Fully Soldered Metal Roofing:
More Complicated Than You Think

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Abstract

Copper roofing has been used for centuries, particularly on ornate institutional or historical buildings where access and roof maintenance are impractical. When fully soldered, copper roofing can provide a watertight, durable roof with a decades-long service life; however, these roofs are highly dependent on proper design and careful craftsmanship during installation. The presenters will discuss common issues with fully soldered metal roofing, including improper accommodation for thermal expansion, improper rivet or joint detailing, and drain details for contemporary copper roofs that incorporate membrane underlayment.

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FULLY SOLDERED METAL ROOFING:
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INTRODUCTION
Copper roofing has been used for centuries, and metal roofing is still regularly used today, particularly on ornate institutional or historical buildings where access and regular roof maintenance are challenging. When fully soldered, metal roofing can provide a watertight, durable roof with decades-long service life; however, these roofs are highly dependent on both proper design and careful craftsmanship during installation. Industry guides—such as Revere’s Copper and Common Sense (C&CS), the Copper Development Association’s Copper in Architecture Handbook, the Sheet Metal and Air Conditioning Contractors’ National Association’s (SMACNA’s) Architectural Sheet Metal Manual, and the National Roofing Contractors Association’s (NRCA’s) roofing manuals—provide designers and installers with direction for basic system details and general joining procedures (e.g., locking, riveting, and soldering), but careful consideration is required to carry these concepts through to project-specific conditions.

In this paper, we discuss common pitfalls associated with fully soldered metal roof applications, with particular focus on joining procedures, detailing for thermal expansion, and drainage of “bi-level” metal roof systems that incorporate a membrane underlayement.

FULLY SOLDERED METAL ROOFING APPLICATIONS
“Metal roofing” covers many applications and configurations, such as field-fabricated standing or batten seam, corrugated panels, composite metal panels, prefabricated “snaplock” systems, etc. Most metal roofing applications are used on steep-slope roofs and are constructed with loose locked seams or lapped joints; these systems are not watertight and rely on the roof slope and a weather-resistant underlayement material to function. These types of water-shedding systems are not the focus of this paper. This paper instead focuses on fully soldered low-slope metal roofing and built-in gutter applications. These applications collect or hold water (or ice/snow) and must remain watertight to provide durable and reliable performance. Fully soldered metal flashing is often similarly relied upon for watertight performance. The material selection, expansion detailing, and jointing discussion contained in this paper also generally applies to such flashing, though flashing is not the focus of our discussion.

Sheet Metal Materials
Most architectural sheet metals can be soldered (with the correct materials and techniques); however, copper (either as uncoated “red” copper, zinc-tin-coated copper, or lead-coated copper) and stainless steel are the most commonly used metals in soldered roofing applications for the following reasons: Both are common construction materials readily available in sheet stock, they are relatively easy to bend and join in the field, and they are well-suited for exposed roofing conditions due to their relatively long expected service life and low risk of corrosion from atmospheric conditions or contact with other typical construction materials (e.g., fasteners, flashing, and drain hardware).

Copper is particularly well-suited for soldered roofing as it is relatively soft and easier to form and work in the field than some other sheet metals. Copper also has high conductivity, which helps draw solder into joints; and it does not oxidize as quickly as some other metals, thus requiring less rigorous cleaning and flux application during soldering.

Stainless steel requires more patience and skill to solder than copper, but it can also be used for soldered metal applications—particularly where required for aesthetic reasons or where copper may result in green patina staining on porous materials below. Stainless steel sheets are stiffer and more difficult to form and work than copper of similar thickness. Soldering stainless steel also typically requires higher heat due to the material’s lower thermal conductivity. Overheating the metal can result in warping and buckling, so the soldering process for stainless steel typically requires a cooler iron in good contact with the metal to transmit more heat to the work. The solder used for stainless steel also typically has a higher melting point, making it more difficult to keep hot enough to flow through seams.

While copper and stainless steel have different material properties, they present similar challenges in soldered roofing applications. For simplicity, the following sections use the terms “sheet metal” or “metal roofing” interchangeably to indicate both copper and stainless steel systems, unless noted otherwise.

GENERAL JOINING PROCEDURES AND JOINING ISSUES
Sheet metal is durable and watertight; the problem is, it typically cannot be transported and installed in sheets larger than 3 to 5 ft. wide and 10 ft. long. As such, metal roofing performance relies significantly on the joinery between sheets. For watertight sheet metal applications, these joints are typically soldered. Sealant or welding can also form watertight joints; however, the blind application of sealant into locked seams does not provide reliable watertightness, and the sealant’s expected service life is typically less than that of solder. For these reasons, sealant is typically only appropriate for steep-sloped or noncritical applications (for example, note C&CS recommends sealant-filled joints only for roof slopes greater than 3:12). Welding or brazing is often not practical for the thin sheets used in sheet metal roofing applications.

Soldering
Unlike welding, which requires higher temperatures to melt the base material, soldering is done at a lower temperature and involves melting a soft alloy metal that bonds to the base metal. Soldering uses a heat source (e.g., a soldering iron or soldering torch) to apply sufficient heat to the base metal so that the solder flows freely and can be drawn (or “sweated”) into locked or lapped seams.

To facilitate the soldering process, soldering alloys must have a relatively low melting point and, typically, a lower ductility than the base metal; unfortunately, these
traits make the solder weaker than the base metal and prone to failure when exposed to tensile or shear stresses. To prevent joint failure from thermally induced stresses or mechanical loads (e.g., live loads, sliding snow, etc.), soldered sheet metal seams must be mechanically locked or—for thicker sheets—strengthened with rivets. These mechanical attachment methods are discussed further in the next section.

Copper roofing applications typically utilize tin-lead alloy solders. Tin is the primary soldering component, but the lead reduces melting temperature and adds ductility to the alloy. Pure tin or tin-silver solders are used in lead-free applications and for stainless steel seams; these lead-free solders have a higher melting point and, thus, require more care and patience to sweat into seams, particularly on vertical or sloped applications.

The following provides a very brief summary of typical soldering procedure. The industry guides listed in the introduction provide further description of these steps for interested readers.

- **Cleaning.** The base metal must be cleaned immediately before pretinning or before soldering joined seams to remove all debris or contaminants that may prevent the solder from flowing freely through the seam. The soldering irons must also be cleaned to remove any contaminants that may negatively impact the soldering process.
- **Flux.** Flux is an acidic paste used to dissolve oxides from the surface of the base material and improve the wetting ability (flow) of the solder. Excess flux should be removed from the completed seam surface; otherwise, it will stain or patina the base metal.
- **Pretinning.** The soldering iron and base sheet metal (where feasible) should be pretinned prior to soldering to facilitate solder flow and promote bond of the solder to the desired surfaces. Pretinning is essentially the process of melting and applying a thin layer of solder on the soldering iron and lock or seam surfaces that are to be soldered (Figure 1). Flat seam panels and other components that can be shop fabricated are often pre-tinned by dipping sheet edges into a molten solder bath.
- **Dressing.** Dressing is the process of hammering down locks and seams so that they are flat and tight, and so that all surfaces within the joint are...
within close proximity to promote capillary action for the solder.

- **Heat Source.** Historically, architectural sheet metal was soldered using a pair of copper soldering “irons” that were heated with a gas or charcoal pot. Most contractors now use a soldering torch, which utilizes a gas-burning nozzle to continuously heat a heavy copper bit at the front end of the torch. Either method can produce acceptable results, but because the torch bit is continuously heated, it is typically much lighter and easier to work with than conventional soldering irons, which require mass to retain heat while in use between turns on the heat source. Architectural sheet metal should not be soldered using an open flame or with electric torches.

- **Soldering.** The heat source is used to melt and maintain a small liquid puddle of solder near the tip of the soldering iron on the low side of the seam (Figure 2). The iron or torch bit is then dragged along the seam, heating the sheet metal evenly and adding solder as necessary to fill the lock or lap. If properly done, the heat will cause the solder to “sweat” (or be drawn) into the seam through capillary action.

At vertical sheet metal joints or where extra quality assurance is desired, the seams should also be laced. Lacing involves applying additional solder across the seam in a stitched pattern. This second laced application of solder requires relatively uniform heating across the seam, which can help draw the initial solder application more fully through the lock or lap. It also helps to ensure full coverage of rivet heads/holes and provides a neat appearance that may be aesthetically desired in exposed applications (Figure 3).

While the concept of soldering is straightforward, the actual exercise takes practice and requires a skilled craftsman. Insufficient solder can result in weak seams or gaps, or leave rivet heads exposed and prone to water infiltration. If the iron is moved too quickly along the seam, the solder will cool quickly, and flow into the lock or lap will be limited. Moving the iron too slowly can overheat the base metal, which can cause warping and/or oxidation.

Given the skill required to achieve well-soldered seams and the difficulty in addressing inadequate soldering after the fact, designers and owners would be prudent to specify a reasonable quality assurance program, particularly on public work or projects that require multiple bidders. A program successfully used by the authors includes the following:

- Require the contractor (specifically the mechanics performing the work) to have a minimum of five years’ experience with sheet metal fabrication and soldering, and to submit references, including current contact information, for past completed sheet metal work.

- Require all workers who intend to perform solder work to complete a “soldering test.” The test includes soldering one linear foot each of a vertical lock joint and a vertical riveted joint (Figure 3); the soldered samples are then cut and inspected by the designer (Figure 4).

This approach seeks to provide quality assurance and demonstrate the minimum quality of workmanship that the contractor and workers must meet for a given project. It does not, however, provide any quality control of the completed product. Completed seams can be visually inspected for general quality, but (barring obvious deficiencies) destructive testing is typically required to confirm the efficacy of the soldering operation.

![Figure 3 – Solder test sample demonstrating lacing across the seam.](image1)

![Figure 4 – Soldered test lock join cut for inspection. This sample would not pass because the solder is not sweated through the entire seam.](image2)
Rigidly soldered sheet metal seams must be as strong as the base sheet; otherwise, they are prone to cracking or deformation when subjected to stresses from regular thermal movement of the sheets or mechanical loads. A simple lap with solder alone is insufficient to develop the seam strength necessary for sheet metal roofing applications. As such, sheet metal roofing seams should be locked or lapped and riveted, to provide a mechanical bond between sheets; the solder provides some additional bond, but is primarily used to provide watertight seams.

Lock joints are created by interlocking ½- to ¾-in. bent hooks formed along the edges of adjacent sheets. For soldering applications, this lock is typically folded down flat against the base sheet metal surface, forming a “flat lock.” Lock joints require straight and crisp cuts and folds so that the lock can be tightly “dressed” to allow for capillary solder flow through the entire joint. Where feasible, the majority of the sheet metal cutting and forming operation should utilize a shear and bending brake, respectively. Hand shaping, trimming, and seaming should be performed only at locations where no other option is feasible.

For thicker copper sheets (24 oz. and above) and most stainless steel applications, lock joints are not sufficient to develop the full sheet strength, or may not be practical to fold; and riveted seams are required. Riveted seams are constructed with a simple overlap, with rivets installed through both sheets, typically in a staggered pattern (Figure 5). Rivet installation requires predrilling the base metal, and care must be taken to ensure the underlying materials (e.g., membrane underlayment) are not damaged. To the extent possible, rivets should be installed prior to setting the sheet metal in place, or rigid protection must be provided beneath the lapped joint.

Well-executed seams require careful cutting and forming of the base sheet metals to form uniform locks or laps. This seems like common sense, but can be a difficult process over atypical substrate geometries and/or if installers do not provide sufficient attention to detail. Improper seam construction or dressing will prevent capillary solder flow through the seam, or leave gaps that are too wide to be filled with solder (Figure 6). When possible, flat-seam roofing panels and other uniformly shaped sheets should be preformed and pretinned in the shop.

The sheet metal’s attachment to the substrate must also be considered when selecting a joining method. Sheet metal cleats can be incorporated into locked joints, allowing for regular attachment to the substrate along seams. Riveted seams cannot incorporate such attachment; and, as such, riveted roofing or gutter sections rely on attachment along unriveted sheet edges or hold-downs through the face of sheets larger than 18 in. wide.

Solid Versus Pop Rivets

Two general types of rivets are available for sheet metal roofing applications: solid rivets and blind rivets (also known as “pop” rivets). Solid rivets are mush-

Figure 5 – A lapped and riveted joint using solid rivets.

Figure 6 – Poorly constructed lap joint, resulting in a gap that was not filled with solder.
room-shaped fasteners that, once inserted through the sheet metal seam, are fitted with a burr (similar to a washer) and hammered or compressed until deformed into a barbell shape, thus securing the sheets together. Blind rivets are also mushroom-shaped, but have a hollow shaft that is filled with a metal mandrel. To install, a special tool is used to pull the mandrel, causing the shaft to deform and expand, and form a barbell-like shape that secures the sheets together.

Solid rivets require access to the underside of the seam and can be difficult to hammer into place without damaging underlayment, plywood substrates, or the sheet metal. Access to the underside of the seams can be difficult with large sheets. Where practical, sheets can be joined prior to installing into their in-situ location (Figure 7).

Unless specified otherwise, sheet metal roofing contractors tend to use pop rivets due to their relative ease of installation. Unfortunately, pop rivets have several drawbacks and present some challenges that are often misunderstood or ignored:

- Pop rivets are hollow and typically weaker than solid rivets, and therefore are not suitable to develop the necessary seam strength in thicker sheet metals. Industry guides such as C&CS state, “in the absence of test data that shows that [pop] rivets have sufficient strength for use with 24-ounce and 32-ounce copper,” they should only be used for “non-structural applications.” Designers can also choose to compare the relative shear strength of a selected pop rivet versus a typical solid rivet and adjust spacing or quantity to provide similar strength. Higher strength pop rivets can also be used. The key point is that pop rivets require some additional design and are not a direct substitute for conventional solid rivets.

- Pop rivets form a “mushroom” head on the underside of the base material (Figure 8). These protruding heads can damage or puncture membrane underlayment or restrict normal expansion movement of the sheet.

- Some pop rivets have mandrels that are intended to break off and remain in the hollow rivet body. In these cases, the mandrel material must match (or be galvanically compatible with) the rivet body and sheet metal.
Figure 9 – Inadequate lacing. Note pop rivet heads are visible through the solder.

materials; otherwise, galvanic corrosion may result in staining or seam failures.

- Full solder coverage of pop rivets is particularly important, as water can flow through the hollow rivet body (Figure 9). Capped pop rivets are available, but are not standard.

THERMAL EXPANSION

Architectural sheet metal installations are often subjected to wide temperature changes in service, resulting in significant thermal movement and stresses. The thermal movement in sheet metals is proportional to the length of the subject material and the temperature of the sheet, not to the changes in ambient temperature. Exposed to full sun, sheet metal can conceivably reach temperatures 100°F higher than the ambient temperature. Copper and stainless steel have similar coefficients of thermal expansion and can be expected to expand approximately 1/8 in. per 10 ft. of length with a 100°F temperature change. In many metal roofing applications, this thermal movement is accommodated within the loose-locked “flexible” seams; however, in fully soldered roofing applications, the seams are rigid, and the system must be carefully detailed and installed to accommodate movement at expansion joints and roofing/gutter perimeters.

Industry guides provide strategies for typical roofing and gutter conditions. For example, C&CS recommends, “Large areas of locked and soldered flat-seam [copper] roofing should be divided into sections that are separated by expansion battens...not more than thirty feet in any direction” (3.C.2). C&CS also provides a detailed table for spacing expansion joints within fully soldered copper gutter lines for various gutter sizes and copper thicknesses (9.B.9). These guides also provide typical details for loose lock joints and battens that are commonly used to accommodate expansion.

The difficulty is in executing these guidelines in the field, particularly at atypical geometries, and locating expansion joints (which typically are not watertight) in locations that do not compromise the roofing system’s performance or drainage paths. The following guidelines are intended to aid designers and installers in avoiding common blunders that the authors have regularly observed in the field:

- Fully soldered roofing and gutters will expand from their center or any fixed point (e.g., a drain body). As such, most roofing and gutter installations require expansion provisions along all edges of the roof/gutter—not just an expansion joint located along a roof or gutter’s length.
- Expansion joints or battens must be continuous through all rigidly soldered components (Figure 10).
- Soldered roofing perimeter terminations and gutter edges should be cleated—not directly fastened—to allow movement along the termination.
- At rising walls, the sheet metal must be gapped from the substrate to accommodate sheet metal movement.
- Soldered components should not be soldered to any nonrigid metal components (e.g., standing-seam roofing or valleys).

Figure 10 – Batten-type expansion joint. Provision for expansion was not carried up the rising wall, resulting in the cracked solder joint in the flashing.
Expansion joints should be configured so as to not impede drainage (Figure 11). If necessary, additional drains should be added to decrease the roof or gutter length between adjacent drains.

**UNDERLAYMENT AND DRAINAGE**

Historically, metal roofing and gutter systems lacked any underlayment and relied on simple sleeve drains soldered to the sheet metal. This system lacks redundancy, as the sheet metal provides only a single layer of defense with no backup protection against leakage, should a defect or puncture occur.

Contemporary metal roofing systems now typically incorporate a self-adhering membrane underlayment below the metal. Membrane products are available in high-temperature-resistant SBS asphalt or butyl formulations, which can accommodate the expected high in-service temperatures present under metal roofing without flowing or degradation. All high-temperature membranes and formulations are not equal, so selection of an appropriate membrane may require careful consideration at locations with higher anticipated service temperatures. Even functional membranes may become soft or flow during soldering applications (which can produce temperatures upwards of 400°F), and a separation layer (e.g., building or rosin paper) should be provided to prevent binding the sheet metal to the underlayment at seams.

Self-adhering membrane products have the benefit of full adhesion and some self-sealing characteristics around nail penetrations. However, even a perfectly installed membrane will not remain watertight under a metal roof when subjected to regular or prolonged submersion. Water will eventually work its way through membrane punctures, seams, and fastener holes (e.g., the numerous nail holes from cleats and sheet metal attachments).

An adhered underlayment can be especially useful in low-slope applications, as water is more likely to find any defect in the sheet metal and collect on this secondary roofing layer. However, having two separate roofing layers causes the assembly to become complicated at the drain tie-in. None of the industry guides listed in the introduction provide a drain detail that includes self-adhering membrane underlayment with a typical clamping ring-type roof drain. Thus, the design responsibility for this critical detail falls to the roof designer or installer, who is generally left with two conceptual approaches for designing this drain tie-in: 1) designs that allow drainage at the membrane level, and 2) those that do not.

**Membrane-Level Drainage**

A relatively simple way to allow for membrane-level drainage is to use a typical clamping ring type roof drain and extend both the membrane and sheet metal into the drain body; then provide a spacer or weep between the membrane and the sheet metal to prevent the clamp ring from compressing and sealing the metal to the underlayment at the drain body (Figure 12).
This strategy maximizes the effectiveness of the membrane underlayment. By allowing the membrane to drain, water is less likely to accumulate on the membrane and leak through vulnerable nail holes, seams, or other defects.

Conversely, the method provides minimal protection should the drain clog and back up, as water can travel freely under the sheet metal (Figure 13). Also, while a relatively simple concept, this method can be difficult to detail. The shim or weep used must be a noncorrosive material compatible with both the sheet metal and membrane. It also needs to be either secured or configured around the drain body so it does not move out of place during routine movement or future drain maintenance. Finally, the shim or weep must fit with (or around) the drain body's geometry, which can vary significantly among manufacturers, models, and sizes.

Successful options the authors have pursued to provide membrane-level drainage include:

- Using a reticulated foam weep baffle sheet, cut to fit around the drain inlet and installed between the membrane and sheet metal.
- Installing the clamping ring at the membrane level and providing a separate clamping ring (or soldered clips to hold drain strainer) at the sheet metal layer. For this to work, the drain body must be set in a sump so that the membrane-level clamp ring does not impede drainage at the sheet metal surface.

Designers and installers should consider this method if they have confidence in the drainage system and want to maximize the effectiveness of the membrane underlayment and overall redundancy of the roof assembly. This option should not be used at locations where drains are prone to back up due to frozen pipes or outlets, or roof areas that regularly collect leaves or debris that can clog drains.

**No Drainage at Membrane Level**

The most basic tie-in for a clamping ring type drain is to simply extend both roof system components into the drain bowl, and then clamp down both layers with the drain’s prefabricated clamp ring. This effectively seals the sheet metal and membrane layers to the substrate at the drain inlet. Unless other specific direction is provided, this is the method typically used by installers, in some cases with water block sealant installed between the membrane and sheet metal to further ensure a watertight tie-in at the sheet metal layer. Even if no sealant is provided, a tight clamping ring will severely limit any drainage from between the compressed sheet metal and membrane layers.

This option provides the greatest protection in the event of the roof drain line becoming clogged, since it prevents water from backing up under the sheet metal (Figure 14). Designers and building owners should take every precaution to prevent drainage issues; even though the drain detail may be watertight, standing water is never a good situation on a roof or in a gutter. Even with good maintenance, drains can become clogged or pipes/outlets can freeze.

The risk with this option is that the lack of membrane-level drainage essentially renders the membrane useless as a secondary layer of protection. Any incidental leakage through the sheet metal does not have a path to drain or dry out (both sheet
metal and typical self-adhering membranes are strong vapor retarders), and water will collect on the membrane. Even a small volume of water can quickly fill the tight space between the sheet metal and the membrane, applying a pressure head on vulnerable fastener penetrations and seams in the membrane (Figure 15). Additionally, entrapped water between the sheet metal and membrane underlayment can accelerate degradation of the sheet metal.

Designers and installers should only consider this option if they have the utmost confidence in the sheet metal roof system (i.e., expansion is properly detailed, no loose locks are below the potential level of water and snow buildup, and there are no potential sources of water infiltration upslope that could direct water below the soldered roof system) or if there are known deficiencies with the drainage system that cannot be remedied (e.g., regularly frozen pipes, regular debris/clogging of drains).

Secondary Drainage

Current building codes typically require a secondary (overflow) drainage system for locations where the roof can hold water if the primary drains allow buildup. New sheet metal roofs that have both a main and an overflow drain can utilize both options above to provide maximum benefit. In this configuration, the primary drain can be installed without membrane drainage (e.g., watertight to prevent backflow), while the overflow drain can be designed to allow membrane-level drainage, as the overflow drain is less likely to back up due to limited use and water flow.

SUMMARY

Soldered sheet metal roofing can provide a durable, long-lasting, and watertight roofing system in low-slope and gutter applications. However, these systems are dependent on proper design and execution, particularly of joining or seaming procedures. Soldered sheet metal roofing also presents unique challenges related to thermal expansion of the metal sheet and drainage complications if using a membrane underlayment. These challenges require a well-thought-out design and careful execution by installers in order to function as intended.

Project documents and a well-executed, fully soldered roof installation should include the following:

- Detailed direction for constructing sheet metal seams for each type of application on the project. The designer or contractor should incorporate a quality assurance program to ensure selected installers, including confirmation that mechanics actually performing the work have the skills necessary to fabricate well-soldered joints.
- Performed and pretinned sheet metal from the shop. Limit cutting and forming sheet metal in the field for improved consistency and durability. Hand-shaping, trimming, and seaming should be performed only when no other option is feasible.
- Seams should be mechanically locked or lapped and riveted, and fully soldered to accommodate thermal and mechanical loads.
- Riveted seams constructed with solid rivets. Sequence the work to construct seams prior to installing in their in-situ location to the extent possible.
- Carefully designed expansion provisions. Both designer and installer must consider expansion for all typical and atypical geometries for the project, as missing or short-circuited expansion joints can result in damage to perfectly constructed seams.
- Careful consideration for selection of the membrane underlayment, design of drainage provisions, and detailing of drains. The membrane underlayment must be resistant to the service temperatures to which it is exposed to remain functional. Improper drainage design or installation can negate the intended benefits of using a membrane underlayment and increase the risk of leakage.