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Comparing the Sustainability of Architectural Metals

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Abstract

Appropriate use of architectural metals contributes to sustainable design. Making good choices for different applications can, however, be challenging. Independent, unbiased information upon which to make informed trade-offs between performance and sustainability criteria is not available in any systematic, transparent form. Life cycle assessments (LCAs) for individual metal families are available but can be diverse and difficult to interpret for typical architectural applications. Neither are they easily comparable between metal/alloy families. An attempt is made to look at the major architectural metals/alloys in a systematic and transparent fashion. The first segment focuses on mining through metal production and considers some aspects of where and how metals are mined, where they are produced, and relevant production differences. The second segment examines post-production use, typical service life, the environmental impact of corrosion, and the probability of recycling or reuse. The significant potential impact of the service environment on life cycle performance and metal choice is discussed. Environmental impacts of coatings, paints and repainting, or maintenance are not considered.

Energy Use and Environmental Emissions

Energy and environmental emissions assessments are complex. Mining and production technology and energy sources vary and different energy inputs are required to produce different products from the same metal. Furthermore, data published by metals industry associations are not always directly comparable. Use of scrap can substantially reduce environmental impacts but its rate of use is not controlled by the designer and varies with the metal, product form and availability. While not representative of actual full product profiles, data for primary metal produced from virgin ores provide a generic baseline comparison. Table 1 compares the energy and pollution emissions from producing one kilogram (2.2 lbs) of aluminum, copper, zinc, carbon steel and stainless steel.

Most metals are produced and sold globally. Carbon steel production has traditionally been regional but global competition is increasing. A billet or slab might be produced in Europe, formed in North America, and then fabricated in Asia. The aluminum, copper and stainless steel data are global. The zinc data are for Finland and the carbon steel data are for North America. The zinc and steel data should be representative of European and North American production but might not be representative of areas with different energy costs or less stringent pollution controls. Additional data differences must be considered. First, the values for aluminum, copper and zinc are based on production from virgin ore. The stainless steel values represent material sourced from virgin alloys (nickel, chrome, etc.) and scrap iron. Carbon steel is typically not made solely from primary ore. The carbon steel billet data are for "integrated" production of 70% virgin ore and 30% scrap mix. Second, the aluminum, copper and zinc values are for unfinished metal whereas the stainless steel values are for white (annealed and pickled) hot rolled Type 304, ready for fabrication.

The environmental impact of the total primary energy used is a function of the type of energy. For example, energy produced with coal has high emissions of sulfur, nitrogen and carbon gases relative to hydroelectric power. The relative importance of different fuel sources varies from region to region based on cost and availability. For example, the aluminum industry's intense energy requirements have meant that North American plants typically utilize hydroelectric power, but expanding Middle Eastern aluminum production is reliant on oil and gas, so there will probably be changes in the global emissions data over time.

Table 1: Average Primary Energy and Environmental Emissions Required To Produce of 1 kg (2.2 lbs) of Primary Metal From Ore

	Aspect	**Category**	**Carbon Steel (1,2, 3)**	**Stainless Steel (4,5)**	**Zinc (6)**	**Copper (7)**	**Aluminum (8, 9)**
Energy use	Total primary energy, MJ	Indicator	~ 22	~35	29	70	~180
	Electricity, kWh	Resource use	38	NA	NA	NA	15700
	Coal, kg	Resource use	700	NA	NA	NA	186
Environmental emissions	Carbon dioxide, g	Air emission	2000	4400	1900	4200	1700
	Particulates, g	Air emission	0.35	5.7	NA	33	18
	Chemical Oxygen Demand (COD), g	Water emission	2.0	0.5	NA	1.3	0.46

Note: Values in this table are not directly comparable. See text for explanations.

Recycling

Metals differ from other materials used in construction because all metal that can be collected is recycled and finds its way back into high-value applications. Metal can be repeatedly recycled without degradation of performance, or concern about “down-cycling”. Metal is 100% recyclable and metal producers gladly use as much scrap as they can obtain. Scrap use minimizes the need for additional mining and reduces net environmental impacts.

Recycled content data can be misleading and it is important to ask questions. Recycled content rates can be artificially high if inefficient production generates significant amounts of scrap, if low-quality material is used as feed, or if there is regular premature failure caused by inappropriate metal specification. These problems may increase the availability of scrap but unnecessarily generate re-processing and associated environmental impacts. Moreover, average values may not be representative of the recycled content for specific products. For example, average recycled content rates for aluminum include large quantities of aluminum cans, which are recycled several times a year and are only used to produce more aluminum cans. The aluminum sheet produced for architectural applications has very little or no recycled content.

End-of-life (EOL) collection ratios indicate the percentage of metal that is recycled when an application is demolished and is a more relevant indicator to reducing impacts than recycled content. For example, while aluminum architectural sheet may not contain recycled content, 70% of it is recycled at EOL into new products. Table 2 provides typical recycled content and the EOL collection ratio data from metal industry associations and producers. Most of the EOL collection ratios are actually higher than their recycled content. These data do not consider metal loss to corrosion during service. The EOL collection ratios for stainless steel and zinc are average values for all applications. The other data are specific to the construction industry. The stainless steel industry believes that the collection ratio is higher than 80% for construction. EOL collection is encouraged by high scrap values and good designs that make material separation easy. Current US scrap values for construction applications are shown. Copper and aluminum scrap are currently at historic high levels, reflecting commodity values.

Table 2: Typical Recycled Content, EOL Collection Ratio and Scrap Value

Metal Product	**Recycled Content (%)**	**EOL Collection Ratio (%)**	**Scrap Value $/lb**
Carbon Steel			$0.09
Integrated mills	25-35	70 (flat rolled)	
Mini mills	≥95	97 (beams, plate)	

Stainless Steel	60	>80	\$0.59
Zinc	23	33	\$0.56
Copper			\$1.88
Electrical wire	0	>90	
Other products	70 - 95	>90	
Aluminum (10)			\$0.68
Sheet	0	70	
Extrusions	varies	70	
Castings	≤100	70	

Note: Data was obtained from the industry association websites or telephone conversations except as noted. *American Metal Market* weekly scrap composite values, January 23, 2006 issue

Corrosion And The Environment

The US government determines the annual economic cost of metallic corrosion on a regular basis. The most recent study, completed in 2001, determined that the total direct and indirect cost of metallic corrosion in the US was \$551.4 billion/year [11]. Of that, \$113.6 billion/year was attributed to construction-related metal failures. This figure does not include metal used in infrastructure or industrial construction. These failures range from roof perforation to replacement of components that have become aesthetically unattractive and many can be avoided through better metal selection. In addition to the high economic cost, there is a significant environmental cost.

The probability of failure can be determined by assessing the metal's corrosion resistance; the likelihood and frequency of maintenance cleaning; weather patterns; design; and exposure to acid rain, pollutants, particulate, and chlorides (deicing and coastal salt). Table 3 shows typical standing seam roof thicknesses relative to the average loss in metal thickness after 30 years at three coastal test sites. The expected metal thickness loss was calculated using average long-term exposure data. Although many structures are built in low corrosion environments, most major population centers have at least some exposure to chlorides (coastal and deicing) and/or pollution. Inland sites that are exposed to deicing products and/or industrial pollution can be just as corrosive as coastal sites. Each site should be evaluated carefully prior to metal selection.

Table 3: Average Metal Thickness Loss After 30 Years In Three Coastal Locations In Comparison To The Thickness Of A Typical Standing Seam Roof (12, 13,14, 15, 16)

Metal	**Panel Thickness Inches (mm)**	**New York City Inches (mm)**	**Kure Beach, 80 ft Inches (mm)**	**Durban Bluff Inches (mm)**
Type 316 Stainless	0.015 (0.381)	<0.00003 (0.0008)	<0.00003 (0.0008)	0.0003 (0.008)
Aluminum	0.032 (0.814)	0.0009 (0.023)	0.0006 (0.015)	0.023 (0.584)
Copper (16 oz)	0.022 (0.548)	0.002 (0.051)	0.004 (0.102)	0.029 (0.737)
Zinc	0.031 (0.80)	0.009 (0.229)	0.012 (0.305)	0.13 (3.3)
Galvanized steel	0.024 (0.609)	0.012 (0.305)	0.024 (0.609)	NA

Roof thickness sources: SMACNA Architectural Sheet Metal Manual, sixth edition, September 2003 and Rheinzink, "Applications in Architecture" (pan width of 16 ¾" (430 mm) and a 1" (25 mm) seam height)

The Kure Beach test site was within 80 feet of the mean high tide but pollution levels are low. The New York City and Durban Bluff (South Africa) sites had moderate pollution levels but the Durban Bluff site had a much higher coastal salt (chloride) exposure level. If the wrong metal is selected for a corrosive location, Table 3 illustrates that there can be significant metal mass loss. Metal loss has to be replaced by mining and is not accounted for in the EOL collection (recycling) ratio. If metal has to be replaced prematurely, the energy consumption and pollution emissions associated with the building's total environmental impact are increased.

Environmental Impact of Metal Entering the Environment

Research on roof runoff rates has been conducted at test sites throughout the world. There is a growing trend in sustainable architecture toward capturing and using roof runoff water for human consumption and other non-potable purposes, and the Leadership in Environmental and Engineering Design (LEED) system now offers additional points for this. While a number of metals are important trace nutrients for organisms, including humans, some can also cross the threshold of toxicity at relatively low levels. In this context, roof runoff rates and the bioavailability of the metal are important. This is made more complex by the propensity of the metals to react quickly with surfaces in close proximity to a building, which reduces their environmental entry. Concentrations as low as 0.002 mg copper/l or 0.004-0.007 mg zinc/l are hazardous for algae. As concentrations increase, both metals become hazardous for crustaceans and fish. For crustaceans, only 0.005 mg of copper/l or about 0.05 mg of zinc/l is hazardous. Biotoxicity is a very complex issue that should be considered in fragile environments.

In Sweden, Kungl Tekniska Hogskolan (KTH) conducted long-term field and laboratory tests at varying pH levels to simulate the influence of acid rain. Their primary focus was to determine the influence of atmospheric corrosion on roof run-off levels, bioavailability, and eco-toxicity. The run-off rates of nickel and chromium from stainless steel were well below typical drinking water concentrations and they do not cause eco-toxicity. The zinc and copper run-off levels were approximately 10,000 times higher, both were in a bio-available form and eco-toxicity is possible as evaporation increases metal concentrations. Runoff rates were equivalent for zinc sheet and galvanized roofs. Research has focused on metal immobilization with natural surfaces near the building and on runoff filtration.

Table 4: Swedish Metal Roof Run-Off Study [17]

Material	**Average Annual Run-off, mg/m^2 (mg/yd^2)**
Zinc (1)	1,900 – 2,500 (1,588– 2,090)
Copper	1,200 – 1,500 (1,003 – 1,254)
Type 304 Stainless (2)	
Nickel	0.12 - 0.52 (0.10 – 0.43)
Chromium	0.18 - 0.57 (0.15 – 0.48)
Iron	10 - 140 (8.40- 117)

(1) In the form of galvanized steel and zinc sheet, (2) In many samples, nickel and chromium levels were below detectable limits. The average concentration per liter was well below typical drinking water levels.

The United States Environmental Protection Agency (EPA) has rigorous drinking water standards for regulated contaminants. The EPA maximum contaminant level goals and secondary guidelines for drinking water are as follows: chromium, 0.1 mg/l; and lead, 0 mg/l (action level of 0.015 mg/l); zinc 5 mg/l, copper 1.0 mg/l, aluminum 0.05 to 0.2 mg/l; and iron, 0.3 mg/l. A German Federal Environmental Agency report titled "Erosion of copper and zinc from roofs, gutters, and rainspouts caused by precipitation" found that copper rain gutters alone produced runoff concentration values of up to 1.0 mg/l. Copper roof runoff concentrations were between 4 and 8 mg/l. These values exceed biotoxicity and drinking water limits. The zinc toxicity threshold for aquatic organisms was exceeded when only the rain gutters, downspouts, and chimney sheet metal were galvanized steel. There have been published accounts in Washington state of galvanized steel industrial roof runoff substantially exceeding EPA limits where building owners installed filtration systems to remove metal from the roof runoff water.

Conclusions

A complete sustainability analysis should not stop with a comparison of metal mining, production and recycling rates. These values can be difficult to evaluate and are sometimes not comparable. The EOL collection ratio for an architectural product is more relevant than general recycled content values. Metal loss to corrosion must also be considered along with the impact of any coating, paint, repainting and maintenance. Designers can do many things to increase the rate at which metal is reused, and this will beneficially reduce new mining, energy requirements, and pollution emissions. Careful design can make EOL material separation easier and increase collection rates. Selecting materials intelligently will optimize efficient performance, limit metal loss to the environment, eliminate unnecessary premature recycling and replacement, limit a building's lifetime environmental impact, and reduce resource extraction. Finally, care should be taken when selecting metals and other materials for fragile environments, locations where runoff can concentrate, and where roof runoff water will be captured and reused.

Acknowledgement

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