WHITE PAPER

Part 1: Metal Roofing from A (Aluminum) to Z (Zinc)

History and Materials

The roots and technology of metal as a cladding material date back to Biblical times. It has always been coveted as a premium roofing option but, historically, has been handicapped by a generally higher initial cost than many other options. Today's trends point toward evaluating the long-term costs of owning a roof as more landfills are overburdened with former building components that were discarded because of shortsighted budget-conscious building objectives. The life-cycle costs and environmental appeal of metal truly have some advantages.

▲ A lead roof was chosen for this cathedral in Köln (Cologne), Germany. The cathedral was built in the 13th century.

As metal roofing gains popularity and is specified for more projects, inevitably more failures will occur because of misuse or some perception that metal is magic and will do anything. While material failures are highly unusual, the common pitfalls are inappropriate product selection to suit job specifics and misapplication of the selected products.

Using metal roofing systems involves a good deal of science, so making uninformed design decisions about materials and systems is a bit like playing Russian roulette. Some knowledge and understanding of basic elements of system design, material selection and installation will certainly improve the odds for a successful roofing project and a satisfied (and dry) customer for many years to come while (hopefully) reducing gainful employment for a slew of trial lawyers.

Choosing Metal

One of the first issues to address is what sort of metal should be used. There are a number of choices available, including copper, terne, aluminum, stainless steel, carbon steel, zinc, lead and even titanium. All have pros and cons.

Some soft metals—copper, lead and terne-coated stainless—can have a life expectancy measured in centuries. They also carry a premium price tag and call for a high degree of fabrication and installation skill. I refer to these metals as "crafted roofing" metals. They are favored over coated steel in most of Western Europe. They are also favored here in the U.S. for high-end and historical applications. Their inorganic surface finishes and oxidation characteristics give them timeless beauty and maintenance freedom not enjoyed by organic finishes (painted metals), and they are easily solderable.

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Zinc

Titanium zinc, the soft, gray metal that enjoys immense popularity in Germany and other European nations, is also increasing in popularity here. It is a crafted metal and available in different surface finishes, including pre-weathered. Popular thicknesses are 0.7 mm and 0.8 mm.

Zinc requires some special considerations in fabrication to avoid fracturing of the finished product, as well as care in detailing and underlayment, because the material has a low tolerance for subsurface moisture. Zinc is also easily soldered, but be careful—its melting temperature is much lower than other solderable metals. With appropriate precautions, zinc can have an expected life of nearly a century. ASTM B69 “architectural rolled zinc” is the specification reference for zinc sheet.

Terne

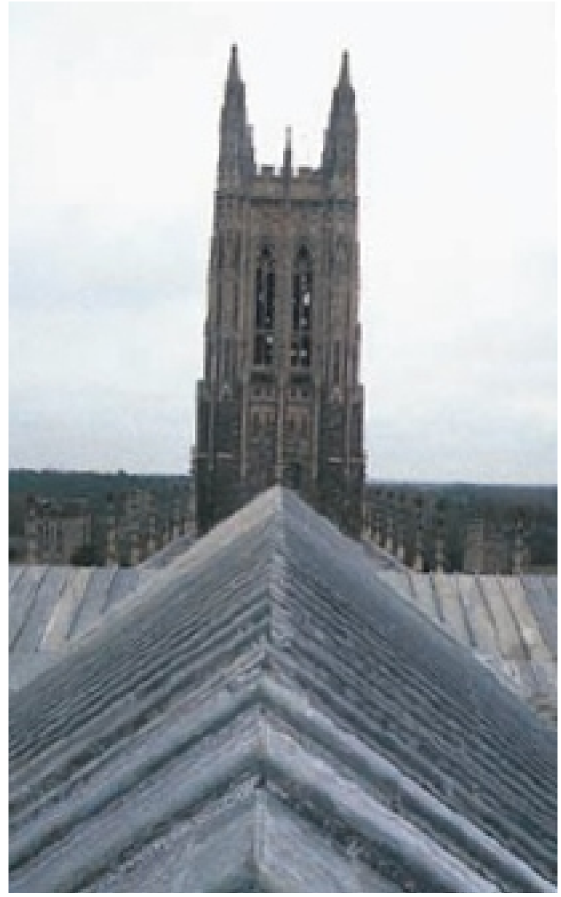
Terne has a life expectancy greater than many other options and a moderate cost, but it requires repeated maintenance (painting). Many early 20th century terne roofs can still be seen all over the eastern U.S. Use of this tin-lead alloy coated steel is responsible for the popular misnomer, “tin roof.”

Terne-coated stainless requires no maintenance and is a solderable material, but it bears a very hefty pricetag as does zinc, lead, titanium and lead-coated copper.

Terne is most commonly used in 28 and 30 gauge, while 26 and 28 gauge are most common for terne-coated stainless. Terne falls under the carbon steel classification of ASTM 625; terne-coated stainless is ASTM A240. There are no federal specification numbers for either of these metals.

Lead

Lead is one of the longest-lasting metals known to man and has been used for more than a millennium on some of the most elegant castles and cathedrals throughout Europe. It may well outlast any other roof type, metallic or not, even in a salt-spray



▲Lead-coated copper, one of the longest lasting metals, covers the roof of the chapel at Duke University.

▲Greater detail and weather integrity can be accomplished with soft-crafted metals as shown on the Kronborg Castle in Denmark.

environment. But lead has a very high thermal coefficient and significant weight, so it must be appropriately designed. The most popular lead applications are "batten-roll" profiles using gentle, radiused folds and joints. Lead has many unique qualities and installation methods. "Lead burning" is practiced by fewer mechanics. Because of these facts, lead's high cost and the bad rap it is receiving from environmental protagonists, the application of sheet lead is becoming a lost art in North America. It's a pity. Metals like terne, copper and stainless, which have typically offered lead or lead alloy coatings, are now using other alloys like tin-zinc to have more "politically correct" public appeal.

Copper

Architectural copper is specified as ASTM B370 and lead-coated copper is ASTM B101. Copper is designated by the ounce-weight, or the weight of 1 square foot of copper in ounces. A 12- by 12-inch piece of copper may weigh 12 to 48 ounces, depending on its thickness. The most common roofing sheet is 16 or 20 ounce; 16-ounce is 0.0216 inches in theoretical thickness while 24 ounce would be 0.0323 thick.

Titanium

Titanium is an option that has recently found its way onto the roofing materials list through its use on the high-profile Guggenheim Museum in Bilbao, Spain. It is unique in appearance; has an inorganic finish; features a thermal coefficient even lower than steel; and offers incredible strength, durability and corrosion resistance. It also has an elite price tag above other metals and only one domestic producer, but it will almost certainly grow in use as more designers learn of its benefits.

The reference number for architectural titanium is ASTM B265 and the most commonly used size is 28 gauge in 4-foot widths. It is also available in coils and custom lengths.

▲The Dome of the Rock, finished in 691 following the Arabian conquest of Jerusalem, is believed to have originally donned a gold roof. It is now gold-leafed aluminum.

Aluminum

High-tensile aluminum is more affordable as a base metal. It also offers some structural capabilities, but has an extremely high coefficient of expansion, which causes a great deal of thermal movement. Still, this material is a cost-effective alternative for salt-spray coastal environments, as well as acid-rain environments where the longevity of coated-steel alternatives may be a bit lacking and budgets do not allow lead or lead-coated alternatives.

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Although it is preferred for salt-spray and acid-rain environments, the detailing must provide for increased thermal movement, and fabrication methods must allow for its more brittle behavior. Aluminum is easily painted by modern coil-coating methods; organic color finishes can be provided at moderate added cost. Another benefit of this metal is that its installation practices are generally consistent with those of coated-steel products; therefore, the availability of installation contractors is widespread.

Aluminum is specified as ASTM B209. The most common thickness for roofing is 0.032 inches with 0.040 inches running a close second. The most common sheet alloys are 3004 and 3105, and the tempers for these alloys are 3105–H14 and 3004–H36.

Steel

Of all the available base metals, steel is the lowest cost and has excellent structural characteristics. Because steel rusts, a protective coating must be selected. Coated carbon steel is the most common choice for metal roofing in North America, primarily for economic reasons. It is only logical, then, that significant development and improvements for metallic coatings used on carbon steel have originated here in the U.S.

This does not imply that other materials do not have their place. In fact, when asked "What is the best roof on the market today?" my response is, "Lead, lead-coated copper or titanium on a 12:12 slope." This response is not often debated in terms of accuracy but often frustrates the inquisitor because such slopes are rather uncommon and few budgets permit the use of these materials.

Because steel dominates the U.S. market at ratios of about ten to one, let's focus on the alternatives available when using steel, such as gauge, coating type and coating weight.

The most common gauge thickness used in the commercial roofing market-place is clearly 24, although 26 is used on rare occasions. Because stringent wind test standards (such as ASTM E1592, and the new FM 4471) emerged following Hurricane Andrew and others, we also see more 22-gauge material being used. (The lower the gauge number, the thicker the material: 22 gauge is 0.030 inches minimum in thickness, 24 gauge is 0.024 inches and 26 gauge is 0.018 inches minimum.)

Many contractors and designers believe that, increasing, the thickness will alleviate the problem of "oil canning," which is a rippling effect in the panel surface caused by stress. It is most pronounced in very flat panels with wider covering dimensions. The stresses that produce oil canning are caused by a number of factors of which few, if any, have to do with the thickness of the metal. Hence, increasing thickness adds significant cost but may not eliminate the problem. A more cost-effective approach to resolving the potential for oil canning involves:

- Reducing panel width
- Working with a reputable manufacturer
- Using well-tuned roll forming equipment
- Using a panel profile with stiffening flutes in the flat area, if not objectionable
- Insisting on tension-leveled coil stock with close camber and flat-ness tolerances
- Ensuring there is adequate provision for thermal movement within the system's design and installation
- Being sure the structure and/or deck is smooth and true-to-line

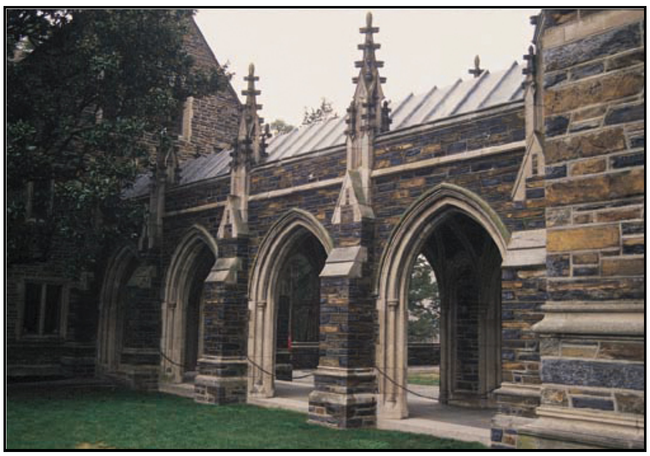
Of all the available base metals, steel is the lowest cost and has excellent structural characteristics.

Another little trick that can be used in architectural installations over a wood deck is to install a strip of backer rod between the deck and panel to cause the "flat" of the panel to arch slightly between seams. See the MCA Tech Bulletin

▲The Roskilde Cathedral in central Denmark date back to 1170 and features a lead roof.

(www.MetalConstruction.org) for more on this subject.

Other specified variables in steel procurement involve tensile, yield strength, coating type and weight. The mechanical properties relate more to the manufacturing process than end use, so they are often considerations with which the contractor, designer or specifier need not be concerned.



▲A copper roof tops the Kronborg Castle in Helsingør (Elsinore) Denmark (above, top), which was built in the 1500s and was the setting for Shakespeare's *Hamlet*. This LCC batten roll roof on the chapel of Duke University (above) was installed in the late 1930s. The craft of metal roofing was brought to North America through such European artisans as Paul Revere.

Coating type and weight, however, are rather important decisions, which should be understood by the contractor or specifier. This refers to metallic coating of steel coil, not paint coatings. All steel coil used in exterior applications is coated with a metallic coating to protect it from corrosion. These coatings are all applied by the continuous hot-dip method and are metallurgically bonded to the base steel. Within the domestic market, there are three distinctive options for coating types: zinc, aluminum and alloys of the two. Within these types, there are also options concerning the rate of application of the coating, designated by weight per square foot (total of both sides). These application rates also result in different thicknesses of coatings.

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Photos courtesy of Metal Roof Advisory Group, Ltd., Colorado Springs, CO, unless otherwise noted.

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Part 2: Metal Roofing from A (Aluminum) to Z (Zinc)

Metallic Coatings for Carbon Steel

Carbon steel sheet is a popular domestic choice for metal roofing, primarily for economic reasons. However, carbon steel has corrosive characteristics, which means it must be protected by some other metallic coating that is less corrosive in behavior. Such a coating provides "barrier" protection for the steel. Because steel requires moisture and oxygen to corrode, the coating must create a thin, moisture-impermeable film so 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 for the use of steel in roofing (above). Coatings (right) are applied in a continuous hot-dip line at the producing mill.

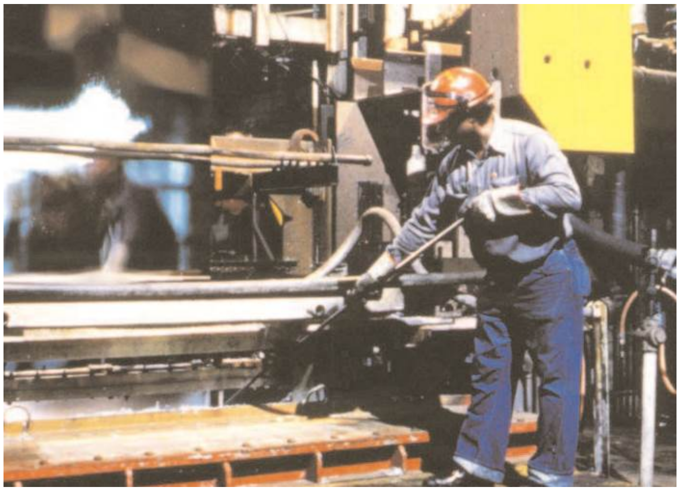
Continuous Hot-dip Process

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 forcibly 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 heating and cooling processes. 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 to 1,100°F) varies with the coating type because the 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 recoiled at the end of the line.

Most often just prior to recoiling, a chemical, passivation or oil treatment (or combinations of these) is applied to extend the shelf life of the material, prevent storage staining or to prepare it for the next step of production—painting or fabrication. When oils are used, they are sometimes water-soluble oils that help to lubricate during the rollforming process and evaporate soon after.

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



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

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 is worth mentioning here that galvanized iron, or G.I., though commonly designated on architectural plans, is a product that has been obsolete for decades.)

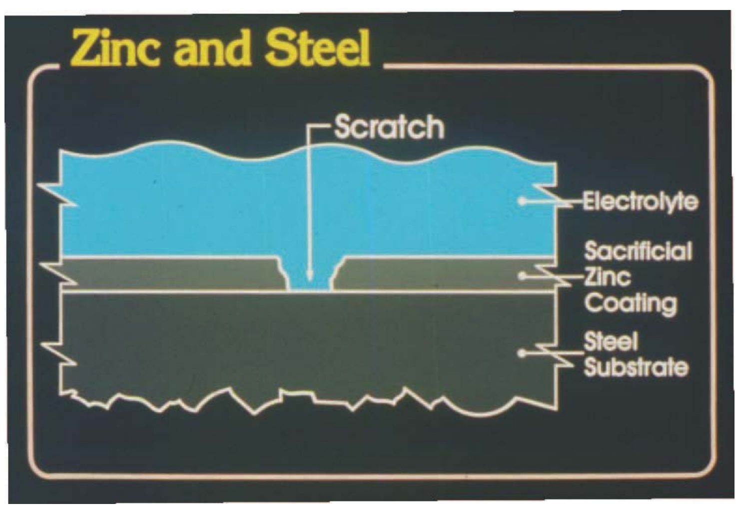
Common coating application rates for galvanized steel are 0.30, 0.60 and 0.90 ounces per square foot, designated as G-30, G-60 and G-90. Long ago, the target application rate for G-90 was 1.25 ounces with 0.90 serving as the minimum requirement. Sophistication of modern application equipment has enabled producers to hold much more consistent and 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 a single spot or triple spot sample according to ASTM procedures.

It is important users understand zinc application coating rates because they have a direct impact on the roof's performance and longevity.

It is important 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 one-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 a single side is about 0.75 mil. Because of coating process tolerances, however, industry standards allow that the minimum on one side can be as low as 40 percent of the total, so the thickness (on one side) could be as low as 0.60 mil.

Because of 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



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radius bends are required in the fabricated product. Another advantage of galvanized steel is that it is solderable.

Galvalume has become the undisputed lead of coated-steel options in unpainted applications and at very low slopes (1/4:12 minimum, as dictated by the warranty.)

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 corrosion 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 outperform it in such applications. It is still considered an acceptable coating and preferred by some 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.

▲Performance of G-90 in a semi-arid climate is demonstrated by this 40-year-old roof.

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 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, I have seen bare G-90 that is 50- or 60-years old and still doing well. In more humid climates, this will not be so because roofs reach dewpoint almost every night, so the roof is wet for one-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 by the producing mill. In general, minimized spangle is preferred when the material is to be painted.

Spec references for galvanized include the following: Federal Spec QQS-775d; ASTM A924, "General Requirements for Steel Sheet Metallic Coated by the Hot-Dip Process," which was formerly ASTM A525; ASTM A653, which was formerly A526, 527 or 446 and is used with the number followed by steel grade, such as A653, Structural Quality Grade 50.

The same ASTM spec 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. many years ago. It is known by the trade names "Aluminized Type I" or "Aluminized Type II." Type I is used in the automotive industry but not in the exterior claddings industry. Type II is used in coating weight of 0.65 ounce (T-265), resulting with a mil thickness of 2.43 (total both sides). Although the coating weight is less than zinc (G-90), the resulting thickness is significantly greater because of the light weight of aluminum. It is also available in other coating weights.

Aluminum coating is a "barrier-type" protection and a better one than galvanized.

Although Aluminized does not have the sacrificial protection of zinc, scratch and cut edge performance is still reasonably good. Corrosion seems to progress very slowly from such areas, presumably because of the durability of the aluminum oxides that provide a protective layer.

Having a "matte" finish without spangle, Aluminized is a good choice for bare applications and will generally outperform many other popular coatings in salt or acid environments. However, the material has decreased in relative market share in the last three decades and is commercially available from only one domestic supplier. Check availability before specifying for roofing/cladding applications.

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

Spec references include Federal Spec. S-4174 B; ASTM A463, Sheet Steel, Aluminum Coated (Type 1 and Type II); and ASTM A754, "Test Method for Coating Weight, Aluminum Coated."

Steel can be welded. Coated steel cannot.

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 Corp.) to 56 producers worldwide, nine of which

▲Newer-generation metallic coatings have led metal roofing into very low-slope applications, which compete with traditional flat-roof alternatives.

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

are North American companies—one Canadian, one Mexican and seven U.S. It is much more popular in North America and in the Far East and Pacific Rim than it is elsewhere on the globe. It is also known by other trade names outside the U.S.

The coating blends the barrier protection of aluminum and its oxide durability with the sacrificial properties of zinc, resulting 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 0.50, 0.55 and 0.60 ounce per square foot (total both sides). These weights are designated AZ50, AZ55 and AZ60, respectively. The AZ55 coating is usually preferred in unpainted applications and warranted by most domestic producers for 25 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.

Field studies of actual performance for more than 30 years now indicate in friendly environments, the coating will almost triple its warranted life, hence the warranties offered by industry are a very conservative representation of its real expected service life.

Galvalume has become 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 substrate and now accounts for a majority share 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 strong acids and alkalis should be avoided. Animal waste and fertilizers can be particularly aggressive to this coating because of their ammonia con-tent even in a gaseous state, so it's use in animal confinements should be guarded. Hog and cattle waste is the worst; poultry waste, not as severe. When insulated and ventilated adequately, good vapor retarders may minimize the problem in this type of structure. On roofs that frequent pigeon and seagull exhaust, occasional power washing may be a prudent investment to prolong coating life.

Galvalume has a tendency to retain cosmetic stains, such as footprints, handprints, etc. Unlike galvanized, these stains are permanent and rarely weather away. For this reason, some producers offer a thin application (about 0.3 mil) of acrylic coating to afford temporary stain protection during handling

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

and installation. The acrylic also eliminates the need for surface lubrication and 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. 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; ASTM A924, "General Requirements for Steel Sheet Metallic Coated by the Hot-Dip Process;" and ASTM A792, "Sheet Steel, Aluminum-zinc Coated (GALVALUME)."

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-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.

These metals are only used in painted applications. Galfan is always prepainted and terne is most often post-painted using special paint though it can be prepainted by coil coating. Post-painted terne will require repainting at about six- to eight-year intervals. Newer terne coatings (Terne II by trade name) are tin-zinc rather than tin-lead alloys.

Copper flashings should not be used anywhere upstream or in electrolytic contact with the coated steel.

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

(Top) Improper storage and/or transit of Galvalume panels can result in damage from trapped moisture.
(Bottom) Alkali in the mortar from this stucco wall induced corrosion of the Galvalume. The black stain is accelerated oxidation of the aluminum.

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

(Top) Choose specialty preformed equipment curbs of all-welded aluminum construction with diverters at their uphill side.
(Bottom) This Galvalume curb was shop-welded, resulting in traces of red rust at the vertical edge of the curb after just one year.

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 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 micro-fractures if such a mini-mum were not observed. G-90 is a little more flexible and will tolerate a tighter radius. Aluminized (and aluminum sheet) are less tolerant and may require even greater bend radii. In most cases, the tooling of rollforming 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.

The weld must be protected from corrosion, however, 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 my opinion 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 anodic metals and should be isolated from electrolytic contact with more noble or cathodic metals, most notably copper. For the contractor, this means 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 runoff onto the roof should be avoided at any cost.

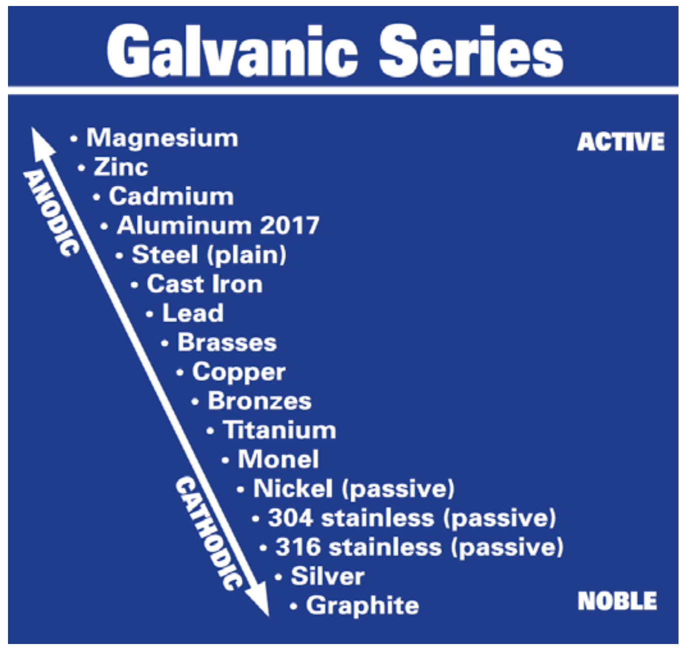
Drippage from a rooftop unit can cause corrosion as shown on this 1 ½-year-old roof. In another year and a half, the white zinc oxide trails will turn red with iron oxide.

Run-off 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 runoff. Alternatively, the run-off can be collected in a condensate pan and directed to drains by use of 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, 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 this scale does not tell the whole truth. Do not conclude that galvanic corrosion is imminent 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 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. For more on "Compatibility of Fasteners" for metal roofing, see the MCA Tech Bulletin (www.MetalConstruction.org).

Metals' compatibility is more complex than a quick look at the galvanic scale. The best practice is to ask 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 salt spray has a detrimental effect on all these coatings and they will not yield the kind of life mentioned earlier.

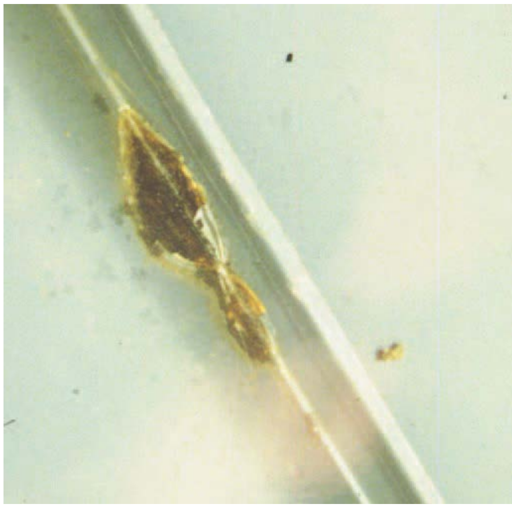


Adequate Drainage

None of these coatings will tolerate moisture that is trapped against their surface for prolonged periods of time. Zinc is 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 subsurface 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 avoidance of 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 because of 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.

Markings from a punch listing by the installer are beginning to show traces of red rust.



The view down into a seam area shows corrosion that began on the inside and worked its way out.

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

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BUILD LEGACIES METAL

Rob Haddock is president of the Colorado Springs, CO-based Metal Roof Advisory Group, Ltd. He is a consultant, technical writer, training curriculum author, inventor and educator. In 2012 he became a charter inductee of Modern Trade's "Metal Construction Hall of Fame" for his many contributions to the industry.

Photos courtesy of Metal Roof Advisory Group, Ltd., Colorado Springs, CO, unless otherwise noted.

Founded in 1983, the Metal Construction Association brings together the diverse metal construction industry for the purpose of expanding the use of all metals used in construction. MCA promotes the benefits of metal in construction through:

- Technical guidance
- Product certification
- Educational and awareness programs
- Advocating for the interests of our industry
- Recognition of industry-achievement awards
- Monitoring of industry issues, such as codes and standards
- Research to develop improved metal construction products
- Promotional and marketing support for the metal construction industry
- Publications to promote use of metal wall and roof products in construction

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BUILD LEGACIES METAL

WHITE PAPER

Part 3: Metal Roofing From A (Aluminum) to Z (Zinc)

Paint Finishes for Metal

A wide variety of paint systems are available for coated steel and aluminum roofing. In this writing, we will look at the basic coating processes and systems that represent the majority of pre-finished applications in metal claddings. In this writing, we will look at the basic coating processes and systems that represent the majority of pre-finished applications in metal claddings.

▲The Sycamore Trails Aquatic Center, Miamisburg, Ohio, features a Snap-Clad (Peterson Aluminum) roof in interstate blue with teal-colored trim.

What Is "Paint"?

In liquid form, paint is comprised of three principal ingredients: resin, pigment and solvent. Pigment and resin are blended in an approximate 50/50 ratio. (The darker the color, the lower the relative pigment content.) The pigment's purpose is to provide color and hiding of the primer and substrate. The resin forms the desired film and binds the coating to the substrate, providing the weather-resistance and durability properties desirable in an architectural coating.

Because pigment and resin materials are solids, they must be dispersed by blending with a solvent. The result is a liquid coating system that can be applied to the metal in coil form. (A solvent is not necessary for powder coatings, but the metal claddings market predominantly uses liquid coating-delivery systems.)

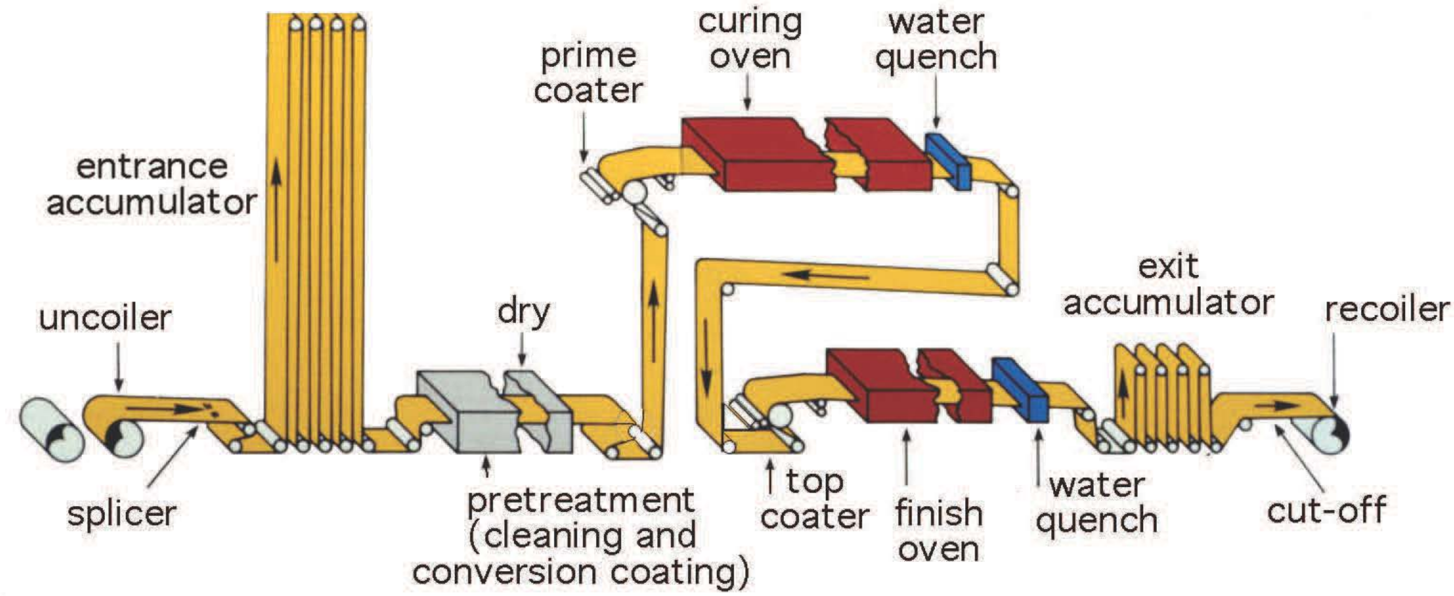
The solvent is therefore the vehicle by which the solids are transported to the panel surface. Although it is more than 50 percent of the volume of liquid paint, it evaporates during the curing process. The resin then becomes a monolithic film that acts as the "glue," holding the pigment particles to the substrate for years to come, surrounding and protecting them from environmental pollutants.

Objectives of Coil Coating

Continuous coil coating is the process used for factory finishing of aluminum and steel panels. Coated steel substrates discussed earlier in this series, including galvanized, Galvalume®, Aluminized and terne, can be coated by this method in a wide range of gauges.

The coil coating method can produce a superior paint finish under controlled conditions and at a relatively low cost per square foot. But the finish must also be durable and flexible enough to withstand the traumas of forming, fabrication, handling and installation. The applied finish must then meet the numerous demands of end use, including aging and weathering appearance criteria while also maintaining adhesion and durability over time.

While it is a common misconception that these type of paint films offer corrosion resistance, they



▲A modern coil coating line represents an investment of tens of millions of dollars and is capable of line speeds up to 800 feet per minute with 72-inch coil widths and material thickness up to 0.135 inch. *Image courtesy of Metal Roof Advisory Group, Ltd.*

may enhance the corrosion performance of the metallic coating when properly applied because they retard galvanic coating loss to some degree.

During coil coating, the flat metal is pulled through automatic processes that clean, chemically pretreat, prime coat, cure, finish coat, cure, cool and rewind—all in a continuous, self-contained, environmentally safe operation. Such automation, when compared to other coating methods, translates into lower costs to the end user. While line speeds can be as fast as 800 feet per minute, normal production speeds of 500 fpm for architectural coatings allow almost 5 square acres of metal to be painted each hour.

Because paint does not stick well to metal, the cleaning and pretreatment processes are critical. Pretreatment chemically alters the surface of the metal, making it more suitable for primer adhesion.

Popular pretreatments for galvanized steel are traditionally zinc phosphate and, more recently, complex oxides and dried-in-place treatments. Zinc phosphate is thought by most to be more effective as a corrosion inhibitor at cuts, scratches and severe

Cleaning, pretreatment and primer applications are the most important to ensure film adhesion and the corrosion protection of the metallic coating at scratches and cut edges.

bends, especially in aggressive environments. Pretreatments for Galvalume are chrome and dried-in-place treatments and, for aluminum, chromium chromate. The industry is experimenting with alternatives to some of these pretreatments because of the targeting of phosphates and chrome by environmental activists.

Primer application follows the pretreatment step. Historically, primers have been epoxy or epoxy-esters. Today, polyester, polyurethane and acrylic water-based primers are being used because they are more flexible and resistant to ultraviolet light. The target thickness of the primer is 0.25 mil and should range from 0.20 to 0.30 mil.

These first steps—cleaning, pretreatment and primer applications—are the most important to ensure film adhesion and the corrosion protection of the metallic coating at scratches and cut edges. Pretreatment makes the primer stick and the primer helps the topcoat stick. After oven curing and cooling of the primer, the topcoat is typically applied at a target thickness of 0.75 mil resulting with total dry-film thickness of both coats of 0.9 to 1.0 mil. This two-coat process is the standard of the commercial claddings industry and by far the most common system used in North America.

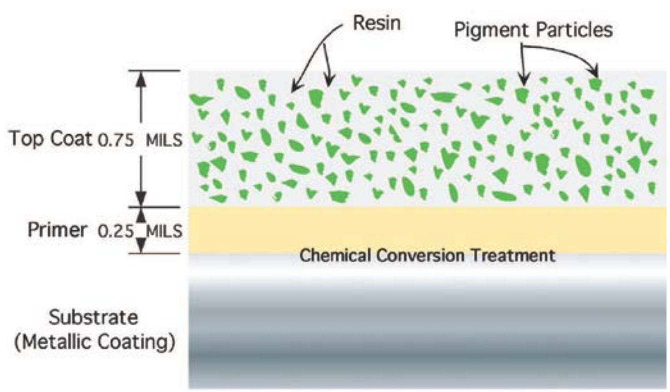
Some newer coating line technologies have also enabled the “printing” of variegated color patterns on metal. Print process incorporates the same types of coatings as standard coil coatings in a three- or four-coat system; however, the coating is applied via a print roll that is engraved with an image, such as a camo pattern, antiqued copper verdigris or wood grain, which is then transferred to the metal coil. Many coating lines will also apply color film laminates using high-performance adhesives.

Paint Resins

Paint is designated by its resin type. Many different coating systems are on the market, and they all offer different performance characteristics at widely varying costs. When we call paint "acrylic, epoxy, fluorocarbon, polyester” or “urethane," we are referring to the resin. Often resins are blended from several different materials.

The resin gives the finish its mechanical characteristics, and some resins are more flexible than others and will tolerate more severe bending during product fabrication. The resin also gives the film its gloss and gloss-retention characteristics, as well as resistance to abrasion, scratching and dirt accumulation. Many of these durability characteristics are the result of hardness, yet hardness also means reduced flexibility and so a delicate balance of the two is requisite.

Typical Two-Coat Paint System



▲Most popular architectural paint finishes are two-coat systems, resulting in a dry film thickness of about 1.0 mil. *Image courtesy of Metal Roof Advisory Group, Ltd., Colorado Springs, CO.*

Polyester resins have enjoyed widespread use due to the broad spectrum of colors available, their applicability to a wide variety of substrates, scratch resistance (hardness) and low cost. There was a time when polyester was considered "low-grade" paint, used primarily for soffit, signage, and industrial or agricultural applications. But polyesters are a broad group of chemical compounds that have diverse characteristics, and many developments within the paint industry have resulted in very resilient, durable polyester resins that can exhibit somewhat higher gloss levels than PVDF when desired.

Some of the newer formulations when blended with ceramic pigments can offer outstanding weathering properties—still not equal to PVDF coatings but much more impressive than thought possible 20 years ago.

Of course, low-grade polyesters are also still out there and when blended with organic pigments will have rather poor performance. Caution should be exercised when making the purchase decision: After a low-cost bright red roof fades to a medium pink in five years, it will be too late to pay the few extra pennies per square foot for a more serviceable product. In addition, severe fading can be non-uniform and very unsightly.

Silicone Polyester and Super Polyesters

Silicone-modified polyester (SMP) paint systems are a blend of polyester and silicone intermediates. Silicone acts to improve the gloss retention and weather resistance of polyester coatings. As a rule, the higher the silicone content, the better the performance of the paint. Originally, silicone contents ranged from 20 to 50 percent. Due to significant advances in polyester chemistry, however, these percentages are less of a controlling factor, and 50 percent SMP (once a premium resin) has not been marketed for many years. New chemistries outside the typical silicone modifications are also emerging that have very good weathering characteristics when compared with straight polyester. These new resins involve proprietary formulations and have been called "super polyesters."

For the contractor, the cost of an SMP or super polyester finish is in the range of 15 or 20 cents per square foot (a bit less for white). These formulations are available in a variety of gloss levels and will retain the gloss longer than polyesters. Some formulations come with up to 40-year warranties but don't be fooled. These warranties will typically specify lower performance levels than PVDF coatings.

PVDF

Fluoropolymers, known chemically as polyvinylidene fluoride or polyvinyl di-fluoride (PVDF or PVF_2) are the current state-of-the-art coatings. Dupont first began exploring the carbon-fluorine bond about 1948. PVDF resin was first developed and manufactured in 1962 and produced and process-patented by Pennsalt Chemicals (later Pennwalt Corp.). Beginning in 1965, it was marketed under the name Kynar® or Kynar 500®.

Elf Aquitaine subsequently bought Pennwalt, but in the process, the U.S. Federal Trade Commission required a breakup of this production and technology. At that time Ausimont USA Inc. purchased production rights in Thorofare, N.J., (one of two production facilities) and subsequently introduced Hylar 5000® to compete with Kynar 500. Kynar 500 is now produced and marketed by ATOFINA Chemicals Inc. (formerly Elf Atochem).

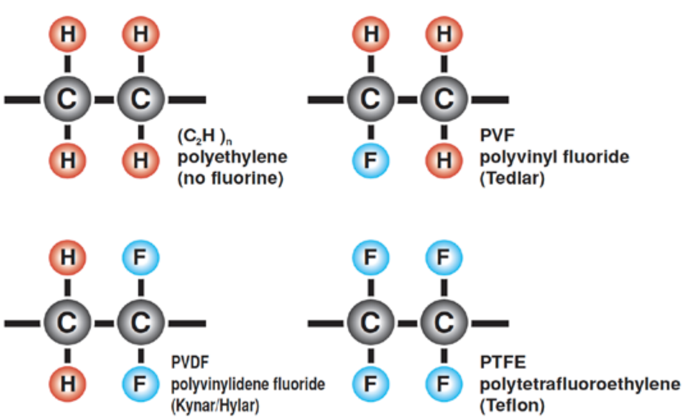
For practical purposes, the two products are in a generic sense alike. The key to Kynar/Hylar performance can be found in its basic chemical foundation: The carbon/fluorine bond is one of the strongest chemical bonds known. The resin's chemical formulation (PVDF) makes it similar in some respects to Teflon (PTFE), the popular nonstick coating for pots and pans. It is a slippery finish that enables most environmental pollutants to wash off in the rain. This is also why adhesives do not stick well to it. Paint using this resin is usually offered in a medium- or low-gloss finish with excellent weathering and color-stability characteristics. When formulated with the "full-strength" 70 percent PVDF resin content, these coatings are offered with 25-year or longer warranties featuring high levels of protection.

The two companies that produce these resins sell the resin powder (under license) to various paint companies who pin their own trade names on the resulting products. Twenty years ago there were six; today only three:

- Trinar® (Akzo Nobel)
- Duranar® (PPG Industries)
- Fluropon® (Valspar Corp.)

To confuse matters further, the paint is sold to panel manufacturers and coil suppliers who pin

Molecular Structure of Fluoropolymer



▲ This shows the molecular structure of fluoropolymer coatings, their respective trade names and a comparison to a polyethylene molecule. These polymers have similar properties derived from their atomic structure and fluorine bonds. *Image courtesy of Metal Roof Advisory Group, Ltd.*

their own trade names on products utilizing that paint type, for instance:

- Butler-Cote® FP 500 (Butler)
- PAC-CLAD® (Petersen Aluminum)
- Signature® 300 (MBCI)
- UnaClad™ (Firestone, formerly Copper Sales)

Contractors and designers can find this profusion of trade names very confusing when reviewing specifications.

Simply specifying Kynar/Hylar, fluorocarbon or PVDF will not ensure paint containing the "full strength" 70 percent formulation, but specifying "Kynar 500" or "Hylar 5000" will. The number designation ensures (by licensing arrangements) that paint containing 70 percent PVDF resin is provided. The remaining 30 percent of the resin is a proprietary acrylic, which varies from one supplier to the next.

PVDF is a thermoplastic. The powder particles are expanded by heat during the curing process, becoming plastic and forming a homogeneous film.

Standard PVDF is typically not available in bright, high-gloss colors because of the matte nature of the resin, and the natural colors of the ceramic pigments. However, it is still widely used in architectural applications and is more expensive for the contractor than SMP, usually 10 or 15 cents more per square foot.

Various PVDF systems are available, including two-, three-, and even four-coat types with varying dry film thicknesses. For specification purposes, two-coat PVDF is the industry standard. Over the years we have seen a direct relationship between coating performance and the 1-mil dry coating thickness of standard (two-coat) systems. A coating applied under spec will not perform as well as the 1-mil finish.

These facts are pertinent because of the higher relative cost of these films. Reduce the film thickness and the cost to the producer is significantly reduced. But at what cost to the material's performance? End users and specifiers should check film-thickness integrity to be sure they get what they pay for. More topcoat than 0.75 mil is also not necessarily better, although most agree that in a salt environment thicker prime coats can improve performance.

Specification References: The Short Version

Chalk
ASTM D-659 (Rating scale of 1-10; 10 is best)

Fade
ASTM D-2244 (NBS or ΔE Hunter units; 0 is no change)

Weathering
These specifications include many standards as measured by ASTM procedures enumerated in the chart titled "Specification References: The Rest of the Story." Acceptable levels of performance are inherently included.

AAMA 603.8, "Pigmented Organic Coatings" (conventional paints)
AAMA 605.2 (92), "High-Performance Organic Coatings" (premium finishes, includes minimums for chalk and fade)

Metallic Finishes

Much of the research and development in PVDF coatings has centered around the production of metallic finishes, such as Duranar XL (PPG), Fluropon Classic II (Valspar), and Tri-Escent II (Akzo Nobel). These finishes have a high-tech look with a deep luster and depth of color and the sheen and reflectivity of a natural metal.

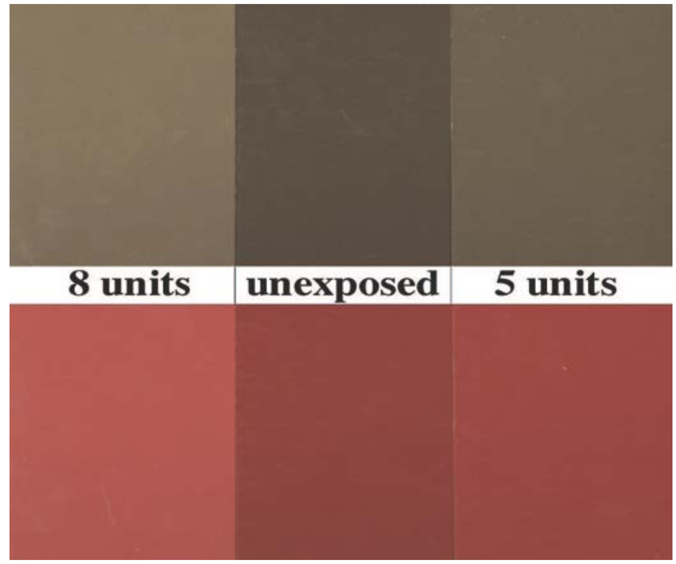
Traditionally metallics have been expensive because they consist of one and sometimes two extra coats. These finishes typically include a primer, a paint coat containing metal flakes (usually aluminum), and a clear PVDF topcoat that protects against ultraviolet light and oxidation of the metal flakes suspended in the coating. As you might expect, the extra topcoat required for this type of finish adds significantly to the cost. On most paint lines, the metal must run through the line twice, increasing handling expenses.

By substituting powdered mica to the paint-blending process, manufacturers can now offer two-coat formulations that cost less to produce and exhibit greatly improved batch-to-batch and panel-to-panel color consistency. Mica lends the reflective sheen desirous in a metallic coating without the reflectivity and weathering concerns inherent in metal flake. The result is "metallic" coating that does not possess the finicky characteristics or high costs of three- and four-coat metallic systems. And there is only a slight trade-off in depth of color and sheen.

Very recent technologies also involve paint films that reflect different pigment layers when the angle of view changes. This produces an illusion that the paint is actually changing color as you walk or drive by. (How cool is that?) It is done by using two pigment layers and chips that reflect one layer or the other, depending upon the optical angle.

Take care when using any of these products as the finishes are all directional. The appearance will be conspicuously different when viewed from opposite directions. If a piece of flashing is inadvertently end-for-ended, it will be quite visually distracting. For this reason, the coater will often code the product with directional arrows on the backside.

▲ Real-world exposure testing is the only infallible way to prove paint performance over time. South Florida is the favored test geography because of high heat, ultraviolet and moisture conditions. *Photo courtesy of Atlas Weathering Services Group, Miami, FL.*



▲ Color change (fade) is measured in NBS Units or Δ E Hunter Units. One unit is the smallest degree of fade detectable to a trained eye. Premium paint warranties usually limit fade to 5 units. *Image courtesy of Metal Roof Advisory Group, Ltd.*

Pigments: Organic vs. Inorganic

Pigment—the powder that gives color and hiding ability to the finish—is organic or inorganic in composition. Sometimes both types must be used to achieve a certain shade or color. Inorganics, which are manufactured from complex metal oxides, have superior color stability and chemical resistance. They are the same ceramic pigments that have been used in the firing of porcelain for hundreds of years.

Metal oxides vary widely in cost; while they are all considered premium products, the stability of these pigments is not necessarily the same from one oxide to the next. In addition, they aren't available in all colors, including bright reds and yellows, so in those cases there is no alternative but to use less stable organic materials. On the flip side, white is only available as an inorganic (titanium-dioxide) pigment; there is no organic alternative.

In general, paint manufacturers will blend ceramic pigments with premium resins and organic

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pigments with less-expensive resins, but there is no industry mandate to do this. Perhaps there should be as cost incentives to use inferior pigments can be significant. The higher-cost inorganics include blue, green and black. Because black is a component of almost every applied color, there is profit to be gained (but performance lost) by using the less-stable carbon black compound. By strict definition carbon black is organic, but it is a raw element so it is often deemed inorganic.

Although PVDF finishes from all producers consistently use the higher-grade ceramic pigments, the same cannot be said of mid- and high-grade alternative resins. Hence polyester and siliconized polyester and other resin blends may exhibit wide variations in color stability from one supplier to the next. In some cases, a producer may use a ceramic pigment in one paint color and an organic pigment in another— yet label the paint with the same trademark. Or the product may have a high organic content with just a smidgeon of ceramic and be advertised as containing ceramic pigment.

In general, the "cleaner," or purer, the color, the more rapidly and drastically the pigment will fade. Bright red is one of the worst. When possible, select colors having muted tones. For instance, if the customer wants red, suggest a brick red rather than a fire-engine red. A darker shade will not necessarily fade more than a lighter one, as long as the color is not pure and it uses good-quality inorganic pigments.

Measuring and Testing Paint Performance

The primary exposure conditions that degrade paint over time are sunlight, heat and moisture. Certain airborne chemical pollutants and acid rain can also accelerate degradation. Because all paints are affected by this degradation, the only quantification is how badly and how quickly it takes place, hence warranty language will always reflect units of measurement over time.

Don’t be fooled into thinking that 70 percent PVDF from company “A” will outperform the same material from company “B” just because the warranty offered is longer term.

Specification References: The Rest of the Story

Most of these ASTM procedures are not pass-fail but quantitative in nature, hence the specifier must know and state the level of performance desired and include the same as part of a performance specification.

Performance Aspect	ASTM Procedure
Film Thickness	D-1005
Specular Gloss	D-523
IR Reflectivity	D-3363
Flexibility	D-4145
Adhesion	D-3359
Reverse Impact	D-2794
Abrasion, Falling Sand	D-968
Mortar Resistance	C-267
Detergent Resistance	D-2248
Acid Pollutants	D-1308
Salt-spray Resistance	B-117
Humidity Resistance	D-2247
South Florida Color Change	D-2244
Chalk Resistance	D-4214
QUVB	G-53
Acid Rain	(Kesternich)

The components of paint vary in quality, performance and cost. If properly applied, the paint system should last well over 30 years in terms of adhesion (resistance to cracking, blistering and peeling). Consequently, when we ask "How long will the finish last?” we are really asking "How long will it retain its true color and gloss?" The answer depends on two factors: pigment stability and resin type/quality.

Ultraviolet light chemically breaks down the components of the finish, resulting in chalk and fade. Moisture and heat exacerbate this chemical breakdown. Chalk, or the appearance of a whitish, powdery substance on the panel surface, is the result of a breakdown of carbon bonds in the finish. It is rated on a scale of 10 to 1, with 10 being no measurable degradation. A chalk rating of 9 is not noticeable while a rating of 7 is quite conspicuous.

Paint performance is not linear with time, so interpolation from short-term testing is not reliable in predicting long-term performance.

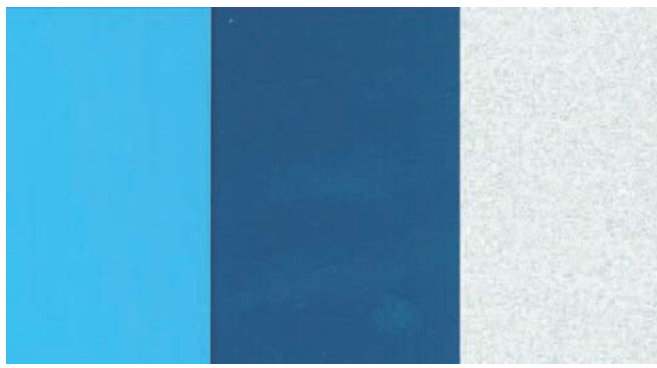
Fade (color change) is caused by loss of gloss and the gradual breakdown of the pigment. It is measured in N.B.S. (National Bureau of Standards) or ΔE Hunter units (referring to the Hunter Colorimeter used to measure color variation). A lower ΔE rating denotes higher performance. One unit is the smallest degree of color change perceivable by the naked eye. A change of 4 or 5 units is detectable to any observer but generally not objectionable, provided that the fade is uniform. Fade, of course, is the most common type of color change with the color gradually "bleaching" toward white. But color change can also occur laterally. Green, for instance, may become more yellowish or bluish with time.

The rate of fade and chalk will be different, depending on the surface's orientation to the sun. The consistency of fade is as important as the rate, but the industry has not established a unilaterally accepted standard for this aspect of paint performance. It may be assumed, however, that considerable risk is associated with a "bargain-basement" finish containing poorly performing resins and pigments. The resulting "checkerboard" effect of inconsistent fade can be as bad or worse than accelerated color change. The loss of gloss, or the pick up of dirt, can also pose visual distractions that contribute to color change but are outside the realm of color change as normally measured by the industry.

The most reliable test of paint performance is exposure to real weathering conditions over time. Because of the degrading effects of heat, sunlight and moisture, the favored spot on the map for testing paint performance is South Florida. Driving around this area of the country, you may see one of many "farms" with row after row of fences containing tens of thousands of metal chips mounted at optimal angle to the south sun. Paint manufacturers use these chips to field test new products and formulations, and they closely monitor their performance by measuring chalk and fade characteristics year after year.

An industry that is dynamic and inventive is always impatient to evaluate new technology. Mother nature takes time, and time is money—big money. Waiting to market a new paint technology until it has been exposed for 20 (plus) years is not often done. But paint performance is not linear with time, so interpolation from short-term testing is not reliable in predicting long-term performance. Because we achieve 2 units of fade in five years does not mean we can expect 4 units in ten. Therefore, the industry sometimes relies on accelerated test methods to evaluate new technology.

One method sometimes used to accelerate weathering artificially is the QUV chamber, which applies intense artificial light (using one of two different ultraviolet bulb types) with heat and moisture. A testing facility outside of Phoenix, called EMMAQUA (Equatorial Mount with Mirrors for Acceleration with Water), is a better method of accelerating weathering because it magnifies the natural effects of the sun by using mirrors and sun tracking in an outdoor environment along with induced moisture. However, both of these accelerated test methods have been shown to be inaccurate in some cases when compared with the real-world exposure tests over real time.



▲ A Megaflon (100 percent FEVE) blue, 70 percent PVDF blue and 70 percent PVDF silver metallic finish. *Image courtesy of PPG Industries, Pittsburgh, PA.*

What Do Warranties Cover?

It is appropriate when discussing paint performance to include some commentary regarding industry performance warranties. Unfortunately, it appears the warranty wars in paint finishes have begun. A 20-year warranty used to be the industry standard for PVDF finishes, and all producers offered essentially the same warranty. Claims were rare, and the performance coverage was oriented to the worst-case scenario: a 45-degree south-facing medium-blue surface exposed to South Florida sun and humidity.

Whereas in the past, the warranty might have been a conservative indicator of expectable paint performance, this is not necessarily true today. We are now seeing 25, 30 and even 35-year PVDF warranties, yet the finish chemistry and technology has changed little—if at all.

While it is true that paint films will perform much better in most climates and environments than they do on maximum-exposure test sites, some of these claims just go too far—with the warrantor perhaps banking on the warranty documents being misplaced and forgotten over time. The fact that a longer warranty is offered is not always evidence that the product is superior. Expected performance and conservative warranty coverage for a PVDF finish is as follows:

- Color Change: 5 or fewer ΔE Hunter units over 25 years
- Chalking: A rating of 7 or higher over 25 years

In both cases, expected performance depends on the environment and orientation of the surface to the sun.




Prints and laminates enable "faux" patterns featuring multiple colors. Clockwise from above: A camouflage print from McElroy Metals; copper vertigris and wood grain prints from Coated Metal Goods; and a stacked stone laminate also from McElroy on which the ribs of the "M-Corr" panel are barely discernible. Prints are typically three- or four-coat systems. Most are premium cost finishes because of the additional coats of film. Laminates are separate (cured) films applied at the coil line or a separate line using high-performance adhesives. *Images courtesy of McElroy Metals and Coated Metal Goods.*

Warranties will normally cover film adhesion and maximum levels of chalk and fade within the warranty period. Nowadays many warranties cover chalk and fade for 25 years and film adhesion for 40 but are advertised as “40-Year Warranty.” Because color is the real function of paint, buyers should beware and scrutinize warranty language and coverage carefully. Vertical surfaces will perform better than horizontal ones, and warranty language may also reflect this.

Warranties exclude certain conditions, such as under-film corrosion. This point bears emphasis: There is a common misconception that if the metal corrodes, it is a covered failure under the paint warranty. This is not true! These thin paint films are permeable, absorbing and releasing moisture cyclically with exposure and temperature change. If that moisture is chemically aggressive, it is possible for the metal to corrode from beneath the paint film, especially at cut edges and scratches. Such a failure is not covered by paint warranties. Therefore, the integrity of the substrate (metallic coating) and its corrosion performance are still of vital concern for prepainted steel panels.

Be sure to scrutinize warranted performance criteria when selecting products. In particular, look for acceptable levels of chalk and fade in terms of NBS or Hunter units. We have seen long-term warranties cleverly written using units that permit your red roof to turn pink and be covered with white powder well within the warranty period and limitations. Read all the fine print and be sure to keep track of the warranty documents for the full term of the warranty.

Don’t be fooled into thinking that 70 percent PVDF from company “A” will outperform the same material from company “B” just because the warranty offered is longer term. Likewise, don’t think that SMP performance will equal PVDF just because warranty language is similar. Put more faith in time-proven products than in warranties.

ASTM spec references are listed on pages **5 and 7**. Additionally, when ordering premium paint systems, reference is suggested to meeting all “Premium Painted Requirements” as set forth in the Glenview, Ill.-based Metal Construction Association Metal Roofing Certification Program.

Innovation Continues

The paint finish industry is a dynamic one, and the technology is continually improving. For example, clear coats are now available that give depth and sheen to coatings that were once only available in lower-gloss finishes. Recent innovations in resin technology have included the development of thermoset coatings, such as Megaflon®, which uses a 100 percent FEVE (fluorinated ethylene vinyl ether) resin called Lumiflon®.

This and other recent resin technologies have broadened the color spectrum and gloss levels of fluoropolymer coatings to include bright plastic-like colors that previously would have been available only in polyester formulations. Also in the works are new-generation polyesters that may approach the performance levels of PVDF finishes.

All these paint systems have their place. Even low-cost alternatives can be used successfully in soffit applications or as architectural accents to shopping mall interiors and other non-critical applications where use of 70 percent PVDF may be considered over-specification. On the other side of the coin, using a bargain-basement paint system in an exposed architectural application for the sake of saving 15 cents a foot is a disastrous error, shackling the end user to costly field painting every few years or total replacement with the material that should have been used originally. Often, this is a mistake resulting from specifier and/or contractor ignorance or haste or a less-than-honest vendor chain.

There are also other resins that have their place. Plastisol is sometimes used in very aggressive environments. Unlike most resins, this vinyl plastic is less permeable because it is used in "thick film" applications of 4 mils or more, thus providing "barrier" corrosion protection and pigmentation. Be careful of vivid colors when using this material because its color change characteristic is often somewhat inferior.

Another recent trend is a result of the focus on "cool roof" issues and involves the use of solar reflective pigments (SRP). These pigments are chemically or physically altered to reflect the infrared spectrum of light, reducing solar absorption, increasing reflectance and hence reducing the temperature of the panel. Although this spectrum of light is what heats the surface of an object, infrared light is invisible; therefore, the eye perceives no difference in color of the panel. Use of these pigments can meet Energy Star criteria for reflectance of 0.65 or greater even for dark, rich colors. When aged reflectance testing is conducted, PVDF coatings with SRP emerge as the undisputed winners as competing roof materials fade and collect dirt and algae growth, reducing reflectance during a few years' time whereas the PVDF does not.

Field Painting and Touch-up

In this age, any new construction design requirement asking for field painting or other air-dried painting of coated sheet steel and aluminum product is obsolete and a customer disservice. Field-applied and other air-dried paints will generally disappoint, not only from a quality standpoint, but also from an economic one. Field painting is three or four times more expensive than coil coating.

Although color-matching is made easy by computer technology, the match of air-dried paint is temporary, and the rates of fade are much different; after several years, the detriment to aesthetics can be quite alarming. Remember this when using touch-up paint and when using painted rooftop accessories. In the field, substrate preparation is highly critical to paint adhesion and very difficult to control.

Film thickness in field applications is also at the mercy of the applicator. In the end, even the highest quality preparation and application methods cannot be expected to render the kind of service life of factory-applied premium finishes.

Prepainted coil or flat sheet is quite available for related flashings and guttering and should be used in tandem with pre-painted roofing sheet. When use of mill steel shapes in exposed application is unavoidable, the appropriate solution is a prefinished sheet metal shroud as opposed to attempts to matching field-applied paints, which inherently pose a continual maintenance problem.

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WHITE PAPER

Part 4: Metal Roofing From A (Aluminum) to Z (Zinc)

Induced Finishes for Metal

There are numerous reasons for alteration of the surface of sheet metal roofing materials. One is corrosion protection. Another is to make a metal solderable or more compatible metallurgically. Then, there are also appearance-related reasons. Of course, the most obvious way to alter a metal's appearance (while adding color) is to paint it; however, paint has organic components that degrade over time causing it to fade. (See Part 3, "Paint Finishes for Metal.")

There are other treatments intended to preserve the original mill finish of some metals. The post application of clear protective films to copper sheet and other metals has been attempted for years. But, it has had very limited success, and is not recommended due to extremely high maintenance costs. There has been success in the mill-application of a thin layer of acrylic to Galvalume®-coated steel, which was discussed in Part 2. Unlike the clear film that is intended to protect indefinitely, this is done to protect the natural mill appearance of the metallic coating from staining only during fabrication, handling and installation. By design, the clear coating will dissipate with several years.

In other cases, the aesthetic objective of an applied finish is not to preserve, but to mask the natural mill finish, and there are a number of ways to do this— all varied with the specific base metal in question and its oxide's behavioral characteristics.

So, while some trends in architecture tend toward the addition of artificial color films to mask the mill finish, others are aimed at being au naturel, demanding induced inorganic finishing of natural metals. The latter objective is a finish that is not an applied film, but rather a mechanically or chemically induced alteration of the metal's surface appearance.

Artificial Aging Chemically

One appearance objective may be to make the metal look aged—weathered and oxidized—even when new. We live in a society that demands push-button results and a technology age that strives to deliver what the market demands. Food is delivered piping hot at the drive-up window 90 seconds after it's ordered. And if blue jeans can be artificially aged, why not metal roofs? Many processes have been developed to give various metals an aged appearance.

◄The Chrysler building, an icon of Manhattan, sports a "2B stainless-steel finish."

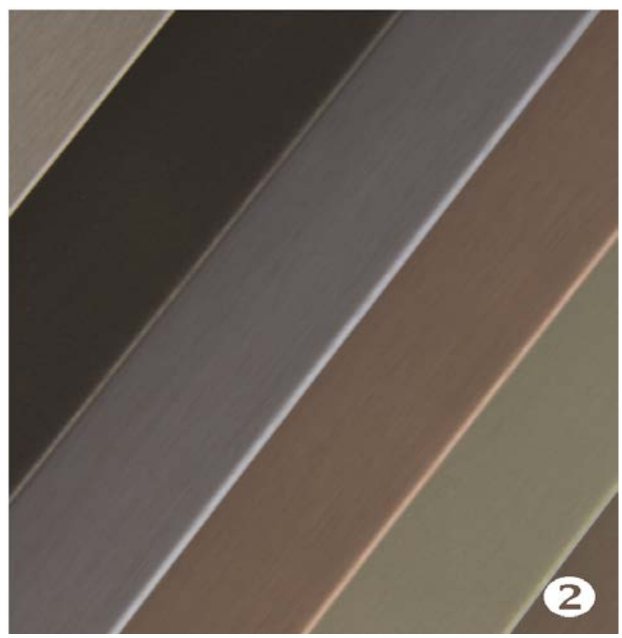
▲ VMZ Double Lock Standing Seam Panels in Pigmento Red from VMZINC were used on the AIA North Carolina chapter building in Raleigh.

However, don't always expect these mill-induced finishes to have as reliable color-consistency as the natural patination process. Many methods have been used to artificially patinate copper. Field application of different acetic solutions is the least desirable and often results with unsightly splotches. Because the induced patination is not natural, it will go through a conversion process as nature takes its course. This transition can be objectionable.

The green/blue color and differing hues found on naturally aged copper are primarily copper-chloride-hydroxide crystals and copper sulfates and result from sulfurous pollutants in the atmosphere, accelerated by heat and moisture. Studies have identified approximately 70 different compounds that may occur in natural copper patina. The ratio in which these occur depends on moisture and air pollutants, so it varies geographically. Like snowflakes, the crystals all have a unique and individual shape. Consequently, they reflect and refract light differently, which accounts for the varied hues of aged copper.

When you see marketing for "weathered Galvalume," it is typically a paint coating and not artificial aging of the metal.

While the coveted copper patination process may take 40 years or more in a dry, pollution-free climate, it is chemically launched at some mills to a jackrabbit start before shipping. Induced patination processes have been attempted for many years with only limited success. Prior to the late 1900s, the only tried-and-true patination process for copper was brush-applied horse urine, which produced somewhat splotchy results. Since that time, more sophisticated techniques have (thankfully) come into play.



▲ VMZINC offers (left to right) mill finish, ANTHRA-ZINC and QUARTZINC, in addition to PiGMENTO colored finishes. They all age to natural weathered zinc over time.

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Many processes have been developed to give various metals an aged appearance.

Revere Copper Products has called its artificially aged copper EverGreen. The process, while induced, mimics the natural weathering process on an accelerated timetable. It involves chemically and mechanically cleaning copper sheets; preparing the surface for patina growth; application of the patinating solution; then "growing" the patina crystals, which are copper-chloride. Revere has taken this product off the market, and we know not whether it will return.

Other copper mills also produce some pre-patina options including KME ("TECU® Patina") and Aurubis Architectural, formerly Luvata, ("Nordic Green™"). Users and designers should always check market availability before specifying any patinated copper products as their introduction to and subsequent removal from the market seems to be the rule rather than the exception. Products that were available last year may not be available next year.

Zinc sheet with an aged look is also in demand. The natural mill finish of zinc has a slight gloss and barely detectable surface grain finish. The natural weathering stages of oxidation dull the mill finish over time, eventually producing a low- or no-gloss deep matte gray, which results from the formation of a protective layer of zinc hydroxylcarbonate that blocks moisture and chemicals from penetrating it.

But for those who don't want to wait for natural aging, chemically induced pre-weathering assimilates the natural oxidation process before the material leaves the mill. This is done by immersing the metal in a sulfurous pickling bath or phosphorus-based solutions. So, in addition to mill finish products, RHEINZINK and Umicore Building Products (VMZINC®) offer varied "pre-weathered" appearance options.

◄Revere Copper Products called their pre-patinated finish ***EverGreen®***.

▼RHEINZINK Preweathered Zinc (center) has the appearance of a directional grain with a subtle blue-gray hue. The mill finished product "Bright Rolled" is at right and the "Graphite Grey" at left.

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VMZINC achieves different appearances with phosphataic solutions that are varied slightly to produce products, called QUARTZ-ZINC® and ANTHRA-ZINC®, the appearance of the latter mimicking black slate. “PIGMENTO” uses pigment technology while retaining the grained texture of pre-weathered zinc. The surface color is created by adding mineral pigments to a durable protective coating, creating organic red, green, blue and brown pre-weathered zincs. Over time, all of these finishes will gradually yield to a natural gray-colored zinc carbonate.

RHEINZINK uses a pickling process for both its pre-weathered products, but then to achieve the darker product, “Graphite-Grey” the sheet alloy is actually altered slightly.

While some metals can be artificially aged, Galvalume steel is an exception. The material will lose gloss slowly over the course of many years. At present, no method to artificially accelerate this aging has been found. When you see marketing for “weathered Galvalume,” it is typically a paint coating and not artificial aging of the metal.

Another chemical process is the anodizing of aluminum. While this is still popular in mechanical and glazing applications, it is going the way of the dinosaur when it comes to exterior architectural metal claddings. This is because modern paint technologies are superior to color anodizing from cost, consistency and weathering standpoints. Clear anodizing is still done on architectural products for reasons pertaining more to corrosion resistance and metallurgy, rather than appearance alteration.

Mechanically Induced Finishes

Stainless steel often receives a mechanically induced finish to achieve gloss and/or finish consistency. The finish can be rolled or polished to achieve a dull or bright finish. The texture of the rolls can also control finish texture. Hot rolling followed by annealing will produce a rough-textured, dull surface, which is designated No. 1.

Cold rolling through unpolished rolls results in a dull finish, which is designated 2D. A bright, reflective finish, which is designated 2B, is accomplished by cold rolling, annealing and a final pass through polished rolls. An example of this finish can be seen on the Chrysler Building in New York. Further polishing, brushing, buffing, or grinding can produce even brighter finishes and other textured effects.

Recently, stainless-steel producers have introduced several embossed (rolled) finishes with roughened, uniform textures. Trademarked names include “Architex®” from J&L Specialty Steel Inc., and “Greystone® Dull” from AK Steel®. These finishes offer low gloss, low reflectivity and

▲ Some stainless producers have developed proprietary finishes, some of which are shown here. *Photo courtesy of AK Steel.*

enhanced aesthetic appeal for a variety of roofing applications. One high-profile application of this material can be seen on the Ronald Reagan Airport in Washington, D.C.

Other types of mechanically induced finishes achieve textured effects. The most common is embossing, which gives the metal surface an “orange peel” look. One reason for embossing may be to reduce the visual effects of oil canning in the finished product. Another may be to reduce the perception of gloss. Embossing is used primarily on coated steel and aluminum. It is often done on-line at the end of the paint coating line or at the beginning of the fabrication process. A third-party specialty house can also do it off-line.

The process uses a large cylinder that presses the pattern into the metal as it passes beneath the cylinder. Because the process can be a bit traumatic to the coating on steel, G-90 is preferred by some instead of Galvalume due to its greater flexibility. It should be noted that “oil canning” effects, as discussed in Part I, are much more pronounced on high-gloss surfaces, hence induced finishes are more often used to tone down a mill finish, rather than to brighten it.

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WHITE PAPER

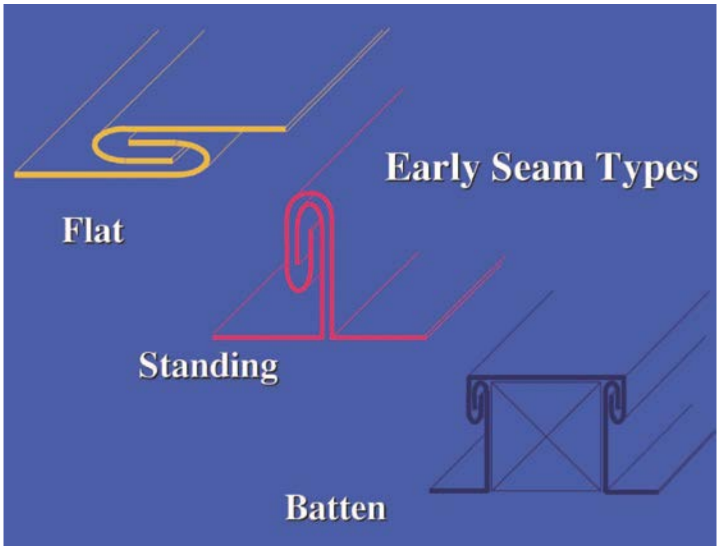
Part 5: Metal Roofing From A (Aluminum) to Z (Zinc)

Profiles and Profiling Equipment

The original shapes of metal panel profiles were quite simplistic, as were the tools used in their making. Smiths hammered out small plates of brass, copper or gold more than 2,000 years ago. They were then folded at their edges and interlocked one-to-the-next to form the "flat-locked" or "flat seam" style roof. The anchorage was accomplished with a small cleat folded into the joint area during installation. This style is believed to be the original metal roof type and is still popular today, especially for irregular shapes, like domes and onion domes. With the advent of soldering in the mid-to-late 1800s, these roofs could be used dead flat with soldered "hydrostatic" joints.

At some point, more than 1,000 years ago, craftsmen learned they could fold the adjacent edges of a flat plate up at 90 degrees and then fold the uppermost portion of the upstanding edges together into a tightly formed 360 degrees, creating a double-folded lock. This resulted with the joint being raised above the drainage plane of the plate an inch or so, hence it was more water-resistant. The joint was now standing up in a vertical orientation, rather than lying flat—hence "standing seam" was an appropriate designation to differentiate from the earlier "flat seam." Once again, the anchorage was accomplished via a small cleat nailed to the structure and folded into the seam. At this stage of evolution, the plates were also growing in length—more like longitudinal "panels."

When the craft migrated from the Middle East to Europe during the Crusades, metal-panel profiles were adapted to the styles of architecture and climate prevalent in western Europe and Scandinavia. Steep roof areas and "tiered" architecture (roofs above lower roofs) would dump snow and ice, damaging fragile standing seams below. A strip of wood inserted between the upstands of adjacent panels would support the seam area, increasing the durability of standing seams and creating a new style—the "batten seam," so called because of the wooden batten strip.

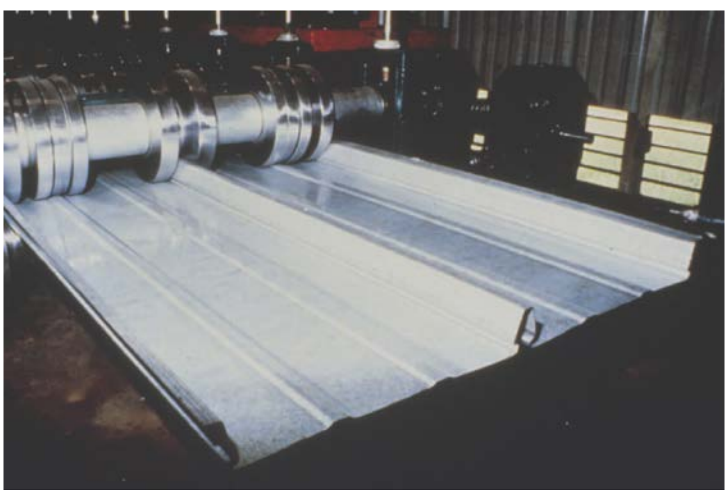


▲ The earliest seam styles (above, left) were simple and fabricated by hand with malleable metals and hand tools. The first profile in history—the "flat seam"—was also the first "hydrostatic" metal profile type when soldering came along. It is still used today (above, right) and is a popular profile for covering irregular shapes, like domes. *Illustration courtesy of Metal Roof Advisory Group, Ltd., Colorado Springs, CO. Photo courtesy of Rob Haddock.*

A significant nuance was the introduction of a separate joining component—the batten cover that locks into two twin up stands and completes the joint. This was a departure from the other profiles that used a “male” and “female” seam edge, which were then interlocked with each other. A modification of the batten seam is the “batten roll.” This profile uses a raised “lap seam” (no separate batten cover) and was developed with and for lead roofing to provide more gentle radii for this unique material.

All these styles were fabricated at the point of installation and with very simplistic tools—mallets; small anvils; tongs; hand and foot brakes; and later, simple pan formers. The metals used were soft, malleable materials and could be meticulously formed, folded and jointed using these tools, shapes and techniques. And so was the craft of metal roofing for centuries of time. It was installed by highly skilled (and highly compensated) copper and silver smiths, and remained relatively unchanged for nearly a thousand years until the Industrial Revolution. Until that point, a metal roof was the finest and most expensive roof that could be had, thus its use was limited to prestigious structures, like palaces, castles and cathedrals.

▼Rollforming technology brought on a host of changes and represented real mass production.



▲Tools became more sophisticated. From the top, an early wooden brake, circa 1860. Next, a variety of early hand tools, including hand shears, spades and malletting anvils. Next, an early pan former for lead “batten roll,” circa 1840. *Photos courtesy of Rob Haddock.*

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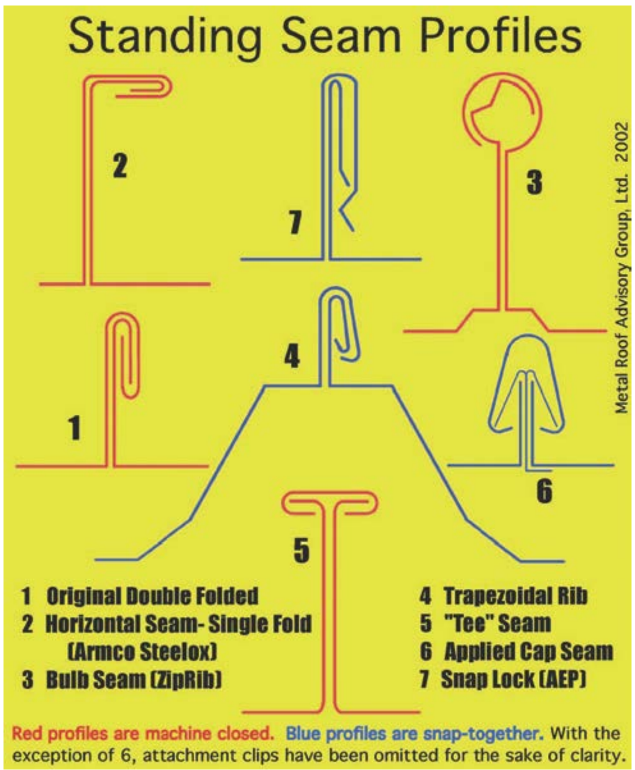
BUILD LEGACIES METAL

The Effects of Changing Fabrication Equipment

With improvements in mining and milling techniques, as well as innovation in fabrication tools and equipment, new styles of metal roofing began to emerge. New materials were coming onto the scene, as well. The steel industry was making huge strides into the commercialization of sheet goods in the early and mid-1800s. The harder, less-expensive material could be fabricated in a newfangled contraption called a “leaf brake.” This device had a long jaw and a hinged apron that could clamp the material and fold a perfect, straight bend far more quickly and accurately than the old (and much shorter) hand and foot brakes. This new equipment made any metal roof style more affordable, saving much time by “pre-bending” standing- and batten-seam profiles in a production environment by less-skilled workers rather than on the roof.



▼ In this sample of shapes, 5 and 6 utilize twin male components with a female cap. The others are male-female interlocks. Many variations of all these profiles are available. For instance, combining a 1 seam type with a 4 rib geometry creates Butler Manufacturing’s “MR-24,” MBCI’s “Double-Lok®” or VP Buildings’ “SSR.” Combine a 6 seam type with a 4 rib geometry for Behlen’s standing seam. Add a small hook to the 2 seam type for McElroy’s “Maxima.”

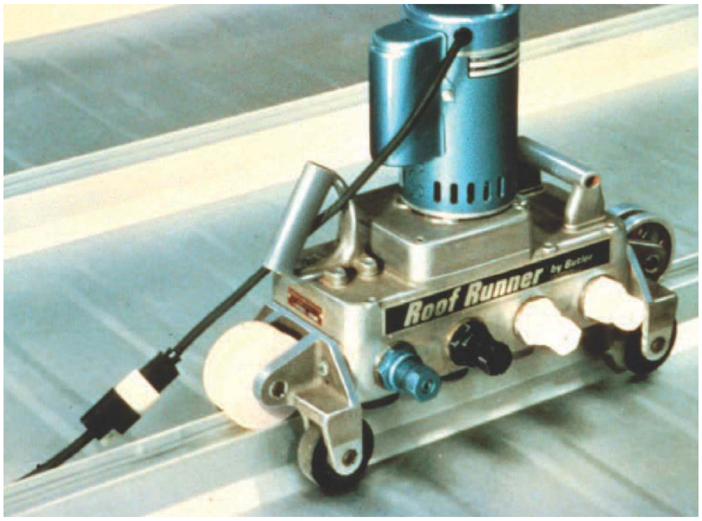
▲Rollforming technology brought on a host of changes and represented real mass production.

Corrugating

Another interesting development around the turn of the 20th century was a process called “corrugating.” Steel producers found they could take a very thin sheet of galvanized steel and press lengthwise wrinkles into it by passing it beneath a “corrugating drum.” The wrinkles stiffened the sheet such that the metal could now span over open supporting structural members without benefit of a continuous deck. Thus a “structural” covering would fulfill the function of deck and roof membrane with one material.

The corrugating of steel panels was the first real mass-manufacturing process for metal cladding, and the resulting products made metal an economical roof material for the first time in history. Whereas metal had always been the most expensive roof, now it could also be the least expensive, making the quantum leap from castles to barns and industrial buildings.

This corrugated metal was attached with exposed fasteners. It was, in other words, “face-fastened,” or “through-fastened,” meaning the weathering surface was pierced with nails (and later screws) to secure the product in place. Early applications located the nails in the “high corrugations,” but later weather-sealing washered screws came into use, as well. Side-seams were joined in overlapping style, as with the earlier “batten roll” methods of roofing.



▲ Butler Manufacturing introduced “MR-24®” in the late 1960s. It utilized the original double-folded standing-seam profile (see standing seam profile previous page) atop a trapezoidal rib shape and closed the seam with an electric machine–in essence, a miniature 4-stage rollformer. *Photo courtesy of Rob Haddock.*

Rollforming

Innovation continued throughout the next half century, and the leaf brake helped birth a few new profiles, including the integrated batten seam; the button punched standing seam; and another structural panel, the “trapezoidal rib.” But the most significant advancement in manufacturing did not come along until World War II when “rollforming” technology was invented. This approach to making a profiled sheet was the first departure from a one-at-a-time manufacturing mentality. The progressive roll tooling of such a mill could produce a finished profile in a continuous process rather than step-by-step bending or sheet corrugating one-by-one.

Another benefit attributable to this new manufacturing method was the precision with which panels could be formed. One end of the panel would be dimensionally consistent with the other—within thousandths of an inch! This had never been possible with leaf braking. The rollforming process also opened the spectrum of available metal panel profiles, allowing intricate shapes, lines and bends never before possible or affordable. This equipment today can operate at line speeds of up to 600 feet per minute, automatically measuring and cutting panels to length with amazing accuracy at the same time.

The concept of continuous manufacturing—dealing with an endless strip of material—now pervades almost every aspect of production and fabrication, including painting, profiling, curving, seam closing, slitting, leveling and even sealant injection. The rollforming process has found its way from large in-plant mills to smaller, portable “on-site” forming machines, as well as electric seam-folding machines. Whenever long, parallel bend lines are found on metal panels, it is a reasonable bet the profile was made by this process.

▲ The concept of roll-tooling and continuous feed are also utilized by other material-handling equipment, including levelers (that stretch and flatten material), cut-to-length lines, slitters and curving machines. *Photos courtesy of Rob Haddock.*

Sometimes press-forming is used in tandem with rollforming to produce still different effects, like some of the popular tile facsimiles available in the marketplace for “crimp curving” or to break a profiled (rollformed) sheet over the ridge area. Press forming is also used for the manufacture of individual shingles or tiles and other textured shapes that are not characterized by long panels with parallel bend lines.

Of course, rollforming technology has made a whole host of new profiles possible and the manufacture of the old ones much more cost-effective. Another new concept to come along in panel profiling within the last few decades was the creation of snap-together seams and snap-on caps. This method uses the spring action of harder and higher-yield metals along with the dimensional consistency of modern rollforming equipment to develop locks and joints that do not require field folding or crimping.

Profiles and Joints for “Structural” Panels

The use of standing-seam joints and profiles on structural steel and aluminum panels is a trend that started with Armco Steel pre-1950. The concept was boosted with Kaiser’s introduction of a product called “Zip-Rib” in the 1960s. This was a “bulb seam” design held in place with concealed clips, and it was popularized worldwide. Also in the 1960s, a sheet-metal craftsman and consultant from Sweden (Ola Svensson) invented an electric rollforming machine that could perform the labor-intensive, double-lock standing-seam folding—automatically. Meeting with rejection in his home country from the trades who relished hand methods, he brought his machine to the U.S. and showed it to Butler Manufacturing in the late ’60s.

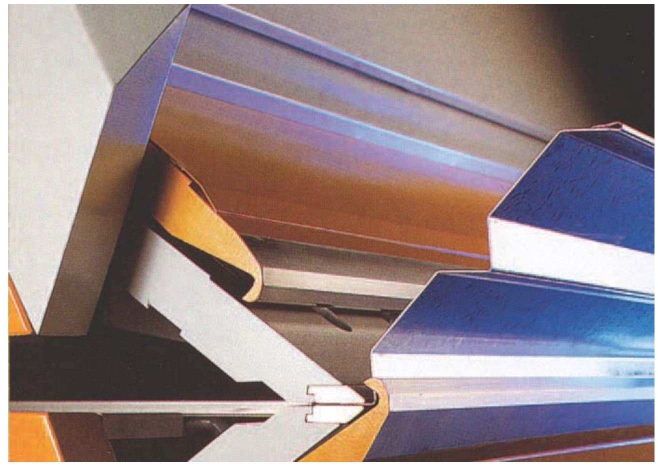
Around 1970, owing to Svensson’s invention, Butler Manufacturing™ introduced MR-24 in the U.S.: the first standing-seam joint used in conjunction with a trapezoidal rib panel profile, all machine folded with Svensson’s contraption. It was a curious blend of old and new. A 1,000-year-old joint on a relatively new material and pro-file—then used atop pre-engineered metal buildings and with the addition of factory-applied seam sealant. This revolutionized the metal-building industry and, since then, every major U.S. manufacturer of pre-engineered steel buildings now offers a structural standing-seam alternative.

There seems to have emerged from within the metal-building industry two panel geometries: the flat pan and the trapezoidal rib. Two different types of joints also have emerged: male-female interlock and applied cap. With applied-cap profiles, the cap is the female component of the assembly, and the panel edges are mirrored male components. Additionally, either of these joint types (interlock or applied cap) may be snapped together or mechanically crimped or folded. It seems that recent trends are more toward mechanically folded seams—probably because they are generally more durable with respect to wind resistance. Clearly, snap-together-type seams are less labor intensive to install. For that reason, they will always remain popular.

Which Is Best?

There is no clear answer to the question: “Which seam and profile is the best?” Everyone has biases, and there are pros and cons to any profile and seam type. My personal favorites are generally folded seam profiles that involve no void within the panel’s cross-section.

Profiles that have void areas within the seam are cumbersome shapes to deal with at panel termination points, especially when those points are skewed, like at hips or valleys—enlarging the void, which must be somehow closed and sealed. But on the other hand, if the job does not involve such conditions, the trapezoidal profile (having the largest void area of any shape) may offer cost efficiencies not enjoyed by other profiles because it has such a material-efficient shape.



▲ Modern state-of-the-art sheet-metal brakes can handle hard metals and are veritable fabrication centers with computerized controls and automated processing. *Photo (above, left) courtesy of Roper Whitney, Rockford, IL. Photo (above, right) courtesy of RAS Systems, Peachtree City, GA.*

All things considered, it is hard to beat the original double-folded standing seam. It has been around for more than 1,000 years and is sure to be around for a very long time to come.

New Technology Brings New Challenges

Prior to the advent of rollforming, panel lengths were generally limited to 8 or 10 feet—the length of a traditional leaf brake. With the rollforming process, panel lengths grew longer and longer, not being limited by fabrication equipment, but only by transportation restrictions. This makes sense because longer panel lengths mean fewer end-to-end joints that are expensive to execute and can be problematic.

As the panel lengths increased, however, we also began to experience roof failures associated with thermal effects. With increasing panel lengths, panel-attachment methods had to gain sophistication to accommodate the increased effects of thermal cycling.

In the next segment, we will look at dealing with thermal-cycling characteristics of metal panel systems.

Rob Haddock is president of the Colorado Springs, CO-based Metal Roof Advisory Group Ltd. He is a consultant, technical writer, training curriculum author, inventor and educator. In 2012 he became a charter inductee of Modern Trade's "Metal Construction Hall of Fame" for his many contributions to the industry.

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Part 6: Metal Roofing From A (Aluminum) to Z (Zinc)

Attachment of Metal Panels

In this article, we look at panel attachment and how it provides the necessary wind resistance while still allowing panels to respond to thermal loads. We also look at "panel pinning"— where, why and how it is done.

Wind Effects and Standards

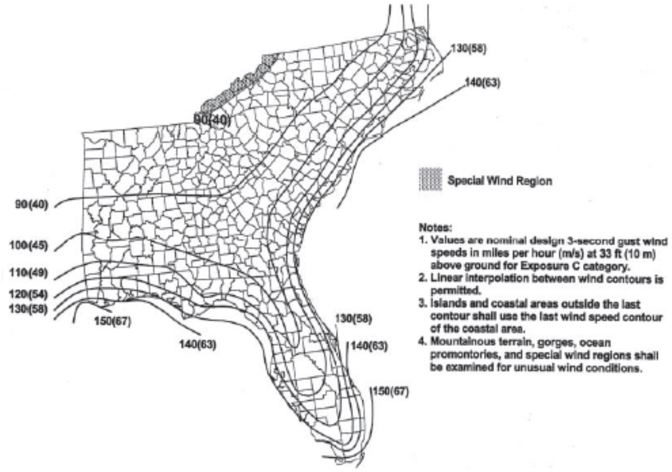
Metal panels that comprise the finished surface of a roof constitute an airfoil of sorts. As wind buffets the walls of the building, it is redirected up and over the roof. As this happens, negative pressure (suction) is created over certain zones of the roof surface, producing "lift" or "uplift". This is the same dynamic that makes airplanes fly and the effect can be quite exaggerated, threatening to tear the roof from its mounting. The frequency and strength of the metal panels' attachment, therefore, can be vital to roof survival during a windstorm.

Wind is measured by its speed in mph, but those units of measurement are not useful for designing structures and roofs. The forces that are exerted on the roof surface are determined by taking the highest historical wind speed and translating it into pounds of positive or negative pressure per square foot of roof surface. The more concerning of the two is the negative pressure (uplift). The translation of wind speed into pounds of uplift force involves a number of tables, equations and a matrix of variables that include the height of the building and other size factors, as well as the "exposure factor" from the effects of the surrounding terrain or nearby buildings, all of which can increase or diminish wind pressures at the roof.

▲ An ASTM E 1592 test bed showing a 16-inch horizontal seam panel system pressurized to 126 psf using S-5 WindClamps™ at panel clip locations. The assembly failed at 220 psf. The failure pressure without seam reinforcement was 110 psf.

The metal roof assembly is a load chain in essence, with the weakest link representing the point of failure.

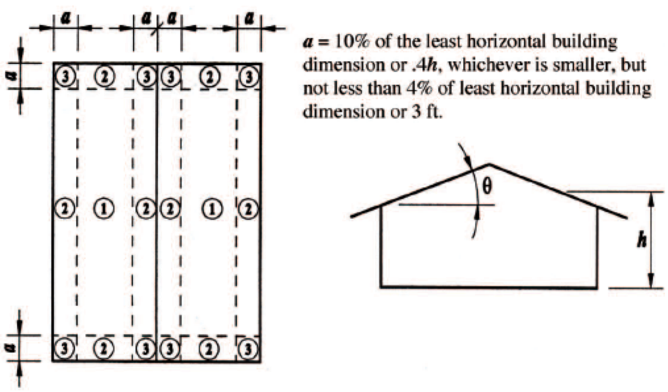
The National Weather Service maps maximum wind speeds from empirical data recorded over years of time for all areas of the country. Although the instrumentation (called an anemometer) measures wind speed at 33 feet above the ground, that speed is generally referenced as "ground wind speed." The ASCE-7.02 design standard is the most widely accepted engineering standard to take the recorded maximum ground wind speed in mph and determine the relative effects of the variables mentioned above to translate it into pounds per square foot (psf) on the roof surface. Note: As a result of increased hurricane severity over the last several decades, the mapping of recorded maximum wind speeds has changed.



▲ Design begins with the fastest 3-second gust as measured on the ground. "On the ground" means 33 feet above and lower. Because of ground friction, as building heights increase, wind speeds also increase; hence, a roof on a 100-foot-tall building will experience more severe wind effects than 1-story construction will. For related reasons, surrounding construction and topography also play a role, resulting in different "exposures."

The ASCE standard divides the roof into "zones", each of which will experience different uplift forces resulting from the same ground wind speed. Corner zones are where the wind effects are the greatest. Perimeters are next along with ridges on steeply sloped roofs.

The "field" (non-perimeter zone) of the roof is where wind uplift effects are the least. The dimensional size of each zone is determined by the building size and height. Once these design pressures are known, the ability of the panel system to resist them must be proven.



▲ Zones 1, 2 and 3 each have pressure coefficients that vary with other aspects of the structure. Zone 3 experiences the greatest pressures; Zone 1 the least. Zones near the ridge are nonexistent when the slope is below 7 degrees.

The resistance of panels and attachments to the uplift forces to which they will be exposed is calculated or tested. Most design parameters and specifications require testing rather than structural engineering calculation.

Wind Testing

Recognized test methods include Underwriters Laboratories UL 580, Factory Mutual 4471 and ASTM E1592. Most codes and standards recognize that these test methods are superseded by actual "wind tunnel" testing as the wind tunnel more accurately assimilates actual building geometries, wind speeds and the resulting wind effects on the roof. Why not simply require wind tunnel testing as a standard practice? The answer is cost. Wind tunnel studies are extremely expensive and each is specific to an individual building and roof geometry.

The named tests use various methods of inducing static pressure on the roof assemblies in an attempt to quantify their performance. Most of them are designed and intended for structural panels (panels installed over open support framing). In my opinion, they generally produce conservative results compared to the real-world effects of wind on a roof surface. This has to do with conservatism within the design standard and test methods, as well as the inability of any test to replicate the unusual "microbursts" that wind produces on a surface as opposed to prolonged sustained pressures.

Some testing at Mississippi State University™ using electromagnetic fields rather than air pressure get closer to the real effects of wind on structural metal panels; however, testing of this type is also too costly to be adopted as an industry-wide procedure. The effects of wind on a roof surface, which is installed over a deck, is known to be mitigated to some degree, but the industry tests noted here cannot reflect this and indeed some of them do not enable testing of these "non-structural" panels.

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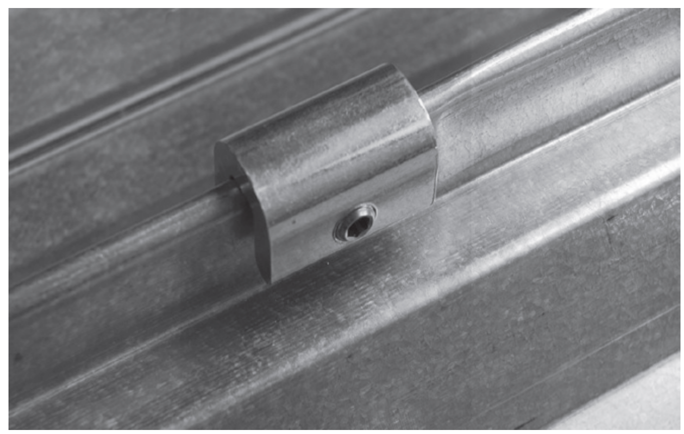
▲ Research funded by the Metal Building Manufacturers Association and American Iron and Steel Institute at Mississippi State University utilized electromagnetic fields to more accurately replicate the effects of wind on a roof surface. *Photo courtesy of the Metal Building Manufacturers Association.*

Because each test is very specific in terms of the material and assembly particulars, a manufacturer testing a new roof product may have to go through a battery of tests for each panel assembly that it wishes to market. This can mean dozens of tests costing thousands of dollars each. Such repetition is necessary, however, because there are many variables in actual assemblies. Those variables include the gauge and mechanical properties of the material, the geometric shape of the seam and profile, the dimensions of the seam, the strength of the clip or other attachment, the attachment frequency and the width of the panel. The metal roof assembly is a load chain, in essence, with the weakest link representing the point of failure.

Changing one of the variables means increasing or decreasing the strength of one of the links. But doubling the strength of one link does not necessarily double the strength of the chain—the failure point may just move to a different link. Frequently, the weakest link is that the panel seam unravels under pressure or lifts off the attachment clip. These modes of failure can be strengthened by the use of external seam reinforcing, such as S-5 WindClamps™, at or between clip locations, often doubling the system's uplift resistance at very low costs.

▲ Solar installation mounted parallel to the angle of the roof can mitigate wind effects.



▲ S-5! WindClamp™ shown on seam.

It should be pointed out that roof-mounted ancillary items, like solar collectors that are a few inches above but planar to the roof, are not subject to the same wind pressures as the roof itself. In fact, they also have a mitigating effect on the pressures on the roof. Because the solar collector is a much smaller area than a roof, with air gaps at its edges that promote "leakage," a lesser amount of suction is exerted on its surface than on the plane of the

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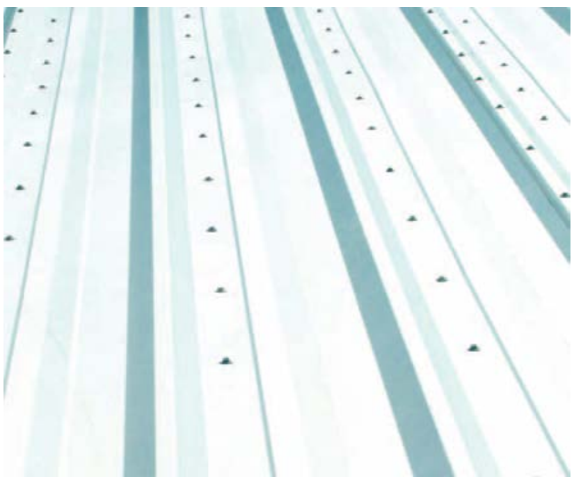
roof. Using the same design standards for such ancillaries will produce very conservative results indeed. Conversely, if the collector is mounted with some angle of tilt, the wind dynamic can be considerably more extreme.

Panel Attachment

Panels are attached with exposed or concealed fastenings. Exposed fasteners are used for certain panel types, including ribbed and corrugated profiles. This "direct" method of attachment can provide increased wind resistance but does not provide for thermal movement of panels and has the obvious disadvantage of penetrating the weathering surface.

Such methods and systems must be utilized with some precaution for these reasons. When the structure to which they are attached consists of wood or steel purlins, thermal cycling is relieved to some extent by flexure or rotation of the purlins.



▲ Through-fastened panels can provide greater wind resistance simply by increasing the fastening frequency, but this direct attachment does not provide very well for thermal response of the panels and adds holes to the weathering surface.

When the same systems are used over solid wood decks or bridged bar joists, however, fastening fatigue can result from repeated thermal cycling. It may, therefore, be a good idea to limit roof lengths for such applications because thermal movement is directly related to length.

Hundreds of years ago, brake-formed shapes were all fix-cleated to the structure, but their end-to-end joining was done with loose locks, and pan lengths were short, so thermal movement was never accumulated. Now, with roll forming manufacturing methods, panels have gotten considerably longer and thus accumulate more movement.

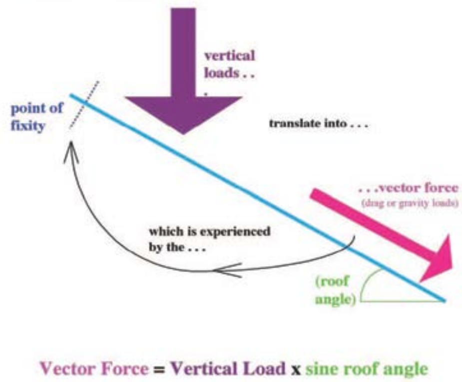
Most (not all) "concealed fastening" provides for differential thermal movement of panels to structure by the interface of the clip with the panel. A simple clip design would have this interface be a frictional engagement wherein the clip is rigidly attached to the building structure but slip-connected to the male seam component of the panel. This (one-piece) clip method is quite popular with most steep-slope roof products and especially those that have "snap-together" seam types. The clip is stationary but allows for differential movement between panel and clip.

▲ Concealed fastened panels eliminate most fasteners from the weathering surface by using attachment clips inside the side-seam joint. The clips permit thermal movement, but because the "flat" of the panel is unrestrained, wind resistance is diminished. Under excessive load, the panel flat arcs upward, rotating the seam and disjointing.

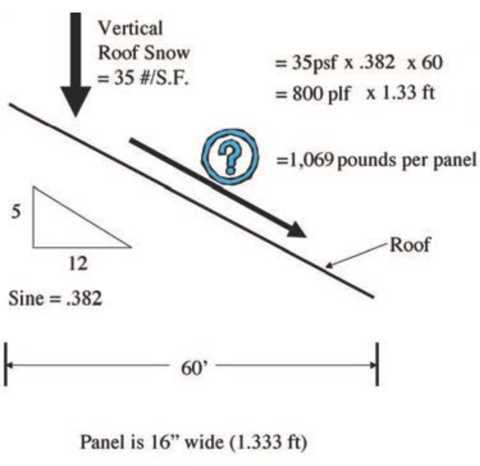
When sealants are used within a panel seam, oftentimes the one-piece clip design cannot work. This is because the differential movement between the panel and clip would abrade the sealant, jeopardizing weather integrity of the seam.

In such cases, a different clip design must be employed. The most popular designs for such a seam involve dual-component clips. The clip base is attached rigidly to the structure and the clip top folds into the panel seam. Differential movement then takes place within the clip itself, between its two components—base and top. It bears mentioning that the clip is an integral part of the assembly and unique in most cases to the panel profile with which it is used.

Calculating Drag Loads



SLOPE :12	DEGREES	SINE
1	4° 45'	0.08281
2	9° 28'	0.16447
3	15°	0.25882
4	18° 30'	0.3173
5	22° 30'	0.38268
6	26° 30'	0.4462
7	30° 15'	0.50377
8	33° 45'	0.55557
9	36° 45'	0.59832
10	39° 45'	0.63944
11	42° 30'	0.67559
12	45°	0.70711



▲Drag loads should be calculated to verify adequacy of the panels' method and frequency of fixidity. In this example, the fixidity point should resist 1,069 pounds for each panel (plus safety factors).

Panel Fixity

Using clip fastenings that allow the panel to cycle freely in response to thermal loads also make it necessary to deliberately "pin" or "fix" the panel at some point along its length to prevent it from migrating out of its intended location. Gravity loads, or "drag loads" as they are sometimes called, will act in a direction parallel to the roof's surface trying to pull the panel down the slope of the roof. These loads are primarily comprised of vertical loads (snow, wind, foot traffic, etc.) on the roof's surface. The only resistance to these loads (other than the panels' designed point of fixity) is friction between panel and structure.

Panel fixity can be accomplished by using one or more "fixed clips," or by some method of direct panel fastening at the desired location. Use of the fixed clip method depends upon the nature of the interface of clip to panel seam; with some designs it is not possible.

The location of choice for fixity of steeply sloped architectural systems is most often at the ridge where direct (or through) fastenings can be hidden beneath a ridge cover. The system will then accumulate movement to its eave end.

Conversely, the popular point of fixity for low-slope systems is at the eave. The primary reason for this preference is that such systems are often hydrostatic by design, and it is much easier to waterproof a joint that is stationary than one that is moving. Exposed fastening is usually tolerable from an aesthetic standpoint on low-slope systems, so it is a logical choice. Such a system will then accumulate thermal movement to the ridge where a "bellows" style ridge flashing can accommodate differential movement of the two opposing roof planes while maintaining a hydrostatic seal.

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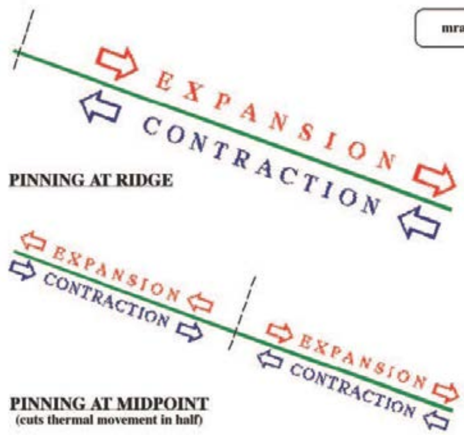


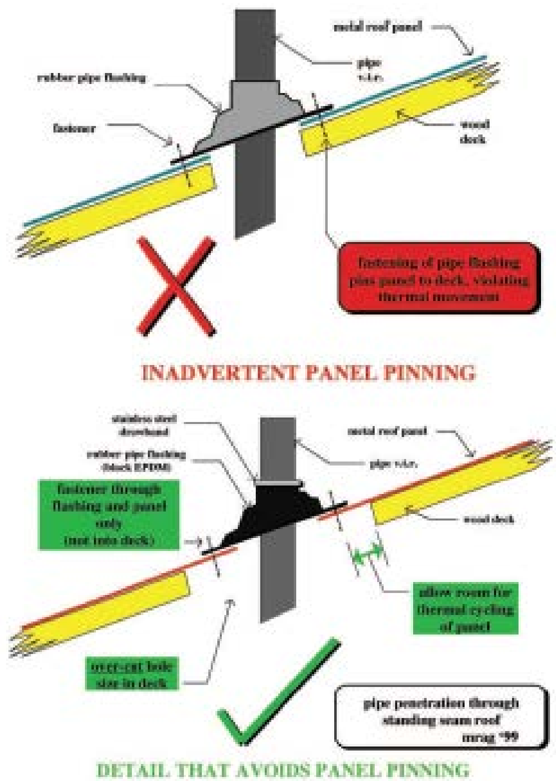
▲ The point of fixity may be at the ridge, eave or some midpoint. It is crucial that this point is singular and "dual pinning" does not occur.

These statements are not meant to be exclusive; there are exceptions in both cases. It is also occasioned in design to see a panel fixed at its midpoint, dividing thermal movement in half by sending it in both directions rather than one.

Having chosen a point of fixity for the metal panel system, it then becomes critical to ensure that such a point is singular. In other words, the panel should not be pinned inadvertently at any other point along its length. To do so would likely produce a failure from the thermal loads. On occasion, the thermal movement integrity of a roof system is violated because some construction detail or roof accessory mounting did not preserve this characteristic. Design and as-built construction should be scrutinized in this regard. A fascia break detail, for example, fixes the panel at the point of the break; to fix it again at its opposite end would constitute dual pinning. Other examples will be discussed in the next segment.

How Does Thermal Movement Occur?

As metal panels get hot, they expand, increasing their length dimension. When they get cold, they contract, reducing that dimension. This cyclical changing of dimension is called thermal movement. This is a linear effect. In other words, it will



▲ Often when a pipe is flashed through a steep roof product over a deck, it results in panel fixity. To avoid this, the deck should be overcut as shown.

accumulate in direct proportion to the panels' "unbroken" length. If panels sections are joined end-to-end with mechanical fasteners through the lap, then the unbroken length is the total length of two or more panels, not just one.

Thermal movement does not accumulate across the width of the panels because the unbroken length in that axis is so small. The geometry of the panels and their joining method at side joints allows flexure at each joint so the thermal effects never accumulate. Small, unitized metal covering products, like shingles, in like fashion minimize unbroken length dimensions; hence thermal movement is rarely a consideration for such systems.

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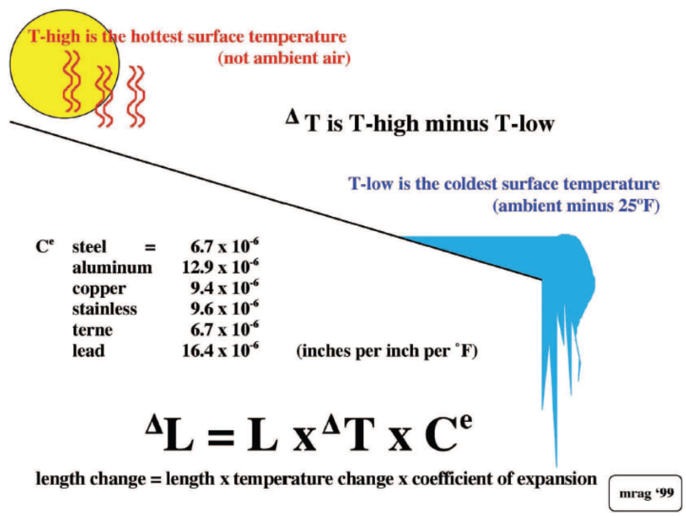
▲ In early days of metal roofing, pan lengths were short, so thermal movement never accumulated. As the “unbroken length” of panels increases, so does the dimensional gain or loss caused by surface temperatures.

Total (or worst-case) thermal movement is calculated by extending the material’s coefficient of expansion over its length and the anticipated in-service temperature range throughout its service life. It is the surface temperature of the material and *not ambient air* that affects these extremes.

The maximum high-end temperature will be conditioned by the color of the panel and its solar absorption characteristics (lighter colors and high-gloss finishes will be cooler than dark colors and low-gloss finishes). A dark-colored panel with low gloss at right angles to the summer sun can approach temperatures of 200 F. Use of “cool” (or reflective) pigments can reduce these temperatures significantly because they lower the solar absorption.

A single metal panel exerts forces measured in tons when it tries to move thermally; hence, undue restriction of this anticipated movement easily can precipitate attachment fatigue and failure.

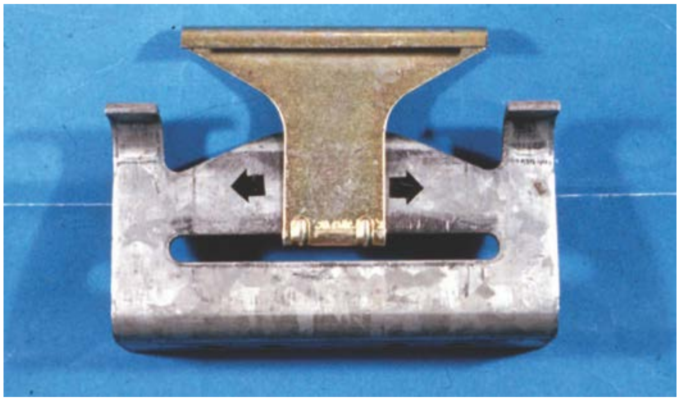
In cold winter nighttime scenarios, the low extremes of surface temperature can actually dip 25 or 30 degrees below ambient air. This is because of the principles of radiant energy. Skyward-facing objects radiate heat energy to the night sky. As this energy transfer occurs, the material loses BTU’s (heat), reducing its temperature. It is this same effect that results in dew or frost on the ground, roof or windshield of your car when vertical surfaces do not experience dew or frost. It is a combination of these factors that can result in **Δ**T (difference of hottest to coldest surface temperatures) figures of close to 250 F in cold northern climates.



▲Different metals have different expansion coefficients. Note that aluminum will gain or lose about double the dimension of steel when subjected to the same temperature differences.

Strictly speaking, it is the differential expansion between roof panels and structure that must be accommodated by the panels’ attachment clips. The clip (or its base in the case of two-piece clips) is mounted to the structure; panels move differentially to both. An open canopy structure may experience some temperature-induced change in dimension that

▲One-piece clip designs provide for thermal cycling by a sliding engagement of the panel seam. The differential movement takes place between panel and clip.



▲ Most two-piece clip designs provide for differential movement within the clip itself. The base is fixed to the structure and the top folds into the panel seam. The top does not move relative to the seam, preserving the integrity of seam sealants.

▲ If a panel is not "fixed" at some location, gravity, or "drag loads," can pull it down the slope of the roof.

would reduce the differential movement of its roof panels. Most often, however, the structure is a conditioned element inside a shaded or insulated building envelope. When this is the case, it experiences little or no change in temperature and therefore no change in length. This means the differential movement between roof and structure is equal to the total movement of the roof with no offsetting or mitigating thermal cycling of the structure.

Unlike many other aspects of engineering and design, calculations involving anticipated thermal movement are not augmented by factors of safety. In fact, it is not unusual to see as low as 80 percent of this theoretical calculated thermal movement actually used in design. Panels distort a bit; structural mountings or members may be deflected and strained, but roofs don't seem to fail.

On the other hand, if thermal-movement calculations are based upon ambient air (a frequent and novice mistake), they will often be only 50 percent of the correct extremes, and I have seen such roofs fail—repeatedly. A single metal panel exerts forces measured in tons when it tries to move thermally; hence, undue restriction of this anticipated movement easily can precipitate attachment fatigue and failure.

I have also seen professional engineers who try to prove the panel will undergo a "buckling" failure before the attachment will fail. In other words, it will hump up, oil-can or otherwise move out of plane to relieve the thermal forces. The trouble with this theory is that a member only buckles in compression (during an expansion cycle). Most attachment fatigue and failure occurs in tension (during cold-cycle contraction).

Manufactured two-piece clips usually include some mechanism to ensure they are centered at the time of installation. In theory, the roof panels are installed somewhere in the midrange of their in-service extremes. Although it may not be exactly at the halfway mark, common practice does not compensate for exact temperatures at installation. It is absurd to suppose that installers will move clips to some predetermined location contingent upon installation temperature. Even if they did, the temperature is likely to be different when the mechanical seaming is done, thus botching the whole theory. Most clips find their own "centering" within the range of thermal cycling of the roof within the first few months of service.

Rob Haddock is president of the Colorado Springs, CO-based Metal Roof Advisory Group Ltd. He is a consultant, technical writer, training curriculum author, inventor and educator. In 2012 he became a charter inductee of Modern Trade's "Metal Construction Hall of Fame" for his many contributions to the industry.

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Part 7: Metal Roofing from A (Aluminum) to Z (Zinc)

Rooftop Equipment Mounting and Penetrations for Low-Slope Standing-Seam Metal Roofs

Standing-seam metal roofing offers a durable, sustainable alternative to other roof types and can provide maintenance-free service for five to ten decades. Sadly, this exceptional lifespan often is sabotaged with the mounting of essential rooftop equipment and ancillary mechanicals.

Regardless of the roof type involved, consultants generally agree that the best way to prevent roof-related problems is to clear the rooftop of everything possible and just let it function as a roof—not a mechanical equipment platform. However, such a perfect roof continues to elude us, as it becomes necessary or convenient to mount HVAC equipment, screens to hide it, piping to fuel it, scuttles to access it and walkways to service it. The list of rooftop mountings also may include plumbing vents, satellite dishes, lightning protection, snow retention systems, solar collectors, advertising signage, and fall-protection systems to maintain all the foregoing.

▲ Metal roofing can make use of special seam-clamping hardware that grips the standing seam without puncturing the membrane. Seam clamps have made metal roofing a preferred roof type for mounting photovoltaic solar arrays.

To help achieve relatively trouble-free roofs, this segment provides some basic understanding of the dos and don’ts in situations where rooftop equipment mounting is requisite.

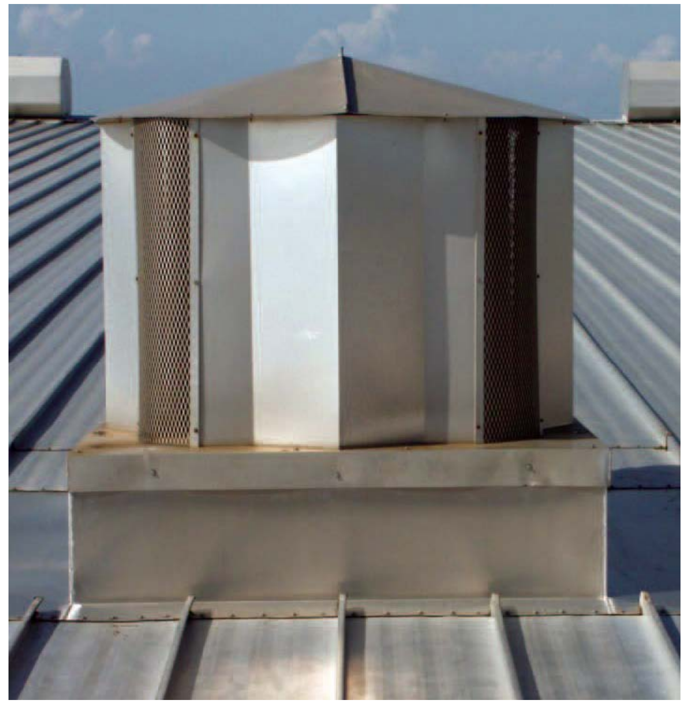
Penetration-free Attachment

A good “first rule” about any rooftop mounting is to avoid penetrating the membrane whenever possible. While this may seem obvious, the tenet is often violated with standing-seam metal. The norm for attaching things seems to involve anchoring the item to the structure through the roof. When this happens, it not only threatens weather integrity, but can also violate the membrane’s thermal-cycling behavior by inadvertently pinning the panel to the structure. Such a point of attachment will fatigue and fail from forces of thermal expansion within a short time. Fortunately, scores of items and equipment can be securely mounted to metal rooftops without any penetration whatsoever, actually making metal roofing more user-friendly than other roof types.

In terms of mounting ancillaries, metal roofing can use special seam-clamping hardware that grips the standing seam without puncturing the membrane. Unlike many other types of roofing, metal is a rigid, high-tensile material. The seam area creates a beam-like structure that can provide convenient anchorage for walkways, solar arrays, condensing units and gas piping without harming the roof’s weathering characteristics. Mechanicals can be safely and cost-effectively secured to these seam clamps, leaving the roof membrane penetration free. Seam clamps can provide holding strength of up to several thousand pounds on some profiles and gauges, last the life of the roof and preserve thermal-cycling characteristics. Using seam clamps when possible for ancillary mounting will eliminate unwanted holes and other potential problems.

Clamps should be made only of noncorrosive metals—typically, aluminum with stainless-steel mounting hardware. These metals are compatible with virtually anything found on a metal roof, except copper (with which there are dissimilar metallurgy issues.) Dissimilar metals in electrolytic contact will induce galvanic corrosion of the less noble metal. In cases involving copper roofing, brass clamps should be used with stainless-steel hardware. Seam clamps generally integrate with the profile and seam folding, and in some way "pinch" the seam material to anchor them in place. Preferred methods of doing this involve setscrews tightened against the seam causing a dent in the seam material

▲ Seam clamps allow even cumbersome ancillary items to be attached to metal roofs without penetrating the rooftop.



▲ Pre-formed structural curbs support weight and seal tightly to the roof.

that in turn creates a mechanical interlock of the setscrew, seam and clamp, providing the greatest holding strength and durability. Setscrews should have round, polished points to prevent galling metallic coatings, which can lead to corrosion. In like fashion, and regardless of the method of engagement, any clamp device should avoid any sharp points or nodes that could potentially pierce or gall metallic coatings of steel or cause fatigue and fracture points of other metals.

It also is important to remember that any loads introduced into the clamp will be transferred to the panels and their anchorage to the structure. Consequently, anchorage must be capable of withstanding the added load. The best practice is to utilize clamps that have been appropriately tested for material and seam-specific holding strength; be sure in-service load does not exceed that of the published holding strength, including factors of safety. The roof manufacturer should also be consulted with respect to approval of devices used.

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BUILD LEGACIES METAL

Mounting HVAC with Structural Curbs

In the case of HVAC and plumbing vents, the roof membrane often must be penetrated. The soil stack must carry gases from the interior to the exterior and the HVAC unit must transfer inside air out, outside air in or both. Holes in the roof are unavoidable; the challenge is to waterproof the penetration area while maintaining thermal-cycling integrity. There are a few rules about handling these kinds of rooftop penetrations in low-slope standing-seam metal that can help ensure a trouble-free installation.

Most small, bottom-ducted HVAC units are curb-mounted, using a preformed structural equipment curb specially manufactured to integrate with the specific roof profile. This curb carries the unit's weight, seals to the roof and maintains the system's thermal-cycling integrity. It is important to engage a company specializing in manufacturing curbs for the metal roofing industry; these companies typically can be identified by the metal roofing manufacturer.

In terms of mounting ancillaries, metal roofing can use special seam-clamping hardware that grips the standing seam without puncturing the membrane.

The best curb is an all-welded design using sheet aluminum at least 0.080 inch thick. Coated carbon steel tends to heat-warp when welded. Additionally, the protective Galvalume or galvanized coating is burned off at welds and cannot be suitably restored. Aluminum welds exceptionally well and does not heat-warp because of its low melting temperature. It is very compatible with sheet steels used for roofing and can provide decades of trouble-free service when correctly designed, fabricated and installed.

It is a common mistake in specification writing to place the equipment-curb scope of work into HVAC or Sheet Metal sections of the spec. Most HVAC and sheet metal contractors do not understand principles of rooftop waterproofing, nor do they understand thermal-movement characteristics of standing-seam metal roofing. The result can be design and installation that violates thermal-cycling and/or weatherproofing issues. Installation that pins the curb flange through the roof and into the structure is a common faux pas, and the use of surface-applied sealants that are ineffective for long-term performance also is a frequent malpractice.

Another common mistake is selecting a curb/flashing design that may be appropriate for steep-slope metal roofing with underlayment, known as water-shedding (or hydrokinetic) design, but is not appropriate for low-slope, hydrostatic (or watertight) design. A suggested practice is to insist the roofing manufacturer approve all rooftop attachments, penetrations and appurtenances—curbs included. The manufacturer should know the type of curb that is compatible with the company's system. And when long-term weather-tightness warranties are specified, they should include all rooftop attachments and penetrations, including curbs.

The best curb design should provide that the curb flange underlays the roof panels at the upslope and overlays them at the downslope, allowing no "back-water" laps. This normally is accomplished by terminating the curb's side flanges by marrying them into a panel seam at either side. The curb walls are built up to a minimum height of 6 inches and flanged at the top to provide an adequate structural mounting surface for the equipment. The sides also are tapered to compensate for the roof slope and provide for level mounting of the unit. The 6-inch minimum height ensures the mechanical unit's interface to the curb is well above the drainage plane of the roof and therefore more forgiving of installation error on the part of the mechanical contractor when waterproofing the equipment to the curb.

It is a common mistake in specification writing to place the equipment-curb scope of work into HVAC or Sheet Metal sections of the spec.

Because this type of structural curb is "floating," (meaning it moves thermally with the roof), there are weight constraints. These curbs can accommodate units weighing up to about 1,000 pounds placed anywhere on the roof. Heavier units can be accommodated if they are located near the roof's point of fixity where movement is minimal. Structural curbs are ordered from a curb manufacturer for a predetermined roof location, specific roof type and by equipment model number. Without a model number, exact equipment dimensions can be used.

The installation details that seal the panels to the curb flange at its upslope end are similar to details used to seal the roof panels at their eave end. Installation involves tape and/or tube-grade butyl polymer concealed within the joints and metal closure components, depending on the panel's rib geometry. All details are hydrostatic in nature for low-slope roofing. Panel ribs are terminated well upslope of the curb wall to allow easy drainage to the sides of the curb. Upslope curb flange dimensions must provide for this.

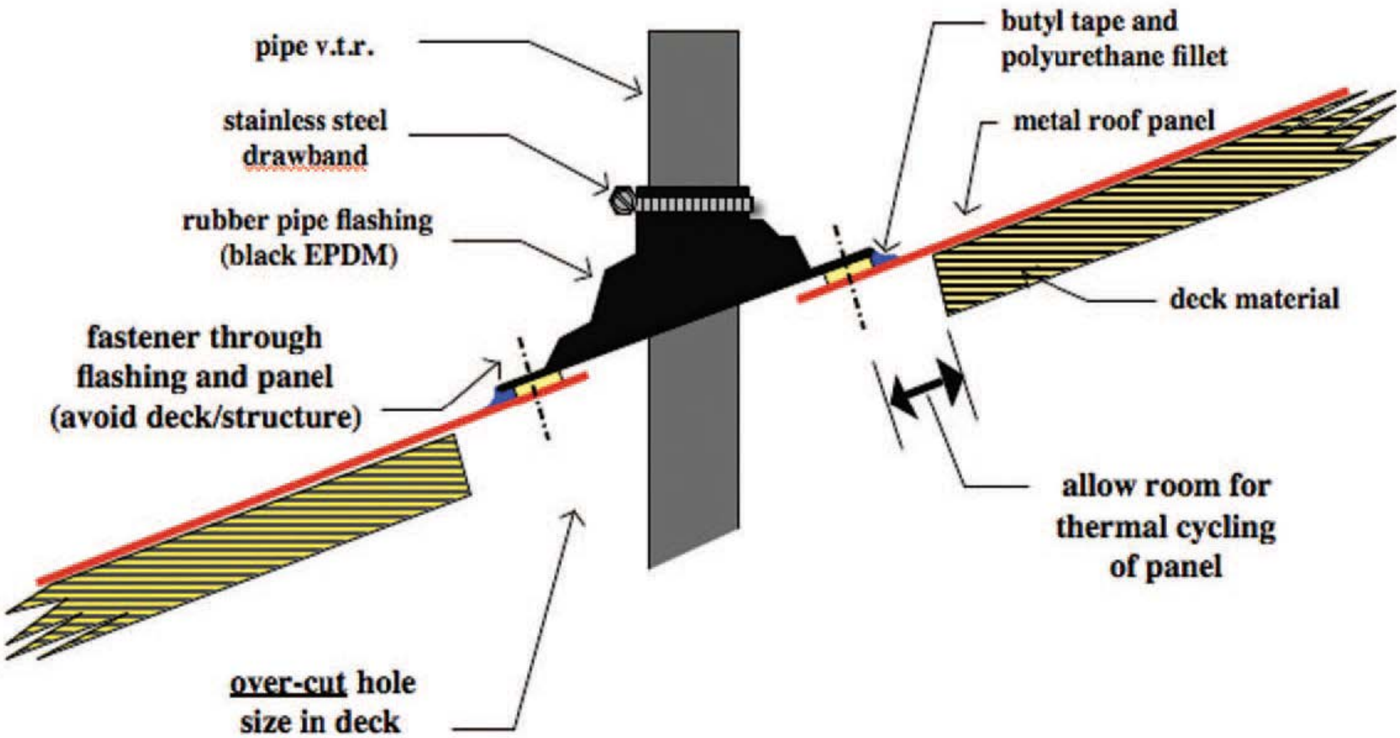
At the downslope joint, the curb flange mates over the flat plane of the roof panels. Rib caps that are furnished loose or welded integrally into the curb flange serve to terminate the panel seams. This also is accomplished with butyl tape and tube seals concealed within the joints. The downslope joint that is created typically is reinforced beneath the assembly with a backup plate or channel. The side flanges are likewise sealed to the roof panels with butyl inside the mating components. All joints are completely hydrostatic with concealed sealants.

Other substructural components may be employed to facilitate the installation; often this type of curb is furnished with board stock insulation mounted to the curb walls. Installation of all critical seals, especially those at seam inter-faces, is of paramount importance, and fasteners must be to the "dry" side of sealant beads or through them. It also is important such a curb and its components are fastened together without pinning to the building structure.

▲ This frame-mounted HVAC unit uses pipe supports that extend to the building structure and are flashed through the roof using rubber pipe flashings.

▲ A frame-mounted HVAC unit can be supported without roof penetration by using seam clamps.

The resulting assembly is free to move thermally with roof panels while sealing completely into the roof "bathtub style," in lay terms, or in accordance with ASTM International E 2140, "Standard Test Method for Water Penetration of Metal Roof Panel Systems by Static Water Pressure Head," in more technical terms. Diverters should be used on the upslope flange of the curb and, whenever possible, the unit should be oriented so the smallest dimension opposes the flow of water. For example, if a unit is 3 by 5 feet, the 5 foot dimension should be parallel to the slope of the roof.



PIPE FLASHING DETAIL

Metal Roof Advisory Group, Ltd. ©1999

Frame-mounted HVAC

Heavier equipment is sometimes mounted above the roof surface on a galvanized steel frame. The frame is constructed using round pipe legs, so they can be flashed with rubber pipe flashings. These legs extend through the roof to supporting structural members. Such a mounting is stationary, meaning there will be differential movement between the frame and roof panels.

Depending on the unit's weight, the support frame also can be mounted on seam clamps to avoid pipe penetrations through the roof. The ribs of structural metal panels are required by ASTM E 1514, "Standard Specification for Structural Standing Seam Steel Roof Panel Systems," and E 1637, "Standard Specification for Structural Standing Seam Aluminum Roof Panel Systems" to support point loads of at least 200 pounds. In other words, a unit weighing 1,500 pounds and spanning across five panel seams can be mounted this way, resulting in 10 bearing points on the five seams, each supporting 150 pounds and well within the ASTM requirement.

When ducting a frame-mounted unit through the roof, it is always advisable to use the smallest hole possible. That is to say, a very large unit only may require a very small duct penetration. A small, sheet-aluminum, all-welded curb is used to waterproof the ducted hole(s) in the roof as before. But in this case, the curb need not be structural because it supports no weight but acts as a flashing only around the duct passing through the roof. The curb style is the same in all other respects.

If the unit is mounted on a stationary frame, the curb must be slightly larger than the actual duct size to allow differential thermal movement between the two. If the unit is mounted to seam clamps, this oversizing is unnecessary because the unit and curb move together in tandem.

Double Curbs

Large, heavy HVAC equipment often also is mounted on a structural curb, which is integral to the building's structural framing system. When such a design is employed, a second flashing curb is used for waterproofing reasons.

The concept is that the first curb, or frame, supports the weight of the unit and the second curb does the waterproofing and integrates into the roof system.

In this case, there is differential movement between the two, so the outer (flashing) curb is oversized to the first and a counter flashing of metal or flexible membrane joins the two, shedding water over the outer curb. The outer curb is of the same design and material as previously described. Again, it need not be of such a heavy gauge because it supports no weight. Installation details of the outer (flashing) curb connection to the roof also are the same as previously described with hydrostatic seals. Because there is differential movement, the joining of the counter flashing is sometimes done with hydrokinetic, or water-shedding, details. This is acceptable because the joint is sufficiently above the drainage plane of the roof. Alternatively, hydrostatic detailing also can be performed when flexible membrane flashings are used.

Using a stainless-steel draw band at the top of the flashing to further secure it will ensure the flashing never inverts itself and typically will add about five years of life to the assembly.

Round Penetrations

Round shapes, such as plumbing vents, should be flashed through the roof using EPDM or silicone rubber pipe flashings. Although these parts are widely available in various colors, black has the greatest UV-resistance and longest life, and although more costly, silicone will far outlast EPDM.

Standard installation is to cut an undersized hole and stretch-fit the rubber to the pipe. Using a stainless-steel #14 by 7/8-inch "lap-tek" screws with #1 drill point at 2-inch centers through the compression ring, rubber and butyl, and into the metal panel.

Ideally, excess butyl tape should be trimmed away, and a bead of one-part polyurethane sealant filleted around the joint thus created (base to roof). This bead hides and protects the butyl from direct exposure to sunlight, ensuring a longer life. After a service life of 20 to 25 years (significantly longer for silicone rubber), this assembly is easily replaced.

When attaching the pipe flashing, it must be anchored solely to the roof panel and not into the building structure or deck. To do so would create an inadvertent pinning of the panel, violating freedom of thermal movement. Ideally, these flashings should be centrally located on the roof panel so there is free drainage to both sides without seam interruption.

If the location of the pipe interrupts a seam and it cannot be relocated, a preformed adapter plate can be fabricated to span both panels adjacent to the seam and the pipe flashed as mentioned above to the adapter plate. Most companies that pre-manufacture curbs will make such adapter plates on request.

Rooftop mountings and penetrations are a challenge for any roof type or material. Following these simple guidelines can help ensure trouble-free and enduring performance for a state-of-the-art low-slope metal roof system.

Rob Haddock is president of the Colorado Springs, CO-based Metal Roof Advisory Group Ltd. He is a consultant, technical writer, training curriculum author, inventor and educator. In 2012 he became a charter inductee of Modern Trade's "Metal Construction Hall of Fame" for his many contributions to the industry.

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