TECHNICAL

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- **1. Fundamentals**
- **2. Copper Alloys**
- **3. Finishes**
- **4. Rehabilitation of Copper**

This section provides a broad background of copper knowledge which serves as a foundation of technical information for the specifier or designer of copper installations.

1. FUNDAMENTALS

NOTE: **Architectural Considerations** covers the following topics: Weathering, Corrosion, Staining, Substrate, Solder, and Sealants.

1.1. Types of Copper and Properties

The copper most commonly used for sheet and strip applications complies with ASTM B370. It consists of 99.9 percent copper, and is available in six tempers designated by ASTM B370 as: 060 (soft), H00 (cold rolled), H01 (cold rolled, high yield), H02 (half hard), H03 (three quarter hard), and H04 (hard).

Soft temper copper is extremely malleable and best suited for applications such as intricate ornamental work. It was historically used in building construction. Because of its low strength, heavy gauge material was required. As a result, the use of soft temper copper is not recommended for most building applications.

With the development of cold rolled copper many years ago, the gauge of the material could be reduced without compromising its low maintenance and long life. Cold rolled temper is less malleable than soft temper copper, but is much stronger. It is by far the most popular copper temper currently used in construction. The properties of cold rolled copper are summarized in **Table 1.1A.**

Table 1.1A. Properties of Cold Rolled Copper

Specific Gravity	8.89 - 8.94
Density	0.322lb./cu. in. at 68°F
Thermal Conductivity	226 BTU/Sq Ft/Ft/Hr °F at 68°F
Coefficient of Thermal Expansion	0.0000098/°F from 68°F to 572°F
Modulus of Elasticity (Tension)	17,000,000 psi
Tensile Strength	32,000 psi min.
Yield Strength (0.5% Extension)	20,000 psi min.
Elongation in 2" - approx.	30%
Shear Strength	25,000 psi
Hardness - Rockwell (F Scale) Rockwell (T Scale)	54 min. 15 min.

The significant properties of the six ASTM B370 designated tempers are summarized in **Table 1.1B**.

In general, cold rolled 1/8 hard temper (H00) copper

is recommended for most roofing and flashing installations. Soft copper may be used where extreme forming is required such as in complicated thru-wall flashing conditions. However, it should be noted that cold rolled copper offers far more resistance than does soft to the stresses induced by expansion and contraction. Copper roof sheet of higher temper should be specified only if indicated for specific and engineering applications requiring such higher tempers.

Table 1.1B. Mechanical Properties

Temper Designation Standard	Tensile Strength (Ksi)		Yield Strength (Ksi) Min.
	Min.	Max.	
060 Soft	30	38	--
H00 Cold-Rolled 1/8 Hard	32	40	20
H01 Cold-Rolled, high yield 1/4 Hard	34	42	28
H02 Half Hard	37	46	30
H03 Three quarter Hard	41	50	32
H04 Hard	43	52	35

The yield strength of cold-rolled high yield (H01) copper is significantly higher than standard cold rolled (H00) copper, up to 33,000 p.s.i. This allows the use of 12 ounce high yield copper in many applications where 16 ounce cold rolled copper is normally used.

The major use for high yield copper is flashing products, where malleability and strength are both important.

Good resistance to corrosion, good electrical and thermal conductivity, ease of fabrication coupled with strength and resistance to fatigue are criteria by which copper or one of its alloys is selected.

Corrosion Resistance: Copper is a noble metal able to resist attack quite well under most corrosive environmental conditions. In the presence of moisture, salt and high sulfur pollution, copper quickly begins to oxidize and progress through the weathering cycle. Its high resistance to corrosion is due to its ability to react to its environment and reach weathering equilibrium.

Electrical and Thermal Conductivity: Copper and its alloys are excellent conductors of electricity and heat. In fact, copper is used for these purposes more often than any other metal. Alloying invariably decreases electrical conductivity and to a lesser extent, thermal conductivity. Coppers and high-copper alloys are preferred over copper alloys containing more than a few percent total alloy content when high electrical or thermal conductivity is required.

Ease of Fabrication: Copper and its alloys are generally capable of being shaped to the required form and dimensions by any of the common fabricating processes. They are routinely rolled, stamped, drawn and headed cold; they are rolled, extruded, forged and formed at elevated temperature.

Copper and its alloys are readily assembled by any of the various mechanical or bonding processes commonly used to join metal components. Crimping, staking, riveting, and bolting are mechanical means of maintaining joint integrity. Soldering, brazing and welding are the most widely used processes for bonding copper metals. Selection of the best joining process is governed by service requirements, joint configuration, thickness of the components, and alloy composition(s).

1.2. Dimensions of Copper

In building construction, copper is generally used in sheet and strip. Strip is 24 inches or less in width, while copper sheet is over 24 inches in width. **Table 1.2A** shows the standard dimensions of sheet and strip copper.

Table 1.2A. Typical Dimensions of Copper Sheet and Strip

	Weight per S.F. in Ounces	Width Inches	Length Inches
Sheet Copper	12	30, 36	96, 120
	16	30, 36	96, 120
	20	30, 36	96, 120
	24	30, 36	96, 120
	32	30, 36	96, 120
	48	30, 36	96, 120
Strip Copper	16	10, 12, 14, 15, 16, 18, 20, 24	96, 120
	20	20, 24	96, 120
	24	20, 24	96, 120
	32	20, 24	96, 120

The thickness of sheet and strip copper is measured by its weight in ounces per square foot. For example, the thickness of 12 ounce copper is such that every square foot weighs 12 ounces. The thicknesses commonly used in construction are between 8 and 32 ounces.

Since the industry often uses gauge numbers or actual thicknesses for sheet metal or other building materials, it is often necessary to convert between the different systems. **Table 1.2B** shows the relationship between the copper weight, thickness, and gauge number.

Table 1.2B. Copper Weight, Thickness, and Gauge

Weight per Sq. Ft.		Nearest Gauge No. (B&S)	Thickness inches (mm)	
Ounces	Pounds		Nominal	Minimum
6	.375	32	.0081 (.206)	.0071 (.180)
8	.500	29	.0108 (.274)	.0097 (.246)
10	.625	27	.0135 (.343)	.0124 (.315)
12	.750	26	.0162 (.411)	.0150 (.381)
16	1.00	23	.0216 (.549)	.0204 (.518)
20	1.25	21	.0270 (.686)	.0258 (.655)
24	1.50	20	.0323 (.820)	.0308 (.782)
32	2.00	17	.0431 (1.09)	.0411 (1.04)
48	3.00	14	.0646 (1.64)	.0621 (1.58)

1.3. Architectural Considerations

Weathering, Corrosion, Staining, Substrate, Solder, Sealants

One of the most important issues concerning the use of copper is the chemical reaction between copper and other materials. Chemical reactions are responsible for corrosion, staining, and even the green patina that develops on copper surfaces over time.

Weathering and Patination:

The oxidation process that gives copper its characteristic green patina is a result of exposure to an acidic atmosphere. The process is, therefore, faster in some metropolitan, marine, and industrial areas, where higher concentrations of pollutants exist. When acidic moisture comes in contact with exposed copper surfaces, it reacts with the copper to form copper sulfate. The acid is neutralized during the reaction with the copper. This patina eventually covers the surface and adheres tightly to it, thus providing a protective layer against further weathering.

Natural Weathering Color Chart - Typical for Moist Industrial Climates, Timespan Varies

Unexposed	4 Months	8 Months	1 Year
2 Years	3 Years	4 Years	5 Years
7 Years	10 Years	15 Years	25-30 Years

Corrosion:

All metals have a property called nobility. It is a measure of a metal's resistance to corrosion when in contact with another metal. A greater relative difference in nobility between the two metals in contact indicates a greater corrosion potential. **Table 1.3A** ranks the most common metals used in construction in increasing nobility, called the galvanic number.

Table 1.3A. The Nobility of Common Metals

1. Aluminum

2. Zinc

3. Steel

4. Iron

5. Stainless Steel - Active

6. Tin

7. Lead

8. Copper

9. Stainless Steel - Passive

When dissimilar metals are in contact with one another in the presence of an electrolyte, galvanic action occurs, resulting in the deterioration of the metal with the lower galvanic number. The electrolyte may be rain water running from one surface to another, or moisture from the air containing enough acid to cause it to act as an electrolyte.

Since copper has one of the highest galvanic numbers or nobility of the active metals, it will not be harmed by contact with any of them. It will, however, cause corrosion of the other metals if in direct contact. The solution is to prevent such direct contact with the use of separating materials, such as specific paints or gaskets.

It is not necessary to isolate copper from lead, tin or stainless steel under most circumstances. The principal metals of concern in terms of direct contact are aluminum and zinc. Iron and steel are generally not a problem unless their mass is similar or smaller than that of the copper.

If paints or coatings are used for isolation, they must be compatible with both metals. Bituminous or zinc chromate primers can be used between copper and aluminum. Either of these or a red lead primer can be effective in separating copper from iron and other ferrous metals.

Taping or gasketing with nonabsorptive materials or sealants are effective methods of separating copper from all other metals. In areas with severe exposure, lead or similar gasketing materials should be used, except between copper and aluminum.

Regardless of the method used to separate the metals, wash from copper surfaces should be prevented from draining onto exposed aluminum. Traces of copper salts in the wash may accelerate corrosion of the aluminum.

Another type of corrosion, which affects copper, is caused by the flow of acidic water concentrated on a small area of copper. This type, often called "erosion corrosion", occurs when rain falls on a non-copper roof such as tile, slate, wood, or asphalt. The acidic water is not neutralized as it flows over the inert material. When water, collected over a large surface, is diverted or collected by a relatively small copper flashing or gutter, the copper may deteriorate before it develops a protective patina. Another type of corrosion occurs at the drip edge of inert roofing material conducting water into a copper gutter or valley. If shingles rest directly on the copper, the corrosive effect is amplified because moisture is held along the edge by capillary action resulting in "line-corrosion". The solution is to raise the lower edge of the shingles with a cant strip, or to provide a replaceable reinforcing strip between the shingles and the copper.

Staining:

The wash of water over copper surfaces can have additional impact. Moisture in contact with copper surfaces tends to pick up small quantities of copper salts. When this moisture contacts porous material, such as marble or limestone, it is absorbed. As the moisture evaporates, it leaves behind the copper salts as a stain on these materials. The green stain is particularly visible on light colored surfaces.

The condition does not occur with heavy rains or similar rapid run-off, since the dwell time of the

moisture on the copper is short and little copper salt is picked up. Staining results from the slow bleeding action of copper laden moisture.

There are a number of ways to reduce staining or its visual impact. Two common methods are: collecting run-off in gutters and directing it away from the building via downspouts; and designing drip edges to a minimum of one inch, helping reduce the amount of copper laden moisture that comes into contact with material below. Coating the adjacent surface of the porous material with a clear silicone sealant can reduce staining by minimizing the amount of moisture absorbed into the surface.

Substrate Selection:

The preparation of the substrate onto which copper will be applied depends in part on the substrate selected and the copper application. A number of considerations, however, must always be taken into account.

In selecting the substrate, a key consideration is the method of attachment of the copper. All applications that rely on nails or screws to attach the copper or cleats to the underlying structure require a nailable deck, nailing strips within the deck, or wood blocking at specific locations. Such applications include standing seam roofs, batten seam roofs, flat seam roofs, continuous edge strips and cleats, and flashings around roof penetrations.

Regardless of the attachment method used, the structural integrity of the substrate should not be compromised. It must be able hold the roof under sustained design wind conditions, as well as to conform to all other required codes and standards.

The most common substrate for copper is wood, usually 1/2" to 3/4" plywood. Lumber should be kiln-dried and laid with all joints true and even to provide a smooth surface. It is recommended that wood be allowed to weather for a few days after installation. During this period it should be protected from rain, allowing it to conform to atmospheric temperature and moisture level, while settling into place.

There have been many recent developments in fire retardant treated (FRT) plywood and lumber. Most of these products use wood or plywood that is pressure-impregnated with chemical salts in water

solution to inhibit combustion. Many of these salts are corrosive to copper, as well as other metals and materials. If leaching of theses salts brings them into contact with the copper, corrosion will occur. This is particularly likely in areas with high humidity, if condensation occurs, or if water is introduced during construction or at a later time. Any areas where salt laden moisture can collect then evaporate, thereby increasing the concentrations of salts, will accelerate the corrosion process. For a complete and updated report on Fire Rated Plywood and Corrosion, contact CDA.

Other materials used as substrates for copper include: concrete, brick, masonry units, terra cotta, and stucco. The guidelines discussed above apply to these materials as well. Smooth, dry surfaces, compatibility with copper, and provision for fasteners are all required for an acceptable substrate.

Substrate Preparation:

Sheet and strip copper applications in construction are inevitably required to provide some level of resistance to water penetration. Anything that can cause punctures or openings in the copper membrane should be avoided. Copper roofs, valley flashings, and gutter linings should always be applied on a smooth, dry, stable surface with no projecting nail heads or other imperfections. Movement in the substrate should be accommodated by properly designed expansion joints.

In such applications, an approved underlayment, usually saturated felt, must be applied to the substrate. The felt acts as a cushion for the copper sheets. A sheet of rosin-sized building paper should be inserted between the copper and the underlayment. This will prevent bonding between the two surfaces that would otherwise restrict the thermal movement of the copper. The only exceptions to this requirement are applications where the copper is not intended to move, not even under thermal stress. For example, continuous cleats and edge strips are nailed down, usually in a staggered pattern of nails 3 inches on center, to limit movement.

Solder and Sealants:

Copper construction methods have traditionally

relied on solder to ensure water-tightness and to strengthen joints and seams. The solder used is common 50-50 tin-lead bar solder for uncoated copper. Alternative tin based solders are available for those who prefer a lead free installation. Solder is typically applied to mechanically fastened or formed, rigid joints. Soldered seams and joints are permanent; they should last the life of the copper. Continuous, long runs of soldered seams should be avoided to limit stress fractures.

In the weathering process, the solder turns from a shiny to a dull tone. Exposed solder in the finished joints can be minimized with the use of blind soldering. In this technique, solder is applied to the back or concealed edge of copper surfaces.

An alternative to solder, where its additional strength is not required, is the use of sealants. Sealant filled joints have been used successfully for standing seam and batten seam roofing applications where roof slopes are less than three inches per foot. Sealants can also be used in joints that are primarily designed to accommodate thermal movement of the copper.

The sealants used should be tested by the manufacturer and designated as compatible for use with copper. Many elastomeric polyurethane, silicone, butyl, polysulfide or other inorganic or rubber based sealants have shown acceptable performance. Acrylic, neoprene, and nitrile based sealants have been observed to actively corrode copper. The use of such sealants is, therefore, not recommended.

1.4. Structural Considerations

Structural considerations play an important role in the proper design of copper applications. They affect the spacing of **7.1. Attachments**, location and design of **7.2. Joints and Seams**, and the configuration of other joints. The requirements may be calculated with the same formulas used in the structural analysis of other materials, such as steel and wood. **Table 1.1A** contains information that is useful in these calculations.

Although there are other structural concerns, the primary focus is upon thermal effects. Movement and stresses related to temperature variations must be accommodated. There are two fundamental methods to do this: prevent the movement and resist the cumulative stresses within the copper; or allow movement at predetermined locations, thereby relieving thermal stresses.

In a limited number of applications, such as gravel stops, base flashings at built-up roofs, and flashings around windows and doors, it is possible and often desirable to prevent movement. These tend to involve narrow copper strips that do not cover large areas. The strips should be nailed frequently to effectively transfer stresses to the underlying substrate before causing buckling in the copper. Nails spaced 3 inches maximum on center in a staggered pattern are recommended.

In most other situations it is impractical and undesirable to restrain a copper section so frequently.

In the interest of watertightness, puncturing the copper membrane should be avoided. It is also better, where possible, to allow the copper to move in order to reduce the chance of metal fatigue.

The yield strength of copper is the same for compression as it is for tension. Since buckling is likely to occur when relatively thin sections of sheet copper are in compression, sections should be designed to resist compressive loads. The compressive strength in sheet copper is the product of two factors: the thickness of the copper and the shape of the section. These factors create "columnar strength" which resists accumulated stresses up to a certain length. Beyond this point, expansion joints must be introduced to prevent buckling.

Once an expansion joint is introduced, the section no longer has to resist the cumulative stresses caused by thermal expansion along its whole length. It need only keep its shape and resist the friction between itself, its fasteners, and adjacent materials. The structural design of sheet copper, for the most part, involves the determination of expansion joint spacing. Each section of copper is designed as a "column" capable of transmitting stresses from a fixed point to the free end or expansion joint.

Table 10B shows the maximum allowable column length for "U"-shaped sections. This is the section most frequently used for such applications as gutters, gutter linings, and fascias. The requirements for standing and batten seam roofs can also be determined, since their pans derive their strength from the flanges that form the longitudinal seams.

1.5. Radio Frequency Shielding

Radio frequency (RF) shielding involves the construction of enclosures for the purpose of reducing the transmission of electric or magnetic fields from one space to another. With the increase in sensitive computer and electronic equipment, the issues of interference, unauthorized surveillance, and protection from high voltages have become increasingly important.

All electronic and computer systems radiate certain frequencies of radio and magnetic waves. These signals can be received by special surveillance equipment, compromising the privacy of their source. In some cases, they can interfere with, or may be affected by, other equipment in the vicinity. Radio frequency shielding enclosures are used in these situations to reduce the levels of RF radiation that enters or leaves the enclosed space.

One of the characteristics of copper is its high electrical conductivity. This feature, combined with its other physical properties, ductility, malleability, and ease of soldering, make it an ideal material for RF shielding. Sheet copper can be formed into essentially any shape and size, and electrically connected to a grounding system to provide an effective RF enclosure.

RF shielding enclosures are usually designed to filter a range of frequencies under specified conditions. Most often, they are constructed for government or corporate groups with particular requirements. Properly designed and constructed copper enclosures can provide a high degree of effectiveness to suit practically any demand.

1.6. Lightning Protection

When lightning protection is desired, it is usually achieved by providing a path of low resistance to ground. Copper roofs offer ideal **lightning protection** where the copper roofing, gutters and rain leaders are electrically interconnected and reliably grounded. The specified thickness of materials, i.e., roof covering sheets, wall claddings, gutters and leaders are usually adequate for lightning protection and in these circumstances additional conductors are unnecessary.

Additional protection may be necessary with lighter gauge copper bonded panels or when some components of the grounding system are made from less conductive materials.

In the absence of adequate grounding through the copper system, additional lightning protection may be required.

It should be pointed out that, due to its excellent electrical conductivity and resistance to corrosion, copper maintains an important role in lightning protection applications. Its use for the grounding of copper roofing overcomes problems associated with mixed metal corrosion. When using copper for grounding in combination with other materials, instructions concerning corrosion protection should be followed.

Those not familiar with lightning protection systems seem to believe that copper components, including roofs, actually attract lightning. Needless to say this assumption is not based on fact.

It is true however, that the high conductivity of copper facilitates the rapid transmission of lightning energy. Lightning takes the path of least resistance and no damage is done to a building if there is a low resistance path to earth. This path can consist of the copper roof, lightning conductor and grounding device.

To ensure proper lightning protection in an installed copper roof system, a separate lightning conductor system should be used including air terminals and intercepting conductors on the roof; a system of ground electrodes; and a system of down conductors connecting the roof and ground components. It is recommended that the copper roof be bonded to the system of conductors. This bonding ensures that the

conductors and roof remain at approximately equal potential and reduce side flashing and possible roof damage.

> The Copper Development Association makes no representation as to the proper, correct or safe design of any lightning protection system. This information is presented as a guide only and the reader is cautioned that the design of any lightning protection system and devices is the responsibility of the electrical engineer. All such system design should be based on local applicable code requirements and sound engineering practice.

1.7. Cost Effectiveness

The cost of building components, such as copper roofing, flashing, gutters, and downspouts, must be evaluated in the context of their use, performance, maintenance, and service life. Many applications of copper involve uses that are critical in maintaining the integrity of the building envelope. Copper performs these functions economically for a long time. There are many examples of copper roofs that have been in service for many decades; even centuries.

In specific applications, economic criteria vary. For example, in selecting flashing material, the initial material cost may be insignificant compared to the cost of repair if the flashing fails. With a roofing system, the cost of maintenance, which may prevent water damage to the interior, must be considered. Copper components typically offer extremely low maintenance and long life, even in coastal or industrial environments. Copper is therefore an economical material for these and many other applications.

When life cycle costs are evaluated, these factors should be quantified. Initial costs, maintenance costs, and the life expectancy of the systems must be estimated, as should the salvage value of the material. Copper is an inherently recyclable material that retains much of its primary metal cost. This is far greater than competing materials whose scrap values range from about 60% down to zero. The results make copper an outstanding material in terms of life cycle costs.

1.8. Recyclability

Will there be enough copper today and tomorrow? Yes. The United States is virtually self-sufficient in its reserves and resources of copper. The U.S. Bureau of Mines and the **U.S. Geological Survey** provide **documented data** about the future supply of this metal that is most encouraging. Known worldwide copper resources are estimated at nearly 5.8 trillion pounds of which only about 0.7 trillion pounds (12%) have been mined throughout history...and nearly all of that is still in circulation, because the recycling rate for copper is higher than that of any other engineering metal.

Each year in the U.S.A., nearly as much copper is recovered from recycled material as is derived from newly mined ore. And when you exclude wire production, most of which uses newly refined copper, the amount of copper used by copper and brass mills, ingot makers, foundries, powder plants and other industries shows that nearly three-fourths (72%) comes from recycled scrap. More than half of this scrap is "new". scrap, such as chips and turnings from screw machine production. The remainder is "old" scrap, such as discarded electrical cable, junked automobile radiators or ancient Egyptian plumbing. (Yes, it's been around that long!)

Copper's recycling value is so great that premium-grade scrap normally has at least 95% of the value of the primary metal from newly mined ore.

All mining and processing of minerals require the expenditure of energy in extracting a metal from its natural ores. Fortunately, copper production is conservative of energy. A recent study concluded that the energy content of a pound of copper totals from 12 to 16 kilowatt-hours depending on the copper content of the ore. Competing materials require three to five times as much energy to produce.

This is the amount of energy required for the entire operation - from moving off the overburden to uncovering the ore at the mine site through the casting of ready-to-fabricate copper refinery shapes.

The range of attractive natural colors of copper and copper alloys, along with their corrosion resistance and other outstanding properties, give today's architects a variety of options in the planning and design of enduring commercial, industrial, public and residential structures. Moreover, at a time of changing world material supplies and energy shortages, users can depend on U.S. self-sufficiency in copper-one of the earth's most recyclable resources. It can be extracted from ores and recycled from scrap with a relatively small expenditure of energy compared to competing metals.

2. COPPER ALLOYS

2.1. Introduction

A wide variety of copper alloys are available for use in construction. The variations in color stem primarily from differences in chemical composition. Production and forming methods may affect alloy selection. Additional information is available upon request. The CDA publication *Copper Brass Bronze - Architectural Applications* (PDF 4MB) covers the selection process in greater detail.

Technically, alloys primarily of copper and tin are considered bronzes, while those chiefly of copper and zinc are brasses. In practice, however, the term bronze is commonly used for a variety of copper alloys, including those with little or no tin. This is because they resemble true bronzes in both natural and weathered colors. **Table 2.1A** lists the characteristics of some of the more popular copper alloys and their common names.

A **Unified Numbering System** has been developed for metals and alloys by **ASTM** and **SAE**. CDA administers the section on copper and its alloys. This system is based on wrought alloy numbers ranging from C10000 through C79999. Cast alloy numbers range between C80000 and C99999.

Nickel-silver alloys C74500 and C79600 are usually called "white bronze"; all others are considered "yellow bronze". "Statuary bronze" and "green bronze" do not refer to specific alloys, but to their naturally weathered or chemically induced colors. The former is used to describe brown to black surfaces; the latter is used for patinas.

In general, most copper alloys eventually weather to the gray-green patina. There are, however, significant variations in their natural colors and in the rate at which they form a patina. The last two columns in **Table 2.1A** contain information about the natural and weathered colors of the alloys. **Table 2.1B** is a color matching table. It depicts which alloys, in various forms, are reasonably well matched in color with the sheet, strip, and plate copper alloys.

2. COPPER ALLOYS

Copper Alloy Table

Table 2.1A. Common Copper Alloys

Alloy	Common Term	Composition	Color	
			Natural	*Weathered*
C11000 / C12500	Copper	99.90% Copper	Salmon Red	Reddish-Brown to Gray-Green Patina
C12200	Copper	99.90% Copper 0.02% Phosphorous	Salmon Red	Reddish-Brown to Gray-Green Patina
C22000	Commercial Bronze	90% Copper 10% Zinc	Red Gold	Brown to Gray-Green Patina in Six Years
C23000	Red Brass	85% Copper 15% Zinc	Reddish Yellow	Chocolate Brown to Gray-Green Patina
C26000	Cartridge Brass	70% Copper 30% Zinc	Yellow	Yellowish, Gray-Green
C28000	Muntz Metal	60% Copper 40% Zinc	Reddish Yellow	Red-Brown to Gray-Brown
C38500	Architectural Bronze	57% Copper 3% Lead 40% Zinc	Reddish Yellow	Russet Brown to Dark Brown
C65500	Silicon Bronze	97% Copper 3% Silicon	Reddish Old Gold	Russet Brown to finely mottled Gray-Brown
C74500	Nickel Silver	65% Copper 25% Zinc 10% Nickel	Warm Silver	Gray-Brown to finely mottled Gray-Green
C79600	Leaded Nickel Silver	45% Copper 42% Zinc 10% Nickel 2% Manganese 1% Lead	Warm Silver	Gray-Brown to finely mottled Gray-Green

Color Matching Chart

Table 2.1B. Color Matching Chart

Forms to be Matched in Color

Sheet and Plate Alloys	Extrusions	Castings	Fasteners	Tube& Pipe	Rod & Wire	Filler Metals
C11000 / C12500 Copper	C11000 / C12500 (simple shapes)	Copper (99.9% Min.)	C65100 Low Silicon Bronze	C12200	C11000 / C12500	C18900 Copper
C12200 Copper	C11000 / C12500 (simple shapes)	Copper (99.9% Min.)	C65100 Low Silicon Bronze	C12200	C11000 / C12500	C18900 Copper
C22000 Commercial Bronze, 90%	C31400 Leaded Commercial Bronze	C83400	C65100 Low Silicon Bronze	C22000	C22000	C65500
C23000 Red Brass, 95%	C38500 Architectural Bronze	C83600	C28000 C65100 Low Silicon Bronze	C23000	C23000	C65500
C26000 Cartridge Brass, 70%	C26000 (simple shapes)	C85200, C85300	C26000, C36000, C46400, C46500	C26000	C26000	C68100 Low Fuming Bronze
C28000 Muntz Metal	C38500 Architectural Bronze	C85500, C85700	C28000 C65100 Low Silicon Bronze	C23000	C28000	C68100 Low Fuming Bronze
C65500 High Silicon Bronze	C65500 (simple shapes)	C87500	C65100, C65500	C65100, C65500	C65100, C65500	C65500
C74500 Nickel-Silver	C79600 Leaded Nickel-Silver	C97300	C74500	C74500	C74500	C77300

2.2. Forming

Numerous methods can be used to form copper alloys into sheet, plate, rod, wire, and irregular shapes. Table 2.2A indicates forming methods appropriate for use with common alloys. The following is a brief description of each method:

Bending: A mechanical forming process performed at room or at elevated temperatures. Bending is accomplished with the aid of rollers, bending shoes and mandrels. Its primary purpose is to produce curved sections from straight lengths of tube, rod, or extruded shapes.

Brake Forming: A mechanical bending operation usually performed on metal sheet, strip, or plate.

Castings: These are produced by pouring molten metal into a mold and allowing it to cool and solidify. This method is used to form irregular shapes. Only specially formulated alloys C80000 through C99999 can be cast.

Explosive Forming: A high energy rate forming method by which shapes are produced using only a single die. The energy is supplied by chemical explosives. Large shapes can be formed without the need for heavy equipment.

Extrusion: The process of producing a metal shape of constant cross-section by forcing the heated metal through an appropriately shaped die. In general, cross-section diagonals should not exceed six inches. The average thickness of copper alloy extrusions should be about 1/8 inch. The resulting shape can be almost any length, limited mostly by the structural requirements of the final object.

Cold Forging: A forming process in which a metal object at room temperature is shaped by repeated hammering.

Hot Forging: A method of forming metal objects in which a heated slug or blank cut from wrought material is pressed into a closed cell impression die.

Hydroforming: A forming process in which a sheet alloy is pressed between a male die and a rubber piece subjected to hydraulic pressure.

Laminating: Bonding of sheet or strip alloys to various substrates such as steel, plywood, aluminum, or rigid insulating material. The bond is typically achieved with the use of adhesives. The resulting panel can be quite strong, even with thin copper alloy material.

Roll Forming: Shapes made from sheet or strip material by passing it between multiple stands of contoured rolls. Generally, the corners are not as sharp as those achieved by extrusion.

Spinning: A mechanical forming process in which sheet or strip alloy is shaped under pressure applied by a smooth hand tool or roller while the material is revolved rapidly.

Stamping: Shaping sheet or strip alloy by means of a die in a press or power hammer.

Forming Chart

Table 2.2A. Forming Methods

Forming Method	Alloys C11000 / C12500	C12200	C22000	C23000	C26000	C28000	C38500	C65100	C65500	C74500	C77400	C79600
Bending	+	+	+	+	+	+		+	+	+		
Brake Forming	+	+	+	+	+	+		+	+	+		
Casting	All Alloys C80000 - C99999											
Explosive Forming	+	+	+	+	+			+	+	+		
Extrusion							+				+	+
Cold Forging	+	+	+	+	+				+	+		
Hot Forging	+	+	+	+	+	+	+		+			
Hydroforming	+	+	+	+	+	+			+	+		
Laminating	All Copper Sheet and Strip Alloys											
Roll Forming	+	+	+	+	+				+	+	+	
Spinning	+	+	+	+	+					+		
Stamping	+	+	+	+	+				+	+	+	

2.3. Joining

Mechanical fasteners, such as screws, bolts, and rivets provide the simplest and most common joining technique. They typically do not require specialized tools for installation, and many can be removed for disassembly. **Table 2.2A** lists the companion fasteners for each sheet or plate alloy by simplifying color matching and reducing the risk of material incompatibility.

Adhesives can also be used in certain applications. The lamination process of a sheet alloy onto a substrate is dependent on adhesive bonding. Relatively thin sheet alloys can be bonded to steel, plywood, aluminum, or certain types of foam, which act as rigid insulation. The strength and rigidity of the resulting composite panel is often achieved by the combined section acting as one unit.

The integrity of the bond is dependent on surface preparation, adhesive selection, bonding procedure, and joint design. Laminated panels for exterior applications should use a thermosetting or high quality thermoplastic adhesive. Edges and joints are the most vulnerable areas on a panel, as they are the most likely entry points for moisture.

There are three commonly used metallurgical methods for joining alloys: soldering, brazing, and welding. **Table 2.3A** summarizes the joining characteristics of each alloy for these methods.

Where the joining material is required mostly for watertightness, soldering may be used. Lead or tin-based filler metals with melting temperatures below 500 degrees Fahrenheit are typically used. Soldered joints typically depend on mechanical fasteners for strength. This method is commonly used for sealing joints in gutter, roofing, and flashing applications. Since the filler material does not match copper alloys in color, soldering should only be used in concealed joints when appearance is critical.

Brazing is a preferred metallurgical method for joining pipe and tube copper alloys. Two metal sections are joined with a non-ferrous filler material with a melting point above 800 degrees Fahrenheit, but below the melting point of the base metals. Blind or concealed joints are recommended, since the color match of filler material varies. Where this is not possible, mechanical removal of excess material may be necessary.

The final metallurgical joining method, welding, is seldom used with copper alloys because of problems with joint distortion and color matching. Welding uses high temperature or pressure to fuse the base metals together, often with an additional filler metal. Silicon bronzes are the only copper alloys which can be readily welded.

With modern equipment and processes, gas shielded arc welding is gaining acceptance for many copper alloys and use.

Joining Chart

Table 2.3A. Metallurgical Joining Characteristics

Joining Method	Alloys C11000 / C12500	C12200	C22000	C23000	C26000	C28000	C38500	C65100	C65500	C74500	C79600
Brazing	G	E	E	E	E	E	G	E	E	E	G
Soldering	E	E	E	E	E	E	E	E	G	E	E
Welding											
Oxyacetylene	NR	G	G	G	G	G	NR	G	G	G	NR
Gas Shielded Arc	F	E	G	G	F	F	NR	E	E	F	NR
Coated Metal Arc	NR	NR	NR	NR	NR	NR	NR	F	F	NR	NR
Spot Resistance	NR	NR	NR	F	G	G	NR	E	E	G	NR
Seam Resistance	NR	NR	NR	NR	NR	NR	NR	G	E	F	NR
Butt Resistance	G	G	G	G	G	G	F	E	E	G	F

E = Excellent G = Good F = Fair NR = Not Recommended

3. FINISHES

The wide variety of textures and colors available with copper alloys provide architects with an almost limitless palette of visual effects. In order to systematize this colorful collection and provide a basis for specification, the National Association of Architectural Metal Manufacturers (NAAMM) and the National Ornamental & Miscellaneous Metals Association (NOMMA) describe frequently used finishes in the *Metal Finishes Manual for Architectural and Metal Products*.[1]

Figure 3A. This lobby in Anchorage, Alaska, artfully displays panels of copper alloys using a variety of colorful chemical and mechanical finishes.

Photograph courtesy of CDA.

Field application is occasionally necessary for colored or oxidized finishes and for items such as large immobile statuary. Choice of worksite is normally reserved for the fabricator with consent of the architect.

There are four recognized classes of finishes for copper alloys: mechanical, chemical, protective coatings and laminated finishes. The following paragraphs, abstracted from the *NAAMM/NOMMA Manual*, describe these and a few other finishes. Use the alpha-numeric codes in **Table 3.7B**, **Table 3.7C** and **Table 3.7D** to specify these finishes.

3.1. Mechanical Finishes

Mechanical finishes are imparted by physical rather than chemical means. As examples, buffing and grinding are mechanical operations; whereas, oxidizing and patinating are chemical in nature.

As-fabricated

These finishes are the mechanical surface conditions resulting from primary production processes, e.g., hot and cold rolling, extrusion, drawing and casting. They are the least expensive finishes, and, while they may contain imperfections, they are uniform enough with sheet goods for applications such as roofing and wall cladding. The term "mill finish" is commonly used for an "as fabricated" finish.

As-fabricated finishes can be marred by secondary operations such as bending, milling and welding, in which case, they may require additional finishing operations. They can also vary in appearance, both intentionally and accidentally. Rolled finishes, for example, will replicate the surface of the final roll in the mill, and as-cast surfaces will betray the nature of the foundry method employed. As-fabricated finishes include:

1. *NAAMM/NOMMA Metal Finishes Manual*, Chapter 2: "Finishes for the Copper Alloys," National Association of Architectural Metal Manufacturers, AMP 500-06, 2006

3. FINISHES

Figure 3.1A. As natural a look as you can get: unfinished copper cathode, 99.9% pure. Typically shipped as melting stock to mills or foundries, cathodes may also be cast into wire rod, billets, cakes or ingots and alloyed with other metals.

Photograph courtesy of CDA.

Unspecified, which place no preconditions on the as-rolled, -extruded, -drawn or -cast metal. For example, unspecified rolled finishes can range from dull to bright and might contain stains imparted by the residues of rolling oils.

Specular, which are bright mirror-like finishes in cold-rolled sheet, strip and plate produced by passing the metal between highly polished steel rolls. Chemical, heat-treated and mechanical design on copper.

Matte, dull finishes produced by hot rolling, extruding, casting or cold rolling followed by annealing.

Polished and Buffed

Figure 3.1B. The specular or mirror finish on this facade reflects the colors and images of its environment.

Photograph courtesy of CDA.

Produced by sequential grinding, polishing and buffing operations, polished and buffed are extremely smooth and bright. Their relatively high cost reflects the added value of preparation. They are frequently used for hardware and small decorative objects. Their high reflectivity imparts a tendency to reveal even slight distortions and lack of flatness. Polished and buffed finishes on interior surfaces are often protected from tarnishing using lacquers. The two subclassifications of buffed finishes are:

Smooth specular, a very bright, mirror-like surface produced by abrasive belt-grinding followed by polishing with progressively finer abrasives and buffing with extremely fine compounds. This is the most costly mechanical finish applied to copper metals. It is especially important to protect smooth specular finishes during installation because they are challenging to apply or touch-up once installed.

Specular is a somewhat less-bright surface. It is also produced by polishing and buffing, but to a lesser extent than that for smooth specular. Surfaces may contain minor scratches and imperfections. Specular finishes are also shop-applied. Field repair is possible but expensive, since it involves extensive hand operations.

Directionally Textured

These finishes are the most frequently used mechanical treatments for architectural copper metals. Their smooth, satin sheen is produced by wheel- or belt-polishing with fine abrasives that leave closely spaced, nearly parallel scratches. The six standard directionally textured finishes are:

Fine, *medium* and *coarse satin*, which reflect the coarseness of the final polishing abrasive. Final grits range from 240 mesh to 320 mesh for fine satin and 80 mesh for coarse satin.

Figure 3.1C. Directionally textured example: C11000, brush finished.

Photograph courtesy of CDA.

Uniform, a cost-effective finish produced by a single pass of a No. 80 grit belt. Uniform finishes are less expensive than satin finishes and are suitable for many architectural applications.

Hand-rubbed finishes are produced by rubbing with No. 0 pumice and solvent on a fine brass wire brush or a woven, nonabrasive pad. This is a relatively expensive, labor-intensive process. It is used where other processes are impractical or where there is a need to smooth and blend other satin finishes.

Brushed finishes are produced by power-driven wire- wheel brushes, wire-backed sander heads, abrasive- impregnated fiber pads or abrasive cloth wheels. Scratches produced using brushes are not as uniform as those made with abrasive belts, but brushing offers the advantages that it can be applied to objects with curved or irregular contours. Brushed finishes are difficult to maintain, and their use is normally restricted to small areas or for highlighting.

Nondirectional Textured

These are matte finishes produced by spraying sand or metal shot against the metal surface. Roughness is controlled by size of sand or shot particles. The process is often used to clean castings and improve appearance of an as-cast surface. Sand blasted surfaces are fairly rough, but smoother finishes can be produced by vapor honing with fine abrasive slurries.
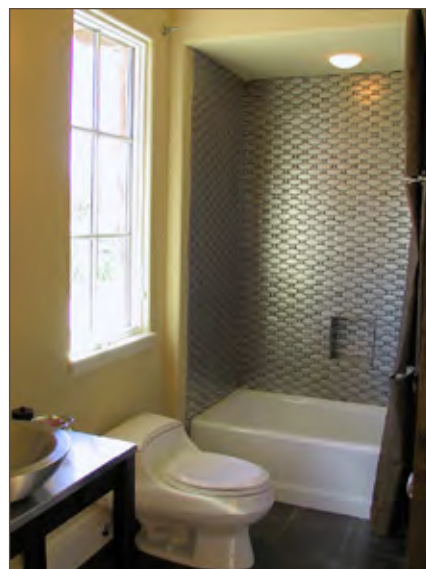

Figure 3.1D. Complementing or enhancing interior spaces, mechanically finished copper alloy surfaces can take on an infinite array of patterns. Their classy look and durability adds value whether in baths, elevators, lobbies or other locations.

Photograph courtesy of CDA.

Hand-applied sand blasted surfaces have non-uniform textures and are generally not suitable for large areas. Also, the surface deformation caused by blasting leaves residual stresses that can warp thin elements. The process is, therefore, not recommended for flat elements less than ¼-in (6-mm) thick. Even fine-grit blasted surfaces are rough enough to retain oils and dirt, and will show fingerprints. For an untarnished finish, sand blasted surfaces require protective treatment.

The three grades of fineness for sandblasted surfaces are fine matte, medium matte and coarse matte; produced by appropriately sized silica sand or aluminum oxide. Degrees of grit fineness range from 100–200 mesh for fine textures to 20 mesh for coarse.

Shot blasted surfaces are not as rough as sand blasted, but minimum sheet thickness recommendations still apply. Metal shot (usually steel) ranges from S-70 for fine texture to S-550 for coarse. There are three standard grades for shot blasted surfaces: fine, medium and coarse.

3. FINISHES

Patterned

Textured, patterned and embossed finishes are produced in light-gauge material by passing sheet between two engraved match-design rolls, impressing patterns on both sides of the sheet (embossing) or between a design roll and a smooth one, thus coining only one side of the sheet. Embossing increases the stiffness of the sheet. It also disperses reflections and minimizes marring in service.

3.2. Chemical Finishes

Figure 3.2A. Chemical treatment opens a wide-ranging palette of colors and possibilities:
a) artificial finish light bronze on naval brass at the Oklahoma City National Memorial, Oklahoma City, Oklahoma [left image]
b) custom chemical treatment of a naval brass panel [right image]

Photograph courtesy of CDA.

Copper alloy surfaces can be chemically altered to produce a wide range of colored finishes. Application is as much a craft as it is a science, and results can vary with such factors as temperature, humidity, surface preparation and skill. Such variability is not necessarily detrimental; it can, in fact, contribute to a finish's charm.

Some chemical treatments are simply for cleaning, as in removing process oils or preparation for subsequent operations. Acid-etching can remove oxides formed during annealing or welding, or to produce a matte surface. "Bright-dip" or "pickled" finishes involve immersing the metal in an acidic bath. They are normally used as intermediate steps before final finishing operations.

Conversion Coatings

These comprise the most important class of final chemical finishes. The metal surface is chemically converted to a stable, protective compound, usually an oxide or a sulfide or another compound, to mimic natural weathering. Common conversion coatings include patinas (commonly called "verdegris"), and statuary (oxidized) finishes.[2]

Figure 3.2B. The oxidized finish on this cast silicon bronze lockset produces a stable compound that inhibits corrosion and maintains its color.

Photograph courtesy of Rocky Mountain Hardware.

Patinas are formed by a variety of methods, all accomplishing in minutes what occurs over years in nature. Synthetic patination replicates the initial period of the natural process to the point where a pleasing color develops. Once placed in service, the natural process continues, reinforcing the applied finish. Early field applied synthetic patination methods yielded coatings that were prone to flaking off, nonuniformity in color and staining of adjacent materials. But, the technology has improved considerably, and modern mill-finished products are more uniform and durable. (See some examples in **Table 3.5A**)

Natural patinas are predominantly mixtures of basic copper carbonate and basic copper sulfate (the latter being the mineral, brochantite). However, compositions are variable and depend strongly on the type and concentration of atmospheric constituents. Thus, patinas formed near the sea contain slightly different percentages of copper sulfates, chlorides and carbonates than those formed in industrial or rural areas. Natural patinas are therefore far from uniform, and architects have learned to take this fact into account.

Figure 3.2C. Natural patinas are seen throughout the world where architects have chosen to use a living metal that projects beauty in any environment and preserves itself for centuries to come.
a) One Atlantic Center, Atlanta, Georgia; copper roof after more than 20 years' exposure in a humid environment. [left most image]
b) Druid Hills Baptist Church, Atlanta, Georgia, mature copper patina, characteristic of over 80 years' exposure in a humid location. [vertical center image]
c) Jewish Federation of Tulsa, Oklahoma, newly installed copper. [top right image]
d) Jewish Federation of Tulsa after five years' exposure in a semi-arid climate. [bottom right image]

Photograph courtesy of CDA.

In addition to atmospheric composition, such factors as temperature, humidity, drainage, insolation and roof slope can affect formation rate and appearance. It would not be unusual for the north- and south-facing surfaces of the same roof to patinate differently or at different rates. A synthetic patina can mitigate these effects; although, one that appears too uniform might look contrived until further, natural weathering takes its course.

Synthetic patinas are normally produced by the action of acid-chloride or acid-sulfate treatments in which the reagents are applied by brushing, sponging, stippling or spraying. Many patinating processes exist, including proprietary, mill-applied versions applied by sheet and strip suppliers. Patented preparations are also available. When large-area uniformity is not critical, two processes found to be suitable for field- or shop-application are:

- *Acid chloride treatments* are based on solutions of sal ammoniac (ammonium chloride) or on cuprous chloride-hydrochloric acid mixtures. Several applications of the sal ammoniac solution may be needed to achieve the desired effect.

- *Ammonium sulfate treatment* finishes contain copper sulfate and ammonia. Treatments are applied by spraying and require six to eight applications to achieve the required density.
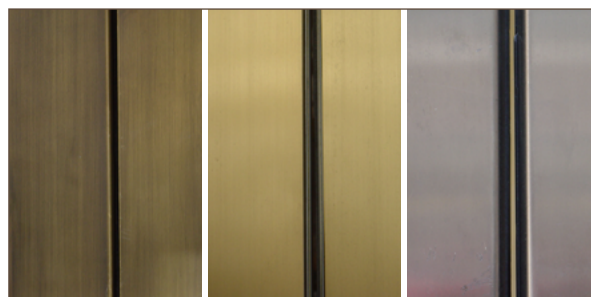

Figure 3.2D. Skillful use of chemical treatment techniques provide a great variety of color tones from a given copper alloy.

Photograph courtesy of Stuart Dean.

Note on chemical weathering in field environments: Chemical coloring of exposed flashings, chimney caps and similar small surface areas are possible with reasonable expectation of success. Chemical weathering of large surface areas, such as roofs, spires, domes and walls, is impractical and should be avoided. Realistic color tone, uniformity and durability is difficult to control, and the hand methods employed are expensive. Where large areas are involved, either natural weathering or use of factory patinated copper sheet material provides superior results.

Patinas are normally reserved for non-traffic areas and areas that will receive little or no maintenance. If placed in a traffic area, a clear organic coating may provide protection, but can alter the color.

Oxide or statuary bronze treatments are based on cuprous oxide, sometimes combined with a mixture of copper sulfides. They are commonly applied to bronzes used as artistic, decorative or, architectural elements. Their brownish colors range from light to medium to dark, depending on the copper alloy, fineness of surface texture and concentration and number of applications of coloring solutions. Popular reagents include potassium permanganate and copper salt solutions.

Finishes are often augmented by mechanical abrasion to produce highlights. Statuary finishes are commonly hand-applied and hand-rubbed periodically with wax or oils to maintain a stable appearance.

Figure 3.2E. Statuary bronze finishes are popular for many uses, including building entries.

Photograph courtesy of Stuart Dean.

Sulfide treatments are similar in color to oxide finishes but are produced by dipping, spraying or brushing the surface with reagents such as potassium sulfide, sodium sulfide, ammonium sulfide and, less frequently, antimony pentasulfide, the latter applied as a paste. Oxide treatments may be applied as a preliminary step to improve adherence.

Selenide treatments produce deep colors. Formation is rapid with use of appropriate selenide solutions, many of which are proprietary. Application can involve exposure to hazardous reagents.

3.3. Protective Coatings

Coatings are finishes applied over copper metals that may or may not have received mechanical or chemical treatment. Coatings are usually applied for protection but, in some cases, may also provide visual effects.

Coatings take two general forms: *transparent* coatings that preserve natural color, texture and metallic luster of copper metals, and *opaque* coatings that impart corrosion and abrasion resistance while retaining formability.

Clear Organic Coatings

Copper metals are inherently corrosion-resistant, but thin tarnish films and/or patinas can form over time. Clear organic coatings can retard formation of such films and thus preserve the metals' natural colors by acting as physical and/or chemi-cal barriers to atmospheric chemicals. These coatings degrade over time, especially in fully exposed exterior applications. When specifying a clear coating, consider effort required to periodically remove the clear coating, refinish the underlying metal and apply a new coating.

Figure 3.3A. The Anchor Center office building in Scottsdale, Arizona, chose to boast its location in the Copper State by preserving the natural color of freshly milled copper sheet with a clear coating. Due to sun and heat, the finish requires reapplication every few years to maintain its pristine look.

Photograph courtesy of CDA.

Clear coatings are compounded from synthetic or natural resins, oils or combinations of the three, usually applied as solutions in a volatile solvent. They can be brush- or dip-applied but are most often sprayed and air-dried (i.e., cured or polymerized), especially for large-area applications. They can also be baked, in which case, a harder, more durable (and a more difficult-to-strip) coating results. Finishing processes are straightforward, but any organic coating will perform best when the underlying surface is properly cleaned and prepared as soon as practical before application.

Inhibited acrylic coatings include those containing protective chemicals in addition to the base resin(s). INCRALAC®-type coatings are the most effective in this class. Based on acrylic lacquers, INCRALAC coatings contain an organic oxygen scavenger, usually benzotriazole or a related compound. The basic composition was developed by the International Copper Research Association, and a number of licensed commercial versions are available. The coatings are normally sprayed and air-dried, although dipping and baking are also approved. Sprayed and air-dried films are normally specified for exterior uses. Baked films are more abrasion resistant and are preferred for interior applications, although periodic maintenance is required.

Prepare surfaces by washing with a cleaning solvent and, for non-specular finishes, abrasive pads. Avoid steel wool (a general precaution for all copper metals) since it sometimes contains a rust inhibitor that can stain copper over time if not thoroughly removed. Alkali cleaning is also effective.

Acrylic coatings without inhibitors provide good abrasion resistance at somewhat lower cost than inhibited versions. They are useful for both exterior and interior applications where wear and exposure to chemical reagents are design considerations.

Alkyd coatings have limited serviceability and tend to yellow outdoors unless modified. They are relatively inexpensive, but must be slow-dried or baked. Exterior performance is improved by compounding with melamine resins. Resistance to chemicals is usually good.

Cellulose acetate butyrate coatings are air-drying, inexpensive and, for interior use, provide fair to good service. They tend to darken when exposed to sunlight.

Epoxy coatings have excellent resistance to impact, abrasion and many chemicals. They are relatively expensive, and application can involve additional costs in that some compositions are two-part compositions requiring compounding on-site, while other versions require heat curing. Interior performance is exceptional, but coatings may darken and chalk when exposed outdoors.

Nitrocellulose coatings are the least expensive, easiest to apply and most common air-drying coatings for mild interior service. Although some of these coatings have limited service life, formulations with alkyd or acrylic resins show improved performance. Exterior use requires stripping and reapplication at approximately yearly intervals depending on exposure conditions. Chemical resistance is low.

Urethane coatings have excellent chemical and abrasion resistance. Cost is moderate to relatively high. The coatings were originally intended for interior use, but modified versions may also be suitable for exterior use. Application entails health risks, and appropriate precautions are absolutely necessary.

Silicone coatings are also relatively expensive, although they provide the best service at elevated temperatures and under severe exposure conditions. Abrasion resistance is moderate, so a topcoat of a more resistant coating may be needed. When exposed to ultraviolet radiation, silicone coatings may discolor unless the composition includes a suitable inhibitor.

Pigmented clear coatings, Pigments are occasionally added to a clear coating to fine tune color match between different alloys.

Oils and Waxes

These coatings can be applied over most chemical finishes to enhance their appearance with richer luster and greater depth of color. The finishes are almost always applied to statuary bronzes, in which case they also protect the underlying oxide/sulfide surface treatment.