Dawson Shanahan
Precision Engineering & Cold Forming

Copper and its use in precision cold forming

A look at Copper, its properties, applications and use in the manufacture of precision engineered components for the electronics, power generation and distribution and automotive sectors.

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Copper: a short history

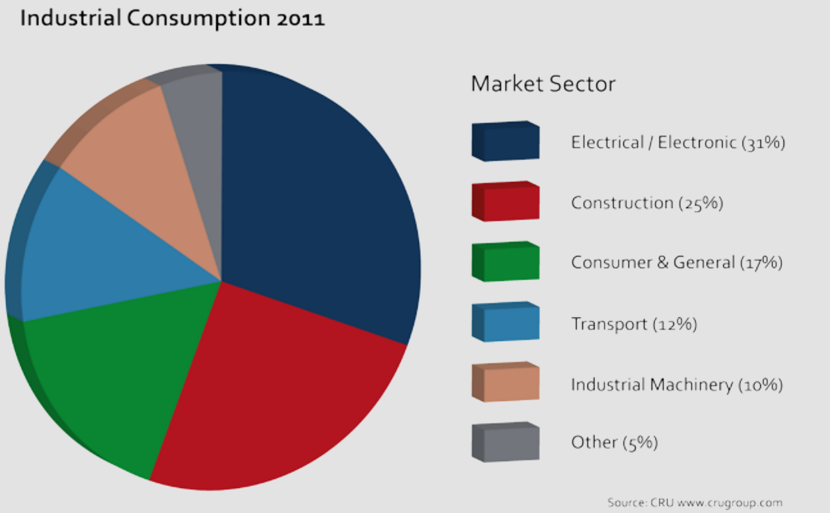
Copper has been mined and worked by humans for thousands of years. One of the earliest recoded Copper artefacts, discovered in Iraq, has been estimated to date from around 9,000 BC. By around 4,500 BC the Mesopotamians, and subsequently the ancient Egyptians and Chinese, had discovered that Copper occurs naturally in a relatively pure form, making it easy to work into decorative and symbolic items, as well as everyday tools such as mirrors, weights and water pipes.

Between 3,500 and 2,500 BC Copper was being mixed with Tin to create Bronze, ushering in what has since been called the Bronze Age. Although the later discovery of Iron effectively ended the Bronze Age, the use of Copper continued. Indeed, under the Romans, Copper was extracted from the ground on an industrial scale, from mines throughout the empire, as far apart as Spain, Wales and Turkey.

Native Copper nugget

Copper: facts and figures

- Atomic number: 29
- Atomic symbol: Cu
- MelTing point: 1,083°Celcius
- Copper is an essential trace mineral – vital for human health
- Copper has excellent anti-microbial properties
- Copper is a valuable metal for manufacturing, with excellent ductility, malleability, thermal and electrical conductivity and resistance to corrosion
- Copper is 100% recyclable
- Around 19 million tonnes of Copper were mined globally in 2014
- There is an estimated 1.6 billion tonnes of Copper left in the earth, of which some 950 million tonnes is economically extractable
- World refined Copper demand is expected to reach almost 40 million tonnes by 2030



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The name Copper has also been handed down to us from the Roman period. It is believed to stem from the Latin word cyprium, which derives from the fact that Cyprus was a major source of Copper.

After the decline of the Roman empire Copper, often alloyed with Zinc to form Brass continued to be widely used, and by the Medieval period was frequently found in religious buildings in Europe and Asia, for decoration, screens, icons, chalices and bells. In South America, the Aztecs used Copper for items ranging from fish hooks and needles to picks and axes, while in North America the native Indians were manufacturing Copper tools, weapons and ornaments.

By the industrial revolution, Copper was being mined, smelted and used in increasing quantities. One wide area of application, for example, was for protecting the wooden hulls of sailing vessels against marine worm, which attacked the wood, and marine weeds that reduced the speed of vessels.

The Great Opencast, Parys Mountain © Copyright Robin Drayton

Typical Copper tools

By the late eighteenth century it had become common practice to sheath the hulls of all naval and many civilian vessels, helping to keep them at sea for far longer than was previously possible.

With the advent of the railways, telegraph and the rapid adoption of electrical systems, the use of Copper increased still further for cables, dynamos, generators, conductors and power distribution systems.

As the number of applications grew, so too did the number of alloys. Today, there are over 400 different Copper alloys commercially available, with this versatile metal being used globally in architecture, telecommunications, automotive, marine, power generation and manufacturing.

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Copper mine, Minas de RioTinto, Andalusia, Spain

Copper production

Copper ore is extracted from open cast or underground mines, either as a Sulphide or Oxide ore; in each case the concentration of Copper is generally below 2%, with the balance being predominantly gangue or waste rock.
The ore is progressively reduced using crushers and grinders to create fine particles. In the case of Sulphide ores, the particles are mixed with water and chemicals to render the Sulphide particles hydrophobic. These are then passed through a froth flotation system, where the hydrophobic Sulphides bond with air bubbling through the flotation tanks, rising to the surface for skimming off; they are then passed through a cleaning and scavenging unit before being sent for smelting. At this stage the concentration of Copper is in the region of 15%.

Smelting of Sulphide ores is normally a multi-stage process of reduction and melting to produce Copper that is around 99% pure. To improve levels of purity still further, the Copper is moulded into anodes and then refined using electro-chemical deposition; Copper from the anodes being dissolved and then deposited on onto Stainless Steel cathodes. This process typically takes around a week, after which the Copper, at a purity of 99.99%, is stripped from the Stainless Steel and then formed into wire, tube, sheets etc.

Oxide ores are normally leeched using Sulphuric acid to release the Copper minerals, creating a solution of Copper Sulphate from which the Copper can subsequently be removed using the same electro-plating process.

At one time, most Copper rod was made by a batch process, which included pouring molten Copper into specially shaped ingots, known as wire-bars, then reheating the bars in a reducing protective atmosphere, followed by hot rolling in air to a rod form. This was followed by pickling in 10% Sulphuric acid to remove any Oxides, and then butt welding of lengths to form larger coils.

Today, a continuous casting and rolling process is used to produce almost all Copper rod and wire. This is far more efficient and helps to eliminate welds and impurities, reduce Copper Oxide particles on the surface and minimise steel inclusions from contact with mill rolls.

Smelting of Copper in the foundry

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The importance of grain

A considerable proportion of the raw Copper used in industrial applications, including the precision cold forming and machining carried out by Dawson Shanahan, is supplied in the form of rolled Copper wire. This has a number of advantages over flat strip, offering a material that has a regular cross section and a consistent molecular structure with regular surface characteristics; it also results in less scrap during manufacture and can be produced cost effectively in large volumes with long wire lengths.

An important feature of Copper wire is its grain structure, which affects the strength, formability, directionality, texture and surface appearance of the finished material.


Rolled Copper wire ready for engineering

Solid metallic materials have a crystalline structure, where the element atoms are bound together in a regular, repeaTing three-dimensional array. By comparison, alloyed metals, including Copper, are polycrystalline, where aggregations of crystals are randomly joined along boundaries. These aggregations of crystals are called grains and the boundaries between them, grain boundaries.

The size of the grains, and therefore the characteristic of the metal, is effectively determined by the annealing or cold rolling processes used to manufacture strip or wire materials. These processes require careful control to ensure that the ideal balance of properties is consistently achieved. For example, cold working of Copper and Copper alloys, by rolling or other methods, increases the tensile and yield strength in a predictable manner, enabling different groups of materials to be easily classified.

Whichever production method is used the goal is generally to produce a material with small grain sizes, as these produce a stronger material. This goal does, however, have to be balanced with the need to maintain ductility and formability to enable the Copper to be easily formed or machined in subsequent engineering operations.

Copper wire is available in a wide range of forms, with the most commonly specified grades being:

- C172 Beryllium Copper
- C197 Copper-Iron-Phosphorus-Magnesium
- C260 Cartridge Brass
- C510 Phosphor Bronze
- C725 Copper-Nickel-Tin

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Copper and conductivity

Copper has excellent thermal and electrical conductivity. Indeed, in its pure form, the electrical conductivity of Copper is so high that it is used as a standard against which the conductivity of other metals is measured using the IACS (International Annealed Copper Standard) scale.

IACS dates from 1913 and was established by the International Electrotechnical Commission. This body set the measurement for the conductivity of pure annealed Copper, stating that at 20°C, commercially pure, annealed Copper has a resistivity of 1.7241x10-8 ohm-meter, or conductivity of 5.8001x107 Siemens/meter. This is normally expressed as 100% IACS. Conductivity values for other metals are referenced against this scale; for example, Iron is 17%, Gold 70% and Aluminium 61% IACS.
It should be noted that Copper alloys typically have a lower level of conductivity than pure annealed Copper: Brass is 28% IACS and Phosphor Bronze 15% IACS; of course, these alloys will offer other characteristics such as strength, hardness, corrosion resistance and colour that may be of greater importance in different applications.

For applications where high levels of conductivity are essential, such as in the power generation and distribution sector, or in electric and hybrid vehicles, the purity of the Copper used is critical, with oxygen-free Copper generally being the material of choice.

Copper components manufactured by Dawson Shanahan

Copper classification

The most common way to catalogue Copper and Copper alloys is to divide them into groups. These typically include:

- Copper - commercially pure Copper with less than 0.7% impurities
- Dilute-Copper (or high-Copper) alloys – containing small quantities of alloying elements such as Beryllium, Cadmium or Chromium
- Brasses
- Bronzes
- Copper-Nickels
- Copper-Nickel and Zinc alloys
- Leaded Coppers
- Special alloys

Each group is subdivided and individual materials classified using the North American Unified Numbering System (UNS), the American Society for Testing and Materials (ASTM) International designation or the European Committee for Standardisation (CEN) nomenclature.

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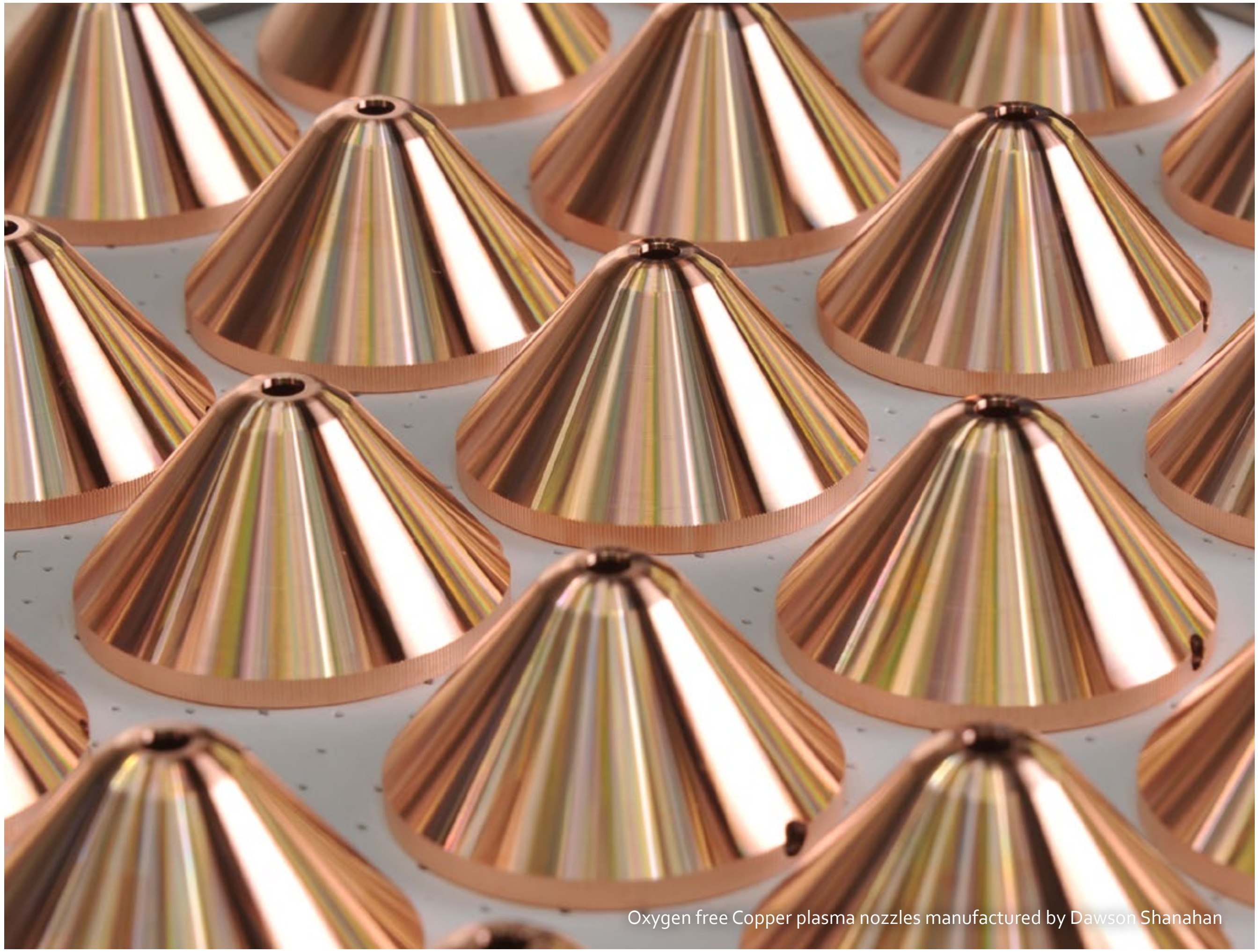
Oxygen free Copper

Oxygen free Copper offers a unique combination of electrical conductivity and chemical purity, There are two different types of Copper that are used for applications requiring exceptional levels of electrical conductivity: high conductivity electolytically refined Copper (HC); and oxygen-free high conductivity Copper.

High conductivity electrolytically refined Copper (UNS C11000) is also known as Electrolytic-Tough-Pitch (ETP) and contains a minimum of 99.90% Copper, with oxygen as the second principal element at between 0.02% and 0.04%. UNS C11000 Coppers have a conductivity of between 100% and 101.5% IACS, making them ideal for the manufacture of wire and cable, busbars and windings.

Oxygen-free high conductivity Coppers (UNS C10100) are often referred to as OF Copper or Oxygen-Free Electronic (OFE) and are produced by casting electrolytically refined Copper in a controlled, non-oxidizing envIronment.

This family of materials contains at least 99.99% Copper, with 0.0005% oxygen content and extremely low levels of volatile impurities, giving it a level of conductivity of at least 101% IACS. This makes it suitable for many high vacuum electronics, laser and plasma applications.



Oxygen free Copper plasma nozzles manufactured by Dawson Shanahan