Conticast® Group

Cu-OF or Cu-ETP?: SOME GENERAL COMPARISONS OF SMALL DIAMETER COPPER WIRE ROD PRODUCTS. V5.5 2006

INTRODUCTION:-

The starting feedstock for virtually all major commercial copper wire production today is invariably based on continuously cast wire-rod products made directly from high quality grade "A" copper cathodes plus a proportion of selected uncontaminated copper scrap.

The most common continuous casting process routes used currently are listed (not in any particular order) as under: -

1) The **CONTIROD**™ casting process (SMS-Demag & Union Miniere)
2) The **PROPERZI**™ casting process (Continuous Properzi Spa, Italy)
3) **SEMI-CONTINUOUS DC CHILL** open topped mould processes. (various suppliers)
4) The **SOUTHWIRE SCR**™ casting process (Southwire Company, USA)
5) The **SHOWA DIP-FORM**™ upwards casting process (Showa Corp., Japan)
6) **VERTICAL UPWARDS** continuous casting systems. (Conticast™ Group UK, & Rautomead™ Limited, UK).

The above processes & derivatives thereof, are described in references i thru' iv.

Processes 1) to 4) listed, are used for the production of oxygen containing coppers, Cu-ETP-1 & Cu-ETP-2 standard composition products. They all involve melting cathode or a mixture of cathode & selected scrap continuously in gas fired reverbatory hearth or shaft type furnaces to produce molten copper at controlled oxygen contents, which is then fed into a moving or reciprocating mould to produce an ingot feedstock which is normally followed by extrusion or immediate in-line hot rolling, coating, coiling and packing downstream processes, to achieve the desired coil weights of ~8-14mm Ø redraw wire-rod.

Processes 5) and 6) are used for the production of oxygen-free coppers, Cu-OF-1 and Cu-OF-2 products. (<10 ppm O_2 contents)

Process 5), originally developed by General Electric Co., USA, and now marketed by Showa, is a mouldless upwards forming process of casting copper from a melt-bath dynamically around an upwards moving pre-shaved "seed rod". The process uses in-line hot rolling.

The more commonly used processes for the production of Cu-OF, as at 6) involves the use of submerged graphite dies & vertical upwards casting mode for the products.

WHY VERTICALLY UPWARDS CASTING MODE?-

Submerged graphite dies are unsuitable for the production of Cu-ETP quality copper products which commonly have 150 – 550 ppm oxygen contents. These levels of oxygen in the melt solution rapidly destroys the graphite surfaces of the casting die inserts by oxidation due to the general reaction:-

$$C + CuO = CO + Cu$$

Horizontal (or vertically downwards) mode of continuous casting machines with submerged graphite dies, are also unsuitable for the production of high quality pure oxygen free copper (CuOF1 and 2) near to net-shape products. This is due principally to the effect of the metallostatic pressure head of the melt, bearing on the solidifying shell within the casting die, & causing sticking of the very soft fragile solidification copper shell on the graphite mould wall.

The forwards pulling extraction forces, coupled with the friction effect of the metallostatically pressured shell adhering to the mould wall, leads to strand superficial surface cracks, due to shell rupture as it is moved along the mould. Since there is no "mushy zone" in pure metals (being isothermal freezing entities), there is no semi liquid sump which can feed thru' to fill this crack, as in the case of alloys, which do have mushy zone (i.e. freezing range) sumps.

Vertical upwards casting methods, with their negative metallostatic pressure strip action within the mould, have been found therefore to be the only way to produce pure electrical grade oxygen free high conductivity copper (Cu-OF) rod products, using submerged die continuous casting processes.

It is possible to increase the output of upwards casting machines by using separate melting furnaces & by producing larger size sections of strand product. Cold rolling mill processes may be used EG. to directly cold-roll 20 mm Ø as-cast Cu-OF rods down to the standard industry 8 mm Ø.

With 14, 12, 10, 8mm, or under Ø, rod sizes being cast, then normally direct cold drawing of the as cast product will ensue, by means of the normal wire rod industry copper wire drawing machines.

From the standpoint of successful wire drawing, whilst a great deal depends on the internal and surface qualities of the continuously cast product (lack of inclusions & overall cleanliness, structural consistency etc) much depends on the precision of the downstream processing, which is usually rolling, coating, coiling and packing. The majority (but by no means all) of the wire breaks during wire drawing have been established as being due to a variety of singularities associated with the downstream, post casting processes. Many of the faults in wire products boils down to plant conditioning & cleanliness including product surface pick up of inclusions such as small pieces of structural/constructional steels, other metallic/non-metallic factory detritus, clay, silica sand particles etc.

DESCRIPTION OF FEED MATERIALS:-

Copper cathodes are the tankhouse products resulting from electro-refining or electro-winning operations carried out on intermediate refinery products (fire refined anodes or chemical concentrate solutions) after processing the raw copper ores and/or scrap. For economic reasons, more & more high quality cathodes nowadays are becoming available from electro-winning solvent based processes (electro-obtained) as compared to those traditionally produced by the more expensive to run electro-refining plating processes, using fire refined copper anodes.

The quality of the copper cathodes used to produce copper wire rod is critical to the resulting quality of the wire products. In the oxygen free copper wire rod production processes, which are promoted and marketed by the companies listed at 5) & 6), the quality & fundamental characteristics of the copper wire rod product will be as a direct result of the quality of the cathodes fed to the process. International standard Cu-CATH-1 quality is the cathode material which is the required feedstock for oxygen free high conductivity copper rod.

The most important copper qualities are conductivity & to a certain extent anneal-ability, both properties of which relate back to the feedstock & to the production process itself. The raw materials for the Conticast process has to be high quality cathode copper plus in-plant clean & dry scrap material. The latter can be used to varying extents of the infeed weight. Typ. 25%, but overall is governed by the properties achieved in the final products.

Analysis
The Conticast process is for melting & casting & other than the total oxygen removal, does not carry out any refining. Therefore the quality of the copper cathodes as far as impurities are concerned must meet the requirements set out for the cast wire rod stated under.
As a guide, the following can be given for good quality suitable copper cathodes:

Cu + Ag		min. 99.99%
Fe		< 10 ppm
S		< 10 ppm
Bi		< 5ppm
Pb		< 5 ppm
P		< 3 ppm
Fe+Si+Sn+Ni+Zn+Co	total	< 20 ppm

All impurities which influence the electrical conductivity of the copper must be as low as possible.

Raw Materials Consumption: will be determined according to the number of strands cast. Several standard Conticast® models are available for the production of <500 to > 100,000 M tonnes per year.

Process Losses: Weight losses have been stated as commonly 0.05 – 0.15% total comprising principally of moisture, debris and impurities on or within the feedstock.

DESCRIPTION OF PRODUCTS:-

Conticast plant products comprise high conductivity oxygen free copper wire rod, in the as continuously cast (As cast) condition. The size and coil weights will be according to the customer requirement.

Quality: The surface of the as-cast wire rod is clean and smooth without cracks. The surface "tiger stripe" marks present on the as-cast rod are not defects, but are purely superficial stop-&-go marks caused by the nature of the indexing movement of the strand withdrawal process.

Properties: The as-cast copper wire rod is worked down by cold deformation (rolling and/or drawing) for the further manufacture of cables, conductors, enamelled wire and other electric & electronic products.

Characteristics of the as-cast wire rod

- density ~ 8.92 kg/dm^3
- breaking resistance R_m ~ 175 N/mm^2
- elongation at break A_5 ~ 50%

Characteristics of the cold-worked wire rod

- electrical conductivity in the soft condition
  (as-cast wire rod cold-worked down to 2mm dia wire
  and annealed) min. 100 % IACS

- resistivity in soft condition max. 0.15328 $\Omega g/m^2$
  or max.17.241 nΩm

With the exception of oxygen content, the product chemical analysis of the as-cast wire rod and the charged raw material will be the same analysis. Oxygen content in the wire rod will be less than 5ppm.

THE **CONTICAST®** PROCESS FOR THE PRODUCTION OF UPWARDS VERTICAL CONTINUOUSLY CAST COPPER ROD:-

Whilst references i - iv, give considerable information on the various processes, it is worth considering some specific details on the process type 6) as promoted & marketed by the Conticast® Group.

CONTICAST® manufacture a wide variety of continuous casting machines for the production of semi-manufacture products (semis) in oxygen free copper (Cu-OF) & many of its alloys. By far the largest application by volume of these semis is 8mm diameter as cast Cu-OF-1 quality redraw wire rod, which is then used directly as a feedstock for cold drawing, & is the basis for copper wire production throughout the world, for high quality electrical conductors in the wire and cable industries.

The high temperature furnace technology supplied by CONTICAST® utilises a fully lined graphite containment system for holding the bath of molten metal, in conjunction with using high thermal extraction efficiency submerged graphite casting dies and cooler assemblies **(ULTRACOOLERS®)**. This is probably the best technical system in the world today, which exists for processing high conductivity copper materials. The personnel at CONTICAST® have been at the forefront of this breakthrough metallurgical technology development, over many years.

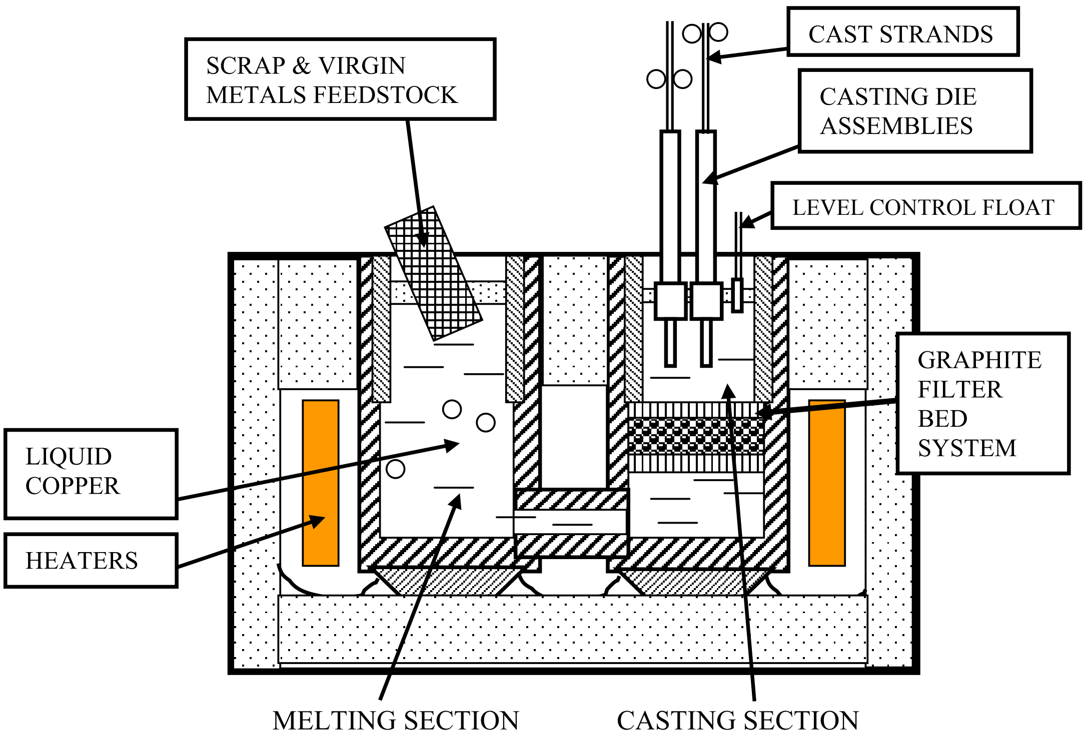


FIG 1: Schematic outline of the CONTICAST® Vertically Upwards Continuous Casting Process for the production of Cu-OF materials.

The extensive use of speciality graphite melt containment materials means that the process is based on the naturally chemical reducing environment of liquid copper melt in contact with massive carbon, which converts/removes many elemental oxides, including copper oxide, commonly present to varying degrees within copper melts.

The copper rod product emanating from this type of process is therefore essentially rendered oxygen free (Cu-OF), & has oxygen contents typ. 1 - 4 ppm. These levels are typical oxygen levels specified as a requirement for Cu-OFE (oxygen free copper of electronic quality - <5ppm oxygen specification). The emphasis with respect to the chemical purity of the feedstock for the process therefore is that the cathode must be of grade A quality (Cu-CATH-1 see Table 1 in APPENDIX), with none of the conductivity lowering elements present to any significant extent, since there is no excess copper oxide (Cu_2O, cuprous oxide, or cuprite) phase present in the final semi-product copper matrix to act as a “getter” for complexing conductivity lowering impurity elements.

With a few exceptions (e.g. silver) most other elements in solution, such as iron, silicon, phosphorous, etc. are deleterious to the conductivity requirements for electrical conductors. Many of the impurity elements which find their way into Cu-OF products end up in a substitutional solid-state solution within the standard copper face centred cubic (FCC) atomic lattice structure & cause sufficient FCC atomic matrix distortion such that the smooth flow of electrons is impeded during the conduction cycle of the material, hence lowering the electrical conductivity of (…or alternatively, imparting higher resistivity to…) the product.

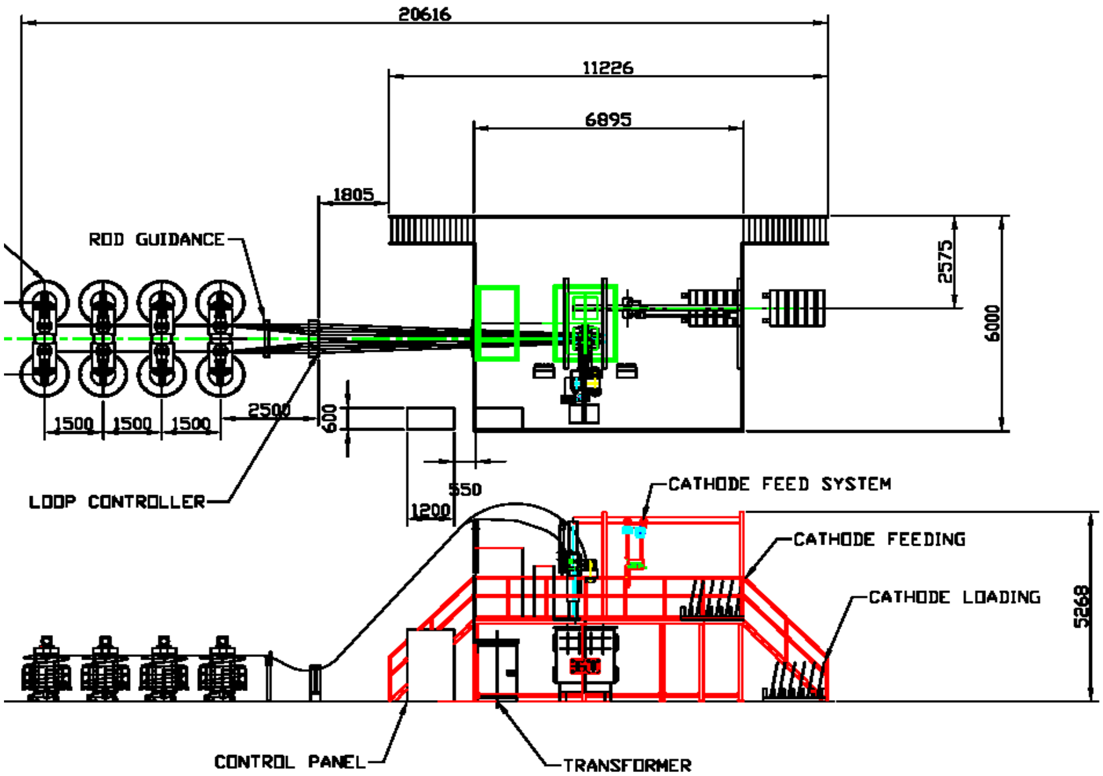
This is one of the fundamental differences resulting between Cu-OF oxygen free and Cu-ETP oxygen containing coppers, where in the latter products, the cooling morphology is such that all the impurities remain "locked in", associated as multi-metal oxide systems & complexes with the copper oxide phase "pools" or islands, within the pure copper FCC atomic structure matrix. (IE copper oxide in solution acts as a getter/solvent for all the impurity elements in the melt solution, & which then associate with it on oxide phase separation after solidification.

Figure 1 shows schematically an outline schematic of the **Conticast** process for producing Cu-OF copper wire rod. Figure(s) 2 show the general extent of a layout example of such a plant installation.

Apart from the nature of the input copper feedstock quality & its consistency, the principal aspects for successful operation for the process to produce high quality product, is mainly influenced by the die and cooler design.

The die assembly is immersed to a controlled depth in the melt, well protected by a specially selected carbonaceous cover. The melt then flows into & solidifies in that area of the mould where it is influenced by the water jacket cooler, whereupon the newly formed solid, is then extracted further in an intermittent manner of controlled stop-go movement. In secondary cooling zones within the cooler system, the temperature of the product is lowered to avoid any surface oxidisation of the product, which is undesired, following whence, the product exits the die system into the open air, at a designed temperature of $<80^{o}C$.

The Cu-OF cast strand product from the process, as a semi-manufacture, is then wholly ready for immediate drawing or rolling to the various intermediate & final high conductivity products required. Products for storage should be treated with proprietary di-azo type surface protection inhibitors, in order to prevent staining oxidation.



8 Strand Vertical Upwards Mode Copper Rod Continuous Casting Production Machine Installation
FIG 2 © Copyright MMVI Conticast Limited

Features of CONTICAST® Equipment in producing Cu-OF rod:-

OUTPUTS:-

Post solidification, the cast strand wire rod moves in relation to the die & the rod extraction requires to be carried out with high precision to obtain a satisfactory quality. The motion is of a intermittent nature (stop/go) in which the length of the "go" cycle motion or pulse, frequency, acceleration, deceleration and overall speed are all part of the critical combination of variables.

Plant outputs are limited by a combination of the above variables & by the heat flow extracted from the solidifying melt to the water running through the cooler. Typical speeds of 1.0- 2 M/min are normal for 20mm diameter Cu-OF-1 copper rod and 3 – 5 M/min for 6 & 8mm diameter rod. There is some evidence that for no.1 internal structure quality rod, the lower speeds of the ranges mentioned are necessary.

The graphite die inserts in which the casting liquid melt to solid phase change takes place are the main wear parts of the production tooling, having to be replaced periodically; conveniently & typically by many users, on a weekly frequency.

The furnace crucible system comprises two distinct chambers - a melting chamber & a holding/casting chamber. Thermocouple sensors are positioned within the melt and furnace system, & use is made of micro-processor control systems for close control of power. Temperatures close to the casting die position are maintained within a band +/- 5^{o}C to set point. This degree of melt temperature control & stability is essential for successful consistent production of the highest quality products.

Vertically upwards continuous casting technology for Cu-OF-1 products is used for a wide spectrum of output requirements from <500 MT/yr, upwards to >100,000 MT/yr, utilising multiple plant installations.

CATHODE FEED:-

Cathode feeding can be manual or semi/fully-automatic, using pick-&-place arrangements. A lifting device can be used to lift individual cut cathodes from a magazine positioned close to the machine & transfer these to the feed orifice at the melting side of the machine. The cathode pieces & other feedstock are lowered into the molten bath in a controlled manner. An electronic level control system is provided to prevent over-filling of the furnace.

STRAND TRANSPORT:-

Strand transport & rod withdrawal is effected by using double gripper roll mechanisms, positioned above the die-cooler assemblies. These comprise driven, profiled pairs of withdrawal rolls mounted on shafts, each pair having individual adjustment, thus permitting strands to be started & stopped independently of the others.

The standard withdrawal drive for the task is configured to operate in a stop-go pulsed fashion, capable of producing over 1,000 pulses per minute (ca.>15 Hz).

The rods emerging from the machine in the as cast condition are fully soft & have a typical as-continuously cast structure - figure 3. Exit temperature is characteristically <100^{o}C thus the material has a bright clean surface finish.

COILING:-

Rod coilers with fully powered coil layering swifts, are provided as standard equipment to coil the product into well ordered and layered coils of 2 - 4 metric tonnes to facilitate simple pay off to the wire drawing machine. This aspect of the process is important, since coils have to pay-off smoothly into high speed wire cold drawing machines. Forklift truck or overhead crane may handle coils.

Coils of copper wire rod are dynamically in-line coated with a proprietary di-azo complex material from an applicator, to protect & inhibit the wire rod surface from undesirable air oxidation (staining) during storage.

OTHER MATERIALS:-

Although the principal use of vertical upwards continuous casting machines is the production of Cu-OF, oxygen-free high conductivity wire-rod, they may also be used for production of silver-bearing copper & other dilute high copper alloys such as CuCd1, CuMg0.4, CuAl10Fe1, Cu64.5Zn, Cu64.5Ni18Zn, CuSn6, CuSi3 & c . Some alloying components may be introduced into the melt & stirred in with inert gas bubbling, whereby dry clean nitrogen or argon gas is bubbled from the base of the crucible to provide stirring & thorough mixing of alloy additions made to the copper.

MANNING:-

One operator per shift is normally required to run a vertical upwards continuous casting machine. The operator's principal function is to patrol the process & monitor the performance of the machine's systems from the cathode feed through to rod coiling. Other duties include the changing of the casting die inserts (approx. each week of production) & periodic removal/restarting of product coils of wire-rod. Additional part time assistance is required to prepare **ultracooler®** die assemblies & the start-up of the machine.

OPERATING HOURS:-

Continuous Casting machines run at their most efficient on an uninterrupted basis, seven days per week. In normal circumstances, it should not be necessary to stop the machine for maintenance attention more frequently than each 3 - 6 months. If, for other reasons, it is necessary to stop the machine, it may be left in a "stand-by" mode, with the copper molten in the crucible, the casting dies lifted out of the melt & the lids closed. In this mode, power consumption is ~ 13% of the running rate.

SPACE REQUIREMENTS:-

Each **Conticast**® machine installation is compact in its nature. A typical layout is shown on fig. 2. Space required depends on the method of handling of cathode & rod coils, in addition to that space allowed for feedstock and product storage. No special foundations are required as the equipment has the convenience and capability of being installed on top of a regular type of level factory floor surface. A normal standard air entrained & reinforced concrete floor of 150mm maximum thickness is sufficient.

ENVIRONMENTALS:-

The **Conticast**® process using electric powered melting, is thus inherently clean & non-polluting. Melting clean copper feedstock in the system does not give rise to any fumes. No effluent is produced. Sound levels at the normal positions occupied by operators do not exceed 79 dB(A).

WIRE DRAWING CHARACTERISTICS :-

Cu-OF-1 AS CAST WIRE-ROD PRODUCTS:-

For reasons of quality, the as cast Cu-OF wire rod product must not contain significant quantities of chemical impurities such as iron, tin, silicon, phosphorous etc., above certain levels & the level of deleterious dissolved gases must be low. This reflects substantially on the soundness of the melting practice, melt transfer (if applicable) and casting processes within the overall continuous casting regime. Melt temperature control, protection from the open atmosphere, the use of clean, moisture/organic vehicle free raw materials & design of process equipment are all critical in ensuring the production of sound product of high internal structure integrity.

As continuously cast Cu-OF wire rod, even at the smaller rod size of 8mm diameter, is relatively large grained. The grain size is typ.1 x 3mm, with mixed chill and (mostly) columnar shaped grains present (figure 3). As a consequence the as-cast (chill cast) structure, the product has a degree of macro grain segregation present. It is however an entirely consistent repetitive structure is produced during the steady state plant operation.

8mm dia. CuOF wire rod 12mm dia. CuOF wire rod

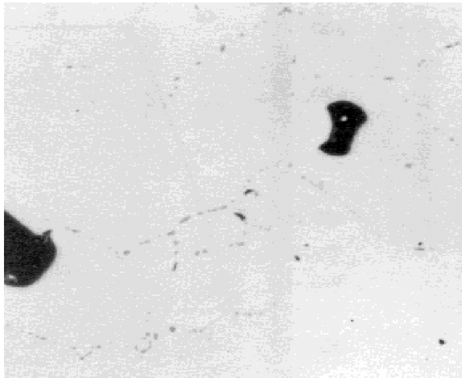
Figure 3. shows the typical longitudinal and transverse section grain structure of as cast 8mm and 12mm diameter Cu-OF product.

The above type of grain structure requires to be heavily cold worked (to >80% cold work cross sectional area reduction), with a subsequent anneal heat treatment applied, whereupon a cold worked, annealed and recrystallised microstructure structure is achieved which then yields the typical structure and properties of a wholly wrought homogenous product. (Figure 7)

CONTINUOUSLY CAST & ROLLED (CCR) Rod - CONTIROD™ , PROPERZI™, & SOUTHWIRE SCR™ Cu-ETP WIRE ROD PRODUCTS:-

Copper produced by the above processes always include oxygen, the levels of which can vary normally between 100 - 500 ppm (0.01 - 0.05% by weight). According to literature, the maximum solubility of oxygen in copper is ca. 2ppm (0.0002%) & that oxygen which is present in excess of this, reacts with the copper to form copper(1)-oxide (Cu_2O). (fig.4)

8mm diameter Cu-ETP rod from SOUTHWIRE SCR®, PROPERZI® and CONTIROD® processes, have all been hot rolled to varying extents & the products show a relatively homogeneous grain structure (figure 5). Part of the technical success of these large volume output processes, is their undoubted ability to control the copper oxide phase quantity, particle size/shape & distribution.



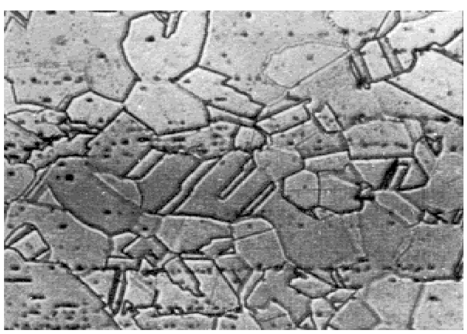
This microstructure consists of irregularly-shaped primary grains of α outlined by a network of α + Cu_20 eutectic. (The α constituent of the eutectic has become absorbed by the primary grains & is not visible as separate particles.) The large black areas associated with the eutectic are gas cavities. Although under normal vertical illumination Cu_20 is blue-grey in colour with a purple sheen, it appears bright red in polarised or oblique lighting. This can be used to distinguish Cu_20 from other constituents of similar colour found in copper.

Unetched x 100

Figure 4. shows a typical structure from a Cu-ETP as-cast product.

Photomicrograph, courtesy Copper Development Association

Continuously cast copper ingots in Cu-ETP production processes have the copper oxide present within the structure in a eutectic form of non-coagulated network paths around the individual copper grain boundaries in the microstructure. However, these are substantially broken up and deform longitudinally in the direction of hot rolling during that process. In consequence & in turn, they transform into discrete elliptically shaped particle dispersions which become evenly distributed throughout the structure during the high deformation part of the process route (multi stand hot rolling) from cast ingot to 8mm diameter finished size wire-rod.



The above microstructure shows that hot working has broken down the cast structure to give twinned equiaxed grains. The Cu_20 eutectic particles have been aligned in the direction of working & their distribution is no longer confined to grain boundaries. All traces of porosity have been removed. The grain structure is lightly delineated by the use of ammoniacal hydrogen peroxide etchant.

Ammoniacal hydrogen peroxide x 200

Figure 5. shows a typical structure from a Cu-ETP as-cast and hot rolled product.

Photomicrograph, courtesy Copper Development Association.

Chemical impurity elements commonly found within copper such as iron, tin, silicon, lead etc are substantially oxidised by the presence of the oxygen in the copper. This can be somewhat beneficial, since oxidising these impurities reduces their negative influence on the conductivity property of the copper matrix. Similarly, the presence of oxygen to certain levels minimises any negative effect of gas porosity, which can potentially be caused by any dissolved hydrogen picked up during the various stages in the processing & including melt transfer of the copper.

Cold drawing the 8mm diameter Cu-ETP product by the initial breakdown drawing process normally concludes with an in-line anneal. The higher the oxygen content of the rod, the better is the capacity for recrystallisation of the structure. The principal effects of increasing amounts of oxygen in copper are to increase the tensile strength, increase the recrystallisation tendency (or decrease the recrystallisation temperature), & lowers the fracture elongation.

Cu-ETP wire may be further cold drawn as required. Reports give the product as being drawn successfully down to 0.05mm diameter product wire (reference x).

Any drift of control parameters relating to the copper oxide amounts & distribution, can on occasion, potentially give rise to local accumulations of Cu_2O particles, which can accordingly induce cup and cone fractures in wire drawing. Various workers, references vi - x, have published opinions and findings as to optimum oxygen contents & their relationships with respect to wire drawability.

Copper oxide particles within copper matrixes do not plastically deform during cold drawing operations, since they are relatively brittle in nature. Their overall size and shape does however change during cold drawing, in that the particles get progressively smaller as they break up during drawing. The copper oxide particle geometry changes and this has been well documented in reference ix. In drawing to wire sizes less than 0.1mm dia. (100µ), oxide particle sizes ranges have been documented as normally between 1.5 - 2.1µ X 1 - 1.3µ (L X W), reducing to 1.1 - 1.5µ X 0.7 - 0.9µ for 0.05mm dia.(50µ) wire.

In general and provided there are no areas present where oxides have segregated or agglomerated, there appears to be no reason for well distributed oxides to be a significant cause of wire breaks, even at the fine wire sizes. (ref x)

COMPARISON OF TYPICAL PROPERTIES Cu-ETP and Cu-OF:-

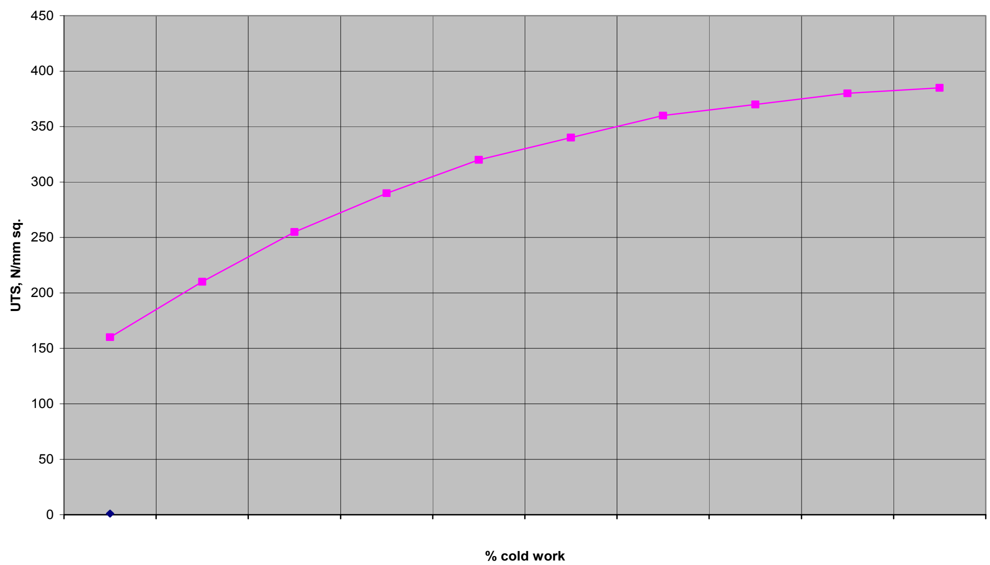
Some properties recorded for 3 types of 8mm dia. copper redraw wire rod are as under:

8mm ROD TYPE > ------------------------------- TEST/UNITS	Contirod® Cu-ETP-1	SCR® Cu-ETP-1	Conticast® Cu-OF-1
YIELD STR, $R_{p0.2}$, N/mm^2	110	120	110
UTS, R_m, N/mm^2	226	234	175
FRACTURE ELONGATION,A_5[%]	59	56	57
CONDUCTIVITY: % IACS	101.5	101	101
OXYGEN CONTENT PPM	210	325	2

Table 1. Note: The above products were all manufactured from Cu-CATH-1 specification raw material.

ROD BREAK-DOWN:-

8mm diameter Cu-OF and -ETP wire rods are typically drawn down initially to an intermediate size range of between 2.5 mm to 1.5 mm diameter then annealed in line on the drawing machine annealer. Because the grain recrystallisation temperature for Cu-OF is higher than that for Cu-ETP, the Cu-OF wire often requires a higher temperature setting for annealing as compared to Cu-ETP wire. It is sometimes often necessary to increase the wire drawing machine in-line annealer voltage by ~10-15% to achieve a fully annealed metallurgical structure for the Cu-OF product. This is well within the capability of most drawing machine manufacturers equipment.



0 10 20 30 40 50 60 70 80 90% CW

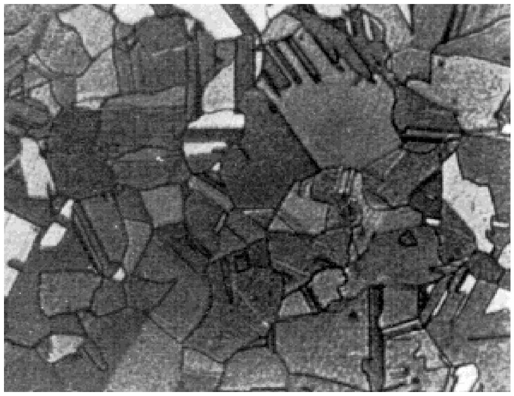
Figure 6. Cold Working (Drawing) Characteristics of 8mm Diameter Cu-OF-1 Rod

NOTE: The cold working graph for Cu-ETP rod is similar to the above with the exception that the UTS (R_m) starting value of the as hot rolled product is ca. 235 N/mm^2.

FINE WIRE DRAWING Cu-OF & Cu-ETP:-

After annealing, all intermediate wires may be further cold drawn as required. Both Cu-OF and Cu-ETP products are all potentially capable of being drawn successfully down to 0.05mm and under diameter (<50μ) fine wire products (ref x). However, due to the aspect that the copper oxide particle sizes commence to become significant, with respect to the overall area size of the wire at these smaller sizes, manufacturers of Cu-ETP wire rod products normally classify their products, sometimes into 4 or 5 different selection categories, since the issue of oxide sizes & distribution within the overall structure becomes critical for fine and ultra-fine wire drawers to ensure that numbers of wire breaks are kept low & at economic frequencies.

As Cu-OF products have no copper oxides within their matrix, the above issues do not apply.



This microstructure shows twinned equiaxed α grains & a complete absence of the Cu_20 eutectic particles as characteristic of Cu-ETP tough pitch copper.

Alcoholic ferric chloride x 200

Figure 7. shows a typical structure from a Cu-OF as-cast, cold worked & annealed product.

Photomicrograph, courtesy Copper Development Association

However, in the manufacture of both Cu-OF and Cu-ETP products, since the production sequence commences by melt and cast processing, the complete absence of melting furnace refractory gangue/other melt or melt transfer detritus as particulate inclusions within the metallurgical structure, is a critical feature & pre-requisite in the objective of obtaining an ultra-clean copper wire internal structure. A clean copper matrix product will provide wire, which will avoid inclusion singularity triggered wire-breaks in the subsequent drawing down to fine wire gauge sizes. (<0.2mm dia.)

Importantly, this often means that EG after partial or full relining or start up of new crucible in melting & casting production plant, etc, a sensible period of system conditioning has to occur, before ultra-clean product can be produced, which is considered as suitable for use in fine or ultra-fine wire drawing processes. IE Second, third or lower quality copper is initially produced during the equipment conditioning cycle, which must be used for relatively non-critical purposes such as chopped anode basket material used in copper plating baths, house wiring heavy gauge sizes.

Some typical measured average properties of 1.5mm diameter drawn and annealed wire, in comparison with the relevant British Standard 4109:1970 are:

1.5 mm dia. wire. -- TEST/UNITS	Cu-ETP-1 and Cu-OF-1	Requirement of BS 4109: 1970
FRACTURE ELONGATION, A_5[%]	32 – 35	30 minimum
CONDUCTIVITY, % IACS	100.8 - 101.3	100 minimum
UTS, R_m, N/mm^2	235 - 255	none

Table 2

8mm diameter Cu-ETP rod from SCR®, Properzi® & Contirod® processes, have been hot rolled to varying extents & the products show, as expected, a relatively homogeneous overall grain structure. Part of the outstanding technical & commercial success of these large volume output processes, is in their ability to control the copper oxide phase particle quantity, size, shape/distribution, within the overall matrix of the copper product.

In addition, the greater output productivity levels, as compared to older wire bar casting and rolling, has led to these being nowadays considered as the world-wide standard production processes for Cu-ETP products.

The as cast ingots for the Cu-ETP production processes have the oxide present in the structure in a eutectic form in non coagulated network paths around the microstructure. However, these are substantially broken up into discrete elliptical shaped particles which are evenly distributed throughout the structure during the high deformation (hot rolling) part of the process, prior to concluding at the standard 8mm diameter finished pack size.

On the other hand, Cu-OF products have the potential to be the cleanest copper wire products of all, due to the complete absence of any inherent matrix oxides. Given a properly housekept, maintained/conditioned Cu-OF production system, fed by clean cathode feedstock, the Cu-OF as-cast strands/rods present as superb starting products for ultra-fine wire production.

SUMMARY:-

In this review, a general outline comparison has been made between the 2 main types of copper wire rod materials used in the world-wide copper conductor wire industry today VIZ:-Cu-OF-1 and -2 oxygen free copper, 1st and 2nd qualities, & Cu-ETP-1 and -2 - electrical tough pitch copper, 1st and 2nd qualities. The term “tough pitch” refers to earlier traditional descriptions of the “setting or solidification quality” of this specific type of oxygen containing liquid copper.

Some observations with comments have been made by the author(s) after a number of year's production experience with both products and review of published literature.

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 The authors would welcome comment-discussion on any of the topics contained within the article. Contacts are conticast@sacomet.com and conticast@aol.com

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6mm wire-rod production die and cooler assembly immersed in melt-bath.

6mm dia. Wire-rod in Cu alloy casting upwards out of the the die assembly.

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