Capabilities and Limitations of Architectural Metals:

Part 1

by Catherine Houska

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Metal offers many attractive design possibilities. But to use metals safely and economically, architects, contractors, and building owners must understand both their capabilities and limitations. A metal providing good performance in one application can corrode rapidly under different circumstances. Strength, weight, desired appearance, corrosion resistance, expected service life, and costs associated with installation and longterm maintenance must be considered.

ADDITIONAL INFORMATION

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Abstract

Metal has become increasingly popular because it provides unique design opportunities, strength, and corrosion resistance. Each metal family has unique characteristics. Performance over time depends on the designer understanding the advantages and limitations of each metal and taking these into consideration during the design process.

This article provides some guidelines for determining the service environments where architectural metals are likely to perform well and where problems may occur. Physical and mechanical properties will be summarized and comparative appropriate thicknesses in sample applications will be shown.

Selection Criteria: Stainless Steels

Stainless steels contain at least 12 percent chromium. They form a thin (invisible), protective, corrosion-resistant passive film on their surface. The film self-repairs quickly if it is damaged or removed during fabrication or polishing. If an appropriate stainless steel is selected, it will retain its original appearance with no corrosion product discoloration of surrounding materials.

The stainless steels most commonly used in architecture and construction are Types 430, 304, and 316. Type 430 and other 400-series stainless steels are magnetic. Types 304 and 316 and other 300-series stainless steels are not magnetic and can be strengthened by cold work. In most architectural applications, stainless steel is used in the annealed or "dead soft" condition. In structural and sheet applications subjected to higher loads or impact, cold working can be an economical means of reducing weight and increasing strength.

Type 430 is used in indoor, rural, or urban locations with low corrosion potential. Type 304 is used in indoor, rural, moderately polluted urban applications, and coastal applications with low humidity and temperatures. Type 316 is used for marine, coastal, or deicing salt exposures and in industrial and aggressive urban locations. In some very aggressive sites, a more corrosion-resistant stainless steel may be needed.

If an appropriate stainless steel is used, there is no reason to apply a protective coating. A variety of mechanical and colored finishes are available. Stainless steel is available in sheet, strip, plate, bar, tube, pipe, castings, and extrusions.

Stainless steel is sometimes mistakenly ordered by gage number. There is no standard definition of stainless-steel gage numbers, and specifiers should always specify the desired thickness.

Selection Criteria: Weathering Steels

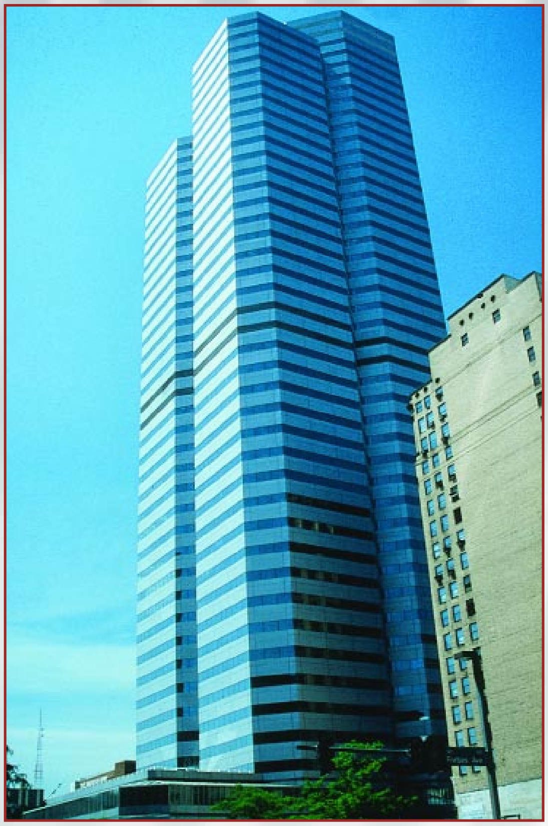
High-strength, low-alloy weathering steels are carbon steels with combined additions of up to two percent copper, chromium, nickel, and phosphorus. They are used in exterior applications and have mechanical properties similar to those of structural carbon steels. In climates with wet and dry cycles, they form a protective, dense, adherent, stable, corrosion-resistant oxide (rust) layer. Corrosive substances can still pass through the oxide film, but corrosion rates decrease as the layer thickens.[1]

This uniform protective layer will not form indoors, or in arid or continuously wet environments. If this layer is allowed to form and is not disturbed, weathering steels provide significantly better corrosion resistance than carbon steels.

Weathering steels should not be used where mechanical or chemical disruption of the film is likely. Mechanical damage could result from windborne abrasive particles, rubbing, or scratching. Chlorides and industrial pollutants disrupt the film. Weathering steels are not suggested for coastal, marine or deicing salts, or industrial environments.[3]

Water coming into contact with weathering steel can stain other materials. Designs must drain water away from other materials and permit the surface to dry. Elements not boldly exposed to the atmosphere should be painted. (See photo at end of article.)

The United States Steel Worker's Building (formerly the IBM Building) was completed in 1963. It has Type 304 stainless steel cladding on the steel lattice trusses and anodized aluminum panels under the windows. Architect: Curtis & Davis.



One Oxford Center has a painted carbon steel curtain wall and was completed in 1983. Architect: Hellmuth, Obata, & Kassabaum.

Selection Criteria: Carbon Steel

Carbon steels are at least 95 percent iron with two percent or less carbon and are classified by grade based on their carbon content. Strength and hardness increase with carbon content but ductility decreases. The grades typically used in architecture are very mild (0.05 percent to 0.15 percent carbon), mild (0.15 percent to 0.25 percent carbon), and medium (0.25 percent to 0.35 percent carbon) carbon steel.[2]

Carbon steels are available in the product forms needed for architecture including structural shapes, pipe, tube, sheet, and strip. Because bare carbon steels will rust in air, they are normally protected with metal coatings, porcelain enamel, or paint. Common metal coating processes include aluminized (aluminum), chromium, copper, brass, galvanized (zinc), Galvalume® (aluminum-zinc), terne (lead-tin or tin-zinc), and tin. The precautions discussed in the zinc alloys section also influence the life of zinc coatings.

The corrosion rate is dependent on the environment and protective coating integrity or the effectiveness of the cathodic protection system (e.g., zinc). Regular exposure to moisture (rain, fog, high humidity levels), industrial pollution, sulfur oxides, and chlorides can significantly increase corrosion rates. If protection is not maintained, rust can discolor surrounding materials, and rust may undermine more of the protective surface layer. Surface rust buildup should be removed or it will retain moisture, concentrate corrosive chemicals, and accelerate corrosion.[3]

Selection Criteria: Copper and Copper Alloys

The natural color of copper alloys varies considerably with alloy content and includes shades of red, gold, and silver. Copper and its alloys form a thin adherent oxide layer or patina which gradually changes the metal's color. The color will vary with the alloy and may not be uniform. If moisture is present, copper can stain porous materials. Detailing should prevent water run-off onto these surfaces. A wide range of product forms are available. Intricate castings are possible.

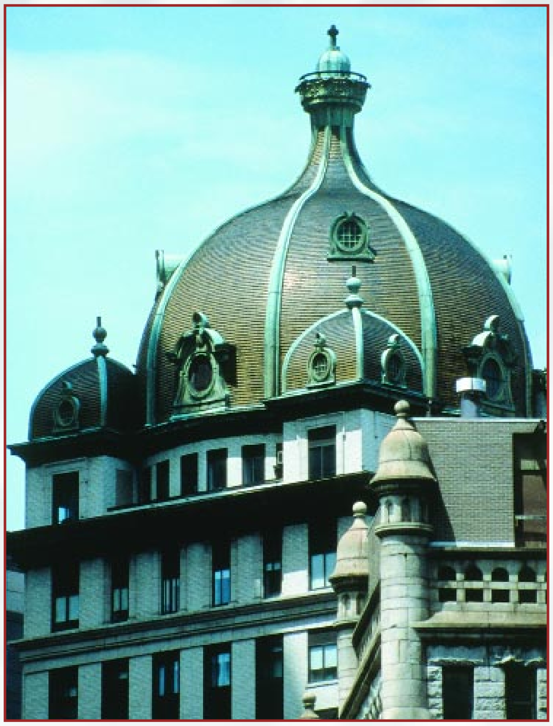
Electrolytic tough pitch (99.9 percent pure) copper, used for roofing, provides good corrosion resistance to chlorides and deareated nonoxidizing acids. Alkalis (which may leach from concrete), ammonia, and sulfur compounds will cause corrosion. Fire-retardant treated wood may be treated with chemicals that corrode copper.

Brass has good resistance to atmospheric corrosion, alkalis, and organic acids. In some potable waters and in seawater, brasses with 20 percent or more zinc may suffer corrosive attack. Moist ammonia, mercury, and moist chlorine gas can cause stress corrosion cracking. Brasses used in architecture include commercial bronze, red brass, cartridge brass, yellow brass, and Muntz metal.

Nickel silvers are copper-nickel-zinc alloys with a golden-silver luster. They were particularly popular during the early 1900s when Art Deco architecture was in style. Other names used for this alloy family are German silver, white copper, white bronze, Paris metal, and dairy bronze.

Selection Criteria: MONEL®

MONEL® is a trade name for a highly corrosion-resistant family of silver-white colored nickel-copper alloys. Alloy 400 is the generic name for the alloy used in



The copper details on the dome of Midtown Towers were installed in 1908. Architect: Thomas Hannah.

Smithfield United Church of Christ is a Historic Landmark built in 1926. The elaborate metal spire is aluminum castings on a steel structural frame. Both are painted. It was the first aluminum spire in the world. Architect: Henry Hornbostel.

architecture. It was very popular from 1909 to the mid-1950s and is sometimes mistaken for stainless steel in restoration work. It continues to be used in roofing. In exterior applications, it will develop a patina ranging from light gray-green to medium brown. It provides excellent resistance to atmospheric corrosion, including relatively severe chloride levels, alkalis (which may leach from concrete), or industrial pollution.

Selection Criteria: Aluminum Alloys

Aluminum alloys are lightweight, silver-colored, and provide corrosion resistance in a variety of environments. Some alloys used in architectural applications are 3003, 3105, 5005, 6061, and 6063. The 3000 and 5000 series alloys can be strengthened by heat treating ("H" tempers). The 6000 series alloys can be strengthened by cold work ("T" tempers).

Aluminum forms a protective oxide film with a high level of corrosion resistance when clean metal is exposed to air. Anodizing strengthens and thickens the film, providing greater corrosion protection. Either anodized or resinous organic coated aluminum is normally specified for exterior applications. Ceramic coatings can also be applied. Aluminum is available in sheet, strip, bar, plate, tube, pipe, forgings, castings, and extrusions.

When aluminum corrodes, the surface becomes rough and chalky with a white or gray film. The film color makes corrosion less visible but there can be some staining of adjacent surfaces. Atmospheric sulfates and coastal and deicing salts can cause corrosion. A heavy protective coating is needed if aluminum will be in contact with concrete, masonry, plaster, or soil.

Wood in contact with aluminum should be sealed with a primer and paint. However, fastenings into oak, chestnut, or western cedar should be avoided unless the wood is well seasoned. Under damp conditions, insulating products can release by-products corrosive to aluminum unless a sealant is used.

Selection Criteria: Zinc

Zinc's low creep strength at room temperature and high thermal expansion coefficient should be considered during design of roof and wall panels. Zinc alloys with at least 0.05 percent titanium and 0.10 percent copper have improved creep resistance and mechanical strength and weather to a grayer patina than pure zinc. A phosphate pretreatment can be used to produce a darker gray patina on these alloys.

Zinc is resistant to chloride corrosion, but industrial atmospheres containing sulfur dioxide can accelerate corrosion. The only common woods that can be used in contact with zinc are pine, poplar, and spruce. If zinc is in contact with another metal and moisture is present, the metals must be electrically insulated from each other because zinc corrodes in preference to all other architectural and engineering metals. This effect is so strong zinc is regularly used as a sacrificial anode to protect other metals.

Zinc and zinc coatings must be protected from condensation and standing water. There should be a free flow of air behind zinc panels to prevent condensation. If thermal insulation is used, the space between the zinc and roof sheeting should be vented. Zinc should not be placed in direct contact with cement, mortar, or other moisture retaining materials.

Extending Service Life

Like all materials used in exterior environments, metals can accumulate dirt and debris. These deposits can be corrosive. The corrosion resistance of metals is improved by regular removal of corrosive deposits from the surface. In environments with plentiful rain, designs encouraging natural rain cleaning can be effective in removing corrosive deposits, particularly if the surface finish is smooth. Building exteriors often have elements not easily washed by rain. Regular cleaning to remove deposits can enhance the corrosion resistance of metals, extend their service life, and keep them attractive.

Mechanical and Physical Properties

Typical mechanical and physical properties of some common architectural metals are shown in Tables 1 and 2. The ASTM specifications should always be used to specify the desired grade or alloy and its mechanical properties. Additional information on physical properties can be obtained from metal suppliers, industry associations, and metals reference books such as the ASM International Metals Handbook series.

Specifying Metal Thickness

Metal strength, strength-to-weight ratios, corrosion resistance, and wear resistance determine the appropriate thickness or weight for a project. Assuming the same thickness is appropriate for two different metals (e.g., steel versus stainless steel) can lead to costly over or under specification. Industry associations and manufacturers

Building Material	Strength to Weight ratio	Tensile Strength, ksi (MPa)	Yield Strength, ksi (MPa)	Ultimate Shear Strength ksi (MPa)	Elong. in 2 in. (50mm), min %
Stainless steel Type 316 Annealed	257	75 (515)	30 (205)	—	35
Stainless steel Type 304 Annealed	257	75 (515)	30 (205)	—	35
Stainless steel Type 430	232	65 (450)	30 (205)	—	22
HSLA Steel, 3/4-1.5 in. (20-40 mm)	239	67 (460)	46 (315)	—	21
Structural steel (plate and bar)	261	58/80 (400/550)	36 (250)	—	23
Carbon steel commercial sheet, cold rolled	164	46 (317)	34 (234)	—	35
Aluminum Alloy 3003-H14	222	22 (150)	21 (145)	8 (55)	40
Aluminum Alloy 3105-H14	255	25 (170)	22 (150)	15 (105)	5
Aluminum Alloy 5005-H16	265	26 (180)	25 (170)	15 (105)	5
Aluminum Alloy 6061-T6	459	45 (310)	40 (275)	30 (205)	12
Aluminum Alloy 6063-T5	276	27 (185)	21 (145)	17 (115)	12
Copper	112	36 (250)	28 (195)	25 (170)	30
Red Brass	158	50 (345)	39 (270)	35 (240)	—
Muntz Metal M20	178	54 (370)	21 (145)	40 (275)	45
Nickel Silver H01 (C74500)	207	65 (450)	45 (310)	45 (310)	25
Cast 20% Leaded Nickel Silver	146	47 (324)	26 (179)	—	10
Cast 25% Leaded Nickel Silver	172	55 (379)	31 (214)	—	16
Alloy 400, cold rolled, annealed	250	80 (550)	35 (240)	—	40
Zinc-Copper-titanium alloy	84	21.8 (150)	14.5 (100)	—	—

Table 1: Typical mechanical properties for architectural metals.[4]

Building Material	Density Lbs/ft^3 (g/cm^3)	Coef. Thermal Expansion 68-212 °F (20-100 °C) µin/in °F (µm/mo °K)	Thermal Conductivity 212°F(100 °C) Btu·in/ft2·hr·F (W/m· °K)
Type 316	0.29 (8.0)	8.8 (15.9)	113 (16.3)
Type 304	0.29 (8.0)	9.6 (17.2)	113 (16.3)
Type 430	0.28 (7.8)	5.8 (10.4)	181 (26.1)
Gray Iron	0.27 (7.5)	6.6 (11.9)	348(50)
Carbon Steel	0.28 (7.8)	6.7 (12.1)	324 (47)
HSLA Weathering Steel	0.28 (7.8)	6.7 (12.1)	324 (47)
Alloy 400	0.32 (8.80)	7.7 (13.9)	151 (21.8)
Copper C11000	0.321 (8.89)	9.4 (17)	2688 (387)
Red Brass	0.316 (8.75)	10.4 (18.7)	1104 (159)
Muntz Metal	0.303 (8.39)	11.6 (20.8)	852 (122)
Nickel Silver	0.314 (8.69)	9.1 (16.4)	312 (45)
Cast 20% Leaded Nickel Silver	0.321 (8.90)	9.3 (16.7)	156 (22.5)
Cast 25% Leaded Nickel Silver	0.320 (8.86)	9.7 (17.5)	176.4 (25.4)
Aluminum Alloy 3003 H14	0.099 (2.73)	12.9 (23.2)	1100 (159)
Aluminum Alloy 3105	0.098 (2.72)	13.1 (23.6)	1190 (172)
Aluminum Alloy 5005	0.098 (2.70)	13.2 (23.75)	1390 (200)
Aluminum Alloy 6061 T6	0.098 (2.70)	13.1 (23.6)	1160 (167)
Aluminum Alloy 6063 T5	0.097 (2.70)	13.0 (23.4)	1450 (209)
Zinc-Copper-titanium alloy	0.259 (7.17)	12 (22)	727 (105)

Table 2: Physical constants and thermal properties.[5]

Pan Width for a Seam Height of 25 mm (1 in.)	Recommended thickness, gage, or weight					
	Stainless Steel	Galvanized Steel		Copper		Aluminum
	Inches (mm)	Gage	Inches (mm)	Oz.	Inches (mm)	Inches (mm)
16.75 to 20.75 (430 to 530)	0.015 (0.38)	24	0.024 (0.61)	16	0.022 (0.55)	0.032 (0.81)
22.75 to 23.75 (580 to 600)	0.018 (0.46)	24	0.024 (0.61)	16	0.027 (0.69)	0.040 (1.02)

Table 3: SMACNA recommendations for standing seam roofs.

Girth	Galvanized Steel		Copper		Aluminum	Stainless Steel
Inches (mm)	Gage	Inch (mm)	oz/ft^2	Inch (mm)	Inch (mm)	Inch (mm)
≥15 (≥380)	26	0.022 (0.55)	16	0.022 (0.55)	0.032 (0.81)	0.016 (0.40)
16–20 (410-510)	24	0.028 (0.70)	16	0.022 (0.55)	0.040 (1.02)	0.019 (0.48)
21–25 (530–640)	22	0.034 (0.85)	20	0.027 (0.69)	0.051 (1.30)	0.025 (0.64)
26–30 (660-760)	20	0.040 (1.01)	24	0.032 (0.82)	0.063(1.60)	0.031 (0.80)

Table 4: SMACNA recommendations for rectangular gutters.

can be a good source of guidelines. *The Architectural Sheet Metal Manual* published by the Sheet Metal and Air Conditioning Contractors National Association, Inc., (SMACNA)[6] is an excellent resource for determining appropriate metal thicknesses, gages, or weights. Examples are shown in Tables 3 and 4.

Fire-Resistance

Resistance to fire and thermal radiation damage can be an important safety consideration. The metals used for architecture exhibit significant differences in strength retention at elevated temperatures even after brief exposure to high temperatures. Copper and aluminum start to experience strength reductions at fairly low temperatures. Aluminum alloys begin to show a reduction in strength at temperatures above 100 °C (212 °F).[3] At 204 °C (400 °F), the tensile strength of copper has decreased about 25 percent and 6061-T6 aluminum has decreased by about 60 percent.[7]

Under continuous loading, carbon steel is usually limited to a maximum temperature of 370 °C (700 °F).[8,9] By the time steel reaches 500 °C (930 °F), it has lost about 30 percent of its tensile strength. Unprotected weathering steel loses about half of its tensile strength above 538 °C (1000 °F).[2] Both carbon and weathering steel are normally encased in insulating materials to limit temperature increase during fires. Types 316, 304, and 430 stainless steel can withstand short exposure times up to 870 °C (1600 °F).

Five industry associations and metals producers sponsored fire and radiation resistance testing of structural materials: galvanized carbon steel, fiberglass-reinforced plastic (FRP), aluminum, and Type 316 stainless steel.[10] The tests used commercially available 10-m (33-ft) long cable ladders uniformly loaded to simulate

A close up of the roof.

The Pittsburgh Mellon Arena had the largest dome in the world and largest retractable roof when it was completed in 1961. The roof is Type 304 stainless steel. Architect: Dahlen K. Ritchey.

the weight of electrical cables. The FRP and aluminum ladders failed both tests.

In the five-minute test for fire-resistance, the metals were exposed to direct flames at 1000 °C to 1050 °C (1832 °F to 1922 °F). The galvanized mild steel passed the five-minute exposure requirement and reached 642 °C (1188 °F). Type 316 ladder passed the five-minute test. The test time was extended to 45 minutes, and it reached 705 °C (1300 °F). The deflection of the galvanized steel after five minutes was 166.5 mm (6.6 in.). The deflection of the stainless steel after 45 minutes was 80.5 mm (3.2 in.).

Radiation testing simulates heating by radiation rather than with direct flame. The test was continued until the ladder temperature stabilized or structural failure occurred. The galvanized steel ladder reached a stable temperature of 552 °C (1026 °F) in two hours. The stainless steel reached temperature stability at 556 °C (1033 °F) in three hours. The deflection of the stainless steel after three hours was about one-third of the galvanized steel ladder after two hours.

Conclusion

When specifying a metal, it is important to identify the specific grade or alloy and the appropriate ASTM standards for the desired product form. Properties and corrosion resistance can vary significantly within a metal family. Specifying just stainless steel, aluminum, or copper is not adequate. The wrong grade or alloy within the metal family could be supplied, and it may not meet application requirements.

Metal performance can vary significantly with the environment. Environments should be carefully reviewed to avoid metal corrosion that could be detrimental to aesthetic, building envelope, or structural requirements. The manufacturer or industry association should be consulted to determine if the metal, coating, thickness, or weights are appropriate for the application.

For additional information on this topic, specifically, "How to Select Metals for Optimal Corrosion Resistance," see the November 2000 issue of *The Construction Specifier.*

The USX Tower has a CORTEN exterior (a weathering steel exterior) and was completed in 1971. The CORTEN was allowed to weather naturally but was eventually painted because the rust was staining nearby buildings. Architect: Harrison and Abramovitz.

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Information Sources
Additional information can be obtained from the following industry associations.

Aluminum Association Inc.
202-862-5100
www.aluminum.org

American Iron and Steel Institute
202-452-7100
www.steel.orgww.steel.orw.steel.org

Copper Development Institute
212-251-7200
www.copper.org

Nickel Development Institute
(stainless steel and nickel alloys)
416-591-7999
www.nidi.org

Specialty Steel Industry of North America
(stainless steel)
202-982-0355 or
800-982-0355
www.ssina.com

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Page 39 Photo credits:
left photo: *Two Mellon Bank Center (formerly the Union Trust Building) has copper canopies over the entrances. It was completed in 1917. Architect: Frederick John Osterling*

right photo: *The ALCOA Building was the first multi-story building with aluminum (anodized) curtain walls. It was completed in 1953. Architect: Harrison and Abramovitz.*

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