

# METAL ROOFING FROM

# A TO Z ALUMINUM TO ZINC

## PART II: Metallic Coatings for Carbon Steel

By Rob Haddock

*Editor's note: This is the second article in a multi-part series about metal roofing in today's market. The series provides an in-depth look at materials and their uses, coatings, system designs, and installation techniques. It is reprinted with permission of Metalmag.*

**C**arbon steel sheet is a popular domestic choice for metal roofing, primarily for economic reasons. Unfortunately, it has corrosive characteristics. This means that it must be protected

by some other, less corrosive metallic coating. Such a coating provides a "barrier" protection for the steel. Because steel requires both moisture and oxygen to corrode, the coating must create a thin, moisture-impermeable film so that air and water

cannot reach the steel substrate. This is what is meant by "barrier" protection. Some (zinc-rich) coatings also provide "sacrificial" protection. This is an electrochemical phenomenon that protects the base metal at the expense of the coating metal.



*Advances in metallic coatings have expanded the applications of steel for roofing.*

### The Continuous Hot-dip Process

These coatings are normally applied to the steel coil at the producing mill using a process called "continuous hot dip." The steel is first meticulously but automatically cleaned, degreased, rinsed, and forced-air dried. It is also "pickled" in an acid bath and preheated. At this point of the process, the mechanical properties of the material can be affected, if desired, by exacting control of the heating and cooling process. Finally, the coil is

passed through a bath of molten metal at temperatures that provide for a metallurgical bond between base steel and coating metal. The exact temperature (800-1100 F degrees) varies with the coating type, since the coating materials have differing melting temperatures. The metallurgical bond between coating and base steel substrate causes monolithic behavior of the material during fabrication and service.

The coating thickness is controlled in most mills with "air knives" – sophisticated pneumatic squeegees that interface with the surface of the coil as it emerges from the bath of molten metal. The material is cooled (and coating solidifies) upon exit from the bath and entrance to the cooling tower. This process is also closely controlled to affect varying surface appearance characteristics. It is during this process that the "spangle" of zinc-rich coatings

is sometimes altered (minimized). Finally, the material is water quenched, dried, and re-coiled at the end of the line.

Most often just prior to re-coiling, a chemical, passivation, or oil treatment (or combinations thereof) is applied to extend



*Coatings are applied in a continuous hot-dip line at the producing mill.*

the shelf life of the material, prevent storage staining, or to prepare it for the next step of production – either painting or fabrication, as the case may be. When oils are used, they are sometimes water-soluble oils that help to lubricate during the roll forming process, and evaporate soon afterwards.

The continuous hot-dip process takes place at line speeds of about 800 linear feet per minute, which can translate to as much as 4,800 square feet per minute, making it a very cost effective method to apply metallic coatings.

## Zinc Coatings

Perhaps the best-known coating for carbon steel sheet is commercially pure zinc, commonly known as galvanized. (It bears mentioning that galvanized iron or G.I., although commonly designated on architectural plans, is a product that has been obsolete for decades.)

Common coating application rates for galvanized steel are .30, .60, and .90 ounces per square foot, designated as G-30, G-60, and G-90. Long ago, the target application rate for G-90 was 1.25 ounces, with .90 serving as the minimum requirement. Sophistication of modern application equipment has enabled producers to hold much more uniform application thickness, so the target rate of 1.25 ounces has gone by the wayside. Target application weight now is much closer to the minimum and verified by testing using either a single spot or triple spot sample, according to ASTM procedures.



*As metal comes out of the zinc pot on the way to the cooling tower, the coating thickness is regulated by air knives or "pneumatic squeegees."*

a single side is approximately .75 mil. Due to coating process tolerances, however, industry standards allow that the minimum on any one side can be as low as 40 percent of the total, so the thickness on one side could be as low as .60 mil. (The paper on which this print appears is 3.25 mils in thickness.)

Due to the slim coating thickness, zinc and zinc-alloy coatings also rely upon the unique ability of zinc's "galvanic protection" at scratches and cut edges. In the presence of electrolyte (water), zinc's active, anodic behavior retards oxidation of the steel substrate. For the same reason, zinc bars are attached to steel-hull ships and often inserted into domestic hot-water tanks – to retard the corrosion of the steel. Zinc coating is preferred by some manufacturers because of its excellent flexibility

(malleability) in fabrication, especially when sharp radius bends are required in the fabricated product. Another advantage of galvanized steel is that it is solderable.

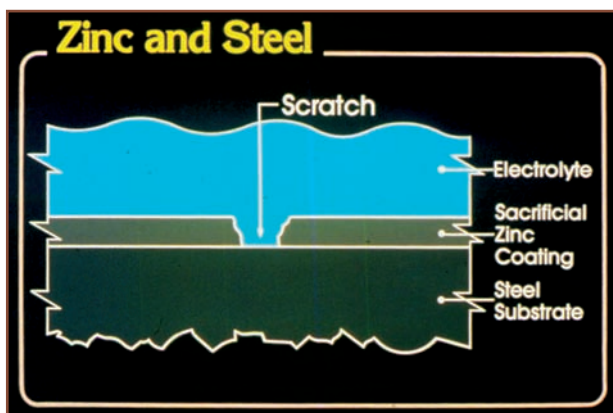
Although technically any coating (including zinc) offers *barrier* protection, zinc is generally referred to as a "sacrificial" coating because its electrolytic behavior is somewhat unique. By design, the coating goes away over time, sacrificing itself to retard corrosion of the steel. Its life, then, is directly proportional to its thickness and the elements to which it is exposed. This "galvanic" activity is a desirable characteristic with respect to the corrosive behavior of steel, especially at surface scratches and cut edges, where the base steel will be exposed and unprotected by a "barrier."

In unpainted applications, galvanized has become outdated. It has been replaced by newer technology coatings that significantly out-perform it in such applications. It is still considered an acceptable coating and is preferred by many when a premium organic finish (paint) is used. Although the paint is not impervious to moisture, it retards the galvanic process, prolonging the life of the galvanized substrate. Because the galvanic process is retarded, however, the corrosion performance at scratches, cut edges, and severe outside radius bends is somewhat diminished.

Galvanized steel is produced by many mills and is widely available. It is not typically warranted by the producing mills for corrosion performance. Because of galvanic behavior and the natural

oxidation process, the zinc diminishes over time. When a substantial volume is gone, the base steel is exposed, and the corrosion protection – barrier or sacrificial – is no longer afforded.

This service life is widely varied in different environments. Because the galvanic process occurs only when an electrolyte is present (when the surface is wet), galvanized steel does much better in dry climates and at steeper



It is important that users understand zinc application coating rates because they have a direct impact on the roof's performance and longevity. For example, with other factors being equal, G-30 will have a third the life of G-90; consequently, it is not used for exterior claddings. G-60 is used only in cost-cutting applications and G-90 is the common choice for steel roofing in pre-painted applications.

The total coating thickness of both sides of G-90 is 1.51 mils. This means that at the target application rate, coating thickness on



*Performance of (G-90) in a semi-arid climate is shown by this 40-year-old roof.*

slopes that keep surface moisture well drained. Hence, the *duration* of wetness on the panels' surface has more to do with service life than rainfall intensity or frequency.

In dry, desert-like climates where roofs seldom dew at night, bare G-90 that is 50 or 60 years old and still doing well is not unheard of. In more humid climates, this will not be so because roofs reach dew point almost every night, so the roof is wet for a third of its life even before the first raindrop hits.

The aggression of the moisture also has much to do with the life of galvanized material. In salt spray or acid-rain environments, the life will be drastically reduced. This is because such contaminants make for a much more effective electrolyte, accelerating the galvanic process. Once the coating is depleted, the steel roof need not be replaced, but it is a good candidate for a field-applied coating to extend its useful life. No known field-applied coating, however, will have the same life expectancy as the original metallic coating.

Zinc coatings are typified by a broad "spangle." This is the metal flake appearance in the finish of the coating. It is actually caused by trace lead or antimony content. The size of the spangle can be controlled or eliminated altogether by the producing mill. In general, minimized spangle is preferred when the material is to be painted.

Spec references for galvanized include: Federal Spec QQS-775d; ASTM A 924, General Requirements for Steel Sheet Metallic Coated by the Hot-Dip Process, which was formerly ASTM A 525; and ASTM A 653, which was formerly A 526, 527, or 446, and is used with the number followed by steel grade – e.g., "A653 Structural Quality Grade 50."

The same ASTM references are also used for Galvannealed, a product that is a special zinc-iron alloy coating. Other zinc coating treatments, sometimes tailored to specific field painting applications, are known by their various trade names.

## Aluminum Coating

The application of commercially pure aluminum to steel sheet is a process developed by Armco Steel Inc. It is known by the trade names "Aluminized Type I" or "Aluminized Type II." Type I is not typically used in the exterior claddings industry. Type II is commonly used in coating weight of .65 ounce, resulting in a mil thickness of 2.43 (total both sides). Note that although the coating weight is less than zinc (G-90), the resulting thickness is significantly greater due to the light weight of aluminum. It is also available in other coating weights.

Aluminum coating is a "barrier-type" protection as opposed to the sacrificial nature of zinc. Aluminum oxides are extremely durable, and the .65-ounce coating application, which is designated T2-65, carries a limited 20-year warranty against panel perforation due to normal atmospheric corrosion. This is a limited, material-only warranty underwritten by the mill and normally "flows through" the panel fabrication process and is passed on to the end user when specifically requested. Twenty-year exposure testing of the product has shown that in most environments it will far outlive and even double the warranted life.

Although Aluminized does not have the sacrificial protection of zinc, scratch and cut edge performance are still reasonably good. Corrosion seems to progress very slowly from such areas, presumably because of the durability of the aluminum oxides. It is used in both painted and unpainted applications. Aluminum coating is more brittle than zinc; hence restrictions on sharp bends in fabrication are more stringent. It is applied by the same hot-dip process but at a bit higher temperatures.

Having a "matte" finish without spangle, Aluminized is a good choice for bare applications, or the material can be pre-painted. It will generally outperform most other popular coatings in salt or acid environments, although its warranty may exclude a 20-year performance

in those situations. Aluminized material has decreased in relative market share in the last two decades, since it has not been as actively and aggressively marketed as other coatings. It is still quite popular in the automotive industry.

Aluminum does not react well with strong alkalis or graphite, so use caution when cementitious mortars are present, and do not mark the material with pencil.

Spec references include: Federal Spec. S-4174 B; ASTM A 463, Sheet Steel, Aluminum Coated (Type 1 and Type II); and ASTM A 463, Test Method for Coating Weight, Aluminum Coated.

## Galvalume™

Although several Aluminum/Zinc (AlZn) formulations are used worldwide, the most popular AlZn alloy coating used domestically is known by its trademarked name, "Galvalume." This alloy is 55 percent aluminum, 43.4 percent zinc, and 1.6 percent silicon (by weight). Measured by volume, the coating is about 80 percent aluminum. Developed by Bethlehem Steel, it was made commercially available in the late 1960s. It has since been licensed by BIEC International Inc. (formerly Bethlehem International Engineering Corporation) to 42 producers worldwide, seven of which are North



*Newer generation metallic coatings have led metal roofing into very low-slope applications, competing with traditional "flat roof" alternatives.*



*Cosmetic surface stains that detract from the appearance of unpainted Galvalume in steep applications can be minimized by using Acralume or Galvalume Plus.*

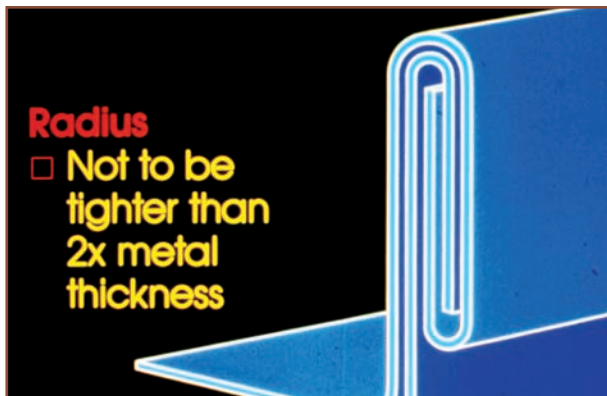
American companies – one Canadian, two Mexican, and four U.S. It is much more popular in the U.S. and in the Far East and Pacific Rim than elsewhere. It is known by various trade names, including Zinalume, Zintro-alum, and Galval.

The coating blends the barrier protection of aluminum and its oxide durability with the sacrificial properties of zinc. This results in a synergistic alloy that has superior weathering properties when compared to galvanized, yet maintains the “galvanic” corrosion protection of zinc at scratches, cut edges, and severe radius bends.

Galvalume is used in various application weights, including .50, .55, and .60 oz. per square foot (total both sides). These weights are designated AZ50, AZ55, and AZ60, respectively. The AZ55 coating is the most widely used and is warranted by most domestic producers for 20 years. Its thickness (both sides) is 1.76 mils. The warranty is generally an assurance that the panel will not perforate (in a “normal” environment) due to corrosion.

Once again, field studies of coating loss over 20 years’ or more exposure indicate that in friendly environments, the coating will double or even triple its warranted life. For this reason, some domestic producers are now extending the warranty on AZ55 and painted AZ50 to 25 years.

Galvalume is the undisputed leader of coated steel options in unpainted applications and at very low slopes (1/4:12 minimum as dictated by the warranty). It is also gaining popularity as a painted



*Galvalume® material warranties have certain exclusions. One is exposure to salt spray. Another is inadequate slope. Adequate slope is 1/4:12 or greater. The material must also be formed without sharp bend lines. The minimum radius is 2T, or two times the material's thickness. A sharper bend may result in excessive "thinning" or microfracturing of the coating.*

substrate and now accounts for almost 50 percent of such applications. Because paint retards the galvanic process, its performance at scratches and cut edges will not be as good on painted applications as on unpainted applications.

While Galvalume inherits the strengths of both its alloy metals, it also inherits their respective weaknesses. Contact with both acids and alkalis should be avoided.

Galvalume has a tendency to retain cosmetic stains such as footprints, handprints, etc. For this reason, some producers offer a thin application (about .3 mils) of acrylic coating to afford temporary stain protection during handling and installation. The coating weathers away in a few years. This option, dubbed “Acrylume” or “Galvalume Plus,” depending upon the producer, is used only for unpainted applications and is becoming more popular domestically.



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It has been used in Western Europe for quite some time.

Spec references include: Federal Spec. Army CEGS-07413; Army CEGS-07415; Army CEGS-13120; Navy NFGS-13121; and ASTM A 924, General Requirements for Steel Sheet Metallic Coated by the Hot-dip Process; and ASTM A 792, Sheet Steel, Aluminum-zinc Coated (Galvalume).



*Exhaust flues that discharge gases from burning fossil fuels can cause a micro-acid rain environment near the flue.*

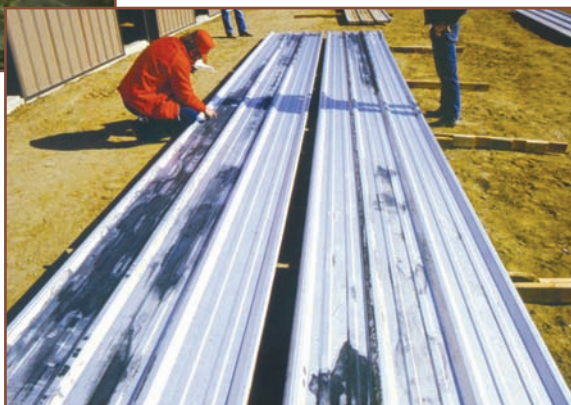
### Other Coatings for Steel

Other coatings for steel include “Galfan,” which is about 95 percent zinc by volume – almost reciprocal of Galvalume; and terne, which is a solderable tin-lead alloy used over special copper-



*Alkali in the mortar from this stucco wall (far left) induced corrosion of the Galvalume. The black stain is accelerated oxidation of the aluminum.*

*Improper storage and/or transit of Galvalume panels (right) can result in damage from trapped moisture.*



*Below: The best practice is to choose specialty preformed equipment curbs of all welded aluminum construction with diverters at their uphill side.*



bearing steel in thin gauges. Terne has been around for more than a century. Its advantages are the cost efficiency of steel combined with the ductility of softer metals, as well as solderability.

Both these metals are only used in painted applications. Galfan is always pre-painted, and terne is most often post-painted using special paint, although it can be pre-painted by coil coating. Post-painted terne will require repainting at about 6- to 8-year intervals. Newer terne coatings (“Terne II” by trade name) are tin-zinc, rather than tin-lead alloys.

### Limitations of Coated Steel Products

Precautionary measures when using metallic coated steel are primarily chemical and metallurgical. Contact of these coatings with strong acids should be avoided. Heavy discharge of sulfurous and nitrous oxides from flues and the like will shorten coating life adjacent to those areas. When using aluminum or aluminum alloy, strong alkalis are also detrimental to the aluminum. For this reason, use of these products with wet cementitious mortars such as reglet flashings is precluded, unless the metallic coating is first protected with a good, heavy coat of spray or brush-applied clear coating such as acrylic to protect it until the mortar cures. When work adjacent to Galvalume, Aluminized, or aluminum involves cement mortar, the trades should be sequenced such that the masonry trades are complete prior to placement of metal panels. Cured mortar poses no threat.

There are also some mechanical precautions to be observed. Warranties on Galvalume will usually specify a minimum bend radius of “2T” in fabricated shapes. This means that the radius of a bend must be at least double the thickness of the metal. This is because the material is stretched into tension on the outside of the radius and may develop microfractures if such a minimum is not observed. G-90 is a little more flexible and will tolerate a tighter radius. Aluminized (and aluminum sheet) are less tolerant yet and may require even greater bend radii. In most cases, the tooling of roll-forming equipment anticipates these limitations, so there is no need for concern. There are exceptions, however. Sometimes panels or related flashings are brake-formed. Often common leaf-brakes will violate the minimum bend restrictions of some coated steel products. The result may be premature corrosion at tension bend lines.

## Weldability

Contrary to many industry claims, the simple truth is that coated steel cannot be welded. *Steel* can be welded. Coated steel cannot. When coated steel is welded in some fabrication or manufacturing process, the first step is to completely remove all coating from the area to be welded. Having done that, it is no longer coated steel but bare steel, and the integrity of the metallic coating cannot be restored.



*This Galvalume curb (left) was shop welded, resulting in traces of red rust at the vertical edge of the curb after just one year.*

The weld must be protected from corrosion, however, and so the fabricator often utilizes a brush-applied, air-dried paint of sorts (sometimes with zinc or aluminum particulate) for the needed corrosion protection. This secondary applied coating cannot hope to have the life or maintenance freedom of the original hot-dip metallic coating. It is this writer's opinion that the specification of such a process is a disservice to the end customer, who thinks he is buying a maintenance-free, hot-dip coated steel roof system.

## Compatibility Issues

Zinc and aluminum are both anodic metals and should be isolated from electrolytic contact with more noble or

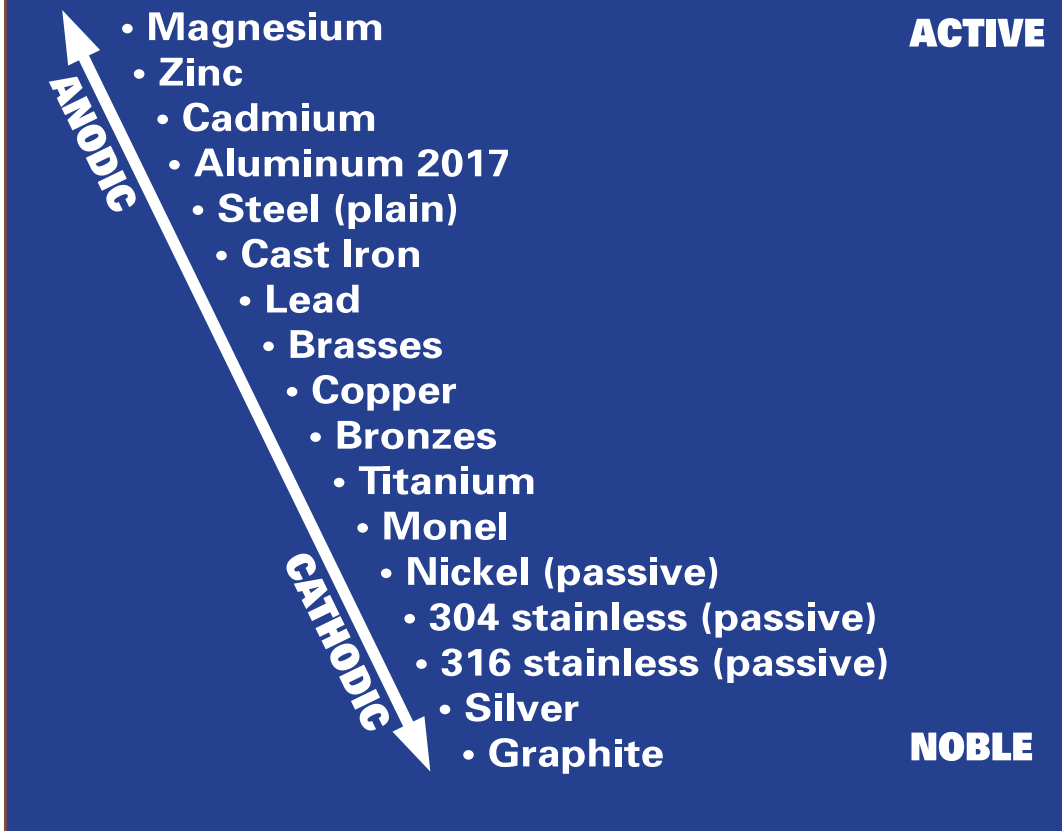


*Dripping from a rooftop unit can cause corrosion as shown on this 1-1/2-year-old roof. In another year and a half, the white zinc oxide trails will turn red with iron oxide.*



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# Galvanic Series



use a felt-tip marker for layout lines and so forth.

A “galvanic scale” can be used as a tool for determining dissimilar metals, and the same is included in many reference materials. However, the user should be aware that this scale does not tell the whole truth. Do not conclude that galvanic corrosion is eminent on the basis of the scale alone. For instance, lead is distant (cathodic) from zinc (anodic) on the scale, but zinc is soldered with lead alloy solder with no adverse effects whatsoever. Nickel steel is distant from both zinc and aluminum, but stainless fasteners are not only used, but also preferred for these metals. Aluminum nails can be used in galvanized steel, but the reciprocal presents a problem.

Metals compatibility is more complex than a quick look at the galvanic scale. Although Galvalume producers have always warned to avoid contact with lead flashings, in practice this writer has never seen lead flashing adversely affect Galvalume. The best practice is to ask

cathodic metals, most notably copper. For the contractor, this means that copper flashings should not be used anywhere upstream or in electrolytic contact with the coated steel. Additionally, any rooftop equipment involving copper lines that will drip condensate or rainwater run-off onto the roof should be avoided at any cost.

Runoff from copper contains copper salts and will cause rapid galvanic corrosion of any of these coatings. It is not unusual to see a trail of red rust downslope of a roof-mounted air conditioner after a few years of service. Copper lines should be jacketed with insulation to prevent electrolytic run-off. Alternatively, the run-off can be collected in a condensate pan and directed to drains by PVC piping, isolating it from the roof panels.

Another common mistake is the use of graphite pencil to mark aluminum, Aluminized, or Galvalume coated steel. Graphite has a severe corrosive effect on aluminum and will cause etching of the surface. In the case of coated steel and a wet climate, heavy pencil marks can display trace red rust in as little as one year. Instead,

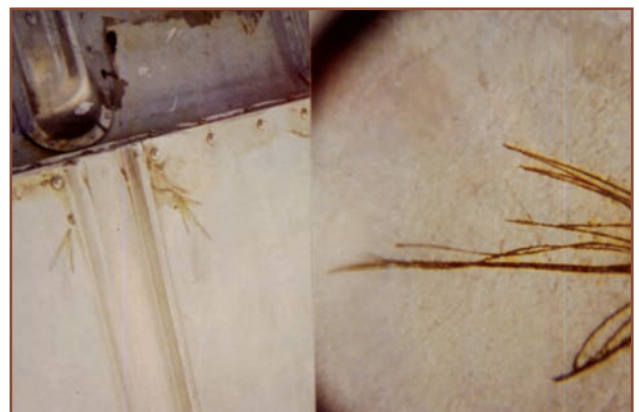


*A heavy graphite pencil mark turns to white rust from zinc oxide after one-year exposure in southern Florida.*

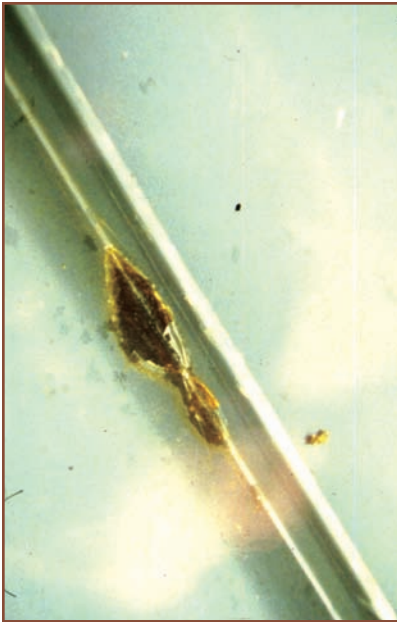
more questions if metals are found to be distant on the scale. Although coated steel panels are a popular choice for coastal applications, users should be aware that salt spray has a detrimental effect on all these coatings, and they will not yield the kind of life mentioned earlier.

## Adequate Drainage

None of these coatings will tolerate moisture that is trapped against their surfaces for prolonged periods of time. Zinc is



*Markings from a punch listing by installer are beginning to show traces of red rust (enlarged view from left).*



*This view down into a seam area shows corrosion that began on the inside and worked its way out, or "inside out corrosion."*

markedly less tolerant of this than aluminum, but they all like to be freely drained and able to air dry readily. Warranties will typically exclude sub-surface corrosion resulting from this latter condition. Topside corrosion can also be induced from the same phenomena where water ponds on the panel or where leaves, pine straw, or other debris retain moisture on the surface of the coating. Periodic inspection and routine cleaning if necessary will go a long way toward preventing such induced coating corrosion.

Coated steel is the most widely used of all metals for roof coverings in the U.S., by a ratio of

about ten to one. These options have excellent strength-to-weight ratio, good formability and paintability characteristics, and are durable enough for engineered structural applications over open framing. Other factors being equal, they can offer superior wind uplift performance due to their strong mechanical properties. In many environments, they can have a service life of four decades or more, and are a cost compelling choice as well. ■

***The topic of applied paint finishes for steel and aluminum panels will be covered in the next of this multi-part series.***

## ABOUT THE AUTHOR

**Rob Haddock**, director of the Metal Roof Advisory Group Ltd., is a well-known expert and educator in the field of metal roofing technologies. He is an international metal roofing consultant and innovator, holding numerous U.S and foreign patents. He is a contributing editor for several trade publications, a member of the National Roofing Contractors Association, ASTM, the Metal Building Contractors and Erectors Association, and the Metal Construction Association. He is also a course author and presenter for RCI, NRCA, and the University of Wisconsin School of Engineering. Haddock is a past recipient of RCI's prestigious Horowitz Award for contributions to *Interface* journal.



**ROB HADDOCK**