Adding Value and Growing Markets through Wire Rod Production

Paper presented by Sir Michael Nairn, Chairman, Rautomead Limited at Metal Bulletin International Copper Conference, Sofia, June 2008

Introduction

By way of introduction and before developing the topic of this paper, I would like to focus attention briefly on copper as a material. Copper is, after all, the theme of this international conference and is a quite remarkable, naturally occurring chemical element, on which much of our daily lives have come to depend. Copper has unique properties and characteristics: good heat conductivity, good corrosion resistance and good machinability. Copper is malleable and is non-magnetic and especially relevant to the topic of this paper, it has outstanding electrical conductivity properties, second only to silver. As long ago as 1913, copper was accorded the arbitrary value of 100% in terms of the International Annealed Copper Standard (IACS) by which other conductors are ranked. Through long and dedicated effort and investment, the copper refining industry has developed very high standards of purity in electrolytically refined copper cathode to give copper its remarkable properties in electrical conductor applications. In the London Metal Exchange standard, this is commonly expressed as Grade A cathode (CU-CATH-1), with a minimum copper content of 99.9935%. And that is not all. The chemistry of the 0.0065%% remaining is also of critical importance in achieving the necessary properties for use in electrical conductor applications. The standard requires that the group of elements Bi+Se+Te is restricted to not greater than 0.0003%, As+Cd+Cr+Mn+P+Sb to not more than 0.0015%, Co+Fe+Ni+Si+Sn+Zn to not more than 0.002% and S to not more than 0.0015%. Oxygen content is not specified in the cathode standard, but is commonly 60-80 parts per million. The requirements of the standard are shown in the table on page 2.

The importance of chemical purity and the avoidance of specific other contaminants in electrical conductor applications can be illustrated by the following chart which shows the effect on resistivity (inverse of conductivity) of small amounts of certain other chemical impurities.

Introduction (cont'd)

Element	Symbol	Specification	ISA Brands (typical)		Typical Rautomead Rod – Customer A	Typical Rautomead Rod – Customer B
		Grade A	JB	OLYDA		
		ppm	ppm	ppm	ppm	ppm
Bismuth	Bi	<2.0	<0.8	<0.2	0.24	0.04
Selenium	Se	<2.0	<0.3	<0.3	---	1.5
Tellurium	Ti	<2.0	<1.0	<0.2	0.05	<0.3
group		**<3.0**	**<2.1**	**<0.6**		
Arsenic	As	<5.0	0.8	0.1	0.86	<0.2
Cadmium	Cd		0.1	<0.1	0.05	<0.1
Chromium	Cr		<0.5	<0.1	0.01	<1
Manganese	Mn		0.4	<0.1	0.005	<1
Phosphorous	P		<0.3	<0.1	0.04	<2
Antimony	Sb	<4.0	<1.0	<0.1	---	<0.5
group		**<15.0**	**<3.0**	**<0.5**		
Lead	Pb	<5.0	2.0	<0.1	0.28	0.5
Sulphur	S	<15.0	6.9	<4.0	8.0	5.9
Cobalt	Co		<0.5	<0.1	0.01	<2
Iron	Fe	<10.0	2.0	<0.7	0.7	1.5
Nickel	Ni		1.3	<0.1	0.19	0.4
Silicon	Si		0.6		0.62	
Tin	Sn		<0.3	<0.1	0.01	0.2
Zinc	Zn		<1.5	<0.1	0.09	0.2
group		**<20.0**	**<6.0**	**<1.0**		
Silver	Ag	**<25.0**	**12.0**	**<5.0**	**9.3**	**7.4**
Oxygen	O				1.8	<2
Carbon	C				<0.4	
Aluminium	Al				0.11	
Boron	B				0.01	
Total		**<65.0**	**<32.0**	**<15.0**		

Table 1 : CU-CATH-1 Chemical Composition

Introduction (cont'd)

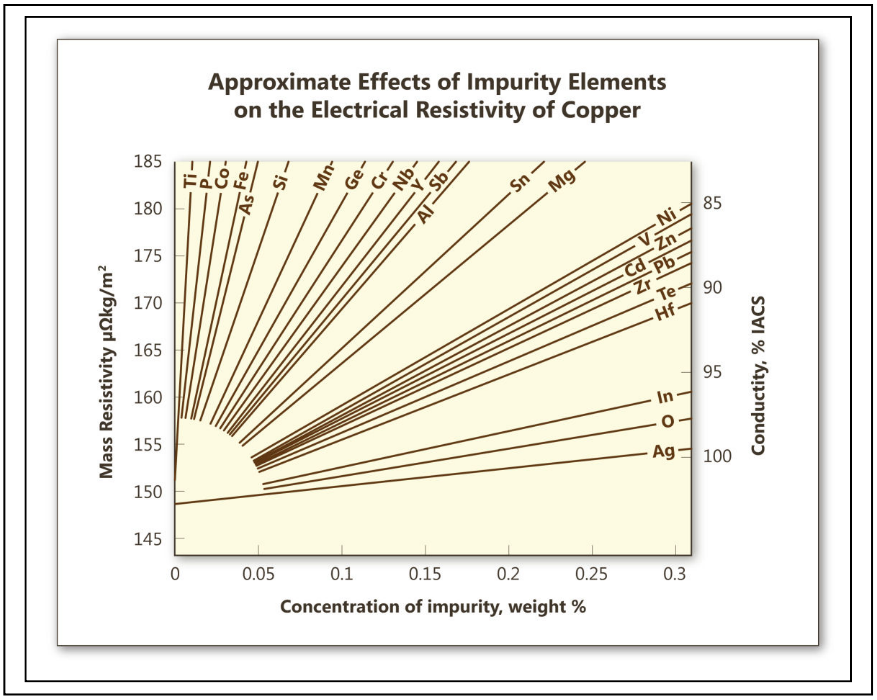

Fig 1 : Approximate Effects of Impurity Elements on the Electrical Resistivity of Copper

The chart above shows the comparative effects on electrical resistivity of copper of some other elements

These introductory comments on refined copper are made only to emphasise the very high chemical purity of copper which is both required and is achieved on a daily basis by leading copper refiners where copper is to be used in demanding electrical conductor applications and where IACS requires to be 100% or better.

Fig 2a
Grade A - electrolytically refined full deposit cathode.

Fig 2b
Grade A - electrolytically refined ISA Process™ cathode

Casting Technology Options for the User

Development of Casting Processes

In the1960s, when static casting of 100 kg wire bars represented the accepted technology and practice of the day, a wire break in drawing operations each 100 kg, coinciding with the welded joint between wire bars was a real risk. Casting technology has advanced a long way in the intervening years. Modern casting processes can be distinguished into two fundamental types:

Semi-Continuous Casting,

where copper is cast vertically downwards from a tundish, solidified in moulds and cut into discreet “log” lengths. The downwards vertical semi-continuous casting process is a convenient and efficient means of producing large section extrusion billet, which is subsequently cut again to extrusion billet lengths, re-heated and fed to an extrusion process.

Continuous Casting,

which, as the name implies, can continue to cast without interruption, so long as molten metal is fed to the casting die or until the die itself is eroded or worn. The continuous casting process has been developed to cast downwards, horizontally and upwards. Each orientation of the process has been developed to suit different applications and these are usually not interchangeable. Variants of the continuous casting process include:

Continuous Cast and Roll (CCR)

The CCR process has been developed as the successor to the earlier technology of casting and hot rolling of copper wire bars. These are large, capital intensive plants with annual capacity in the range 40,000 tonnes up to 300,000 tonnes. The commonly produced product is HC copper which is far the most widespread copper specification used in the wire and cable industry and also for motor, generator, transformer and instrument windings, radio and television parts, switches, terminals, earthing rods, commutator segments and anodes for electroplating. Certain alloyed coppers including CuAg can also be produced by the CCR process. Krupp-Hazelett Contirod™ system of Germany, Continuus-Properzi™ of Italy and Southwire™, of USA and are the leading European/USA brands. Essential features of these processes are that the copper cathode is melted in a gas fired shaft furnace and transferred to a holding furnace, where metal temperature and oxygen level are carefully controlled, normally in the range 120-300ppm.

Casting Technology Options for the User (cont'd)

Continuous Cast and Roll (CCR) (cont'd)
The conditioned copper is continuously cast either between moving steel belts (Contirod) or round a wheel (Continuus-Properzi and Southwire) as a continuous single strand of bar 1,500 to 9,500 sq mm section, according to plant capacity. The cast bar is hot-rolled in line to finish as a single strand of wrought rod, normally 8mm diameter, though larger sizes may also be made. The plants can incorporate an acid pickling stage, washing and waxing to protect the rod surface. Many of this type of plant are operated by the leading copper refiners themselves who prefer to sell their copper as wire rod or as drawn wire, rather than as cathode sheets. Such large scale plants operate at their most efficient when making a single rod product day-in-day-out.

Upwards Vertical Casting
The upwards vertical casting process was developed in the 1970s. The process casts multiple strands, either at 8mm or larger rod sizes up to 30mm diameter. The process has the great convenience of enabling the casting dies to be changed quickly and safely, without disturbing the bath of molten metal below and with minimal interruption to the production process. In its modern versions, the process for oxygen-free copper involves no rod rolling. The cast rod is available directly for drawing to wire. Certain low-alloyed oxygen-free conductor coppers can also be produced by the upwards vertical casting process, including CuAg, CuSn, CuMg and CuCd. Rautomead™ and Upcast™ are the leading European/Scandanavian brands.

Hot Rolled HC Copper

As-Cast Oxygen-Free Copper

Fig 3
Comparison of hot-rolled HC copper and as cast Oxygen-free 8mm copper metallurgical structures

Casting Technology Options for the User (cont'd)

It is an essential distinction of the upwards vertical process that the cast copper is oxygen-free, compared with HC copper produced by the CCR processes described earlier. This is a necessary feature of the upwards vertical process in order to achieve an economic life for the graphite casting dies through which the metal is cast and solidified. Conversely, it is not possible economically to produce HC copper by the upwards vertical casting process, on account of the oxygen present and its deleterious effect on the graphite casting dies.

One of the consequences of the reduction of oxygen in oxygen-free copper is that impurities will remain in solid solution in the metal, rather than as insoluble oxides, as is the case in HC copper. The presence of such impurities in oxygen-free copper thus can have a more marked and negative effect on electrical conductivity than in HC copper. Conversely, in its pure form, oxygen-free copper has an inherently greater conductivity than HC copper. Other benefits of oxygen-free copper include better ductility, lower "noise" and the avoidance of the risk of hydrogen embrittlement which can occur in HC copper during annealing, brazing and welding operations.

Upwards vertically cast copper exhibits significantly lower oxides layer on the surface of the cast rod, compared with HC copper rod. This can be an advantage when the rod is used as a feedstock for the continuous extrusion process, by eliminating the need for a preliminary rod surface cleaning process.

Characteristically, oxygen-free copper rod plants are smaller than the CCR plants for HC copper rod production and are often installed by wire and cable producers as a form of backwards integration. Plant capacities range from 2,000 tonnes per year to 40,000 tonnes per year. Many oxygen-free copper plants have been installed on the principal ground that the output capacity suited the user's production requirements, rather than for any specific requirement that the copper should be oxygen-free.

Within the range of Upwards Vertical Casting Plants, there are two types:

Combined Melting, Holding & Casting Plants
In the smaller Upwards Vertical Casting Machines in the capacity range 3,000 tonnes to 12,000 tonnes/year, cathodes are melted and rods are continuous cast upwards in a single electrically heated furnace, divided internally into graphite casting dies surrounded by water jacket coolers are immersed in the molten copper. The copper solidifies as it rises through the die, pulled by an extraction device mounted above. A heavy layer of charcoal or graphite flake is used on top of the melt to reduce the oxygen to less than 0.0005%. This is necessary to ensure a reasonable life for the graphite casting dies. Machines of this type are equipped with three to twelve individual strands, casting into layer wound coils of 4-5 tonnes capacity.

Casting Technology Options for the User (cont'd)

Such plants are compact, inexpensive and relatively simple to operate and maintain. Users have a choice of heating systems in these smaller machines, either electric resistance heating using a graphite crucible, or channel induction heating with a bricked ceramic furnace lining. The copper rod is nominally oxygen-free. In practice, the oxygen content of such rod is likely to be less than 3 parts per million.

Fig 4 : Rautomead RS 3000 integrated melting and Casting machine. 6 strands, 5,500 – 6,000 tonnes/year

Use of a single furnace for both melting and casting calls for not only grade A cathode to CU-CATH-1 specification but also cathode which is clean, free of surface oxidation, surface nodules, residual copper sulphate, trapped electrolyte or other surface moisture. These unacceptable features can arise through operating failures in the refinery tank house or in careless transport and handling. Small amounts of clean mill scrap can also be blended with the cathode.

Casting Technology Options for the User (cont'd)

Upwards Vertical Casting (cont'd)

Separate Melting and Holding Furnace Casting Plants

Larger capacity Upwards Vertical Casting Machines up to 40,000 tonnes/year use separate furnaces for melting and holding/casting, with a hot-metal transfer between them. These larger furnaces are invariably channel induction heated. The feedstock is CU-CATH-1, but the systems are larger and are more tolerant of minor imperfections in surface quality of the cathode used. Oxygen reduction occurs principally in the melting furnace, using a charcoal cover. Care in the design of the machine must be taken to avoid oxygen pick-up in the transfer of the molten copper to the holding furnace, as "oxygen-free" copper remains essential for good life in the graphite casting dies. Rod casting technique is very similar to that used in the smaller machines, except that there are more strands – normally up to 32 strands - mounted in individually controlled banks of six or eight. In the larger machines it is normal to mount the coilers in two tiers to reduce the overall length of the line. Like the smaller plants, copper quality is oxygen-free.

Fig 5 : Rautomead RDG 360 copper rod casting machine. 32 strands, 28,000 - 30,000 tonnes/year.

The theoretical cost of production from a relatively small scale oxygen-free copper rod plant producing say 10,000 tonnes per year will be greater than the equivalent cost of production from a large scale HC copper rod plant with a capacity of 120,000 tonnes per year or more.

Casting Technology Options for the User (cont'd)

The break-even volume for a large HC plant will be relatively high, so that its operating cost advantage is only realised when it is operated at the high output rates of which it is capable. Depending on the competitive situation in the local market, this cost benefit of HC copper may or may not be passed on to the wire and cable producing customer. Often, the justification for a wire and cable producer to invest in his own relatively small-scale oxygen-free copper rod plant will be in cases where a high rod premium demanded by the large HC copper producer makes such an investment attractive.

A further feature of the upwards vertical casting process is the ability to cast a wide range of tin-bronzes, nickel-silvers and binary brass wire rod. The metals are usually melted, alloyed and the composition checked in a separate melting furnace, before pouring to the casting machine. Such plants commonly cast wire rod at 19-21mm, followed by a succession of rolling/annealing/drawing stages, though more recently, several such plants have been installed to cast binary brass wire rod (60:40, 64:36, 65:35) at 8mm for direct drawing and with no rolling to make Electrical Discharge Machining (EDM) wire.

Dipform

Until about ten years ago, the Showa Dipform™ process for production of oxygen-free copper rod was extensively used by leading cable companies in Japan, but the majority of these plants have since closed.

Horizontal Continuous Casting

Compared with upwards vertical continuous casting, the horizontal process is simpler and less expensive from an engineering standpoint. Despite considerable effort and development expenditure, it has not so far proved possible to produce oxygen-free copper wire rod economically by the horizontal process. It is however commonly used for continuous casting of large diameter extrusion billet and in production of smaller diameter (typically 12mm-20mm) copper alloy wire rods.

Casting Technology Options for the User (cont'd)

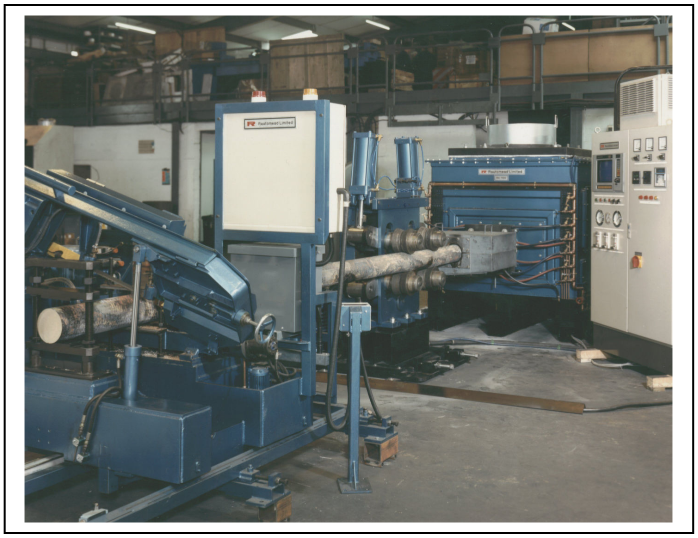

Fig 6 : Horizontal Continuous Casting – Copper Alloy Extrusion Billet

Fig 7 : Horizontal Continuous Casting – Copper Alloy Wire Rod 12-120mm Diameter

Downwards Vertical Casting

The picture would not be complete without reference to downwards vertical casting. Oxygen-free copper wire rod could be produced by such a process, but given the well-developed upwards vertical process and the inherent safety considerations of downwards vertical casting, it does not feature in a paper considering options for wire rod production. Downwards vertical continuous casting is however a good and efficient means of production of large diameter extrusion billet and also of hollow bars, with an ability to produce very concentric hollow sections.

Interchangeable Use of HC Copper and Oxygen-free

Good quality hot-rolled HC and as-cast oxygen-free copper rod may be used interchangeably in most wire drawing operations. Minor adjustment in drafting in the initial rod breakdown stage and in annealing temperatures may be necessary when switching from one to the other. In many instances, the user will be comparing the rod quality available from his commercial source of HC rod with the quality which he makes or could make from his own oxygen-free upwards vertical casting plant. In such cases, caution should be expressed in terms of the HC rod available. Many of the existing plants still in use are now 30+ years old and depending on the history, the management and plant maintenance, may not consistently produce high quality HC rod. In adopting modern multiwire drawing technology and in drawing to fine and superfine wire, the instances of rod breakage may be substantially greater and the cost of operation substantially higher than when using Oxygen-free rod from a modern upwards vertical casting machine.

Oxygen-free is a more ductile material than HC and in this the favoured copper in such applications as automotive wiring harnesses and control circuits in moving machinery (robotic arms etc). Oxygen-free wire produces less electronic “noise” than HC and is thus the favoured copper in high quality audio systems, aircraft headphones and similar specialist applications.

Wire Market Trends and Alloy Development

World market

Total world consumption copper in 2007 is estimated to have been 18.1 million tonnes*. Of this, approximately 13.6 million tonnes*, or 75%, was used in wire rod applications. Year on year growth in copper wire rod consumption in 2007 was approximately 4.5%. This growth, which is at a higher rate than in past years, is clearly fuelled by demand from the developing world, especially in China, India and Russia as the infrastructure in those countries is developed and as disposable personal incomes rise. These simple statistics show clearly the pivotal position of copper wire rod within the world copper industry. The steep rise in the price of copper over the past three years appears to have had a minimal effect on demand or to have resulted in significant substitution in electrical conductor applications. This underlines the unique “fitness for purpose” of copper as an electrical conductor and its essential nature in the daily lives of the world’s growing population.

* source: CRU International Ltd

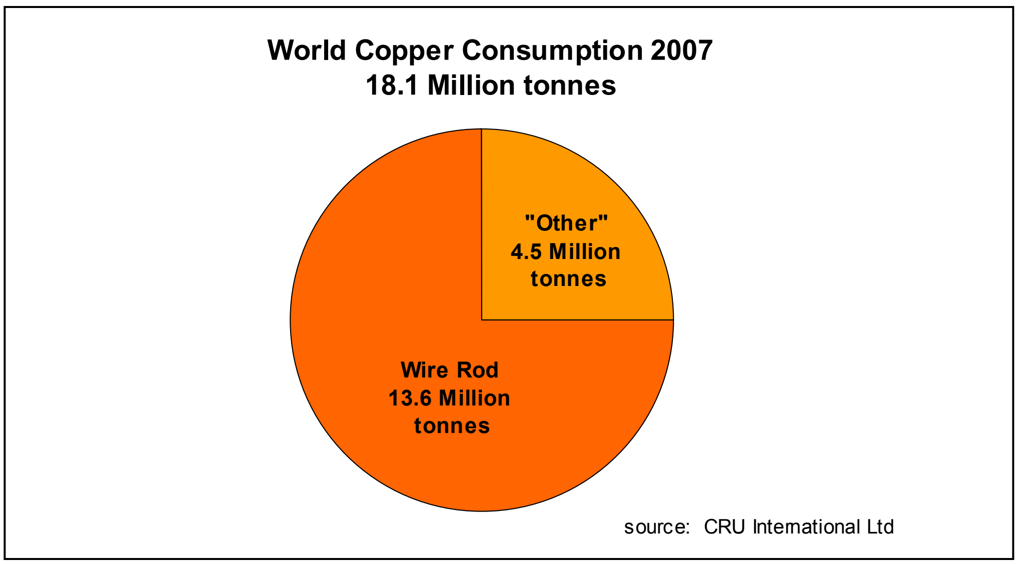

Fig 8 : World Copper Consumption

Alloy Development

Conductor Alloy Wire Rod

While HC copper and to a lesser extent oxygen-free copper meet the majority of market needs for copper in electrical conductors, other specialist applications call for low-alloyed copper conductors (generally defined as less than 2% alloy addition) to impart to the end-product additional tensile strength, creep resistance, thermal stability or higher softening temperatures, while still benefiting from the good electrical and heat conductivity of the copper itself. Individual market volumes are relatively modest, but premiums over the LME copper price are higher, sometimes much higher, relating the value of the alloying elements and the complexity of the manufacturing processes required. Copper alloys in this category include:

Copper-Silver (0.01% - 0.12%Ag)
Provides greater creep strength in elevated temperature applications without loss of conductivity. Used in motor windings and in trolley wire

Copper-Tin (0.2% – 0.4%Sn)
Provides greater tensile strength with modest loss of conductivity. Used in trolley wire.

Copper-Magnesium (0.1% - 0.5%Mg)
Provides high tensile strength with modest loss of conductivity. Rapidly work-hardening alloy. Used in High speed trolley wire

Conductor Alloy Wire Rod (cont'd)

Copper-Cadmium (0.7% - 1.2% Cd)
Provides excellent balance of high tensile strength with reduced loss of conductivity. Also used in heating pads, electric blanket elements spring contacts, connectors, high strength transmission lines and applications where wire is subjected to repetitive movement. No longer accepted in some applications on account of toxicity of Cd fume

Copper Chromium (0.3% - 1.4% Cr)
Provides good high temperature strength and stability with good conductivity. Precipitation hardening. Contact wire for high speed rail. Resistance welding tips.

Copper Chromium Zirconium (0.5 -1.2% Cr: 0.03 - 0.10% Zr)
Contact wire for high speed rail. Resistance welding.

Alloy Development (cont'd)

Engineering Alloy Wire Rod

A wide range of more dilute copper alloy wire rods is used in non-conducting applications, taking advantage of the other properties of copper, including heat conductivity, corrosion resistance and malleability, especially in association with the properties of the alloying elements. The brief list below describes those alloy groups which are customarily continuously cast and which are subsequently drawn to wire.

Tin-bronzes (5% – 8% Sn)
Usually continuously cast at approx 19mm, rolled, annealed and drawn to wire
Applications in wire mesh for screens and conveyor belts

Nickel-silvers (typically 18% Ni, 27% Zn)
Usually continuously cast at approx 19mm, rolled, annealed and drawn to wire
Uses of nickel-silver wire include zippers, spectacle frames, jewellery and musical instruments

Binary brasses (35% – 40% Zn)
Usually continuous cast at 8mm, drawn and annealed
Use in high precision Electrical Discharge Machining (EDM) applications

Special brasses (30% Zn & other minor alloy additions)
Usually continuous cast at 8 – 12mm, drawn and annealed
Uses in wire mesh for screens, with particular sub-sea applications

The above group of copper wire rod alloys should be distinguished from a separate group of copper-based engineering alloys which are also continuously cast in the form of solid bars, flats and hollow sections, which is beyond the scope of this paper.

Economics of Wire Rod Production – Can it work at a smaller scale ?

In a hypothetical situation of perfect competition in which all resources are allocated and used efficiently, conventional copper redraw rod for electrical conductor applications would be manufactured as 8mm diameter HC copper rod, using large production capacity CCR plants, probably installed close to the copper refinery. Equally, in such a perfect market, the place of the smaller types of upwards vertical continuous casting plant would be to meet the demand for "special" products, defined in terms of

- Less common copper wire rod sizes
- Conductor alloys
- Special applications calling for oxygen-free rod
- Engineering alloy wire rods

However, we live in a very imperfect world in which a myriad of factors distort the economist's theory of perfect competition. In this sense, the market for copper and copper alloy wire rod behaves no differently from any other.

Thus, examples are found of production from high capacity CCR plants being diverted from standard 8mm HC copper rod production to produce relatively small runs in larger sizes of rod or of silver-bearing copper. In some geographical areas, the business risk associated with multi-million dollar investment required for a new CCR plant has been considered too great, giving rise to a succession of smaller oxygen-free copper rod plants to satisfy local demand. In other areas, the existing CCR rod plants are now old and are not being replaced. This similarly, has led to investment by the local wire and cable industry in a battery of smaller oxygen-free copper rod plants to protect their vital supplies of redraw rod as their principal manufacturing raw material and to secure the future of their businesses.

There are other benefits of backwards integration into small scale wire rod production. Depending on the location and surrounding circumstances, points which may contribute to such an investment decision include:

- Control of quality of the company's essential feedstock material
- Superior quality and reduced wire breaks in multi-wire drawing machines and in drawing to fine and superfine wires
- Inherent quality advantages of oxygen-free copper in applications where superior ductility and low noise are important
- Convenient output capacity to match user's requirements
- Flexibility to choose alternative brands of cathode feedstock
- Control of the supply chain

Economics of Wire Rod Production – Can it work at a smaller scale ? (cont'd)

- Flexibility to produce different rod diameters
- Flexibility to produce alloyed coppers as well as oxygen-free copper
- Modular expansion possibilities as demand grows
- Attraction in terms of security of inwards transport of copper in form of cathode sheets, rather than coils of rod or drawn wire rod
- Ability to recycle scrap arisings from cable-making operations
- Differential tariff barriers applicable to copper cathode and rod imports

Thus, there can be no doubt that the majority of the world's growing demand for copper redraw rod will be HC copper and will be manufactured using one of the well-developed CCR processes. Separately, there are specific smaller market applications where the upwards vertical continuous casting processes have both a technical and a commercial advantages. In between these two extremes, there will remain cross-over points, where for reasons of imperfect market competition, the upwards vertical process, in particular, will be found making 8mm copper redraw rod for use in conventional building wire applications.

Ends