THE RAUTOMEAD UPWARDS VERTICAL CONTINUOUS CASTING PROCESS

by

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BACKGROUND

The Rautomead company has specialised since its inception in 1978 in the design and construction of continuous casting machines for manufacture of finished products in non-ferrous and precious metals. The applications of Rautomead's technology has been over a wide spectrum of industries: automotive, electronics, jewellery, numismatics, building products, medical and general engineering. Over 180 machines have been built, the majority of which have been horizontal mode casting machines although, some have been of the downwards vertical type.

A special feature of Rautomead technology is the use of a fully graphite lined containment system for the molten metal , used in conjunction with submerged graphite casting dies with inert gas protection. Many of the installations are set up as combined melting, holding and casting units, though some of the larger machines are configured to be fed with molten metal from separate pre-melting furnaces.

The use of modern high quality graphite materials has proved to be a thoroughly satisfactory basic design feature of the equipment. Graphite is a superb high temperature engineering material, an excellent heat susceptor which is highly stable at elevated temperatures and is not wetted by most liquid metals. It acts as a neutral to reducing environment for containing many materials, where it chemically removes some of the oxides which may be present in melts and is thus conducive to avoidance of many inclusion problems associated with other casting techniques which employ inert ceramic lined melt bath containment systems. Each crucible is machined from a solid block of graphite, and. with proper care, long life can be expected. A customer in the brass industry has achieved a life of over eight years from a single crucible in regular daily production.

Rautomead casting furnaces are electrically heated, using low voltage graphite heater elements around the crucible. An inert gas atmosphere is applied to give protection to the heaters and the crucible itself. Power is provided to each machine from a double wound mains transformer, using solid state thyristor power control and regulation.

The casting machines are extensively used to cast at near net shape, thus affording to the user the economic benefit of a significant reduction in the process steps to a final product. Depending on the material, this may also eliminate the need for highly capital/labour-intensive hot metal extrusion and hot and cold rolling of billets and larger diameter wire rods.

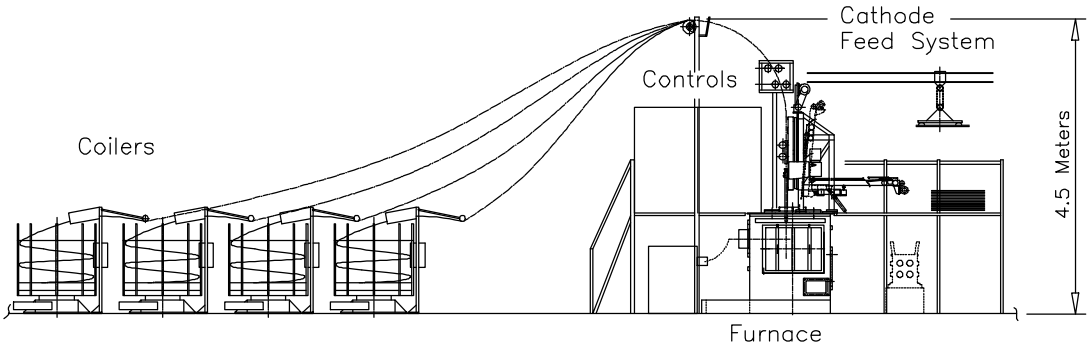
Upwards Vertical Continuous Casting

Over many years, Rautomead had been requested to provide continuous casting machines for the production of 8mm diameter high conductivity copper rod, but it did not prove possible to produce this product satisfactorily by either the horizontal or downwards vertical processes. Development of the upwards vertical continuous casting process commenced in 1992 and it was launched as the RS series of continuous casting machines at the Wire Exhibition, Dusseldorf in April 1994.

The Design Objective

The fundamental design objective was to produce a series of machines for the production of 8mm diameter oxygen-free high conductivity copper rod which were:

- economic to operate
- from a cathode feedstock
- allowing addition of some mill arisings of scrap
- capable of high quality and consistent production
- reliable and safe
- simple to use and to maintain
- small to medium scale e.g. 2,000-12,500 tonnes/year, per installed unit machine



Model RS 2200/8/8 Continuous Rod Casting Machine

Basic Criteria

Design

The basic design was to be based on Rautomead's well proven graphite melt containment technology and using submerged dies with inert gas protection. This is probably the best metallurgical system which exists in the world for melting, holding, and casting many copper materials. Heating was to be by low voltage electric high intensity graphite heater elements, using solid state microprocessor control and power regulation, to provide the ultra-stable temperature regime essentially required.

Single Furnace

To contain the equipment capital cost and to minimise the labour required to operate it, the plant was designed for integrated single furnace melting, holding and casting operation. This brought with it other benefits - notably the elimination of hot metal transfer, with its associated potential problems of heat loss and oxygen pick-up. With pure copper, the question of alloy adjustment in a separate melting furnace, before committing to the casting process did not arise.

Oxygen-Free Product

A natural consequence of the inherent design of the Rautomead equipment by the reducing effects of the graphite melt containment system, was that the product was wholly oxygen free. This is an important element in contributing to good graphite casting die insert longevity, where oxygen attack from the melt can be one of the major causes of wear and failure. The product has typically less than 5 ppm oxygen content. An internal specially packed bed of small graphite ring shapes is incorporated into the base section of the crucible, so that the liquid copper transferring from the melting chamber of the crucible to the casting die chamber, passes through this region of high surface area of graphite, thereby ensuring that the melt becomes truly oxygen free.

Output

Several factors came together in determining output. A retention time of the molten copper in the graphite crucible system of approximately 3 hours was determined as ideal. Crucible capacities were selected such that graphite blocks wide enough to accept whole copper cathode plate feedstock could be used. This conveniently allows for machines of capacities of 4, 8, and 12 strands, equating to typical plant outputs of 2,500, 5,000 and 7,500 tonnes/year of 8 mm diameter copper wire rod. Each strand runs at a minimum casting speed of 3.1 metres per minute.

From the initial specification laid out, a whole range of machines have now been designed to accommodate annual output tonnages ranging from 2,000 tonnes upwards.

Operating Cost

A prime operating cost of not more than approximately £50 per metric tonne of good quality rod produced, based on costs applicable in UK was considered necessary for economic viability. The appendices show some typical prime costs to produce.

Features of Rautomead RS Series Casting Machines

Energy Conservation

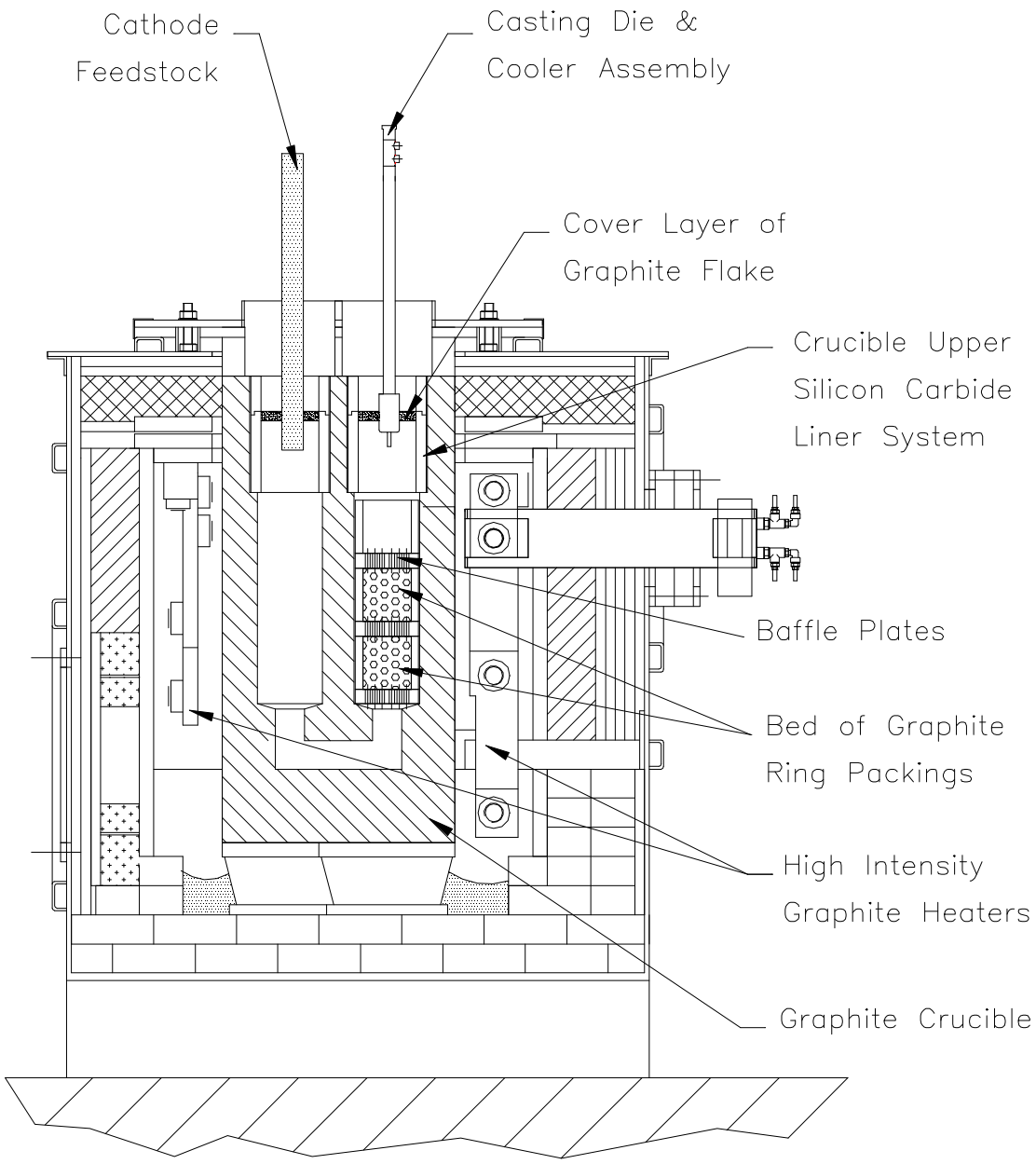
The furnace is designed for long periods of uninterrupted production. It is insulated internally to a high standard with low thermal mass insulation to achieve an exterior furnace shell temperature not exceeding 40 deg C above ambient. The enclosed nature of the process also contributes significantly to energy conservation. Energy requirement of the model RS 2200/8/8 in continuous production of copper rod is approximately 370 kWh per tonne of rod produced.

Temperature Control

The furnace crucible comprises two distinct chambers - a melting chamber and a holding /casting chamber. Heating is biased towards the melt side. Two separate thermocouples are positioned within the furnace system, and by using a micro-processor cascade control system for the thyristor power regulation system, temperatures close to the casting die position are maintained within a band +/- 5 deg C to set point. This degree of melt temperature control and stability is essential for the successful production of the highest quality products.

Cathode Feed

Cathode feed is semi-automatic, using a pick-and-place arrangement. A suction pad is used to lift individual cathodes from a pile positioned close to the machine and to transfer these to a tilting feed table above the feed orifice of the machine. The feed table is equipped with a pneumatic clamping device which holds the trailing edge of the cathode and lowers it into the molten bath in a controlled manner. An electronic inter-link is provided to prevent over-filling of the furnace.



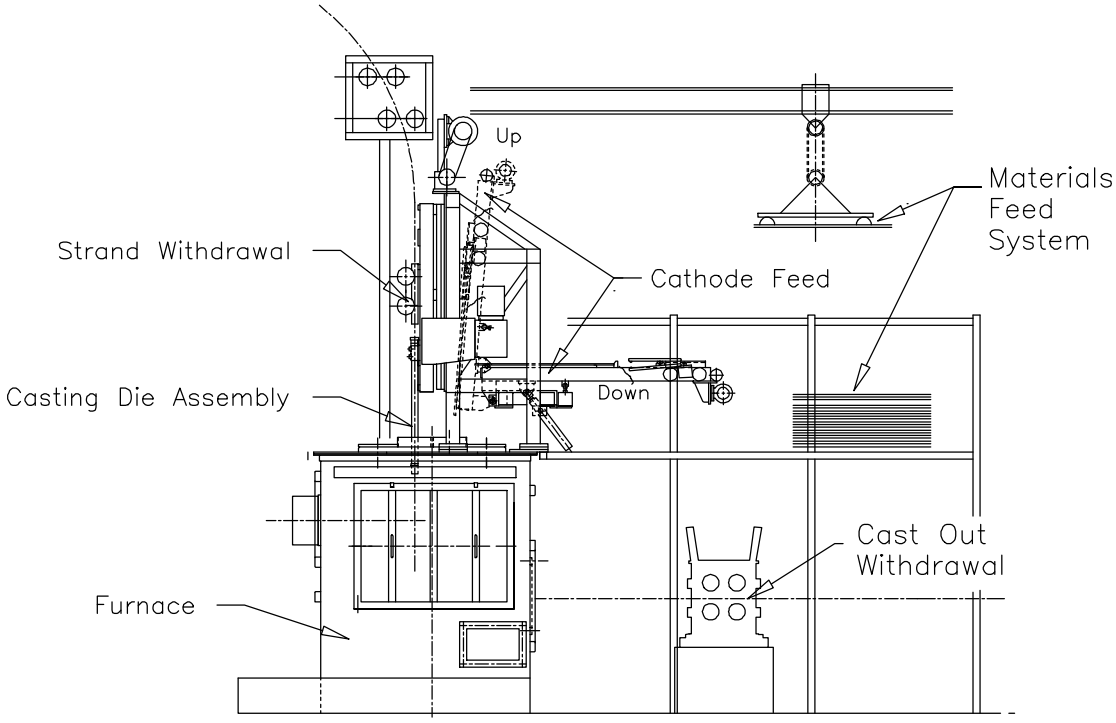
Section Through Model RS2200/8/8 Upwards Vertical Continuous Casting Machine

Metal Cover

A critical aspect of operational importance is that the surface of the molten metal at both the feed and casting chambers are covered by a layer of fine graphite powder, which protects the melt surface from oxidation. This graphite flake powder also reacts with oxides which may be present on the surface of the cathode - all conducive to achieving a truly oxygen-free product. The graphite powder is a consumable item, with consumption of approximately 1.25 kgs per tonne of rod produced.

Casting Dies

Casting dies are small tubular graphite inserts, machined from high quality fine grained material. These are fitted into super-cooler die assemblies, comprising a casting insert, a series of secondary backer inserts and a multiple wall copper cooling jacket, through which cooling water is circulated. Each assembly is clamped into position in a frame above the crucible and the lower end of the casting die is submerged to a predetermined depth in the molten metal. The frame is arranged to move up or down by means of an automatic optical level control to maintain a constant immersion depth, relative to the surface of the metal.



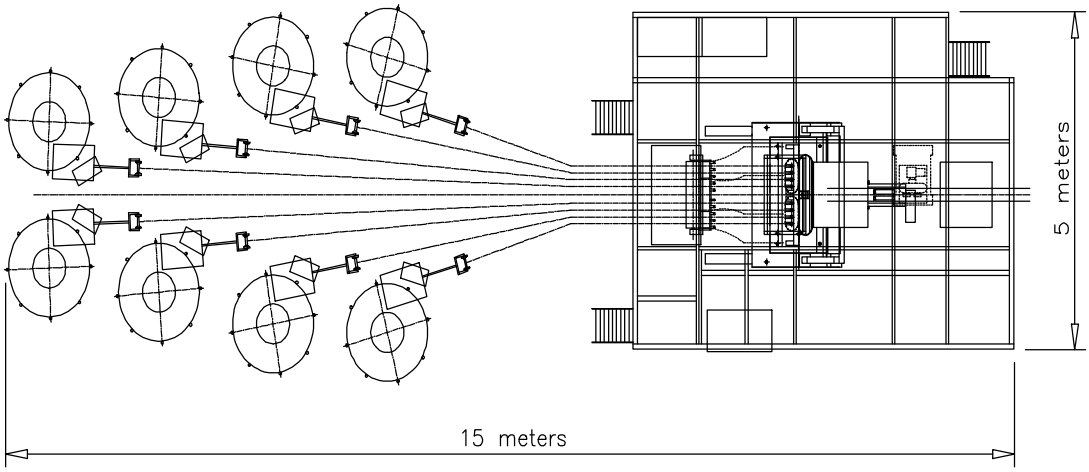
Model RS 2200/8/8 Continuous Rod Casting Machine
elevation, showing cathode feed arrangement

Rod Withdrawal

Rod withdrawal is effected by using double pinch roll transporter mechanisms, positioned above the super cooler die assemblies. These comprise driven, profiled withdrawal rolls mounted on shafts, opposed and pressurised pneumatically by profiled idler rolls. Pneumatic pressure is adjustable on each pair of rolls individually, thus permitting one strand to be started and stopped independently of the others.

In 8 or 12 strand machines, two separate drives are fitted, enabling greater versatility of production to be achieved. Standard withdrawal drive is in a pulsed fashion using a vacuum actuated clutch-brake system, which is capable of producing well over 1,000 pulses per minute. For copper alloy work, a computer controlled AC servo drive may be alternatively specified.

The rods emerging from the machine are fully soft. Exit temperature is characteristically less than 100 deg C and the material thus has a bright clean surface finish.



Model RS 2200/8/8 Continuous Rod Casting Machine
plan view with cathode feed and coilers

Coiling

Jumbo rod coilers are provided as standard equipment to coil the product into well ordered layered coils of 4 - 5 metric tonnes to facilitate simple pay off to the wire drawing machine. Where customers prefer, Rautomead offers to provide a kit of proprietary components with the necessary drawings and instructions, to permit the coilers to be fabricated and assembled locally. Where smaller coil weights are required, rod down coilers with a coil capacity of 2.5 tonnes are available alternatively.

Coils may be handled either by fork lift truck or by overhead crane, according to the facilities available.

Other Materials

While the principal purpose of the RS series casting machines is the production of oxygen-free high conductivity rod, the machines may also be used for production of silver-bearing copper, and other copper alloys. Alloying components may be introduced into the melt associated with an inert gas bubbling feature, whereby gas is bubbled from the base of the crucible to provide stirring and thorough mixing of silver with the copper.

While not the subject of this paper, passing reference is also made to the production of high copper alloys, bronzes, brasses and nickel brasses, using the Rautomead upwards vertical casting process. Significant results have been achieved in the production of certain alloys, with substantially higher casting speeds than is possible with horizontal casting. Downstream processing characteristics of these materials are also excellent, when they have been produced using the optimum casting parameters and settings.

Operators

One part-time operator per shift is required to run the machine. The operator's principal function is to patrol the process and to monitor the performance each major component of the machine's systems from the cathode feed through to rod coiling. Casting dies must be changed approx. each week of production. Coils of rod require to be removed and re-started approx. every 50 - 60 hours or 5 tonnes. Additional part time assistance is required to prepare super cooler die assemblies and at start-up of the machine.

Operating Hours

The RS series machines run at their most efficient on a continuous basis, seven days per week. In normal circumstances, it should not be necessary to stop the machine for maintenance attention more frequently than each six months. If, for other reasons, it is necessary to stop the machine, it may be left in "stand-by" mode, with the copper molten in the crucible, the casting dies lifted out of the melt and the lids closed. In this mode, power consumption is about 18-20% of the running rate.

Space Requirements

The Rautomead RS series machines are compact, consuming little factory floor space. The model RS 2200/8/8 has a footprint of only 15 metres by 5 metres and a height of 4.5 metres. Space required depends on the method of handling of cathode and rod coils, but it is recommended that a space of 15 metres by 10 metres be allowed, with a factory height of not less than 7 metres. No special foundations are required. A normal reinforced concrete floor of 150 mm thickness is sufficient.

Environmental Considerations

The Rautomead process uses clean electric melting and thus is inherently clean. Melting of copper in the system gives off no fume and no effluent is produced. Sound levels at normal positions occupied by operators do not exceed 79 dB(A).

DRAWING CHARACTERISTICS TO FINE WIRE

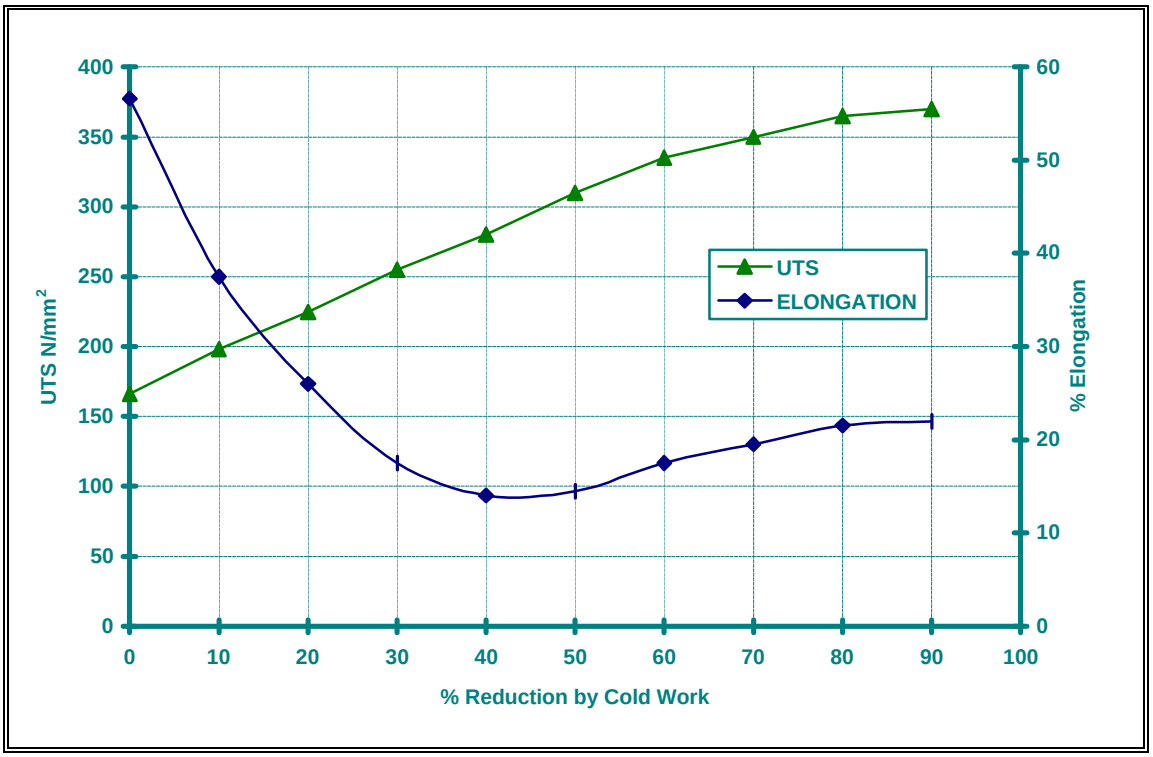
Comparisons with Continuous Cast and Rolled (CCR) Rod

The 8 mm continuous cast product from the Rautomead RS series machines is a fully soft as-cast product, whereas the CCR Rod which has been rolled is slightly harder. Typical properties are:

	Rautomead as-cast	**CCR rod**
elongation	40%	40%
UTS	175 N/mm^2	220 N/mm^2
conductivity	101 - 102 % IACS	101 - 102 % IACS
oxygen content	0.0 - 4.0 ppm	180 ppm

Rod Break-Down

The 8mm diameter rod is typically drawn down initially to an intermediate size of from 2.5 mm to 1.5 mm and annealed in line on the drawing machine. Oxygen-free copper requires a higher temperature for annealing as compared to tough pitch oxygen containing copper and it is therefore necessary to increase the in-line annealer voltage by 10-15% to achieve a fully annealed and recrystallised metallurgical structure.



Cold Drawing Characteristics of Rautomead 8mm Diameter OFHC Rod

Fine Wire Drawing

After annealing, the wire may be further cold drawn as required. The product has drawn successfully down to 0.05mm diameter product. Because the production sequence commences by melt and cast processing through a wholly graphite system, the complete absence of refractory and/or copper oxide particles as inclusions in the metallurgical structure, yields an ultra clean metal internal structure. This in turn provides a product which is highly suited to the avoidance of rod breaks in drawing to fine wire sizes.

Typical properties of the drawn wire, in comparison with British Standard 4109 : 1970 are:

	Rautomead as-cast drawn **1.50 mm diameter**	BS 4109 annealed/drawn **1.50 mm diameter**
elongation	30% - 32%	30% min
conductivity @ 20 deg C	100.8% - 101.3%	100% min

Though not a requirement of the Standard, it should be noted that the UTS of the Rautomead rod at 1.50 mm diameter, after drawing, is in the range 235 - 250 $N/mm^{2.}$

Other Processes

The as cast rod copper rod product has been also successfully processed through the Conform continuous extrusion process, to create a variety of electrical rectangular sections. The large coil piece weights are a distinct advantage for high productivity, and the Rautomead rod feedstock is conducive to good tool and die longevity, having the advantages of no abrasive copper oxide particles occluded within the microstructure.

THE RAUTOMEAD PROCESS.

The Rautomead Upwards Vertical Continuous Casting process, presents a unique opportunity for producers of wire and other related products to utilise a high productivity process, which produces large package weights of a near net shape rod of excellent quality, with no expensive intermediate processing or handling necessary, prior to normal wire drawing.

Truly a process which goes from “Melt to Wire”.

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Some suggested further reading and references:

Horizontal Continuous Casting of Copper Based Rods and Sections: S.R.Cochrane, From Melt to Wire Int'l Conference, Torremolinos, Spain, 1979.

Developments in Continuous Casting of Some Copper Based Alloys: S.R.Cochrane, R.W.Johnson, Int'l Conference on Casting and Forming, Nov 1984, Montreux, Switzerland.

Continuous Casting of Small-Sized Hollow Sections: S.R.Cochrane, R.W. Johnson, Int'l Conference on Tomorrow's Tube, Birmingham, England, June 1986.

Continuous Casting of High Quality Tube Stock: S.R.Cochrane, M.Nairn, Tube International, March 1988.

The use of Ceramic Materials in Continuous Casting, S. R. Cochrane, S.Johns, and R.Wilson, Int'l Seminar in Continuous Casting, Dundee, Scotland, June 1989

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diameter	2	cm	ELEMENT	CONTENT
Inner diameter	0	cm	Ag	
Casting speed	100	cm/min	Al	
Density	8.96	gm/cc	Au	
Liquid Density	7.95	gm/cc	Be	
Latent heat	49	cal/sec	Bi	
Specific heat (liquid)	0.118	cal/sec	C	
Specific heat (solid)	0.092	cal/sec	Cd	
Water in temp.	21	C	Co	
Water out temp.	44	C	Cr	
Water flow	21	l/min	Cu	100 %
Melt temp.	1140	C	Fe	
Mean liquidus/solidus	1083	C	In	
Metal exit temp.	80	C	Mg	
			Mn	
Area	3.141592	sq cm	Mo	
Mass	46.91445	gms/sec	Nb	
Qig	6943.432	cal/sec	Ni	
Qw	8051.61	cal/sec	P	
Cooler eff.	86.23657	%	Pb	
			Pd	
			Pt	
			Rh	
			S	
			Sb	
			Se	
			Si	
			Sn	
			Te	
			Ti	
			V	
			W	
			Zn	
		Balance	Alloy	