RAUTOMEAD INTERNATIONAL LIMITED

XXII MINT DIRECTORS CONFERENCE
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MANUFACTURE OF HIGH QUALITY PRECIOUS METAL STRIP FOR COIN PRODUCTION

PRESENTER
JOHN BRADBURY

Background

Prior to the 1970s, most precious metals for coin manufacture were produced as bars by a batch casting process involving melting the precious metals in small crucibles and pouring into vertical chill moulds. Over the years, this traditional process has been progressively superseded by continuous casting techniques for most precious metal applications, although some manufacturers retain the traditional method for low volume production and special alloys.

Introduction

Rautomead International Ltd design, manufacture and supply continuous casting equipment for the non-ferrous and precious metals industries.

Rautomead offer a wide range of continuous casting equipment which can be divided into the following categories:

- Upward vertical continuous casting for wire, rod, strips and tubes
- Downwards vertical continuous casting of rods, strips and tubes
- Horizontal continuous casting for billets, rods, strips and tubes

The continuous casting process, converting ingot, process scraps, virgin metal and a combination of these by melting and casting to produce a semi-finished section is one of the initial manufacturing processes in the production of many non ferrous metal products.

End products manufactured by customers utilising Rautomead continuous casting technology are diverse and incorporate many industrial sectors:

- Copper wire for wire, cable, telephone and computer wires
- Copper alloy wires for automotive wiring and overhead catenary cable for electric trains and trolleys
- Bronze bars and hollows for machine bearings
- Copper tube for domestic and industrial plumbing
- Brass bars for forged and machined components
- Electronic contact materials and solder pre-forms
- Dental alloys
- Sputtering targets for the production of thin metal coatings to glass and CD's
- Jewellery products, silver cutlery, picture frames, gold chains
- Gold and silver coins and medals

Rautomead have supplied more than 240 machines to customers in over 40 different countries. Of these, 20 machines are being used specifically for the continuous casting of precious metal strip for subsequent processing to coins and medals.

Most of these customers are using one of the smaller model horizontal continuous casting machines. The choice of machine is determined by a number of factors, including the required production capacity and the preferred as-cast section size.

Fig. 1: Gold and silver proof coins produced from a Rautomead continuous casting machine

Advantages of continuous casting

There are many advantages of continuous casting over conventionally produced materials.

Technically, compared to the traditional processes, the ability to continuously cast a semi-finished product close to near net shape minimizes the number of subsequent downstream operations required to produce the finished product. The quality of the semi-finished product and its production in larger continuously cast piece weights can significantly improve the production yield.

Commercially, the improved yield, close control of metal product quality, recycling of blank waste material and reducing the number of operations, lowers the cost of production.

Rautomead design features

Most Rautomead continuous casting equipment incorporate the same fundamental design features, graphite containment and casting crucible, graphite electric resistance heating elements with nitrogen gas bubbling and protection of high temperature components. The process uses a single furnace in which to melt, hold and cast the precious metal.

Rautomead design features (cont'd)

The characteristics which favour the use of graphite include the purity of this material as elemental graphitised carbon, its machinability, its thermal conductivity, its naturally reducing function, and its excellent high temperature stability and strength. Any oxygen present in the molten metal will react with the carbon and be eliminated from the melt. Gold, silver and copper are virtually inert relative to graphite at the temperatures necessary for continuous casting and gold, silver or copper in the molten state does not wet graphite.

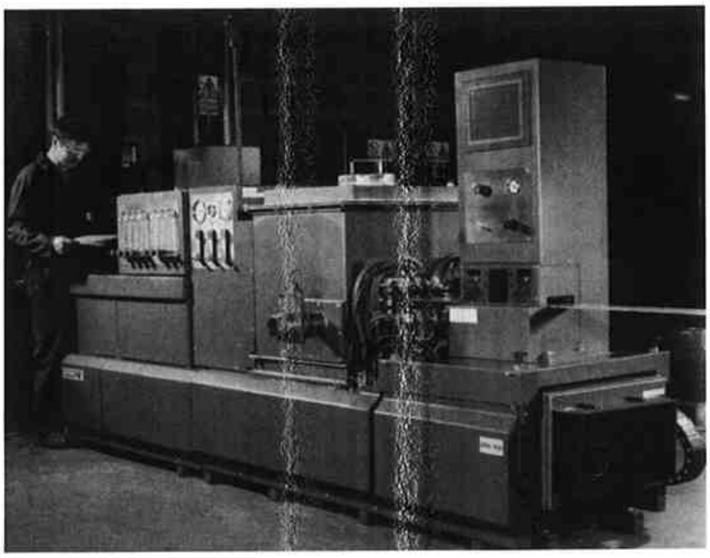

Fig.2: Model RMK 050 horizontal continuous casting machine

Furnace heating is by electric resistance by means of a chain of graphite heating elements, positioned adjacent to the wall of the graphite crucible. Graphite resistance heating is preferred for accurate and stable furnace temperature control and is conducive to a still, quiescent metal bath and an ideal condition from which to cast. Graphite heating elements operate at safe low voltages and an inert gas atmosphere is maintained inside the furnace to protect the graphite hot-working parts from erosion.

Casting is through water-cooled graphite casting dies. The preferred material for the fabrication of strip die coolers is copper chromium zirconium, an alloy that combines both high thermal conductivity and mechanical strength.

The cast product is pulled from the die by a withdrawal unit powered by a PLC controlled servo motor drive. The withdrawal parameters and furnace temperature for each alloy and section size to be cast are stored in programmes within the PLC. This ensures that the same casting parameters are used for repeat casts of the same cast product.

All the production casting data, including casting speeds and temperatures is stored at minute intervals onto a data ram card for transfer to a separate PC for subsequent analysis and manipulation in Microsoft Excel.

Quality control

The control of the casting process is important in order to obtain a high quality final product suitable for the manufacture of coins. This section of the paper describes the ways in which the users of continuous casting furnaces control the parameters, which affect the quality of their processes. The actual production sequence for coinage strip varies from one manufacturer to the next according to their respective individual preferences and internal quality targets.

Properties of strip for coinage blanks

When considering the specific production of precious metal medallions and coins where a fine grained, uniform, metal structure is requirement, the thickness of the as-cast strip is determined by the reduction process deemed necessary to achieve the required metallurgical structure in the coinage strip.

The emphasis must always be on product quality. Coins and medallions, especially proof quality ones, demand a top quality coinage strip free from defects with a fine grain size capable of accommodating detailed designs on coining.

Assay control

Before cast bars are processed to coin blanks it is important to confirm the assay meets the required specification.

The assay is carried out by spectrographic analysis or by the traditional fire assay technique.

Accurate alloy composition can be maintained within tight tolerances by careful control of feedstock to the furnace. Ideally in coin manufacture, the charge should be pre-alloyed in the form of grain or ingot together with known scrap alloyed blanked sheets. The balance can be made up with other alloyed material or virgin metals.

The major constituent metals encountered in the common precious metal alloy systems involve gold, silver, copper and possibly zinc. These metals have widely differing densities and simply mixing virgin metals in the crucible is difficult to ensure a completely homogeneous melt. Limited mixing and stirring of the melt is provided with nitrogen gas bubbling through the liquid metal.

Liquid metal control

A layer of high purity graphite flake or charcoal is used to protect the surface of the molten metal from oxidation. Further protection is provided by nitrogen gas and can be supplemented by carbon monoxide.

Silver has a high affinity to oxygen so it is important to protect the molten surface of silver to minimize any absorption.

Liquid metal control (cont'd)

The quality and cleanliness of the feedstock used is of critical importance in production of good quality cast strip. The feedstock should be free from surface oxides and contaminants when added to the furnace. More importantly, the feedstock should be perfectly dry otherwise explosions will occur which could cause injury to the furnace operator.

Gas bubbles can be a major cause of rejection because they do not appear during the rolling stage, but manifest themselves later as a blister on the surface of the annealed blank. The entrapped gas expands during the annealing process, stretching the surface of the metal to form a blister. The nitrogen bubbling is effective in removing dissolved gases from the melt and also raising any lighter oxide particles to the surface of the melt, away from the casting die.

The continuous casting furnace can be used purely as a casting machine, using a separate pre-melter to melt the precious metal and transferring the molten metal into the furnace via a heated launder. Care should be taken to ensure metal oxide particles from the launder and melting furnace refractories are not transferred with the molten metal. During metal transfer, molten metal exposed to the atmosphere can potentially absorb oxygen and covering the metal with a protective gas should minimize this. Impurities may be present in the metal as both metallic and non-metallic oxides. If these oxides are sufficiently hard and present on the surface of the blank, the material flow on coining results in a scoring mark on surface of the finished coin and hence rejection. Oxide particles can also damage the surface of the coining dies themselves, leading to further rejections.

Copper oxide particles if they are present on the surface appear as black spots. Carbon too has a high affinity for oxygen and will chemically react to reduce certain metallic oxides including copper oxide at the melting temperature. The main advantage of the graphite crucible together with a graphite cover on top of the melt, is the provision of a chemically reducing environment for the liquid metal.

Microstructure of continuous cast strip

The metallurgical micrcostructure of continuously cast strips inherently has a relatively large grain size. The grain size of the cast product depends on the metallurgical properties of the metals being cast together with the heat transfer through the cooler system and the withdrawal sequence used to pull the cast product through the die.

In general, precious metals prefer a pull-stop type withdrawal sequence, which has a short pull stroke performed frequently, but this varies from one alloy to the next. The withdrawal forces required for precious metal casting is quite low and can be handled easily by precisely controlled servo motors. The coolers for precious metals are high efficiency CuCrZr alloy coolers, closely coupled to the graphite die.

If there is insufficient cold working applied to the strip to break down the as-cast structure and recrystallisation of these grains during the processing of the strip, orange peel type defects will be apparent either at blanking or coining.

Microstructure of continuous cast strip (cont'd)

It is called orange peel because it closely resembles orange peel in appearance and is a rough surface resulting from deformation processes in the grains. Orange peel type defects are minimized by using fine-grained material.

Normally, depending on the metal being processed, it is necessary to provide at least a 50% reduction in thickness by cold rolling, from the as-cast section size, followed by an annealing cycle to achieve the required change in grain size suitable for the production of coins. However, this may not be adequate for top quality coinage strip and it is often preferred to have at least two stages of mechanical reduction of 50% each followed by annealing to guarantee the elimination of potential orange peel defects. As a general rule, the as-cast strip should be at least 4 times the thickness of the finished coin.

As mentioned earlier, the process route must be determined accurately to ensure that the quality requirements are met in the finished product. It may be necessary to cast at a larger thickness to allow extra reductions necessary to achieve to the desired properties.

Porosity

The large central shrinkage cavities or pipe seen in the upper sections of statically cast ingots or castings are not present in continuous cast metals because liquid metal is fed continuously into the solidification zone. By limiting the casting speed of certain wide freezing range alloys, micro-porosity can be avoided.

Surface quality

Although the surface of a cast strip improves as the strip is rolled, large reductions and anneals are required to completely remove the as-cast surface from the strip and achieve a top quality surface. The casting die is made of graphite, which is a soft material compared to those metals being cast and mechanical wear will occur after many hours of casting, particularly in the solidification zone of the die. The surface of the graphite will erode to a point when the surface quality of the strip being cast will be unacceptable for production. At this point, the casting will be stopped and the die changed.

The die exit temperature of the cast product is typically below 100C when casting thin section strip but thicker sections cast at higher speeds the die exit temperature can be high enough to give an oxide film on the surface. Secondary water cooling can be used to reduce the cast exit temperature and hence oxidation of the cast surface can be prevented.

Tiger banding

Silver copper alloy strip, particularly high copper 800 grades, has an additional problem associated with inverse segregation. Segregation is not seen on pure metals, fine silver and gold, only on alloys. In continuous cast material this manifests itself as 'tiger banding', seen as stripes on the surface of the as-cast strip, formed at the pulse marks during casting and still faintly visible on the finished rolled strip.

Tiger banding (cont'd)

The surface of these cast copper silver alloys is 'copper rich' and fortunately only confined to a surface layer no more than 50 microns (0.05mm) deep. It can be gradually assimilated into the matrix of the alloy during several stages of rolling and annealing but the most popular method is to mechanically remove the copper rich layer together with any other surface defects from the casting process. This can be achieved, before commencing the reduction sequence, by milling or machining the surface or removing the surface by rubbing the surface with abrasive paper.

Control of continuous casting parameters

Maintenance of stable production parameters is one of the most important criteria for production of good and consistent quality strip. Among these parameters, none is more important than stable control of temperature at the point of casting. In the Rautomead process, the furnace temperature is measured by a thermocouple positioned close to the crucible wall and thermocouples are inserted into the casting dies at positions close to the solidification zone to monitor the temperatures within the die.

It can be seen that the control of the casting process can reduce the occurrence of defects that only appear at later stages of the coining process. The Rautomead continuous casting machines offer the facility to control and monitor all of the key production parameters to allow repeatability of conditions from one cast to the next and traceability for quality audit purposes.

Summary

It can be shown that the control of the continuous casting process effectively prevents many of the common defects found in the manufacturing of coins.

It does not however eliminate the need for careful selection of feedstock materials and similar detailed attention to all stages of the coin manufacturing process. The benefits of this cast production technology are playing an increasingly important role in coin manufacture, enabling coin manufacturers to obtain the best efficiency from their production.