Hansjörg Lipowsky
and Emin Arpaci

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Copper in the Automotive Industry

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Preface

Copper, gold and tin were the first metals which mankind learnt to use. Copper and gold are amongst a few metals that can be found in nature as solid metals. As copper can be worked easily the oldest known civilisations used it to make useful items as early as 10,000 years ago.

In spite of this people nowadays are less aware of copper than of other industrial metals. Many engineers in the automotive industry are surprised that copper is even used in automobiles. At best mechanical engineers think of copper in connection with the board circuit and starter and generator.

Indeed wire harness, generator, auxiliary motors and electric actuators make up the lion's share of the copper in a car. The implementation of hybrid drives and fuel cells will also see a further increase in the use of copper.

The hybrid drive saves fuel and leads to less harmful exhaust gas. The change from hydraulic to electric actuators and power functions benefits the car and the environment. Electric functions are better suited to consume energy only when there is an actual demand, can be better controlled intelligently, and operating liquids like hydraulic and brake fluids do not need to be disposed of at the end of the vehicle life.

Copper also serves for dissipating waste heat of the control units of power electronics or from engines. The above mentioned applications use copper as it's electrical or heat conductivity is higher when compared to other technical metals.

Most automotive and mechanical engineers are not aware of the many advantages which copper alloys can have for mechanical parts. Of great benefit is the precise hot and cold formability which enables the production of precision parts which, because of their shape, cannot be produced by machining.

The excellent machinability with long tool life and high precision often results in parts for instance in brass being less expensive than in other metals which may be considerably cheaper. Well known gliding properties of copper alloys and the high wear resistance of some special alloys can be combined with very satisfactory strength properties.

Copper is environmentally friendly. It is essential to man, even indispensable for maintenance of the body's defences. It is germ-killing, which may be highly desired in air conditioning units and water pipes. Copper and its alloys are corrosion resistant in various environments (see section "Corrosion"), as centuries

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old copper roofs and Bronze Age artefacts show, which have lain for millennia in the soil. Copper is perfectly recyclable. Secondary copper has absolutely identical properties as primary copper. Therefore no particular specifications (see Annex) are needed for remelted copper and alloys.

The mission of this book is to spread this information primarily to the automotive industry, but also to other fields, and to support them with data and facts.

Hepberg, July 31, 2006 *Hansjörg Lipowsky*

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Raw Material Resources

1.1
Primary Raw Materials [1]

The earth has an average copper content of approximately 0.006% [1]. Copper is the twenty-third most common element in the earth's crust [2]. There are traces of copper in almost all types of rock. Like iron, copper has the tendency to combine easily with sulfur and oxygen, which accounts for why both metals are often found together in ore as sulfurous minerals.

Copper is seldom found in metallic form, although there are examples in the Urals, at Lake Superior in the USA and in New Mexico. The most important copper ores are copper pyrite (chalcopyrite) and copper glance (chalcosite). Copper pyrite ($CuFeS_2$) contains 34% copper and copper glance (Cu_2S) 79%. Important ores in mining include sulfide mineral peacock ore (bornite) and the oxide minerals: malachite, blue malachite (azurite) and red copper ore (cuprite).

1.2
Availability

Copper ores are mined in underground and open pit mining. Figure 1 shows the main copper mining areas: in Africa, e.g. Zambia and the south, the west coast of South America, central and northern Chile, Peru, Mexico, the lakes area of North America, Canada, the south west of the USA and the former Soviet States: Russia, Kazakhstan and Uzbekistan. There are also significant deposits in Australia, China, Indonesia, Papua New Guinea and the Philippines. In Europe, the only deposits worth mentioning are in Portugal, Poland (Upper Silesia), Serbia and Bulgaria. Chile with 35.5% of mining output worldwide was the largest copper producer in 2005.

Known copper reserves are estimated at 940 million tonnes (2004), of which 470 million tonnes are commercially extractable under current conditions. Potentially usable reserves of copper are currently estimated at 1.6×10^9 tonnes. There are more reserves in maritime "manganese nodules", which are today not

1) Unless stated otherwise, these details refer to per cent by weight.

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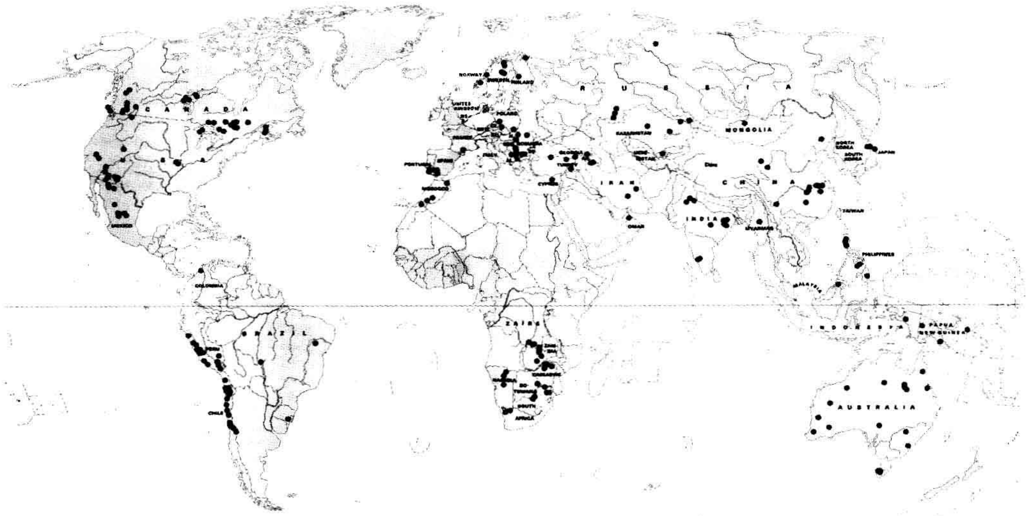

Fig. 1 Copper in the World [2]: The mining output of copper ore in 2003 produced around 14.4 million tonnes of copper [3 a]

commercially viable. The copper content of the manganese nodules alone is estimated at 0.7×10^9 tonnes [3]. Work is now being carried out on processes for commercial copper extraction from these deposits, which are low in metal or difficult to mine.

The supply of copper in the form of deposits and reserves has constantly increased over the years and is thus assured for the foreseeable future.

2
Production

2.1
From Ore to Copper Concentrate [1, 4]

Crude copper ores have a significantly lower copper content than pure copper minerals. The ores mined nowadays often contain only about 1% Cu and even as little as approximately 0.35% Cu in some larger mines. The latter can only be economically extracted in the more cost-efficient open pit mining using state-of-the-art extraction methods. The terrace-shaped open pit copper mines are the largest ore mines in the world. Although much less copper than iron is produced, the amount of rock displaced corresponds to that of the world's entire iron ore mining.

Large quantities of "barren" rock (gangue) are separated from the copper-bearing ore before smelting. The ore is crushed and pulverised into particle sizes often less than 100 μm. Sulfide copper ores are enriched into concentrates by flotation whilst the minerals are separated from one another by various surface properties. The concentrates normally have a copper content of between 20 and 30%; 50% in very favorable cases.

In contrast, copper is extracted from mixed sulfide oxide or oxide ores (about 15 to 20% of all copper ores) by combined special processes or by hydrometallurgy whereby the copper is dissolved from the crushed ore with acid and precipitated by electrowinning.

2.2
From Copper Concentrate to Refined Copper [1, 4]

Copper concentrates are nearly always processed pyrometallurgically. Formerly the process involved three processing steps: partial roasting followed by smelting into copper matte with a copper content of 30 to 50%, which is then processed in the converter into blister copper (crude copper with a copper content of 96 to 99%) and fire-refined into copper anodes with a copper content of ≥99% and oxygen content of <0.2%.

Today, the flash smelting process (e.g. Outokumpu process) is generally used [5], which is especially cost-effective for large quantities of material. The pre-

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dried concentrates are simultaneously roasted and smelted in a reaction shaft using oxygen-enriched blast air at 1300 °C, with a hearth area underneath to separate the resulting matte and slag. A waste heat boiler and filter have been added to the exhaust gas line to cool down the gases and separate flue dust from the gases. Sulfuric acid is produced in contact towers from the filtered furnace gases containing SO_2.

The copper matte is periodically tapped out of the furnace hearth and transferred to the converters. The remaining iron sulfide is oxidised by blowing air into the copper matte whereby sulfur is discharged as SO_2 from the converters with the waste gas and subsequently used for the production of sulfuric acid. The iron is oxidised into iron oxide, forming a slag in combination with added silica. The remaining copper sulfide is finally decomposed, the sulfur being extracted again as SO_2.

Direct processes which unite all the reaction steps – roasting, smelting and converting – in one process have had considerable success in recent times. The Mitsubishi and Kennecott processes enjoy large-scale use in this area.

Crude copper extracted by pyrometallurgical means is firstly refined in a molten state (fire refining) and then by electrolysis. Fire refining without subsequent electrolysis is only performed to a very small extent nowadays.

In fire-refining (solidified crude copper or scrap, see secondary copper production), impurities can be removed by injecting air into the copper melt in the anode furnace. The remaining sulfur is thus removed and later the oxygen content reduced in rotary furnaces (anode furnaces) by injecting a reducing gas like methane or propane, natural gas, naphtha or ammonia. In former times, and still today in areas where gases are not available or expensive, the reduction step can be performed by immersing wooden logs into the liquid copper, thus creating a strongly reducing atmosphere. The fire-refined tough-pitch copper with a copper content of $\geq 99\%$ and an oxygen content of $\leq 0.2\%$ is partly cast in continuous casting plants into shapes, such as billets, slabs and ingots. However, the larger part is cast into anodes on casting wheels and subsequently refined by electrolysis.

Impurities in the copper have to be eliminated or reduced to a minimum of some ppm (parts per million), as even very small amounts can seriously affect copper's thermal and electrical conductivity. In the electrolytic tankhouse, the anode sheets cast from fire-refined copper and thin cathode starter sheets made of electrolytic copper, or long-life stainless steel cathodes in the case of more modern plants, are suspended in tankhouse cells filled with a copper sulfate solution. The anode copper dissolves on applying an electric voltage and is deposited on the cathodes as very pure copper while the impurities and accompanying metals either dissolve in the electrolyte or sink to the bottom of the cells as anode slimes. The copper cathodes thus produced are sold or remelted and cast into shapes (billets, cakes and wire rod) of semi-finished products.