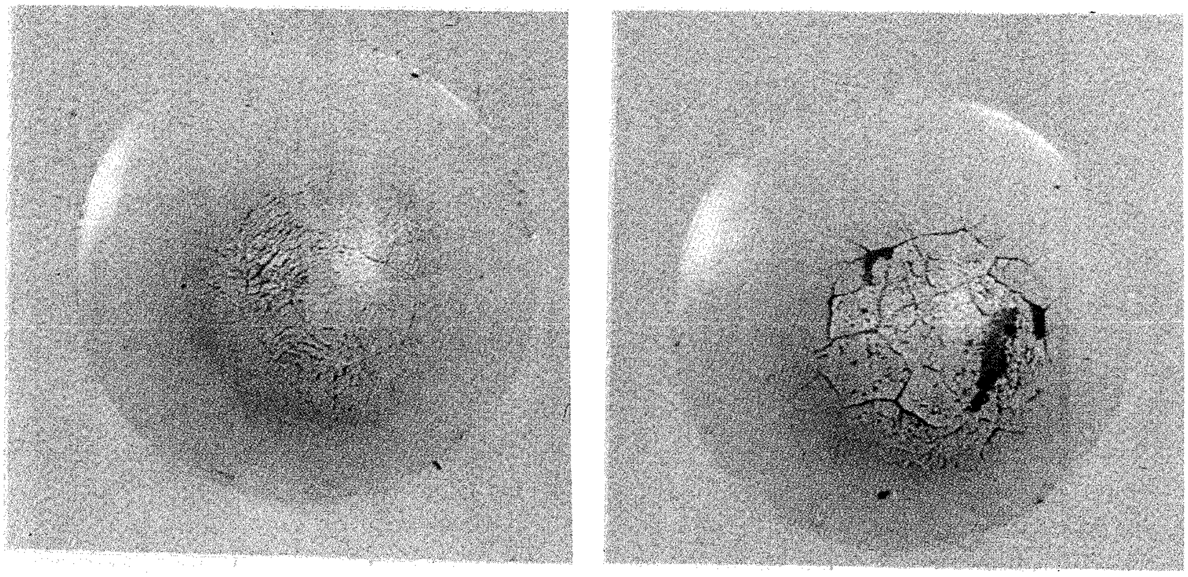
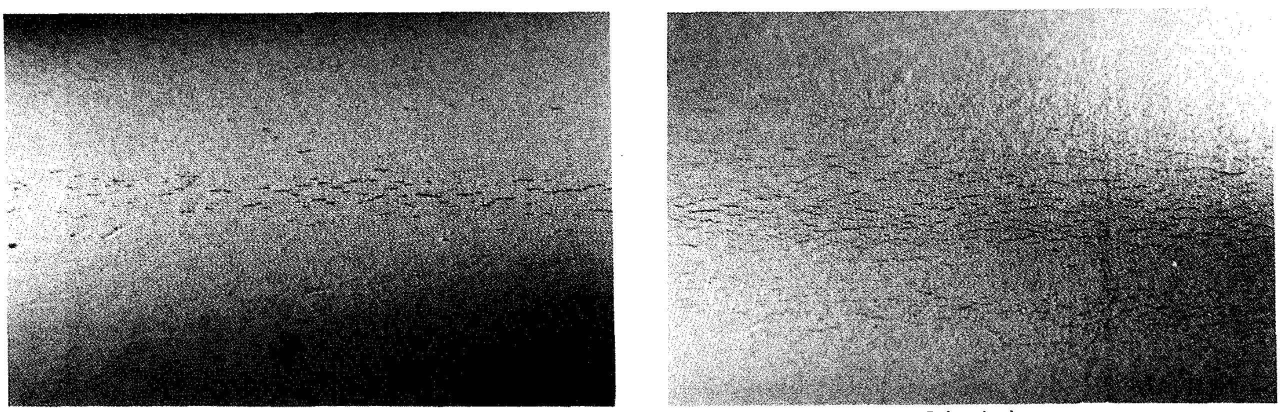


Photo. 6. Appearance of coated steels after 13 years in the atmosphere (Skyward surface)



Al-Zn coating Galvanized

Photo. 8. 80 Inch-lb impact and tape ($\times \frac{13}{3}$)



Al-Zn coating Galvanized

Photo. 9. Paint crazing on 1/8" radius bend ($\times \frac{1680}{237}$)

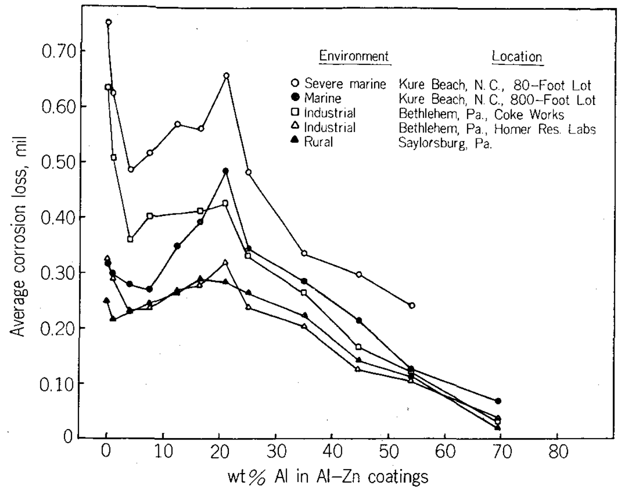


Fig. 2. Effect of aluminum content on the corrosion performance of Al-Zn alloy coatings after 5 years' exposure in various atmospheres.

progressively to 70% Al. Thus, additions of aluminum above 22% markedly increase the corrosion resistance of aluminum-zinc alloy coatings, with 25 to 70% Al being the optimum range of aluminum content for corrosion resistance.

The ability to provide galvanic protection to the steel base is also an important quality of a coating alloy. Inevitably, coated steel products are subject to mechanical damage of the coating during processing or in service. Scratches through the coating or sheared edges of sheet can be subject to rust staining if the coating does not provide minimal galvanic protection.

During the test programs over a period of years we examined the sheared edges of sheet samples with 1–70% Al coatings for evidence of galvanic protection of the sheared edges of 0.019" (0.48 mm) coated sheet during atmospheric exposure. Visual appraisal of rust staining on the faces of the panels and microscopic examination of the sheared edges for rust and rust growths show that the 1–70% Al alloys are about as good as galvanized coatings in their ability to protect sheared edges and are clearly superior to aluminum coatings. This protection is especially evident in the case of the 55% Al coating, which was found to be the optimum composition in terms of providing both excellent corrosion resistance and good galvanic protection of sheared edges. These results may be clearly seen in Photo. 3, which shows the 7.5X magnified appearance of the sheared edges of 55% Al-Zn-coated sheet, galvanized, and aluminum-coated sheet after a six year exposure at Bethlehem, Pennsylvania, a moderate industrial atmosphere. The aluminum-coated sheet edge shows heavy rusting and rust growths, whereas galvanized and 55% Al-Zn-coated sheets show a small amount of local rusting but no edge roughness due to rust growths. The same behavior was observed at Saylorsburg, Pennsylvania, a rural site (Photo. 4). This behavior can be explained by the fact that in industrial and rural atmospheres galvanized and 55% Al-Zn coatings do provide galvanic protection to steel sheared edges, whereas aluminum coatings do not because the Al_2O_3 film formed on aluminum prevents galvanic activity by aluminum toward steel in these atmospheres. On the other hand, in marine atmospheres where the chloride ion breaks this film down, galvanic activity by aluminum toward steel is free to occur and prevent rust growths from developing on the sheared edges of aluminum-coated sheet (Photo. 5). Thus, in marine atmospheres all three coatings galvanically protect sheared edges.

These observations on galvanic behavior are based on the long-term performance of thin sheets such as those used for roofing on preengineered buildings.

We need to acknowledge that as the steel sheet thickness increases and, therefore, as the area and distance over which galvanic effects must be exerted also increase, 55% Al-Zn coatings become less effective than galvanized coatings in edge protection. However, in this respect they remain quite superior to aluminum coatings.

To sum up, the developmental work to define the optimum composition among the 1–70% Al-Zn coatings pointed to the 55% Al-Zn alloy as having the best all-round properties as an improved coating for sheet steel and other ferrous products.

Corrosion Resistance of 55% Al-Zn Alloy Coatings

Atmospheric Corrosion Resistance

Coatings of the 55% Al-Zn alloy have now been in atmospheric exposure for 15 years, with excellent results being observed. Photo. 6 shows the appearance of coated sheet in comparison with one-mil (25 micron) G90 galvanized and Type 2 two-mil (50 micron) aluminum-coated sheet after a 13 year exposure at four test locations.

1) *In the severe marine atmosphere* the galvanized

coating, which had started to rust after a four year exposure, is now heavily rusted. In contrast, panels with 55% Al-Zn as well as two-mil (50 micron) aluminum coatings are still in good condition, although some corrosion products are starting to creep inward on the faces of panels from cut edges.

2) *In the marine atmosphere* of the 800-foot lot all three types of coatings are still in good condition.

3) *In the industrial atmosphere* most of the galvanized coating has been corroded away, and more than three-quarters of the steel surface is rusted. The Al-Zn alloy and aluminum-coated panels exhibit superficial light-brown oxide stain due to particulate fallout from nearby steelmaking operations but are otherwise in good condition.

4) *In the rural atmosphere* all three materials are in good condition, but there is some rust staining apparent along the edges of the two-mil (50 micron) aluminum-coated panels.

Figs. 3 through 6 are the corrosion-time curves for these same three materials after a 13 year exposure[4]. In order to facilitate a comparison of the corrosion resistance of a 55% Al-Zn coating with that of a conventional galvanized coating, we calculated the ratio of the 13-year corrosion losses for the two coatings:

Site	Ratio of 13-Year Corrosion Losses Galvanized/55% Al-Zn
Kure Beach, N.C., 80-ft lot	4.2
Kure Beach, N.C., 800-ft lot	2.0
Saylorsburg, Pa.	3.4
Bethlehem, Pa.	6.2

Coating thickness is typically 0.8 mil (20 micron) for G90 galvanized and 55% Al-Zn. Accordingly, it can be predicted that the commercially available 55% Al-Zn coating will outlast G90 galvanized by two to six times in a wide range of atmospheric environments.

The concentration of zinc in that part of the coating which corrodes initially is about 90% Zn (Fig. 7) and decreases with time. In the rural and industrial environments the composition of the corroded phase seems to level off after nine years at roughly 80% Zn, whereas in the marine environments it continues to decrease[4].

Atmospheric Corrosion Mechanism

To account for the exceptionally good performance of the 55% Al-Zn coating, it is useful to consider the mechanism and morphology of the corrosion process.

The time dependence of the corrosion potential for 55% Al-Zn coatings exposed to laboratory chloride or sulfate solutions is shown schematically in Fig. 8. Subsequent to first immersion (Stage 1) the coating exhibits a corrosion potential close to that of a zinc coating exposed under identical conditions, generally about −1.0 to −1.1 V (SCE). During Stage 1 the zinc-rich portion of the coating

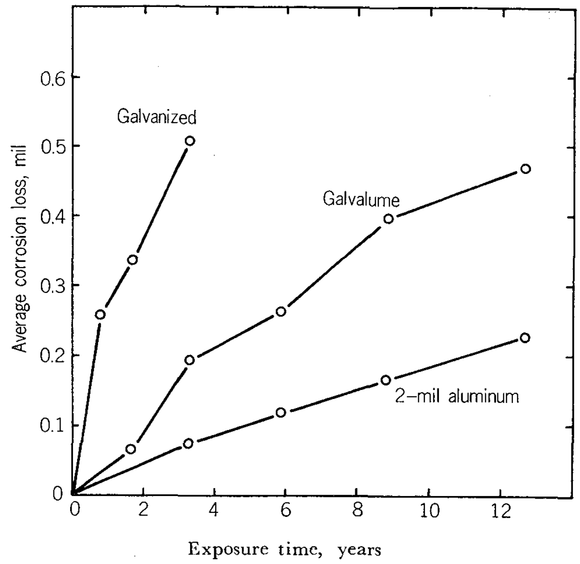


Fig. 3. Corrosion performance of galvalume, galvanized and 2-mil aluminum-coated steels in severe marine atmosphere (Kure Beach, 80-Foot Lot)

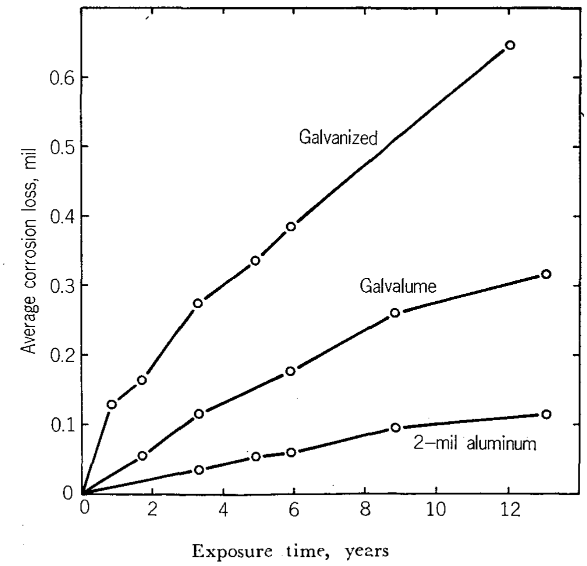


Fig. 4. Corrosion performance of galvalume, galvanized and 2-mil aluminum-coated steels in marine atmosphere (Kure Beach, 800-Foot Lot)

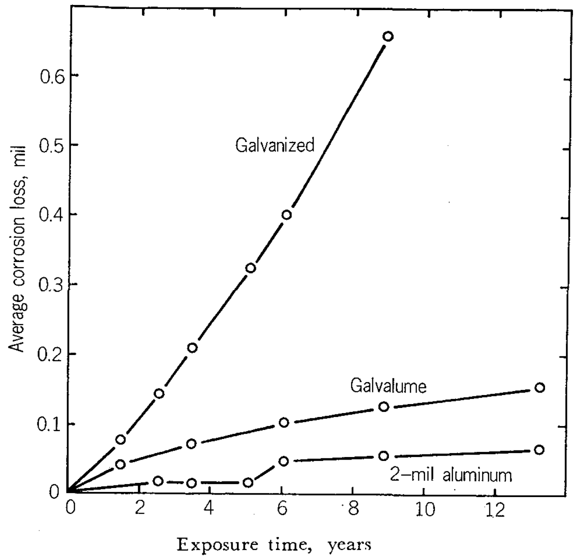


Fig. 5. Corrosion performance of galvalume, galvanized and 2-mil aluminum-coated steels in industrial atmosphere (Bethlehem, Pa.)

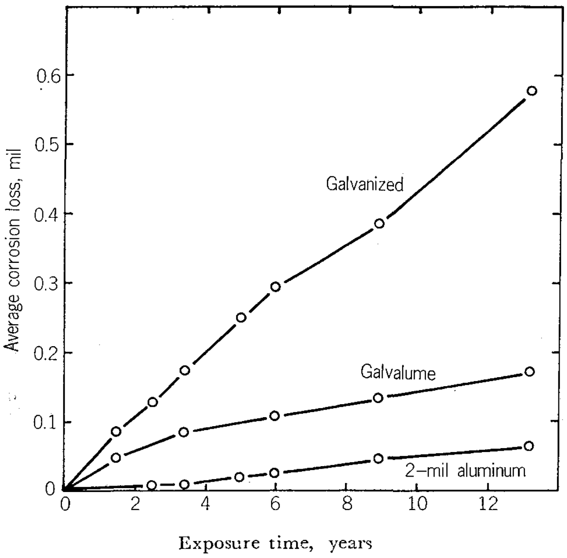


Fig. 6. Corrosion performance of galvalume, galvanized and 2-mil aluminum-coated steels in rural atmosphere (Saylorsburg, Pa.)

dissolves preferentially, and the coating, like zinc, is anodic to steel. Stage 1 persists until the zinc-rich interdendritic portion of the coating is consumed, the exact time depending on the thickness of the coating (mass of available zinc) and the severity of the environment (rate of zinc corrosion). Following depletion of the zinc-rich fraction, the corrosion potential rises and approaches that of an aluminum coating, generally about −0.7 V (SCE). During this period (Stage 2) the coating behaves like an aluminum coating, passive in sulfate environments but anodic to steel in chloride

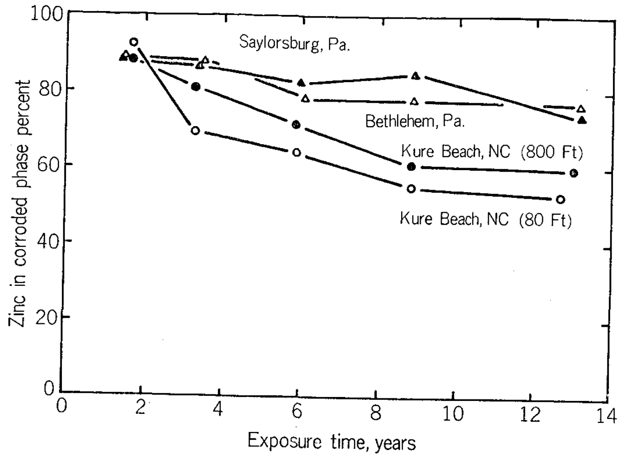


Fig. 7. Zinc content of the corroded portion of 55% Al-Zn coatings.

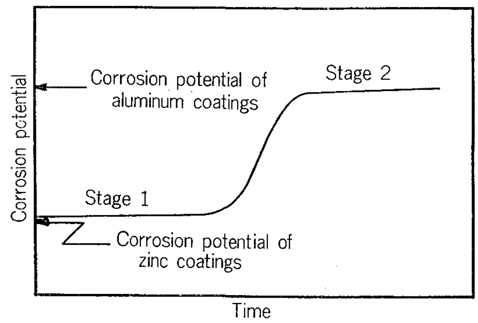


Fig. 8. Schematic time dependence of corrosion potential of 55% Al-Zn coating in aqueous solutions.

environments.

The behavior of the 55% Al-Zn coating during atmospheric exposure appears to proceed in a manner analogous to that observed in laboratory solutions, although the time scale is greatly extended. The zinc-rich interdendritic portion of the coating corrodes preferentially, as evidenced by the composition of the corroded phase (Fig. 7). During this period the coating is sacrificial to steel, and the cut edges of thin steel sheet are galvanically protected. The initial overall rate of corrosion of the Al-Zn coating is less than that of a galvanized coating because of the relatively small area of exposed zinc.

As the zinc-rich portion of the coating becomes gradually corroded, the interdendritic interstices are filled with zinc and aluminum corrosion products. The coating is thus transformed into a composite comprised of an aluminum-rich matrix with zinc and aluminum corrosion products mechanically keyed into the interdendritic labyrinth. The zinc and aluminum corrosion products should offer continued protection as a physical barrier

Table 1. Undercar tests comparing 55% Al-Zn and galvanized coating resistance.

Coupon pair	Exposure time	Distance driven	Corrosion rate		
			G90 Galvanized	55% Al-Zn	Superiority ratio of 55% Al-Zn
A	26mo	29 137km	3.33 microns/y	0.47 microns/y	7.1
B	15	31 472	1.56	0.42	3.7
C	21	12 893	1 54	0.21	7.3
D	16	26 410	1.40	0.68	2.1
E	26	38 294	1.10	0.65	1.7
F	14	23 189	1.90	0.24	7.9

Table 2. Water fog and immersion corrosion resistance.

Test condition	Material	Time to first rusting
22 h/d water fog 2 h/d air drying	55% Al-Zn-alloy-coated	35 days
	Galvanized	5
	Aluminum-coated Type 2	5
22 h/d water fog 2 h/d air drying	55% Al-Zn-alloy-coated	90
	Galvanized	64
	Aluminum-coated Type 2	5
22 h/d distilled water immersion 0 air drying period	55% Al-Zn-alloy-coated	114*
	Galvanized	90
	Aluminum-coated Type 2	16

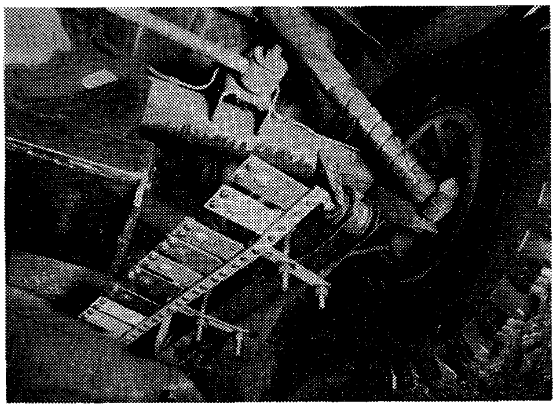


Photo. 7. Undercar corrosion coupon rack mounted on rear axle control arm of a passenger car.

to the transport of corrodents. In addition, as others have also reported[5], zinc corrosion products may act as a cathodic inhibitor and thus, as they are gradually leached from the coating, serve to provide continued protection at cut edges. The decreasing corrosion rates with time in the industrial and rural environments (Figs. 5 and 6) appear to reflect a gradual change from active, zinc-like behavior to passive, aluminum-like behavior.

The intermetallic layer is generally cathodic to the steel substrate as well as to the other components of the coating. Accordingly, this layer appears to function as an electrochemical barrier that prevents corrosion of the steel substrate subsequent to interdendritic corrosion of the overlay.

Other Corrosion Environments

1) *Automotive Corrosion Resistance.* 55% Al-Zn alloy coated sheet has been exposed to undercar corrosion testing (as shown in Photo. 7) for one to two years. Undercar corrosion resistance is two to seven times better than G90 galvanized coatings (Table 1).

A fleet car test of 30 automotive mufflers and 30 tailpipes of 55% Al-Zn coated sheet in comparison with similar numbers of aluminum-coated mufflers and tailpipe are both showing a predicted mean service life of four years or more at this time.

2) *Underwater Corrosion Resistance.* 55% Al-Zn alloy coatings have been exposed to condensing water exposure in the Q-Panel test for four years without rusting compared to 0.67 years to rusting of G90 galvanized coatings.

When exposed to standing water as occurs on a flat roof, the 55% Al-Zn coating is more resistant to rust initiation than either G90 galvanized or aluminum coatings (see Table 2). These laboratory test results are supported by inspections of flat roofs where 55% Al-Zn coatings are more resistant to standing water after two years than

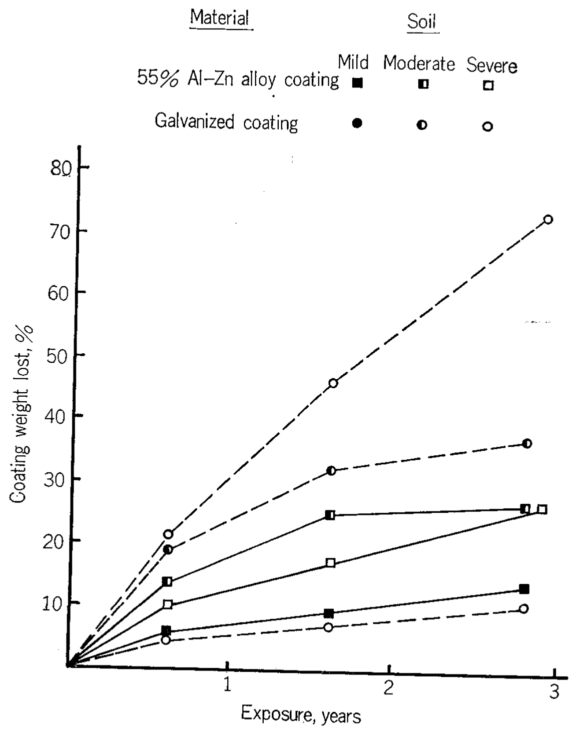


Fig. 9. Soil corrosion resistance of coated sheets.

aluminum coatings. Similarly, in a service test of culverts the invert of 55% Al–Zn-coated culvert (24-micron coating) is at least as durable as G210 galvanized coatings (44-micron coating).

3) *Underground Corrosion Resistance.* When embedded for up to three years in local soil (76 000 ohm-cm resistivity)—with and without applications of $CaCl_2$-NaCl-$MgSO_4$ solution to reduce soil resistivity to 35 000 ohm-cm and 1 700 ohm-cm to increase corrosivity—55% Al–Zn alloy coatings showed lower coating losses, as percentage of initial coating weight, than thicker G210 galvanized coatings (Fig. 9).

4) *Wet Storage Staining.* 55% Al–Zn-alloy-coated sheet when properly chromate-treated is much more resistant to wet storage staining in coil or stacks of sheet than similarly treated galvanized sheet (Fig. 10). However, wet storage staining, if it occurs eventually, will be gray to black compared to a white to gray appearance on galvanized sheet. Slushing oils containing barium dinonyl napthalene sulfonate corrosion inhibitor further enhance the wet storage stain resistance of chromate-treated 55% Al–Zn alloy coated sheet.

Thus, in most natural-media environments 55% Al–Zn-alloy-coated sheet has been found to be significantly more corrosion-resistant than gal-

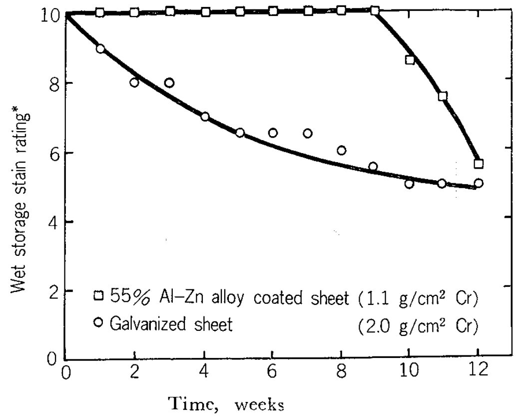


Fig. 10. Typical time dependence of storage staining for chromate-treated steel sheet.

* Ratings are : 10 is no stain; 5 is 5% stained; and 0 is 100% stained.

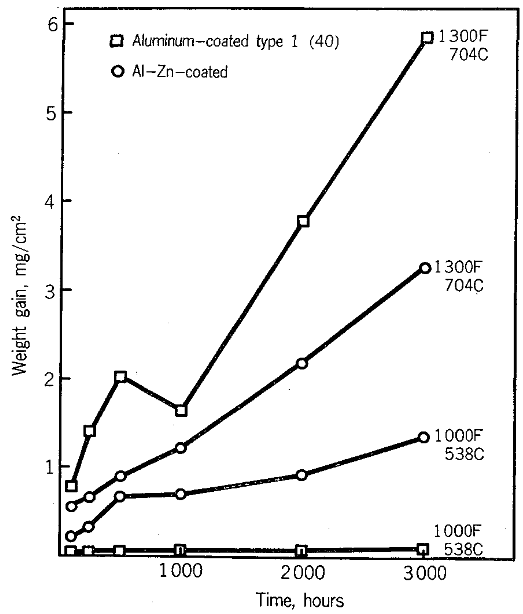


Fig. 11. Results of oxidation tests.

vanized sheet and superior in many cases to aluminum-coated sheet.

High-temperature Performance

Continuous Oxidation

Fig. 11 shows the relative weight gain due to high-temperature oxidation of 5×10 cm samples of 55% Al–Zn-alloy-coated sheet compared to Type 1 aluminum-coated. At 540°C, the weight gain for 55% Al–Zn-alloy-coated steel was higher than for aluminum-coated steel, although the weight gain for both materials was low. At 705°C, the weight gain for 55% Al–Zn-alloy-coated steel was less than for aluminum-coated steel.

Heat Reflectivity and Discoloration

The average heat reflectivity based on emissivity

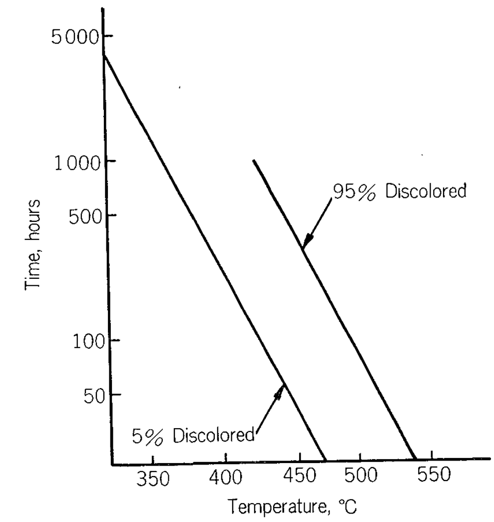


Fig. 12. Galvalume alloying discoloration caused by heating.

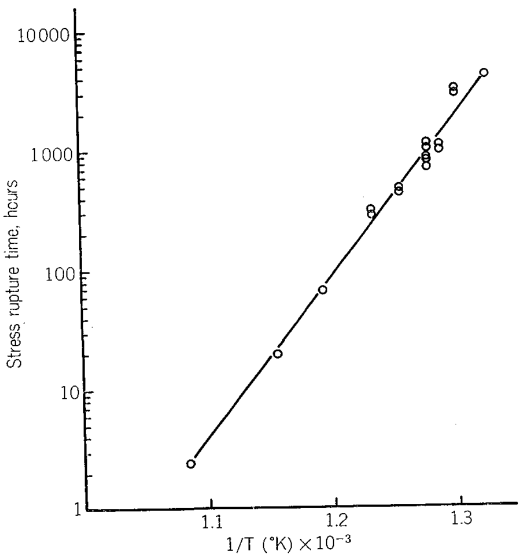


Fig. 13. Rupture time as a Function of temperature for galvalume sheet.

measurements at a 2.4-micron wavelength for the 55% Al-Zn-alloy-coated sheet surface was 88%, whereas the reflectivity of the Type 1 aluminum-coated sheet was 76%. Reflectivity was found to be quite uniform over the 55% Al-Zn surface, whereas it varied widely over the surface of the aluminum-coated steel. When heated for long times at high temperatures, the 55% Al-Zn coating will alloy with the steel base and discolor (see Fig. 12), thus reducing its heat reflectivity.

High Temperature Stress Rupture

55% Al-Zn-alloy-coated sheet tensile specimens (ASTM E139) were loaded at an initial stress of 41 MPa and tested to rupture at temperatures between 480 and 760°C. Time to failure is plotted as a function of temperature in Fig. 13.

Paintability

55% Al-Zn-alloy-coated sheet provides an excellent and consistent surface for coil coating. Commercial paint systems and pretreatments, such as phosphate, chromate, and complex oxide, for coil painting both galvanized and aluminum sheet have proven suitable. However, at present the emphasis is on the use of chromate pretreatments because of their proven track record on aluminum and 55% Al-Zn alloy surfaces. Large quantities of 55% Al-Zn alloy coated sheet have been coil-coated by *John* Lysaght of Australia, with excellent field performance.

Initial Paint Adhesion

Paint adhesion is excellent with a variety of pretreatments common for galvanized and aluminum. Adherence is good over a wide range of treatment conditions and is much less sensitive to the condition of the surface and to coil-line operating parameters than is galvanized.

The two samples seen in Photo. 8 are examples of the better paint adhesion to the 55% Al-Zn alloy coating compared to galvanized. Both these samples were recently coated on a coil line with the same silicone polyester paint system, then subjected to an 80-inch-pound (9 Joules) impact test and taped. The 55% Al-Zn alloy coating sample on the left shows almost perfect paint adhesion, whereas the galvanized sample on the right shows significant loss of adhesion.

Flexibility

The improved flexibility of prepainted 55% Al-Zn alloy as compared with prepainted galvanized is also demonstrated in Photo. 8.

Further evidence of this benefit may be seen in Photo. 9, which shows the typically lower level of paint crazing and metal coating crazing at bends of prepainted 55% Al-Zn-alloy-coated sheet. The same silicone polyester paint system was applied to both materials on a coil line. Both samples were bent to a 1/8″ (3.2 mm) radius.

Atmospheric Corrosion Resistance

On the basis of seven-year exposure tests, prepainted 55% Al-Zn alloy coating provides excellent atmospheric corrosion resistance. We—along with coil coaters, paint suppliers, and pretreatment companies—have been observing the exposure test results on painted 55% Al–Zn alloy coatings in a variety of environments. The data include the severe marine environments of Kure Beach, a high–humidity, high–ultraviolet–light environment in Florida, a mild industrial environment at Bethlehem, Pennsylvania, and a rural environment at Saylorsburg, Pennsylvania. Specifically, painted 55% Al–Zn alloy is equal to or better than painted galvanized in retention of adhesion and in corrosion protection at flat areas, paint–damage areas, and bends and formed areas where the paint has crazed or fractured.

Prepainted preengineered buildings with Galvalume have been in serice for some six years. The condition of these buildings is very good, with good retained paint adhesion and film integrity and no underfilm creep at paint damage areas and at bends. Sidewalls do not represent particularly aggressive conditions in normal atmospheric exposures, and we would not expect failure after only six years. Indeed, we do not generally see failures on galvanized buildings after this time. But, in one instance of a building near the ocean, where the sidewalls were constructed of alternating prepainted 55% Al–Zn–alloy–coated and galvanized panels, the 55% Al–Zn–alloy–coated panels were in good condition, whereas the galvanized panels were starting to show rust and stain at the bends where the paint had crazed.

Roofs represent a more corrosive environment than sidewalls, and galvanized roofs often show much more rust at sheared edges, such as drip edges at the ends of panels after four or five years, than 55% Al–Zn.

Typical Mechanical Properties

Commercial–quality or full–hard 55% Al–Zn–alloy–coated sheet has mechanical properties similar to those of equivalent galvanized products made by the continuous galvanizing process. Typical yield strengths for the commercial–quality sheet with the 55% Al–Zn alloy coating range from 38 000 to 50 000 psi (260 to 345 MPa), depending on gage. Tensile strengths range from 50 000 to 65 000 psi (345 to 450 MPa), and elongation values range from 24 to 34%. Typical Rockwell B scale values range from 50–65.

Tensile strength for the full–hard 55% Al–Zn–coated sheet is approximately 90 000 psi (620 MPa), with a total elongation ranging from 3 to 6%. The full–hard product is produced to meet an 80 000 psi (550 MPa) minimum yield strength and an 82 R_B hardness aim.

Mill bend tests on the 55% Al–Zn–alloy–coated sheet, made in accordance with ASTM specifications, show that the coating generally has excellent adherence to the steel substrate. Cracking of the 55% Al–Zn coating will occur on the outside of 180° OT bends as do galvanized coatings. This cracking is not associated with any loss in adherence between the coating and the base steel. The coating may flake may occur under some reverse bending conditions. Where flaking has occurred at the reverse bends, increased die radius at the bends has eliminated the problem.

Fabrication of 55% Al–Zn Alloy Coated Sheet

Forming

Both commercial–quality and full–hard sheet are being successfully roll–formed, the biggest application being that of roofing panels for preengineered buildings. Roll–forming practices are generally the same as for other coated sheet steels. However, unlike galvanized sheet, the 55% Al–Zn coating requires lubrication to avoid metal pickup on the forming rolls.

Welding

55% Al–Zn–alloy–coated sheet is readily weldable with conventional resistance and arc welding processes. Conditions for resistance welding are similar to those used on galvanized steel. Spot welding electrodes should be redressed as required to maintain nugget size. Conditions for arc welding with the shielded metal–arc and gas metal–arc processes are also similar to those for galvanized sheet, except that the lower zinc content of the 55% Al–Zn coating results in considerably less zinc fuming during arc welding, thereby reducing the fume hazards for welders.

Commercial Applications

In the U. S.

In the U.S., 55% Al–Zn–alloy–coated sheet has been used primarily for unpainted roof panels in preengineered metal buildings. Other areas of application include high–temperature appliances and automotive parts. Bethlehem identified the roofing application as one in which this new product, because of its excellent atmospheric corrosion resistance, could compete successfully with

Type 2 aluminum-coated sheet. Growth of the product for this application has met or exceeded expectations. Thus, 55% Al-Zn-alloy-coated sheet is probably the most widely used material for preengineered metal building roofing in the U.S. at this time.

Bethlehem recognized that the markets for appliance, automotive, and agricultural applications would require a longer-term development. However, 55% Al-Zn-alloy-coated sheet is already beginning to enjoy acceptance and growth in the appliance and automotive industries, and we are implementing an orderly expansion of capacity to meet these new market demands.

Domestic appliance applications include toasters, toaster ovens, refrigerators, laundry dryers, air conditioners, ranges and ovens, trashmashers, and factory-built fireplaces. Commercial appliance applications include space heaters, vending machines, burner parts, and commercial refrigerators. 55% Al-Zn has mainly replaced aluminum-coated sheet in these applications but has also replaced some painted and bare galvanized sheet and painted cold-rolled sheet. It has even successfully replaced aluminum sheet in some corrosion-resistant applications and some applications of the decorative-trim type.

The automotive applications include subfloors and embossed interior panels of school buses, oil-filter tubes, windshield wipers, and exhaust-system components. Exhaust systems are expected to be the most significant use, primarily as a substitute for aluminum-coated sheet in original-equipment systems and as a substitute for galvanized and cold-rolled sheet for replacement exhaust systems.

Agricultural applications are, at the moment, limited, but the long-range potential is good for animal feeders, tobacco dryers, greenhouse structural members, grain bins, grain storage buildings, silo roofs and silo accessory equipment.

In Other Countries

Roofing and walling are a major application of 55% Al-Zn-alloy-coated sheet. These are roll-formed products having 200 g/sq m coatings in unpainted applications and 150 g/sq m coatings when painted. Other large applications include flashings, ridge capping and rain water goods (guttering and downpipes). Garage doors and sheet fencing are also significant applications. Other major applications anticipated are rain water tanks, automotive muffler systems and appliances such as toasters and stoves, air conditioners, freezer and clothes drier components and heat exchangers.

Production of 55% Al-Zn Alloy Coated Sheet

55% Al-Zn alloy coated sheet is currently being produced in the U.S. and Australia on nonoxidizing continuous hot-dip coating lines formerly used to produce galvanized sheet but modified to produce Al-Zn-alloy-coated sheet. Two important equipment requirements for the production of 55% Al-Zn-coated sheet are:

- A refractory-lined pot,
- Increased cooling of the coated sheet after coating

The nominal coating weight for Galvalume is 150 g/sq m (total both sides), which is equivalent to a coating thickness of about 20 microns on each side of the sheet. Heavier coatings can be provided for products, such as culverts, that are subjected to severe exposures.

Conclusions

Results summarized in this review of the properties and performance of 55% Al-Zn-coated-sheet in comparison with competitive hot-dip-coated sheet products show that:

1) 55% Al-Zn alloy coated sheet is generally superior to zinc-coated sheet in corrosion resistance, heat resistance, and other desirable qualities of high-tonnage mill-coated product.

2) 55% Al-Zn alloy coated sheet is about equivalent to aluminum-coated sheet in long-term atmospheric corrosion resistance and certain heat-resistance applications.

Thus, Bethlehem's new coated sheet product has a combination of properties that will favor a substantial growth in its commercial use both in the U.S. and other countries.

Acknowledgments

The foregoing summarizes the inventions and innovations of many of my colleagues at Bethlehem Steel Corporation, particularly *J. B.* Horton, *A. R.* Borzillo, *L. P.* Pellatiro, *J. J.* Connolly and *A. K.* Potter.

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