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Metals for Historic Roofing: An Update

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Fig. 1.
A new flat seam and standing-seam copper roof on an historic house in Ithaca, New York. The flat seam pans were installed earlier than the standing seam pans and have already begun to form a brown patina. All photographs are by the authors.

Much has changed in recent decades regarding metals used in the repair, rehabilitation, and replacement of historic roofing materials, and the field is certain to continue to evolve. Nevertheless, this paper provides an update on the topic, as of mid-2022, with a focus on solderable metals most commonly used in historic roofing applications and their more recent substitutes.[1]

Copper continues to be the most consistently used metal in historic preservation work for flashings, rainwater conduction systems, and the primary roof covering of buildings. It is with the so-called "gray metals"—lead coated copper, terne coated stainless steel (TCS)™, tin zinc alloy coated stainless steel and copper (TCS II™, Independence Gray™, FreedomGray™), tin coated stainless steel (Tin Matte), lead, and zinc—where much of the change has occurred. Rounding out the field, stainless steel and Monel® will be discussed as well. See Table 1 for a summary of the ASTM standards associated with each of these metals, as well as solders and fluxes commonly used in their fabrication. While other metals, such as aluminum, Galvalume™, and painted steel, are widely available in today's marketplace, their use is largely dedicated to new construction and therefore beyond the scope of this paper.[2]

Table 1. ASTM Standards and Soldering Guidelines for Metals Used in Historic Roofing

Metal	ASTM Standard	Solder*	Flux**	Comment
Copper	B370	50/50 tin/lead	A	
Lead-Coated Copper	B101	50/50 or 60/40 tin/lead	A	
TCS		60/40	B	
TCS II	A240 (base stainless steel)	Lead-free, 100% tin	B	Terne II™ similar
Independence Gray	A240 (base stainless steel)	Lead-free, containing antimony***	C	
FreedomGray	B370 (for base copper)	Lead-free, containing antimony***	C	
Tin Matte	A240 (base stainless steel)	Tin/lead containing at least 30% tin	D	100% tin solder may be used for lead-free applications.
Stainless Steel	A167 or A240	60/40 tin/lead	E, F	Do not overheat; use cooler irons and longer contact to account for low thermal conductivity.
Monel	B127	60/40 tin/lead	E, F	Do not overheat; use cooler irons and longer contact to account for low thermal conductivity.
Zinc	B69	50/50, tin/lead	G	Surface preparation is dependent on zinc alloy and finish; follow manufacturer's recommendations.
Lead	B749	N/A****	N/A	Gases used in the torch should be hydrogen and oxygen only. Avoid burning through or reducing the thickness of the lead seam.

* Typical solders complying with *ASTM B32, Standard Specification for Solder Metal*; other solders may be appropriate as well.

** The letters in this column refer to different types of flux, as follows:

A. Muriatic acid neutralized with zinc (killed acid), such as Blitz™ by American Solder & Flux Co., Paoli, Pennsylvania. RubyFluid™ Flux, Superior Flux & Mfr. Co., Cleveland, Ohio, is preferred in some regions.
B. Rosin flux or zinc chloride-based flux. Follansbee's Speed Flux™ was used in the past.
C. Flux containing mild chlorides in paste form mixed with pure tin and with a melting temperature of 450 degrees Fahrenheit. Johnson's E-127 Flux-'N-Solder with Pure Tin™, Johnson Manufacturing Company, Princeton, Iowa, is recommended by the Revere Copper Products, Inc., Rome, New York (Revere).
D. Proprietary flux marketed by Roofinox or phosphoric acid-based flux.
E. Phosphoric acid type flux such as LA-CO "M-A" Stainless Steel Soldering Flux, Liquid™, by LA-CO Industries, Inc./Markal Company, Elk Grove Village, Illinois.
F. Zinc chloride flux containing free hydrochloric acid, such as Johnson's No. 1 Stainless Steel Flux™, Johnson Manufacturing Company, Princeton, Iowa.
G. Today, zinc manufacturers have specific recommendations for their products. Consult and comply with manufacturer's recommendations.

*** Johnson's #497 SuperFloPure Lead-Free Solder™, Johnson Manufacturing Company, Princeton, Iowa, is recommended by Revere.

**** Lead is technically "burned" (welded) to melt and fuse the lead sheets, not soldered. Burning rods should be the same composition as the lead sheet.

All of the metals discussed below are very durable. Note that the expected service lives cited below are for the field of a roof and assume the use of heavier gauges where available (for example, 20-ounce copper in lieu of 16-ounce), installation in accordance with industry standards and manufacturer's recommendations, timely maintenance, and non-industrial applications. As is true of many types of long-lived roof systems, areas that experience concentrated water flows, such as gutters, valleys, and gussets/crickets, will wear more quickly than the field of the roof and may require repair or replacement approximately midway through the service life of a metal roof. Such localized repair or replacement should be considered a standard practice and does not necessarily warrant full roof replacement. Special care should be taken when specifying metals and their alloys that will be subject to salt spray, such as those located near a seacoast (typically within approximately one mile of the coast), including discussions with manufacturers. Please note that the information presented in this paper represents the knowledge and experience of the authors and is intended to educate the reader about the benefits and limitations of several materials and products. This article is not intended to promote or criticize any particular product or any material and does not constitute project-specific advice by the authors or by the Association for Preservation Technology.

Copper

Copper, sometimes referred to as "red copper" or "mill copper" to differentiate it from coated copper, has been used for centuries to clad the building envelope; it was the most commonly installed architectural metal until the mid- to late twentieth century, when it was surpassed by both steel and aluminum (Fig. 1). Copper's popularity is attributable to its workability, aesthetic beauty, solderability, and, more recently, its capacity to be easily and efficiently recycled. Copper is specified with reference to its weight in ounces per square foot, with historical uses for roofing employing 12-, 16-, 20-, 24-, and 32-ounce copper. Heavier weights were and still are available; however, they are rarely used. The use of 12-ounce copper for roofing is no longer considered cost-effective; 16-ounce is generally the lightest roofing material used today. Copper roofing has an expected service life of up to 100 years.

Copper's workability relates to its ductility, which varies depending upon the temper of the metal. Cold-rolled copper, sometimes called 1/8 hard, or ASTM B370 H00 temper, historically has been used for roofing purposes. Soft, or "dead soft," B370 O60 temper copper has traditionally been used for ornamentation such as pressings (rosettes, crockets, etc.) or spun elements (balls). Soft copper is also used as a flashing for irregular substrates, such as rock-faced stone masonry.

The beauty of copper is provided by the patina it develops over time. The natural patination process varies with geographic location and roof slope and requires water and oxidizing chemicals (air pollutants), which turn the copper from a shiny bright red to dark brown within a few weeks or months, and eventually to green. With the reduction of the use of coal and the resultant decrease in the amount of sulfur dioxide in the atmosphere, the time for copper to patina to its final green color has increased from 25 years in the past to an unknown time in excess of 25 years in the present day. In some instances, the final green patina may not develop within the life expectancy of the material. Copper's patina protects the underlying copper from additional oxidation, although it can be removed or prevented from forming in areas with high-volume water flow and where wash water contains acids, as is the case when used in conjunction with cedar roofing (tannic acid) or asphaltic mastics.

Induced patinas have long existed; however, they have largely changed from site-applied vile concoctions, sometimes containing urine, to factory-applied chemicals. Since the oxidizing chemicals associated with the natural patination process vary with the location of the installation, with each creating its own unique hue of green, the factory patina will invariably be less uniform and different from that which occurs naturally. Newly developed factory heat treatments can provide a uniform, dark brown copper to avoid the glare associated with shiny new copper. Heat treatment provides the initial stages of patina, but when heat-treated copper is formed by hand or in a brake or roll former, or scratched, or otherwise abraded, such as in preparation for soldering, it will show the shiny unoxidized red copper below.

The mixing of different types of metals on a roof is strongly discouraged due to the possibility of galvanic corrosion. If, for example, wash water containing copper ions is allowed to flow over less noble metals such as aluminum, zinc (including galvanized metal), and iron, rapid and severe galvanic corrosion of these less noble metals will occur. Note, as well, that the wash water from copper that flows over light-colored or porous materials, such as limestone and concrete, will cause green staining of these materials.

Lead Coated Copper

Lead-coated copper (LCC) was developed in the early 1930s by Revere Copper and Brass Co. to serve as a lighter and more durable substitute for lead roofing and flashings less prone to problems associated with creep (sagging and tearing). Although the use of LCC has declined in recent years, it is still employed on a limited basis, primarily for preservation projects. While copper by itself is corrosion-resistant and very durable,

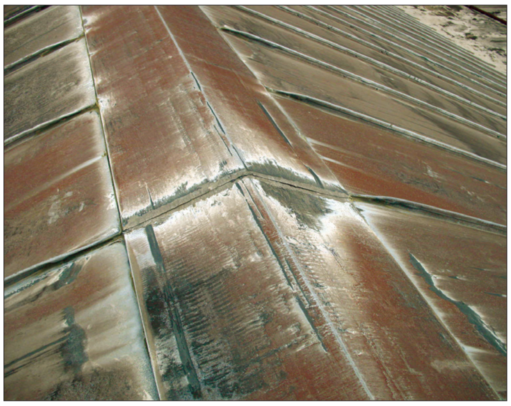


Fig. 2.
Twenty-year-old lead coated copper standing-seam roofing and flashings on an historic theater in Philadelphia, Pennsylvania.

Fig. 3.
A red lead oxide patina has formed on this standing-seam lead coated copper roof.

the addition of the lead coating (weighing 12 to 15 pounds per 100 square feet, or 6 to 7 1/2 pounds per side) protects the underlying copper from weathering and provides an anticipated service life of more than 100 years. Although all weights and tempers of copper can be coated, in the past the use of 16-ounce and 20-ounce LCC was most common. Mounting public concern over the environmental and health impacts associated with lead and the runoff from LCC roofs has reduced demand for LCC in recent decades. Domestic manufacturers ceased regular production of LCC by about 2011. Today, some metal fabricators and contractors are dipping copper sheet in molten lead to produce LCC on an as-needed basis. There may be, however, long lead times to procure the material; large quantities may be difficult to obtain; and quality may vary based on the method of dipping and on the source of the base copper sheet.[3] Due to the limited availability and associated environmental hazards, substitute materials may warrant consideration for preservation projects. Where a gray metal is historically appropriate, tin-zinc alloy-coated copper, tin-coated stainless steel, stainless steel, or zinc may be acceptable options (see below for more information on each of these metals).[4]

Over time, changes in the atmosphere have altered the way LCC patinates. Prior to the late twentieth century, sulfur-based pollutants (primarily from the burning of fossil fuels) reacted with the lead coating to form a relatively uniform, dark gray, lead sulphate patina (Fig. 2). Following passage of the United States Clean Air Act in 1970, decreasing amounts of sulfates in the atmosphere changed the way the lead coating oxidizes, often resulting in an uneven, sometimes streaky, appearance that, depending on the local environment, can be rusty red (red lead oxide), white (lead carbonate), or black (thought to be a lead oxide) in color (Fig. 3). In most cases, the discoloration is believed to be primarily an aesthetic issue that does not impact the metal's performance. Over extended periods of time (around 30 to 70 years), the lead coating on LCC gradually wears off, exposing the underlying copper sheet, which naturally develops a green patina. This gradual color change from gray to green is not a sign of deterioration, and the underlying copper should continue to perform reliably. The environmental implications of the gradual erosion of the lead coating should not be ignored, though. Lead carried by rainwater washing over the metal's surface can be absorbed by, or redeposited on, materials in the drainage path, including soil and groundwater. Evidence of lead-containing runoff can be seen in white stains that develop over time on dark building materials, such as black slate shingles, located below LCC.

Independence Gray™

Although TCS, TCS II, and Independence Gray products are no longer available, they did play an important role as gray metals in preservation work for more than 40 years during the latter half of the twentieth century and into the second decade of the twenty-first century.

TCS, short for terne coated stainless steel, was developed and used in historic preservation work primarily as a more durable substitute for terne metal (tin/lead alloy on steel sheet) and LCC.[5] TCS was manufactured by Follansbee Steel of Follansbee, West Virginia, from about 1968 to 1997. It consisted of Type 304 stainless steel sheet with an 80 percent lead/20 percent tin alloy coating on both sides.[6] As such, its appearance was much like that of terne and LCC (Fig. 4). The total thickness of the coating was approximately 25 microns. TCS offered advantages over traditional terne metal. TCS was very durable (with an expected service life of 100 years or more), was virtually maintenance free, and generally weathered to a pleasing dull gray color. Terne, however, had to be painted on a regular basis to help mitigate corrosion. TCS could be painted (Follansbee maintained a line of linseed oil-based paints called Terne-Cote I, a primer, and Terne-Cote II, a finish coat), but it did not have to be coated to remain free of corrosion. TCS's main advantage over LCC was the added durability and the stiffness of its stainless-steel substrate sheet. Like LCC, TCS was subject to red lead oxide staining.

Follansbee Steel replaced TCS with Viromet™ (a 50 percent zinc/50 percent tin-alloy-coated stainless steel) ca. 1997. Viromet was touted as being environmentally friendly because zinc was substituted for lead in its alloy coating. Viromet was renamed TCS II in 1998 and was employed widely in both preservation work and new construction (Fig. 5).[7] Follansbee Steel closed in 2012. Revere purchased the intellectual property and equipment associated with TCS II from Follansbee and briefly marketed it in 2014 under its rebranded name, Independence Gray. Although some of the product did make it onto roofs, the challenges of manufacturing Independence Gray proved too great, and production ceased shortly after its introduction.

Tin Zinc Alloy Coated Copper: FreedomGray

Portending its exit from the manufacture of LCC in 2004, Revere introduced FreedomGray, a tin-zinc (T-Z) alloy coated copper, in 1999. Produced in partnership with Follansbee Steel, using Follansbee's patented coating process, FreedomGray T-Z alloy consists of copper sheet with a 0.5-mil thick (0.0005 in.), 50 percent zinc/50 percent tin-alloy coating on both sides. With Follansbee's demise, Revere acquired the technology for the manufacture of FreedomGray in 2012. After reestablishing the production line at its headquarters in Rome, New York, and some production delays, Revere successfully reintroduced FreedomGray in 2014 and continues to manufacture the product today. FreedomGray has an expected service life of approximately 100 years, although the T-Z coating may erode more quickly in areas of concentrated water flows.

Besides being more environmentally friendly than LCC, FreedomGray offers several other advantages, among them:

- Not being affected by the sulfur content of the atmosphere, FreedomGray weathers to a fairly uniform, soft, slate-colored gray within one to five years.
- Unlike LCC, the rainwater runoff from FreedomGray will not impart a whitish haze or stain on dark colored materials. such as black slate shingles.
- FreedomGray is supplied with a pre-weathered (painted) finish to reduce its initial reflectiveness (Fig. 6).

Design limitations associated with FreedomGray to be aware of include the following:

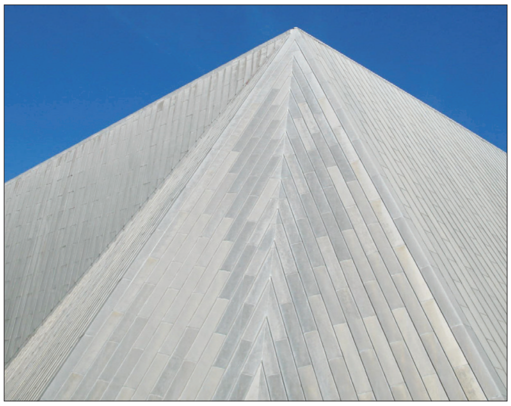
- Its incompatibility with other metals. FreedomGray should not be used in contact with or below other metals, especially copper, due to the possibility of galvanic corrosion.
- Its incompatibility with organic acids, such as hydrochloric acid contained in some masonry cleaning products, and tannic acids found in cedar shingles and shakes.
- Specific soldering requirements, including cleaning methods and the use of a particular proprietary tin-loaded flux and lead-free tin/antimony solder. Pre-tinning is recommended as well.
- Not recommended for use in some marine environments located within one mile of saltwater.

Tin Matte

Tin Matte consists of Type 304, Type 316L, or Type 439 stainless steel sheet with an electroplated and brush-rolled coating of pure tin on both sides. It develops a matte, medium charcoal-gray patina over time (typically within about two to three years) and can be used in lieu of lead coated copper, traditional tin and terne, and TCS II for roofing, cladding, flashings, and rainwater conduction systems.

Tin Matte is manufactured by Roofinox. Roofinox stainless steel was developed in the 1990s in Germany. Roofinox America was established in Eatontown, New Jersey, ca. 2017 and then moved to Chicago, Illinois, in July 2019. Compared to traditional stainless steels used in roofing, such as Type 304 with a 2D (low reflective matte) finish, Tin Matte's tin coated stainless steel is far less reflective, more malleable, less hard, simpler to work (brake, form, fold), and, because of the tin coating, easier to solder. Tin Matte is very durable in most environments and backed by a 60-year manufacturer's warranty, which covers materials and surface finishes.[8]

Caution is recommended when considering the use of Tin Matte as cladding on vertical surfaces and soffits due to the potential for uneven patination. Even on roof surfaces, local climate conditions—humidity, precipitation, tree coverage, salts in the air—can influence the uniformity and speed with which the patination process takes place. Other limitations include yellow staining, gray or black spots, and uneven patination prior to achieving its fully developed patina; the recommended use of stainless-steel tools so as to limit iron spotting; and the need to avoid direct contact with concrete substrates to preclude corrosion.



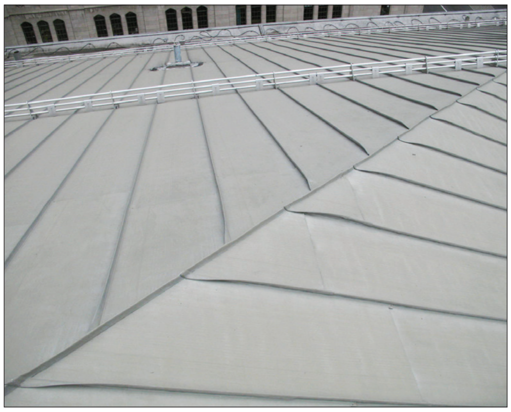


Fig. 4.
Partial view of a standing seam TCS II roof located in Philadelphia, Pennsylvania.

Fig. 5.
Forty-year-old standing seam CS roof located in mid-Atlantic region.

Fig. 6.
Newly installed FreedomGray coping cap on a church in Haddonfield, New Jersey. Note that the copper counterflashings in the upper left were separated from the FreedomGray using a concealed isolation membrane.

Fig. 7.
A batten seam stainless steel roof shortly after completion. The reflectiveness of the Type 304 stainless steel is somewhat subdued due to the roof being in shadow in this photograph.

Tin Matte is available in only two thicknesses (0.0197 in./26 gauge for Type 439 stainless steel and 0.0236 in./24 gauge for Type 304 and 316L stainless steel). A limited number of metric sheet and coil standard sizes are available, although any width up to 39 inches may be specified, as long as the drop-off is purchased.[9]

Stainless Steel

Although production of stainless steel in the U.S. dates to the early twentieth century, its use as a roofing material has never been widespread. In contemporary construction, stainless steel is often used for flashings, and, in certain situations, it may also be appropriate as a substitute material for historic metals that are no longer available or in limited production. The addition of chromium to steel is what imparts the corrosion resistance for which stainless steel is well known.

More than 50 stainless steel alloy formulations are available; they vary in their chromium and accessory metal content and, therefore, in their ability to resist corrosion. Most stainless steels used for architectural applications fall into the 300 or 400 series as defined by the American Iron and Steel Institute (AISI).[10] Chromium also imparts a hard, reflective finish to the metal, which does not change or weather significantly over time. Even with a No. 2D finish, which is classified as matte and non-reflective, stainless steel is still rather shiny and may not be appropriate for all preservation projects (Fig. 7).[11]

While stainless steel can be expected to provide a service life in excess of 100 years, its use in architectural applications poses several challenges. Stainless steel is stiffer than other metals used for roofing, which makes it more difficult to form, especially when using hand tools in the field. In addition, its low rate of thermal conductivity and the presence of a tenacious chromium oxide coating (the attribute that protects the metal from corrosion) make soldering stainless steel exceedingly challenging, even for experienced mechanics.[12] Successful soldering of stainless steel requires the use of appropriate flux and solder, time to distribute the heat through all layers of metal in the seam, careful monitoring of the soldering iron's temperature so as not to warp or discolor the metal, and neutralization of the flux upon completion.

Monel

Monel, specifically Alloy 400, which is used for roofing applications, is comprised of approximately 65 percent nickel and 30 percent copper (other alloys are available, but they are too difficult to work in the field and are not considered suitable for architectural applications). Monel was introduced in 1905 by the International Nickel Company, Inc., and was first used for roofing and cladding shortly thereafter. It is a shiny gray metal with a coefficient of thermal expansion similar to that of copper, and it patinas to a gray or honey-brown color. If protected from the weather and exposed to chlorine (such as when installed near bodies of saltwater), Monel will patina to a soft green due to its copper content. Monel is recognizable by its patina, but also by (a) ink printing that was applied on one side of the material identifying it as Monel, (b) the fact that when scratched it reveals a bright silvery finish, and (c) its being slightly magnetic. Monel is not toxic to humans, but its wash water will retard organic growth, much like copper and zinc.

Monel is highly resistant to corrosion, more so than either of its nickel and copper constituents alone. That said, Monel can be adversely impacted by the chemicals used in chromated copper arsenate (CCA)-treated wood preservatives, which can create pinholes in the metal if CCA-treated wood is placed on top of the metal as sleepers or walkways.

While Monel as thin as 0.018 inch was available historically, the most common thickness used for roofing was 0.021 inch, which has a life expectancy of over 100 years (Fig. 8). The application of architectural Monel was typically limited to governmental, ecclesiastical, or high-end projects up until World War II, at which point its use all but stopped as copper and nickel were needed for the war effort. It was replaced by stainless steel, which has many of the characteristics of Monel, such as similar aesthetics, workability, solderability, and durability. After World War II, Monel never regained popularity, in part due to its high cost relative to that of stainless steel. Flat stock Monel is not widely available today, but a few specialty metal suppliers may have some quantity of 0.021-inch sheets available. Custom orders are also possible, but with minimum quantities.

Zinc

Zinc has been used as an architectural metal in the U.S. since the early nineteenth century, first as an import, then with domestic production beginning in the late 1830s. Historically, zinc has been used for ornamentation, roofing pans, and flashings for other types of roofing, such as slate and tile. While not as prevalent as other architectural sheet metals, zinc increased in use beginning in the late 1980s, due to the development of new alloys that improved its workability and due to growing environmental concern over the use of lead and lead-coated copper (Fig. 9). Zinc patinas to a uniform, soft, blue-gray color. Today, zinc is sometimes used as a replacement metal for lead and LCC roofing and cladding, due to the similarity in their patinas. Zinc is ductile, which allows it to be readily formed or pressed into intricate shapes. It is often used to create ornaments for galvanized-steel cornices.

Zinc is anodic to iron and thus the major component in the coating process of steel, known as galvanizing. Zinc is close to aluminum and steel on the galvanic chart and is therefore compatible with these metals. Zinc is a much less noble metal than copper. As such, the use of copper and zinc on the same roof should be avoided to prevent galvanic corrosion of the zinc. The wash water from zinc will not stain or corrode most other materials.

Standing water on zinc should be avoided due to the potential for corrosion. This includes the time period prior to installation, while the material is being stored on the job site. Venting of the underside of zinc roofing is considered best practice; without it, the corrosion process is interrupted prior to the formation of a stable and protective layer of zinc carbonate, which will cause the zinc to thin over time. Condensation on the back side of zinc in the presence of acids, such as tannic acids contained in wood substrates and acidic materials such as asphalt underlayments, will rapidly corrode zinc, causing widespread thinning and pinholes. Wood preservatives containing copper in the presence of condensation can also rapidly corrode zinc.

Zinc becomes brittle at temperatures around 50 degrees Fahrenheit. Working of the metal near or below these temperatures should be avoided to preclude cracking and fracturing of the metal. Zinc cannot withstand a hard 180-degree bend. Rather, a bend radius of at least two times the material thickness (sometimes four times or more) is needed to prevent cracking. This property of zinc makes it well-suited for wall panels that typically use only single lock, rather than double lock, seams.

Zinc has a relatively high coefficient of thermal expansion, approximately twice that of copper. Expansion provisions, even in small pieces of zinc roofing and flashings, should be allowed for in its design detailing and installation. For these reasons, and the fact that most other metals are easier and less expensive to install and solder, the use of zinc in built-in gutters is not common.

Today's zinc-alloy sheets (known as titanium zinc), all of which are imported from international mills, are composed of zinc and small amounts of titanium and copper and can be pre-finished at the factory to provide several patinas and colors or left with a mill finish to patina naturally. Zinc is easily prepared to receive coatings, such as paint, to match a metal cornice. Some manufacturers offer a protective coating on one side of the zinc to improve its resistance to corrosion from underside condensation, although venting of coated material is still recommended. The use of zinc in coastal environments should be undertaken cautiously, since salt deposits not washed away by rain, such as at soffits and walls, will corrode the metal. Material thicknesses used today for roofing are most commonly specified as 0.7 millimeter and 1.0 millimeter. The new zinc alloys have a proven track record of 30 years, but their ultimate life expectancy is, as of yet, unknown.

Lead

Lead roofs on historic buildings are relatively uncommon in the U.S. Instead, lead was typically used in smaller, more decorative roof elements, such as turrets and eyebrow dormers (Fig. 10). The use of lead as a flashing material, however, was fairly widespread and continued well into the twentieth century, especially as counterflashings at rock-faced vertical walls and as through-wall flashings set below masonry coping stones. Because lead is very malleable and can easily be formed

Fig. 8.
This roof contrasts 80- to 95-year-old batten seam Monel, a 20-year-old Monel gutter liner, and new Type 304 stainless steel coping caps with a 2D finish.

Fig. 9.
A zinc clad vented soffit.

Fig. 10.
Decorative flat-seam lead roofing and a lead finial atop a church baptistery. The use of rounded battens and small pans helps to mitigate fatigue and creep failure.

Fig. 11.
Fatigue cracking in a lead counter-flashing.

into ornate shapes, it was a common choice for the cladding of cupolas, steeples, and fleches, as well as other architectural details. Its use has declined in recent decades due to environmental and health concerns, though its malleability still makes it desirable for certain uses, such as flashings associated with curvilinear tile roofs, including Mission style and S-tile roofs.

Lead sheet is still available and may be used in preservation projects where appropriate. Properly designed and installed lead roofs and flashings may be expected to provide a service life of up to 100 years. This can be reduced, however, to 70 years or less by creep and fatigue cracking, the material's primary failure mechanism. The most common weight used for architectural applications is 4-pound lead, though many other weights are available.[13] When specifying lead, its environmental impact and tendency to stain dark-colored materials, as described above for LCC, should be considered, along with the following issues.

- With a coefficient of thermal expansion that is almost two times greater than that of copper, lead expands and contracts more than most other architectural metals in response to changes in temperature. Thermal movement creates stress, which, combined with lead's malleability, make it particularly susceptible to fatigue cracking (Fig. 11).
- Soldering lead can be tricky because it is a relatively poor conductor of heat and because the oxide film that forms on its surface interferes with wetting (solder's ability to adhere to the metal).[14] More durable joints are produced by "burning," a welding process by which the metal is melted to join two pieces together.
- Lead's density prevents it from fully contracting back to its original position after expanding. Over time, this tends to result in creep, particularly if the substrate is steeply sloped and the metal is not well secured.
- Squirrels, rodents, and some birds gnaw on lead flashings, creating holes. Application of mastic or a clear sealant will usually mitigate the problem.

Where appropriate, other gray metals, such as tin-zinc alloy coated copper, tin coated stainless steel, or zinc may warrant consideration for use in repair and replacement work.

Metals available for use in the preservation of historic structures are constantly changing with the marketplace and as new innovations and products are introduced. This paper endeavors to serve as a much-needed update but is inherently limited to a point in time. To stay abreast of ongoing changes in the industry, it will be necessary to remain in contact with manufacturers' representatives, attend trade shows, and review industry and technical literature, or consult with those that do. Despite all of the change that has occurred in the past, and that yet to come, our ability to sympathetically address the insidious weathering of historic metal roofing materials remains bright.

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Notes

1. Soldering is a process whereby two pieces of metal are bonded together by flowing a molten filler metal (the solder) through a seam or joint using a heated iron. Solder has a lower melting point than the metal pieces being joined. Flux is applied to the seam prior to soldering to both clean the metal surfaces and help facilitate flow of the solder through the seam. Importantly, the iron is used to heat the metal being joined to the melting point of the solder. Holding the bar of solder to the metal thus causes the solder to melt and flow though the seam via capillary action and by "following the heat." Not all metals solder with equal ease due to the variability with which they conduct and retain heat.

2. Still other metals, such as copper-clad stainless steel (for example, CopperPlus by the Wickeder Group of Wickede, Germany, formerly available from Hayco Metals in Reading, Pennsylvania) and copper-clad aluminum, which currently may be available to a limited extent, were not used historically and do not constitute a large segment of the North American roofing market.

3. North American–produced copper may be necessary to ensure that the metal's properties comply with *ASTM B370, Standard Specification for Copper Sheet and Strip for Building Construction.*

4. The authors' experience suggests that LCC was often used to replace older copper roofs, to the detriment of the structure's historic integrity. The presence of a LCC roof on a building today does not necessarily mean that LCC was the original roofing material. In those cases, uncoated ("red") copper would be a more historically appropriate choice.

5. Terne metal, or terne plate, is composed of copper-bearing carbon steel coated on both sides with terne, an alloy consisting of approximately 20 percent tin and 80 percent lead. Terne plate production began in England in the early nineteenth century and, according to "A Historical Survey of Metals" by Margot Gayle and David Look in *Metals in America's Historic Buildings* (Washington, D.C.: U.S. Dept. of Interior, Government Printing Office, 1980), 9, it was first produced in the U.S. by Joseph Truman in New York City in 1825, gradually replacing traditional tinplate roofing (carbon steel sheet coated with pure tin). Neither is available in today's marketplace. Follansbee's Terne II (carbon steel sheet coated with a tin-zinc alloy) is also no longer available.

6. Follansbee Steel was founded in 1812 and was one of the earliest producers of tinplate in the U.S.

7. Follansbee's paint for TCS II (which, like TCS, did not have to be painted, but could be) and Terne II was a water-based acrylic primer and finish coat system called RAPIDRI™.

8. Other tin coated stainless steel products do exist but may not be as readily available as Tin Matte in the U.S. Uginox™ Patina, by Aperam of Luxembourg City, Luxembourg, is an example.

9. "Drop-off" refers to the "waste," or that portion of the sheet or coil that remains after being cut to the desired width.

10. Type 300 stainless steels (the austenitic types) contain 16 percent to 26 percent chromium and 6 percent to 14 percent nickel, depending on the alloy, and offer greater corrosion resistance than the 400 series (the martensitic and ferritic alloys), which contain 11 percent to 18 percent chromium and little to no nickel.

11. Four standard mill finishes, varying from dull to highly reflective, can be produced through various hot- and cold-rolling, pickling, and annealing processes.

12. The thermal conductivity of copper is approximately 239.0 BTU/(hr./ft./°F), which contributes to rapid, uniform heating of the metal and helps the molten solder flow. By comparison, the thermal conductivity of stainless steel is approximately 8.09 BTU/(hr./ft./°F). This means that heat from the soldering iron is transferred across a piece of copper about 29 times faster than stainless steel.

13. Lead's gauge or thickness is expressed in pounds per square foot. A 4-pound lead has a thickness of approximately 0.0624 inch.

14. The thermal conductivity of lead is approximately 21.2 BTU/(hr./ft./°F).

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