Part II: Metal Systems and Architecture

1. Properties of metals

Class of elements distinguished from other materials by:

- Ductility
- Malleability
- Hardness
- Conductivity
- Ability to form alloys
- Qualities of appearance

2. Primary Architectural Metals

Stainless steel
Aluminum
Copper
Zinc
Lead composites

Introduction

Of all known elements, metals make up the majority.Within periodic table there are five separate families of metals

1. Alkali metals: very reactive metals, none of these used in architecture.
2. Alkaline earth metals: magnesium and beryllium are used as alloyins constitutents. Otherwise not used for architectural applications.
3. First transition metals: known for hardness and strength, especially when tungsten, chromium and vanadium are used as alloying agents.
4. Second transition metals: iron is major architectural element of this group. Nickel is alloyed with copper to produce monel and with iron and steel to produce the stainless steels.
5. Third transition metals: included here are copper, silver, zinc. All of these play an architectural role. Zinc and copper are sought for their superior stability in atmospheric conditions.

Metal-like elements: with both metal and nonmetallic properties

1. Boron and carbon family: includes the oldest architectural metal, lead and the newest, aluminum.
2. Rare earth metals: not architecturally significant.
3. Nitrogen and oxygen group

First transition metals

titanium, chromium, molybdenum, tungsten, manganese

Second transition metals

iron, cobalt, nickel, platinum

Third transition metals

copper, silver, gold, zinc, cadmium, mercury

Boron and carbon families

Lead, tin, aluminum

Weathering and corrosion resistance

- Metals age with the formation of oxides and hydroxides on their surfaces.
- Often this layer is more layered, roughened surface that reduces the reflectivity.
- Generally, a smoother surface will resist corrosion better. A smoother surface will offer less surface area for atmospheric penetration. A smooth surface also self-cleans better (mostly with rain and snow).
- In coastal climates, the presence of chlorides from salt is the primary agent of corrosion. Salts will accumulate in dews and other moisture forming on the cool metal surface. Salt deposits become concentrated at edges, drips and horizontal edges.
- In urban/industrial environments corrosion occurs through the attack the surface by sulfur dioxide, which combines with moisture to develop sulfuric acid, which can stain and deteriorate many metals. Most metals are susceptible, includin stainless steels. Regular cleaning and maintenance is required.

Environments of exposure are ranked as follows:

Most Severe

- Marine
- Coastal Urban
- Northern Urban Street Level (road salts)
- Urban Industrial
- Coastal
- Urban
- Urban-Arid climate
- Urban-Protected
- Arctic
- Rural
- Interior-Entrances
- Interior
- Interior-Protected

Least Severe

Appropriate environments

1 = Rural environments
2 = Urban, industrial
3 = Coastal

Performance
G = Good
M = Moderate
P = Poor

Env	Titanium	Stainless steel	Monel	Copper	Lead	Painted alum.	Ptd zinc-coated steel	Zinc	Aluminum	Steel	Polished brass and bronze
1	G	G	G	G	G	G	G	G	G	M+	G
2	M+	M+	G	G	G	M	M	M	P	P	P
3	G	M+	G	G	G	P	P	P	P	P	P

Weathering and corrosion resistance

Metal	Color	Reflectivity (1=high, 5=low)	10-year aging characteristics
Zinc-natural	Gray-blue	2	Dark bluish gray color
Preweathered zinc	Dark blue-gray	4	Dark bluish gray color
Carbon steel	Gray dark blue	4	Red rust
Tin	Gray silver	2	Dark gray tones
Lead	Dark gray	5	Dark gray to gray black
Galvalume (aluminum-zinc alloy)	Gray-light tint	3	Gray
Stainless steel	Chrome silver	1	No change
Titanium	Gray-medium	3	No change
Clear anodized aluminum	Gray-medium	3	Very little color change
Copper	Reddish-pink	2	Gray-green patina
Commercial bronze	Reddish gold	2	Green-gray patina
Yellow brass	Yellow-gold	2	Green-grey patina and black streaks

Galvanic relationship

Electromagnetic scale (in terms of solution in seawater)

- Usually not an issue, because surface area between differing metals is small
- Overall differential determines polarity
- The greater the differential the greater the polarity and therefore the faster the decay from the more active (or in this scale the more negative) to the other metal.
- Example:

  zinc = -1.03

  lead = -0.27

  diff. = 0.78
- Consult particular characteristics of each metal for maximum polarities.
- Generally, oxides will inhibit the full polarity.
- Use gaskets and coatings to eliminate the conduction between metals.

Anodic polarity	Volts	Metal
Least noble end of scale	-1.03	Zinc
	-0.79	Aluminum
	-0.61	Steel or iron
	-0.53	Stainless steel
	-0.36	Copper
	-0.31	Bronze
	-0.29	Brass
	-0.28	Tin
	-0.27	Lead
	-0.25	Monel
Noble end of scale	-0.10	Titanium
Cathodic polarity	+1.29	Gold

Increasingly active metals

Density

Specific gravity is a measure of a material's density in comparison with water.

Metal	Specific gravity
Magnesium	1.77
Aluminum	2.70
Titanium	4.51
Chromium	6.92
Zinc	7.14
Tin	7.30
Stainless steel	7.90
Iron/steel	7.87
Bronze	8.80
Monel	8.83
Nickel	8.90
Copper	8.96
Lead	11.34
Gold	19.32

Hardness and Ductility

- Hardness is independent of a material's density
- Various degrees of hardness can be achieved in many metals through 'tempering', the repeated heating and cooling of the metal.

Metal	Hardness Rockwell B-Scale	Yield strength		Ductility Degree 1 = Very Ductile 5 = Stiff
		Ksi	MPa	
Aluminum	20-25	21	145	1
Copper	10	28	193	1
Bronze	42	35	241	2
Brass	65	49	338	2
Steel-low carbon	60	25	170	2
Cast Iron	86	50	344	5
Stainless steel	88	30	207	2
Lead	5	0.81	5	1
Monel	60	27	172	3
Zinc-Cu	40	14	97	1

Thermal expansion

- Determine expected temperature range that metal will experience.
- For darker metals or painted surfaces, use a temperature at least 50% greater than the maximum ambient temperature expected.

  max. = 100F

  use = 150F
- Temperature at installation is extremely important. (Detailing)

Metal	Coefficient of thermal expansion	Expected expansion over 38 degrees C differential	
		per 120 inch sheet (inches)	per 3-meter sheet (mm)
Aluminum	23.2	0.11	2.79
Copper	16.8	0.08	2.03
Bronze	18.4	0.08	2.03
Nickel silver	16.2	0.07	1.78
Iron	11.7	0.05	1.27
Steel	11.7	0.05	1.27
Cast iron	10.5	0.05	1.27
Stainless steel	16.5	0.08	2.03
Lead	29.3	0.13	3.30
Tin	23.0	0.10	2.54
Zinc	32.5	0.15	3.81
Titanium	8.4	0.04	1.02
Gold	14.2	0.05	1.27

Thermal expansion

$$\Delta T_{cold} = T_{install} - T_{coldest}$$

$$\Delta T_{hot} = T_{hot} - T_{install}$$

$$C_{te} \times \Delta T_{hot} \times \text{Length (inches)} = \text{Expected expansion (inches)}$$

for a particular length segment

$$C_{te} \times \Delta T_{cold} \times \text{Length (inches)} = \text{Expected contraction (inches)}$$

for a particular length segment

Relative cost comparisons

The overall cost is calculated based on the following factors:

- Cost of base metal
- Cost of the metal surface finish
- Cost of fabrication and installation
- Cost of maintenance over time

Specification notes

- Always require a visual mockup
- Mockup should be constructed by persons actually hired to execute project
- Pre-qualify a company before it bids for a project of architectural metal

Metal	Cost by weight alone	Cost by surface area
Steel	1	1
Iron	1	1
Aluminum	2	1
Lead	2	2
Stainless steel	2	2
Copper	3	2
Zinc	3	3
Brass	3	3
Bronze	3	3
Tin	4	4
Nickel Silver	4	4
Titanium	5	3
Gold	6	5

Stainless Steel

- Formed by adding chromium in excess of 10% to steel.
- Chromium is responsible for the lustre and the hardness of stainless steels.
- Modern stainless steels were developed in France and England simultaneously in 1904.
- Chromium itself is a toxic and environmentally hazardous material, however when alloyed with steel it is permanently ‘fixed’.

Four main groups of stainless steels

1. Austentitic: S30000: iron-chromium-nickel – nonmagnetic, S20000: iron-chromium-manganese – alternative to nickel alloy st.stls
2. Ferritic: iron-chromium alloys, always magnetic. Less ductile than austentitic group.
3. Martensitic: also iron-chromium alloy. Least resistant to corrosion. Mostly used for consumer items like cutlery.
4. Precipitation Hardened: similar alloy compositions as austentitic but magnetic and extremely hard. Considerably more expensive than other alloys.

Stainless steel
- Properties
- Applications

Aluminum

Copper

Zinc

Lead composites

Stainless Steel

Architectural stainless steels:

- S30100, S30200, S30400, S31600 – alloys most commonly used.
- Coastal environments: use Type 31600
- Fasteners exposed to the weather should either be galvanized or stainless steel.
- Type S31000 is a common self-tapping screw alloy and fasteners of this type are used to anchor aluminum and galvanized steel wall and roof panels.

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Stainless Steel Finishes

Finish #	Description	Available forms
1	Dull and mottled	Plates, bars
2D	Dull, matte, consistent	Sheet, strip
2B	Dull, reflective	Sheet, strip
2BA	Highly reflective	Sheet, strip
3	Reflective, coarse grit lines	Plate, sheet, strip, bar
4	Reflective, fine grit lines	Plate, sheet, strip, bar
5	Nonstandard	
Hairline	Reflective, fine parallel lines	Plate, sheet, strip, bar
6	Reflective, long parallel lines	Plate, sheet, strip, bar
7	Very reflective, mirror with lines	Plate, sheet, strip, bar
8	Mirror finish	Sheet, strip, bar
9	Buffed mirror finish	Sheet, strip

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Stainless Steel Finishes

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Stainless Steel Finishes

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Other

Stainless steel

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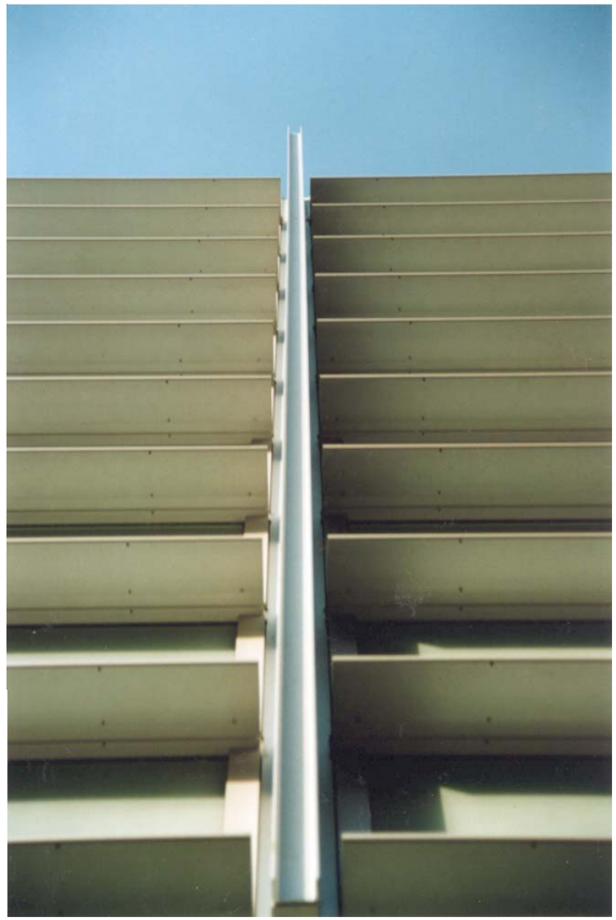
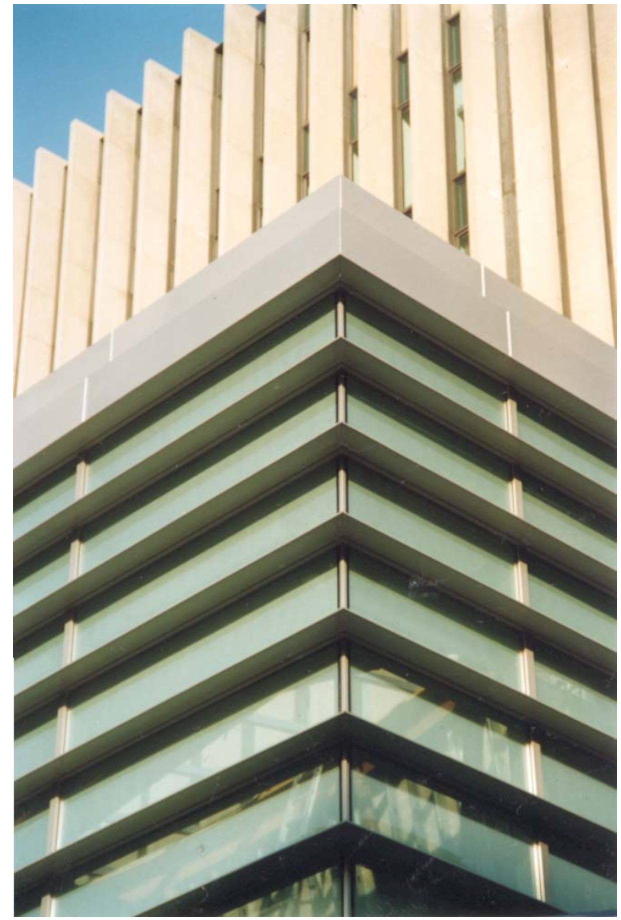
Other





Stainless steel

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Aluminum

- At one time (mid 19th century) more valuable than gold.
- At the time of the casting of the pinnacle atop the Washington monument, the 100 ounce aluminum pyramid was the largest single casting of the materials in the world.
- 1/12 of the earth's crust is composed of aluminum ore (found in bauxite), twice that of iron ore.
- Aluminum is not found in its natural state.
- Nonmagnetic, nonlustrous, white soft metal with a specific gravity of 2.70 (compared with steel at 7.87).
- Aluminum is second to steel in commercial production.
- Building construction products account for almost one third of the total production of aluminum.
- Rockefeller Center (1931) and the Empire State Building (1929) used cast aluminum for spandrel panels.
- Virtually every building now constructed contains some amount of aluminum.

Stainless steel

Aluminum

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Aluminum

- Aluminum develops a natural oxide coating (one millionth of an inch thick) if exposed to the weather that will protect the material from further degradation in less than severe climates.
- In seaside conditions, aluminum will pit extensively.
- Aluminum refinement is extremely energy intensive, requiring 20,000 kilowatt hours per ton of aluminum refined.
- Therefore, aluminum recycling has become a substantial secondary business. Recycled aluminum requires approximately 4% of the original refining energy for reuse. Also, reuse reduces the vast quantities of sludge produced. Metal recovered from scrap accounted for 30% of the entire world supply in 1991.

Stainless steel

Aluminum

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Finishes

- Mill finish: as delivered from the mill. Commonly used as an architectural finish. Upon installation in an exterior condition, an oxide coating forms, protecting the metal. When ordering mill finish the architect should always request “Architectural Quality Surface”.
- Specular, Mirror, Satin and other mechanically produced finishes.
- Anodized: a controlled extension of the natural oxide formation.

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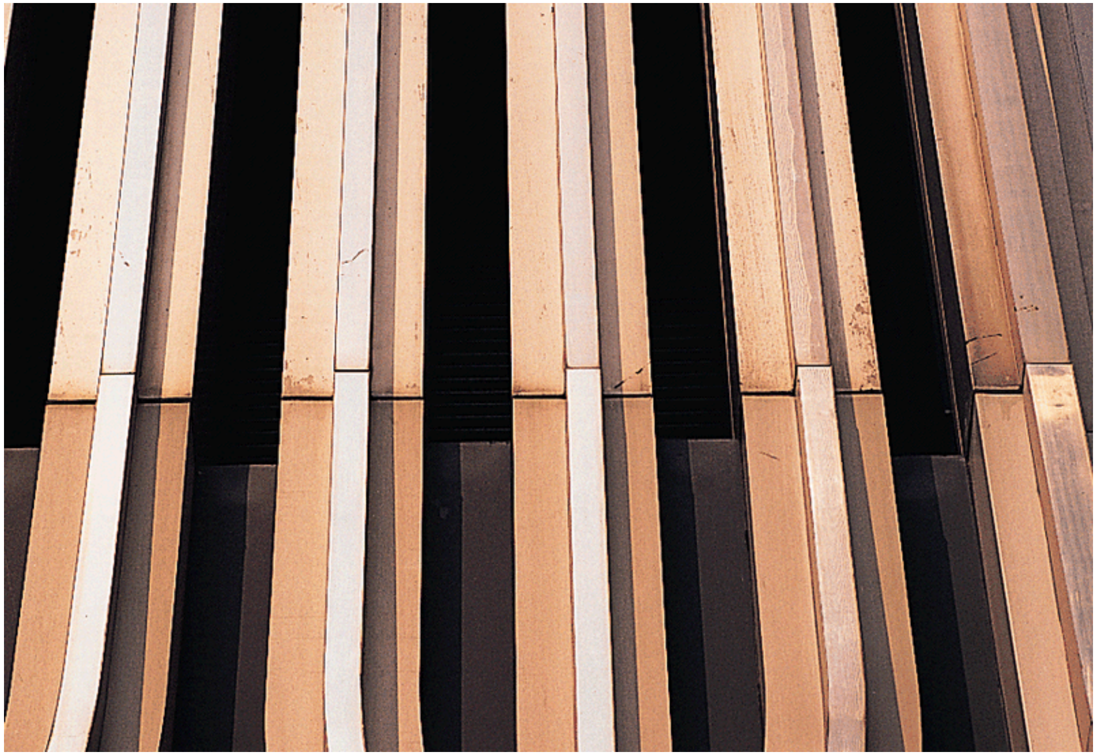

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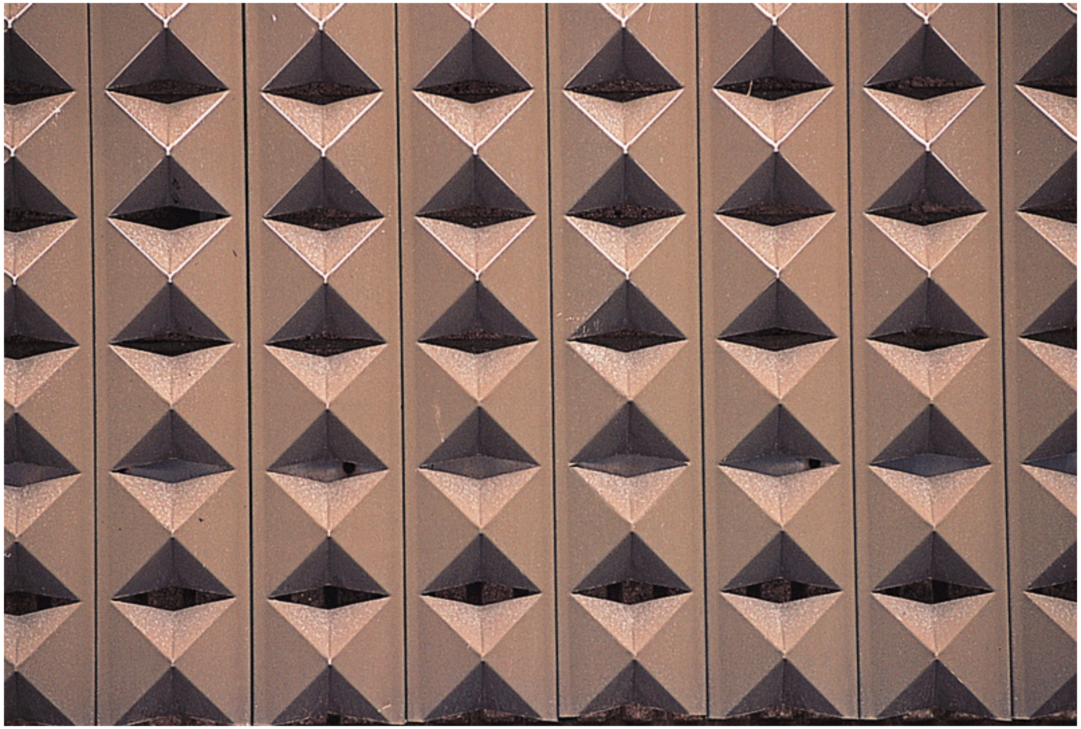

Copper

- Oldest metal to be used continuously. Discovered in Europe and central Asia during the Stone Age about 8,000 years ago.
- Only surpassed as primary metal in construction in the second half of the 20th century.
- Copper is now third most commonly used metal in construction (behind aluminum and iron).
- Used primary as a sheet material (roof and walls) and for wiring and piping.
- Only the element silver has a higher electrical conductivity.
- Copper has a specific weight of 8.96 (iron = 7.87).
- Copper has a very low strength to weight ratio, making it a good dense cladding material but a poor structural material.
- Worldwide supply is on the order of 5.8 trillion pounds. To date 0.7 trillion pounds has been mined.
- Recycling now accounts for 44% of the total US consumption of copper. Wiring uses mostly refined new copper, however the architectural market uses 75% recylced material. Energy consumption of the new copper is primarily spent on mining.
- Major copper alloys

  brass: copper and zinc

  bronze: copper and tin

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Copper

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Other

Images:

Holocaust Museum

Berlin

Daniel Liebeskind

Columbia University Law School

New York City

Polshek and Partners

Stainless steel

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Copper

Zinc

Lead composites

- Properties
- Applications

Other

Part II: Metal Systems and Architecture

transparencies

Part III: New Materials and Systems

- New alloys
- Cellular metals
- Self-weathering steels: Corten

Part IV: Resource Efficiency and other sustainable issues

1. Steel
2. Aluminum