STANDARDIZATION News
WWW.ASTM.ORG
OCTOBER 2004

packaging & copper

Two Venerable ASTM Committees Look Back... and Ahead

Authorized Reprint from ASTM *Standardization News*, Volume 32, Number 10, October 2004 © Copyright 2004 ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959

DIAMOND ANNIVERSARY FOR ASTM copper committee

BY ANDREW G. KIRETA, JR., AND KONRAD J.A. KUNDIG

Figure 1 — Modern copper smelters such as Kennecott Utah Copper's plant shown here remove more than 99 percent of sulfur released during smelting, converting it to sulfuric acid for use in leach/solvent extraction/electrowon operations.

This year marks the 75th anniversary of ASTM Committee B05 on Copper and Copper Alloys. With roots in Committee B02 on Nonferrous Metals and Alloys, from which it was derived in 1929, B05 has a place among the society's longest-standing technical committees. The broad-based makeup of its membership, currently numbering 140, reflects a decades-long association with copper-related industries, organizations and individuals and their day-to-day business that is touched by the 160 active standards under the committee's jurisdiction. Over the years, Committee B05 has also maintained especially close and mutually beneficial ties with the Copper Development Association Inc. and the Canadian Copper and Brass Development Association, the industry's principal North American trade organizations.

Much has changed in the way copper has been produced and used over the past three-quarters of a century, and Committee B05 and its subcommittees have, where appropriate, issued and updated standards that reflect those changes. Details regarding the committee's current work are described in the article by Eric Boes appearing on page 42 of this issue. This article describes a few of the recent important developments in copper and its alloys and some advances that will mark the next era in the history of their 10,000-year service to humankind.

RECENT ADVANCES IN MINING AND EXTRACTION

Until the early 1900s, much of the copper that came to market in North America was derived from native metal and so-called "oxide" ores. Sulfidic ores are the dominant source of copper today, as is the traditional (and costly) crushing-grinding-concentrating-smelting-electrorefining process of extracting metal from them. Smelters, once criticized as sources of atmospheric pollution, have been improved to the extent that modern plants now capture more than 99 percent of the sulfur dioxide they generate. (See Figure 1.)

Over the past few decades, however, smelting has slowly been giving way to hydrometallurgical processes in which sulfuric acid (ironically, a by-product of smelting) and other reagents are percolated through heaped ore and nearly depleted tailings, taking the entrained copper into solution. The leachate is concentrated by solvent extraction (SX) to yield a liquor from which pure copper is electrowon (EW). The leach/SX/EW process operates well with oxides but is difficult to apply to the more refractory sulfidic ores, especially those containing large concentrations of chalcopyrite, an abundant copper-iron sulfide mineral.

Hydrometallurgical processes capable of treating chalcopyrite and other sulfide ores are under various stages of development. A few have demonstrated an ability to produce copper of acceptable purity at a cost low enough to match that of state-of-the-art smelters. The most advanced of these processes is bioleaching, in which naturally occurring bacteria and archaea are used to oxidize the sulfidic copper minerals to sulfates, from which they can be leached conventionally. Commercial bioleaching is basically an improvement on nature that employs selected strains or combinations of organisms. Along with close control of such factors as temperature and oxygen supply, it increases the speed and efficiency of the natural oxidation phenomenon.

Bioleaching is in use at several U.S. locations, as well as in Chile, Mexico and Australia. Currently the world's largest installation is that of the Phelps Dodge Corporation at Morenci, Ariz. Converted from a conventional mining and smelting operation in 2001, this so-called "mine-for-leach" operation relies on native bacteria assisted by injected air to oxidize the sulfide minerals. Cash oper-

Figure 2 — Bioleaching, as shown here at Phelps Dodge's Morenci, Ariz., operations, uses natural bacteria to oxidize copper-bearing sulfide minerals, thus making it possible to apply leach/solvent extraction/electrowon to extract copper economically.

ating costs are projected to be competitive with conventional processing in that much of the expense of comminution is avoided. The end product, in this case electrowon copper, is fully comparable with conventional electrorefined copper, both of which are specified by ASTM B 115, Specification for Electrolytic Copper Cathode. (See Figure 2.)

FROM RAW MATERIAL TO END USE

Figure 3 traces the flow of copper from mine to end-use in 2003. U.S. copper mining, now centered mainly in Arizona, Utah and New Mexico, has decreased by nearly one-half since 1997 due to closure or mothballing of several U.S. mines and the concurrent exploitation of large, high-grade deposits in Latin America and the Pacific Rim. However, America's copper reserves are far from depleted. A deposit rivaling the largest in Chile was recently discovered in Arizona. This one deposit is estimated to contain enough copper to satisfy the entire world's uptake for one year.

Recycled (scrap) copper also constitutes an important supply of raw material, copper being among the most intensely recycled of industrial metals. While secondary copper can be re-refined to the high levels of purity needed for electrical and electronic applications, those uses are ordinarily met by primary copper. Recycled scrap is more often taken up (along with some primary copper) in the production of copper alloys for architectural, industrial and plumbing products. These important uses for copper are the purview of Subcommittees B05.01 on Plate, Sheet and Strip; B05.02 on Rod, Bar, Wire, Shapes and Forgings; B05.04 on Pipe and Tube; and B05.05 on Castings and Ingots for Remelting.

Figure 3 also points out that domestic production from electrowinning now surpasses that from smelting in the United States, a result in part due to smelter closures in recent years. Smelting will, however, continue to play a sizeable role in copper production for a variety of metallurgical and economic reasons having to do with ore chemistry and precious metal recovery, as well as the need for by-product sulfuric acid production for leach/SX/EW operations.

The United States consumed nearly seven billion pounds [3.2 X 10^6 metric tons] of copper in 2003. That figure is much less than the 9.3 billion-pound record [4.2 X 10^6] set three years earlier, although data for 2004 indicate that consumption is again rising. Growth in the overall economy and continued strength in domestic housing construction are driving the resurgence, since building construction constitutes copper's largest end-use market. In terms of functional use, some 58.3 percent of copper and copper alloys produced found their way into electrical applications, followed by uses related to corrosion resistance (22.5 percent), heat transfer (11.2 percent), structural properties (6.3 percent) and aesthetics (2 percent). (See Figure 4.)

ADVANCES DRIVE MAJOR MARKETS

Wire and Cable

Not only are more houses being built (and rebuilt), but the amount of copper wire and cable contained per unit is rising sharply as home buyers increasingly opt to install cabling systems to power and link their computer networks, security and fire alarms, appliances and heating, ventilating and air conditioning equipment and entertainment systems. In industrial/ commercial buildings, concentrations of sensitive electronic equipment — especially computers, servers and telecommunications gear — have also created larger demand for copper, much of it in the form of Categories 6 and 5e communications cable. The cable's high bandwidth obviates the need for fiber optic cable in most instances.

This same electronic equipment can give rise to a variety of voltage and waveform problems associated with poor power quality unless the electrical system is properly designed and installed. Solutions advanced by CDA stress the need for upgraded wiring, grounding and lightning protection systems, all of which call for increased copper use. (See Figure 5.)

Automotive vehicles have also become a growth market for copper electrical products owing largely to consumers' demand for powered accessories, entertainment and comfort systems. The automotive sector is expected to grow even more rapidly as hybrid electric vehicles gain widespread acceptance. A typical HEV contains between two and three times the weight of copper — up to about 150 lb [68 kg] — that is contained in a conventional car or light truck. Larger wiring harnesses, a copper-intensive starter-generator/alternator and regenerative braking systems account for much of the increase. However, part of that additional copper, in vehicles as well as static applications, might be found in the cathodes of nickel-metal hydride, or NiMH, batteries, the type currently favored by several automakers. Recent R&D on NiMH design, supported in part by the Copper Development Association, permits the use of perforated sheets of nickel-plated copper in place of pure nickel for the batteries' cathodes. Copper is less costly and is a more efficient current-carrier due to its higher conductivity.

Sheet, Strip and Plate

Electrical uses are also a major market for copper and copper alloy sheet, strip and plate products. Driven by the rapid changes in automotive and electronic technology, it is here that most new copper alloy development currently occurs. Specifications for these alloys are overseen by Subcommittee B05.01. Among the several tasks currently before the subcommittee is a review of ASTM B 422, Speci-

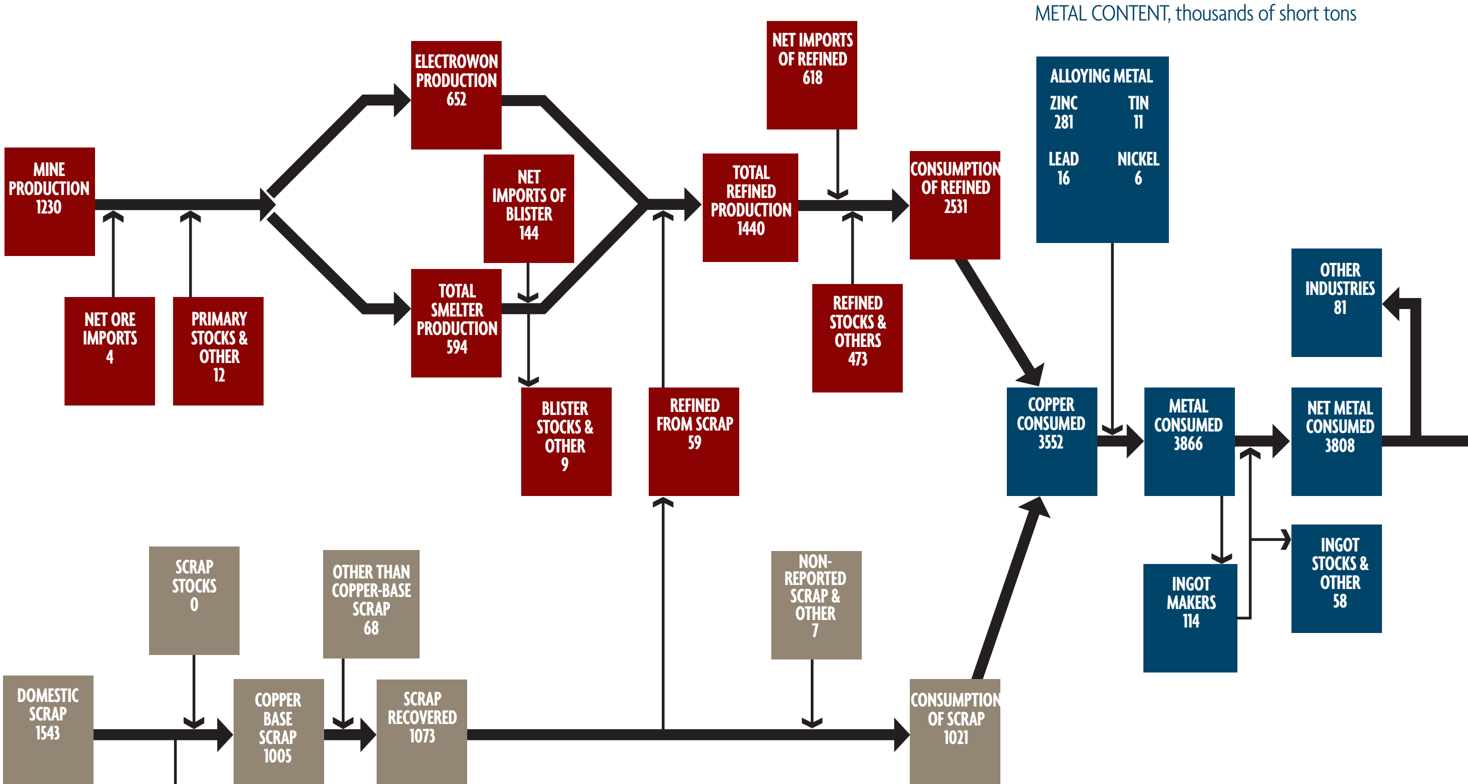
Copper Supply and Consumption in the United States—2003

Supply of primary copper from mine to consumption by wire rod mills, ingot makers, foundries, powder plants and other industries.

COPPER CONTENT, thousands of short tons

Consumption of metals by wire rod mills, brass mils, ingot makers, foundries, powder plants and other industries.

METAL CONTENT, thousands of short tons



Supply of secondary copper from receipt to consumption by wire rod mills, brass mills, ingot makers, foundries, powder plants and other industries.

COPPER CONTENT, thousands of short tons

Note: Numbers may not sum due to rounding.

fication for Copper-Aluminum-Silicon-Cobalt Alloy, Copper-Nickel-Silicon-Magnesium Alloy, Copper-Nickel-Silicon Alloy, Copper-Nickel-Aluminum-Magnesium Alloy, and Copper-Nickel-Tin Alloy Sheet and Strip. (See Figure 6.)

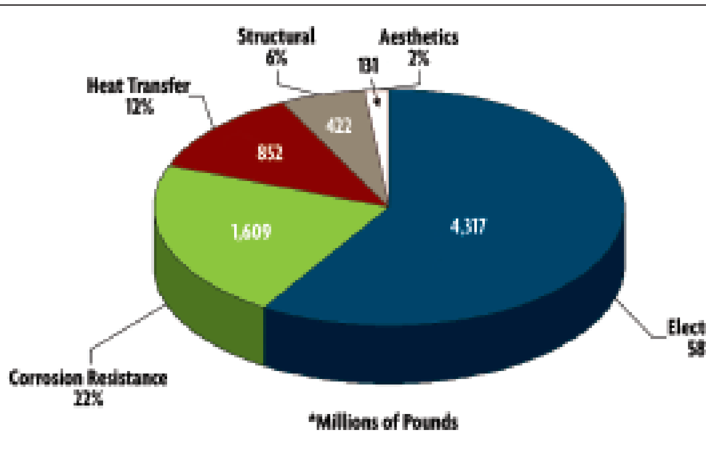


Figure 4 — Copper consumption by functional use. Electrical applications account for more than one-half of copper use, followed by plumbing and other applications involving heat and fluid transfer.

The use of copper and copper alloys in architecture has likewise risen sharply over the past decade, not simply in roofing and gutters, but also as wall cladding, builder's hardware and decorative items. Subcommittee B05.01 is currently completing a five-year review of B 370, Specification for Copper Sheet and Strip for Building Construction, which addresses this highly visible copper application. (See Figure 7.)

Recently, some European countries have shown a concern about architectural copper as a potential source of storm water pollution, as a result of copper-containing runoff water. The concern has also surfaced in the United States, where an ordinance in one town sharply limits the use of roofing copper.

The results of two CDA studies counter these concerns. The first was

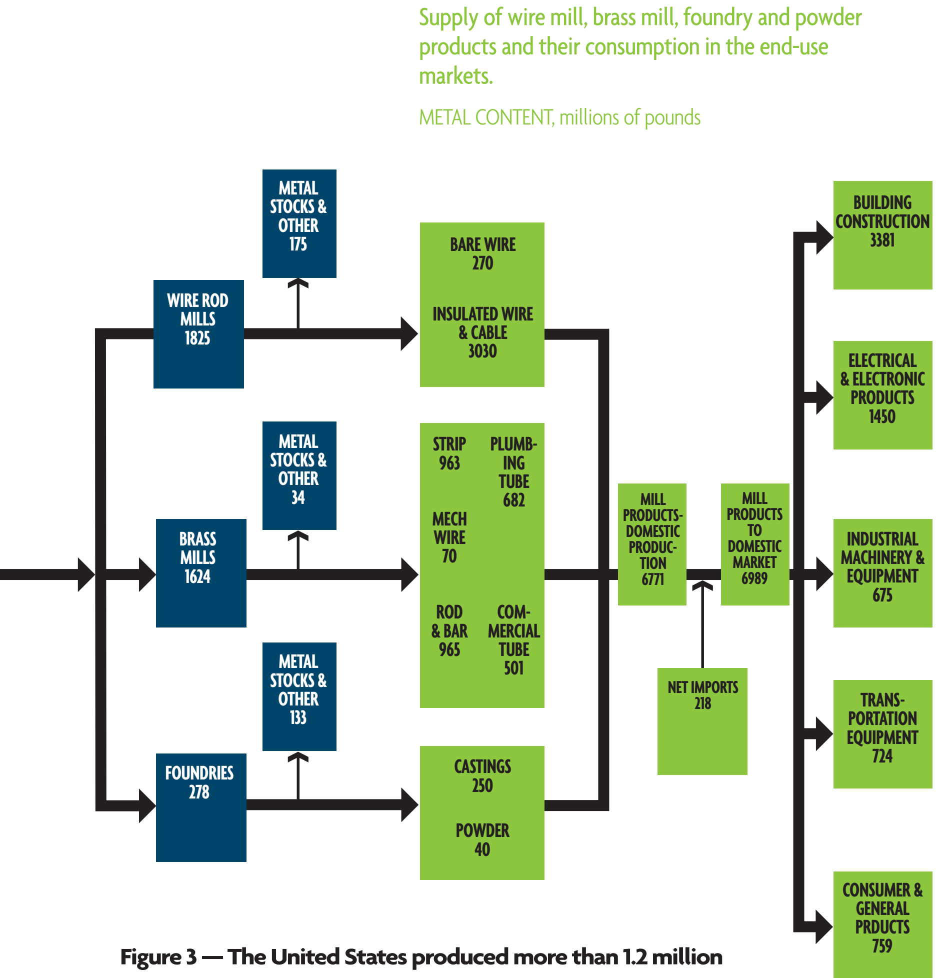


Figure 3 — The United States produced more than 1.2 million short tons [1.1 metric tons] of copper from its mines in 2003. Clean, cost-effective electrowinning now exceeds smelting as the primary means of extraction. Electrical uses, mainly wire and cable products, remain the dominant end products.

conducted at the University of Connecticut. Runoff water collected from a copper roof was examined with respect to copper concentration, speciation and aquatic toxicity. The study found that, while water at the roof's downspout contained copper at levels that were high in the environmental sense, dilution, interaction with piping materials and with organic carbon and other complexing agents rendered the metal nontoxic before it entered a regulated waterway. In a second, more wide-ranging study conducted in the San Francisco Bay, it was found that analogous reactions with naturally occurring agents transformed what might originally have been harmful ionic copper into stable, environmentally benign copper complexes.

A ubiquitous but often overlooked application for copper strip alloys is the coinage used in many countries. Most U.S. coins of denominations larger than the penny (a copper-plated zinc-copper alloy) and the nickel (solid copper-nickel) are manufactured as sandwich structures with copper-nickel surfaces over a pure copper core. The golden Sacagawea dollar utilizes a copper-zinc-manganese-nickel as the exterior clad to give the coin its distinctive color while preserving the electronic and magnetic signatures of the earlier Susan B. Anthony coin. The Canadian one- and two-dollar coins are also struck in copper-nickel alloys, while the one and two euro denominations utilize copper-zinc-nickel and copper-nickel alloys in their bimetallic designs. (See Figure 8.)

Copper sheets were long used to protect wooden ship hulls from damage by worms and to prevent the growth of speed-robbing algae and barnacles. Today's version of that ancient technology makes use of thin coupons of 90-10 copper-nickel (C70600) bonded to a polymeric substrate to yield a flexible yet durable product suitable for adhesive attachment to pleasure craft. Other applications for the corrosion- and biofouling-resistant alloy include heavier-gauge cladding for pilings and offshore platform legs. (See Figure 9.)

Perhaps the most important new use for the biostatic properties of copper and its alloys will come out of ongoing research sponsored by the Copper Development Association that seeks to quantify the ability of these materials to inhibit the growth of methicillin-resistant *Staphylococcus aureus*, or MRSA. This virulent pathogen, one of the so-called "superbugs," is resistant to penicillins, ampicillins, and cephalosporins, and is commonly found in hospitals and healthcare facilities, where infection can have deadly consequences. (In-hospital infections are the fourth leading cause of death in the United States.) The bacteria are transmitted by healthcare workers and others who come in contact with contaminated equipment and surfaces.

Results of the CDA study suggest that several copper strip alloys would make attractive candidates for healthcare facility applications such as doorknobs, push plates, operating tables, fittings, fixtures and work surfaces. Stainless steels, now commonly used in such applications, have virtually no effect on MRSA; whereas C19700 (a copper-iron alloy containing small amounts of phosphorus and magnesium and limited quantities of tin, zinc, lead, cobalt, manganese and

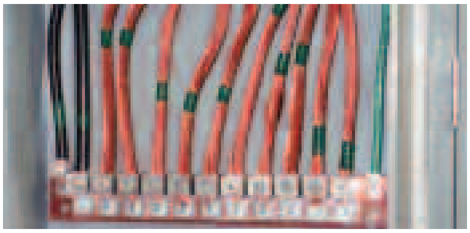


Figure 5 — Massive 750- and 500-kcmil [380 and 250 mm²] grounding cables in a new corporate headquarters building illustrate copper's importance to high power quality. The smaller cables are more than 0.75 in (19 mm) in diameter.

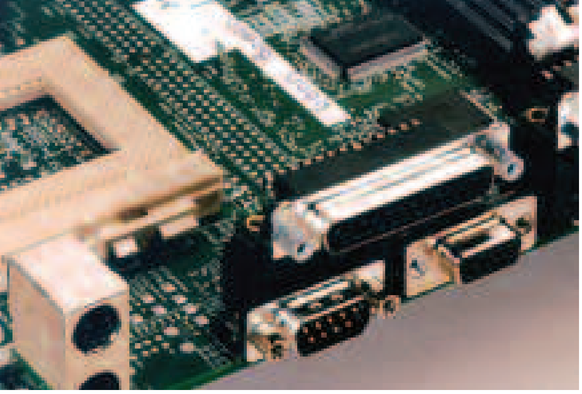


Figure 6 — High-conductivity copper alloys, used in virtually all electrical and electronic connectors, are the subject of ongoing research and development.

nickel) reduces surface contamination by six orders of magnitude in 90 minutes. Alloys C24000 (low brass, 80 percent) and C77000 (nickel-silver, 55-18) are also effective, although to a lesser degree than the higher-copper alloy. (See Figure 10.)

Tubular Products

Standards for copper water tube (B 88, Specification for Seamless Copper Water Tube), commercial tube (primarily B 280, Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service), drainage tube (B 306, Specification for Copper Drainage Tube (DWV)), copper and copper alloy tube for surface condensers and other heat exchangers (B 111, Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock, and B 543, Specification for Welded Copper and Copper-Alloy Heat Exchanger Tube) and other tube and pipe are among the 43 documents under the jurisdiction of Subcommittee B05.04. This very active group currently has eight work items on its agenda, most of which deal with additional testing of two copper grades to verify their resistance to hydrogen embrittlement.

The copper tube market, second only to wire and cable in terms of tonnage shipped, has been challenged in recent years by the growing use of polymeric tubing (with copper or brass fittings) as a low-cost alternative to water tube, and by a gradual shift away from copper-alloy condenser tube in favor of titanium where aggressive cooling waters are encountered.

Copper tube, long approved for use with liquefied petroleum gas, is finding a new and growing use for the distribution of natural gas as well. Stephen Knapp, executive director of the Canadian Copper and Brass Development Association, notes that the new market is evolving rapidly in Canada, particularly for the installation of gas-fired home fireplaces. The evolution of this market led to the creation of a new tubular product used primarily in the Canadian market, the new B 837, Specification for Seamless Copper Tube for Natural Gas and Liquefied Petroleum (LP) Gas Fuel Distribution Systems. In response to specific code requirements in another growing application, B 819, Specification for Seamless Copper Tube for Medical Gas Service, was also developed in the early 1990s.

Also, the National Plumbing Code of Canada will follow the path taken by the U.S. model plumbing and mechanical codes when the 2005 edition is issued requiring all solder joints to be made in conformance with B 828, Practice for Making Capillary Joints by Soldering Copper and Copper Alloy Tube and Fittings, using soldering fluxes meeting B 813, Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube. Both of these standards were created and introduced by the B05.04 committee in the early 1990s. (See Figure 11.)

Figure 8 — Most modern coins are made from copper, copper-nickel and, in the U.S. Sacagawea dollar, a complex manganese brass. Clad and bimetallic structures add beauty and impart unique electrical/magnetic signatures that thwart counterfeiting.

Rod, Bar and Mechanical Wire

Free-cutting brass has made inroads into markets formerly served almost exclusively by leaded steels, especially in automotive applications. A glance under the hood of a modern automobile or truck reveals numerous brass fittings and sensor housings. The components are made on automatic screw machines at a finished cost that is often lower than that realized if the parts were made from steel. The three principal reasons behind this surprising cost difference lie in the higher speed at which brass can be machined, the eliminated need for protective finishes and the cost-effectiveness with which brass is routinely recycled.

Figure 7 — Batten seam panels on the Denver Library Children's Pavilion illustrate one new use for architectural copper other than roofing.

COPPER MOTORS FOR IMPROVED ENERGY EFFICIENCY

The largest source of efficiency reduction in synchronous electric motors stems from resistive, or I^2R, losses in stator windings. The accumulation of these losses is significant because, according to the U.S. Department of Energy, approximately 23 percent of all electricity generated in the country is consumed by motor-driven systems. In industrial settings, motor-driven systems account for more than 65 percent of all energy consumption. The DOE further estimates that between 11 percent and 18 percent of the total energy usage can be saved by taking into account such factors as better designs, installation of variable speed drives, properly sized pumps and the like, and that some 28 percent of the potential savings could be achieved by the use of more efficient motors. That would reduce the emission of atmospheric carbon from power plants by between 3.5 and 6 million metric tons annually.

The Energy Policy Act of 1992 led

Figure 9 — Copper-nickel alloys resist corrosion and biofouling, properties exploited in hull sheathing.

to a rule, which became effective in October 1997, that certain common motors sold in the United States must meet minimum efficiency standards as set forth by the National Electrical Manufacturers Association. So-called EPAct motors exhibit efficiencies that are between one and four percentage points higher than those of older "standard-efficiency" motors. A few years later, NEMA approved a new standard, NEMA Premium™, which further raises the energy bar by about 1.5 percentage points. Efficiency gains are made chiefly by using more copper wire in the stator windings.

Not only do I^2R losses waste energy, they also generate heat that ultimately shortens a motor's life. A rule of thumb in the motor industry holds that for every 10°C increase in operating temperature, a motor's life is reduced by one-half. Since high-efficiency motors tend to run cooler than "standard efficiency" motors, they should operate longer and more reliably.

A recently completed R&D program sponsored by DOE, the Copper Development Association, motor manufacturers and other organizations will take efficiency to significantly higher levels. In this case, gains are made by replacing the die-cast aluminum conductor bars — a key component of what is commonly called a squirrel cage — with die-cast copper. The concept has existed for many years but was thought unworkable because of difficulty in die-casting the higher-melting-point copper without prematurely destroying the casting dies due to the action of severe thermal fatigue. CDA researchers found that the problem could be circumvented by making the molds in a ductile nickel-base superalloy in place of conventional die steel, and by maintaining the molds at approximately 1200°F (650°C) between shots.

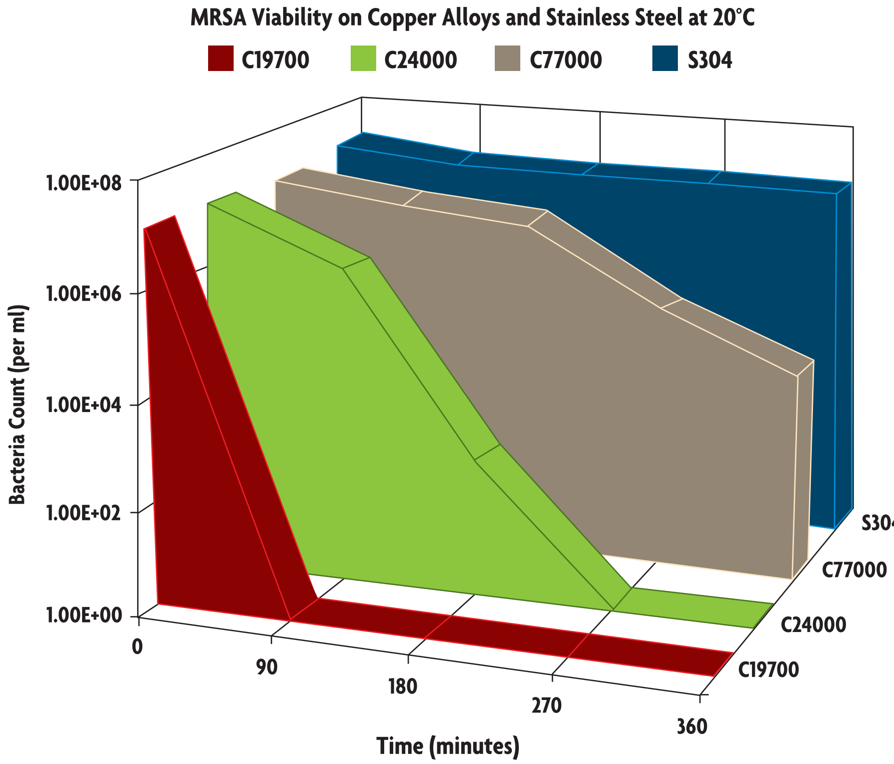


Figure 10 - The biostatic properties of copper and its alloys offer the potential to reduce MRSA infections when used in place of stainless steels in hospital and healthcare equipment.

The results, already commercialized in Europe, are motors with up to two percentage points higher efficiency than that of NEMA Premium motors.

The new motors represent an important new use for copper, but they are only one example of fruitful cooperation between the copper industry and its industrial partners in finding ever-expanding applications for copper. Among other developments on the drawing board now are innovative automotive components and a semi-solid casting process that promises to improve quality and reduce cost in a wide variety of products. Even after 10 millennia, copper still has much to look forward to. //

Figure 11 - ASTM Standard B 837 provides specifications for seamless copper tube for natural gas and liquefied petroleum (LP) gas fuel distribution systems. Fireplaces and gas grills plumbed in copper are especially popular in Canada.

ANDREW G. KIRETA, JR., is a graduate mechanical engineer from Purdue University and CDA's national program manager for building construction. He oversees technical and marketing programs and leads a team of seven regional managers who provide field assistance to engineers, mechanics, contractors, inspectors, architects, builders and others in the design, use and installation of copper and copper alloy products. He serves as membership secretary of Committee B05.

KONRAD J.A. KUNDIG is a metallurgical consultant and technical writer with offices in New Jersey and Arizona. He is the author, co-author and editor of numerous books, handbooks, articles, and reports. He holds a B.S. Met.E. from Lafayette College, an M.S. in Metallurgy from the Pennsylvania State University, and a Ph.D. in Metallurgy from the Case Institute of Technology (now Case Western Reserve University).

REPRINTED WITH PERMISSION OF ASTM INTERNATIONAL

Canadian Copper & Brass Development Association
49 The Donway West, Suite 415 Norh York, Ontario M3C 3M9
http://coppercanada.ca

Copper Development Association
260 Madison Avenue New York, NY 10016
www.copper.org

A4070-XX/04