Some aspects of the continuous casting process

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INTRODUCTION

In view of the importance of the continuous casting process for the metal industry as a whole, it was thought that, in spite of the wealth of articles which have been published on the subject, the 75th Anniversary Supplement would be incomplete without some reference to this revolutionary process. An attempt will therefore be made to provide a brief survey of some developments in the field, assuming that the reader will already be conversant with the basic principles of continuous casting.

Although the process is of the greatest importance to the steel, aluminium and copper industries for the large scale production of billets and similar intermediate shapes for further working, the main emphasis of the present survey will be placed on the use of continuous casting in smaller foundries, for materials which can be used in the as-cast condition, namely cast iron and phosphor bronze. The position with respect to steel will, however, first be summarized.

CONTINUOUS CASTING OF STEEL

Whilst, as mentioned in the introduction, certain materials can be satisfactorily produced by the continuous casting process for immediate use in the cast form, owing to the specific characteristics of steel no-one has yet succeeded in producing satisfactory steel bar, free from internal shrinkage and coarse grain structure; continuous casting of steel is consequently devoted entirely to the manufacture of slabs, blooms and similar products. Although the first production units were introduced in the late 'forties, using the vertically aligned machines and open circuit system previously developed for the non-ferrous metals, relatively little progress was made during the first twenty years and, with 299 units installed, only some 9% of world steel output was being continuously cast by 1970. Once the initial technical problems were overcome, however, this proportion increased spectacularly to 20% by 1974, with 551 units in operation. According to the Metal Bulletin for September 1975, from which the above figures were extracted, it was envisaged that some 734 units would have been installed by 1977. These figures are confirmed by the diagram shown in Fig. 1, reproduced from the Edward Williams lecture for 1978, which also predicts that by 1990 nearly 50% of steel will be produced by continuous casting.

Bearing in mind the great advantages offered in energy saving, higher yield and general savings in production costs, the worldwide swing towards continuous casting would be even greater were it not for the very high capital costs of conversion. This is due not only to the high costs of the actual casting unit, with its tall structure to accommodate the long spray cooling zone required to complete the solidification of steel, but also to the high cost of buildings and lifting facilities associated with vertical casting. The total conversion cost would, of course, be diminished very substantially if one could reduce the overall height of the casting units, ideally by changing from the vertical to the horizontal plane. Various steps in this direction are described.

Fig. 2a shows the conventional vertical machine, in which molten metal is poured into a vertically aligned, water cooled mould and the cast withdrawn from the bottom by means of a dummy bar connected to the withdrawal machine. Additional cooling is provided by water sprays between the mould and the withdrawal unit. Below the withdrawal rolls the cast bar is cut into lengths, which are then tilted into a horizontal position.

Fig. 2b illustrates the first step taken to shorten the height of the machine by bending the cast bar, after solidification, until it runs out horizontally. Further reduction in height is obtained by the use of a curved mould to initiate curvature of the cast bar, which is then straightened, either at the withdrawal rolls or progressively, and run out horizontally, as shown in Fig. 2c. The engineering of curved mould machines is, however, complicated and expensive, the mould design becomes rather involved, and care must be taken when directing the flow of metal into the mould.
The ultimate reduction in height can be obtained by using a horizontally aligned mould seared into the tundish refractory. The cast is then withdrawn horizontally and all operations are carried out at floor level without bending or straightening. Because the mould and tundish are sealed together advantages are gained by eliminating oxidation of the metal stream. In a sealed system it is not necessary to control the flow of metal between the tundish and the mould, so tundish nozzle wear ceases to be a problem, resulting in greater freedom of operation. The horizontal closed system, using a graphite mould insert inside a water cooled die, protruding into the molten metal inside the tundish or holding furnace, has been very successfully employed for the commercial production of grey iron and non-ferrous bar, slabs and sections. This principle cannot, however, readily be adopted for steel because of (a) the solubility of graphite in steel and (b) the relatively low thermal conductivity of graphite.

It is understood, nevertheless, that at least two companies in Europe, namely Technica-Guss and Davy-Loewy, have prototype machines actually producing steel on the closed system principle. Davy-Loewy utilized the conventional water cooled copper mould, but since the copper cannot be allowed to project into the holding furnace of the tundish, a refractory feed nozzle is placed between the end of the copper mould and the tundish refractory. To ensure a metal-tight seal between the end of the feed nozzle and the copper mould, the Davy-Loewy machine uses a specially shaped ring of silicon nitride. Intensive cooling in the copper mould is followed by a secondary cooling zone 20 ft in length and consisting of a series of water spray rings interspersed with support rollers. Following this initial development, in 1977 Davy-Loewy concluded an agreement with Nippon Kokan KK, one of the largest Japanese steel manufacturers, for the supply of designs and operating know-how to enable NKK to build and install a twin-strand horizontal continuous casting machine using Davy-Loewy technology. Under this agreement NKK have, during 1978, built and installed in their Fukuyam Works, a single strand machine to cast carbon steel billets in the size range 75 mm to 150 mm square. Most of the machinery was manufactured in Japan by NKK but the mini computer-based control system was supplied from the U.K. by Davy-Loewy. The equipment is designed for the addition of a second strand later this year.

The machine design is based on the parameters established by Davy-Loewy during their operation of the HCC pilot plant in the Davy Roll Company foundry on Tyneside. The NKK machine is designed for full scale production operation and will be used to establish commercial production operating parameters for multi-strand machines.

Start up of the first strand commenced at the end of 1978 casting a section of 115 mm square in plain carbon steels. Operation is initially on a single heat basis but extended casting periods of up to 2 hours have been achieved thus doubling the longest period achieved on the original pilot machine.

The original Davy-Loewy pilot machine has been rebuilt and is currently being used for development work on the casting of stainless steel billets of 95 mm square.

It is understood that Technica-Guss have a relatively small experimental unit successfully producing round and square bars in conjunction with an induction heated holding furnace; an undisclosed type of cooling system replaces the standard graphite die/water jacket arrangement. This unit is aimed at the section of the industry catering for smaller quantities of special alloy steels.

In view of the undoubted success of horizontal closed circuit machines in the cast iron and non-ferrous fields, there appears to be little doubt that if a similar production unit is successfully developed for steel it will have a very good reception throughout the world, since the savings in overall costs will be very much greater.

**CONTINUOUS CASTING OF NON-FERROUS METALS**

Since continuous casting of non-ferrous billets was first introduced well before the war, the vast majority of billets in copper based alloys are now produced by this method, utilizing either the original open circuit vertical installations, closed circuit units still operating in the vertical plane or, more recently, closed circuit horizontal machines.

**Fig. 3.—General principle of the method used for casting of tubes on closed-circuit horizontal machines.**

As can be seen from Fig. 3, showing the schematic principle of the horizontal machine, in the closed system a water cooled die is built into the holding furnace so that the liquid metal enters the die without coming into contact with the atmosphere. Furthermore, the metal tends to flow more uniformly and is always subjected to appreciable hydrostatic pressure. This, combined with rapid cooling in the die, ensures superior soundness, good surface finish and a homogeneous structure throughout the section. These advantages, coupled with greater safety and ease of working, vastly increase the field of operation of this system for the following applications:

1. Replacement of the old open system vertical machines for production of ingots and billets because of (a) lower installation costs, (b) lower running costs and (c) the greater safety associated with horizontal machines.
2. Production of relatively thin strips of phosphor bronze for subsequent cold rolling, since hot forming operations are impracticable for bronzes with 0-4% P content.
3. Production of small diameter brass bars (less than 30 mm dia.) as raw material for hot forgings, thus bypassing the extrusion process.
4. Production of small diameter bars in a variety of alloys, the product being cooled on completion of the casting operation, for further rolling or drawing.
5. Production of bars, tubes, strips and profile shapes in competition with conventional ingotting foundries, particularly for phosphor bronzes. (See Fig. 4)

Whilst the total tonnage produced under item 5, covering products used in the as-cast condition, is infinitely smaller than that under the first four items, covering material for subsequent reworking, one must not underestimate the contribution made by continuous casting in the former field, because of its ability to produce excellent phosphor bronze tubes for bearings, with much better surface finish and soundness than individual sand castings produced by conventional methods, or even than centrifugal castings,
particularly where small diameter tubes are involved. Some examples of applications machined from bars or tubes in the as-cast condition, without further reworking, are shown in Fig. 5.

Although the vast majority of aluminium billets are produced on vertically aligned machines, there are indications that, following explosions which virtually destroyed two factories, the aluminium producers are also beginning to show interest in horizontal closed system machines, for the manufacture not only of strips but of billets on the grounds of greater safety and lower capital costs. To the best of the writer's knowledge no explosions of consequence have ever been experienced by users of horizontal machines, irrespective of the metal involved.

Table I, based on the experience of one of the leading manufacturers of horizontal continuous casting machines, shows the extent to which these are used in the various fields of the non-ferrous industry.

**TABLE I**

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<th>Breakdown of usage of horizontal continuous casting machines in various fields of the non-ferrous metal industries supplied by one manufacturer.</th>
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<td>47—Machines for production of strips for cold rolling.</td>
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<td>21—Machines for production of billets for further extrusion.</td>
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<tr>
<td>11—Machines for production of small diameter bars for wire drawing.</td>
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<td>5—Machines for production of brass bars for hot stamping.</td>
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<tr>
<td>18—Machines for production of tubes, rounds, rectangles and squares for use in the as-cast condition, or alternatively, for cold or hot forming.</td>
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The figures quoted are probably indicative of the experience of other manufacturers of continuous casting machines. As a user of a horizontal unit for cast iron the author tends to favour this type of unit, but there exist, of course, numerous vertical machines for similar applications in the non-ferrous industries: these are described in some detail in articles by C. J. Evans and A. W. Hudd (see References).

**CONTINUOUSLY CAST IRON BAR**

The advantages of conventional grey cast iron as compared with other materials, especially its combination of wear resistance, machinability and excellent dimensional stability under pressure, are well known to all users. However, since grey iron cannot be forged or rolled, nor can it be easily rectified by welding, users are also aware that a casting may lack soundness or contain other defects associated with castings such as sand inclusions or blowholes. Because of these potential problems some users, particularly in the pneumatic and hydraulic industries, are inclined to be over cautious when using grey iron castings, often tending to specify a higher and, therefore, more costly grade of material than necessary to reduce the risk factor. In this connection it should be emphasised that a far more reliable and homogeneous cast iron is now available in the form of continuously cast bar, whether round, square or rectangular. Certain other simple shapes of the type often produced by extrusion can also be manufactured for special applications, as can be seen from Fig. 6.

As previously explained, closed circuit continuous casting ensures superior soundness, good surface finish and a homogeneous structure throughout the section. In addition, since the mechanical properties of grey iron are governed not only by chemical composition but by cooling rate, the characteristic rapid cooling ensures good and reliable mechanical properties.
In the case of conventional sand castings, using separately cast test pieces, the buyer is offered proof that the material from a given cast has the required properties: this does not necessarily mean, however, that the mechanical properties of the actual casting are equally good. In the case of continuously cast bar, the designer can be confident that the mechanical properties of any size of bar, taken midway between the centre and the outside diameter (or even through the centre in the case of small bars up to 1½ in diameter), will correspond to the BS1452: 1961 graph as reproduced in Fig. 7. It will be noted that this Standard has recently been superseded by BS 1452: 1977, in which S.I. units are employed throughout, but in which the general principles and property levels are similar to those in the earlier edition employed here.

In fact, more often than not, the tensile strength of a test piece taken in the midway position between the centre and the periphery of the bar will lie in the upper half of the recommended band. For example, when using a 4 in. diameter bar to Grade 17, the designer can rely on a tensile strength between 12 and 13½ tons/in² in the midway position or anywhere near the outside diameter. The tensile strength taken in the exact centre of a larger bar will tend to lie near the lower limit of the band or even just below it. Test samples taken from continuously cast bars 1½–2 in diameter corresponding to the prescribed test bar diameter for sand casting will give a tensile strength of 17 tons/in² or more.

Since cast iron bars leaving the pulling mechanism are only partly sawn and are then broken off into individual lengths with a hydraulic ram, the quality of the material can be readily checked by examining fresh fractures on every length produced.

The fine grain structure and fine graphite distribution of continuously cast material as compared with those of conventional sand castings, are shown in Figs 9 and 10. It should be noted that whilst the centres of the bars, particularly in larger sizes, will contain some A type graphite, the outer region will have either fine dendritic or rossette type morphology.

**GRADES AND STRUCTURES OF CONTINUOUSLY CAST IRONS**

The typical structure of the standard material consists of a mainly pearlitic matrix, with no more than 30% free ferrite in the outer regions and nearly 90% pearlite near the centre of the bar. By introducing suitable inoculants and using pearlite stabilizers it is also possible to produce a fully pearlitic structure throughout. The standard material most readily available from stock is grey iron to BS1452 Grade 17 with a Brinell hardness of 200–240. The next most popular material, which is also stocked in certain sizes, is the tin inoculated variety equivalent to Grade 20. In addition to these two basic grades, the following irons can also be produced against specific orders:

- Nodular iron grades.
- A nickel chromium iron which can be heat-treated to give 400–500 Brinell hardness.

Because of the characteristic features mentioned when explaining the basic principle of the process, continuously cast grey iron has numerous advantages over conventional sand castings, or even over castings made in static metal moulds. To reiterate, these are as follows:

1. A complete absence of defects normally associated with sand castings, including surface defects, blowholes, shrinkage and sand inclusions.

2. Homogeneous and close grained structures giving excellent machinability, good wear resistance and ability to
withstand hydraulic or pneumatic pressures.
3. Good surface finish, which means that the material can be highly polished.
4. Availability of a comprehensive range of bar material stock, eliminating the necessity for the user to maintain large stocks.
5. Much easier and compact storage than individual castings, saving valuable space.
6. Elimination of costly patterns, resulting in low overall costs and quick delivery.

Some of the earlier, well established users of continuously cast grey iron could complain that the claims regarding complete absence of non-metallic inclusions and excellent machinability might be somewhat exaggerated, particularly in the case of larger diameter bars, which occasionally contained hard spots harmful to expensive tools used for gear cutting. However, with better understanding of the process by the manufacturers of the continuously cast material, the incidence of both inclusions and hard spots has been reduced to insignificant level.

A further reason for the growing popularity of continuously cast iron bar lies in the fact that the number of small and medium sized cast foundries capable of producing small batches of reliable castings is diminishing year by year, whilst the batch size acceptable to mechanized foundries continues to grow. Faced with the choice of purchasing relatively small batches of not very reliable castings or the large quantities demanded by reputable mechanized foundries, there is an increasing tendency to prefer readily available and dependable continuously cast bar stock.

**FIELDS OF APPLICATION FOR CONTINUOUSLY CAST GREY IRON**

In general engineering, most cast iron bars are used for comparatively simple applications where straightforward turning or drilling are the only requirements. Examples include pulleys, valve guides, sprockets, spindles, bushes, rollers and gears. Continuously cast bar in long lengths is ideal for long production runs, where automatic bar turning machines can be used with considerable savings; bars proof-machined to a tolerance of ± 0.005 in. must, however, be specified for this purpose. Examples of components produced from cast iron bar can be seen in Fig. 11.

The automobile, glass and textile industries consume substantial quantities of bar in either round or specially shaped forms, the biggest orders at the moment are to be found in the machine tool, hydraulic and pneumatic industries. For the machine tool industry, the attraction is the greater reliability of the continuously cast material as far as both surface and internal imperfections are concerned, in order to avoid rejecting, say, a milling bed after a number of expensive machining operations, the cost of which may well exceed that of the actual casting. Thus in this industry, in addition to a variety of components from round bar, special shapes are used for beds of drilling and milling machines, cross-slides for conventional lathes, guides for grinding machines, and similar products. Square and rectangular bars are used for control valve bodies on automatic and numerically controlled machines.

Typical applications in the pneumatic and hydraulic industries are:—pistons, Rams, rotors, glands, end caps, pump bodies, valve bodies, transfer valves and spool valves, machined from either round, square or rectangular sections.

The first important example of bar stock used for a hydraulic application is a piston. These parts were previously made from sand castings, but were changed to bars because of quality problems associated mainly with sand inclusions and

![Fig. 11—Selection of components machined from continuously cast grey iron.](image-url)
inconsistent microstructure, resulting in high machining scrap. The pistons range in size from \(\frac{1}{2}-13\) inches in diameter.

The second large area of bar usage is for hydraulic valve bodies and junction blocks. Both rounds, and shapes such as squares and rectangles, are frequently used for this application; in many instances the shape is preferred to facilitate mounting, static space conservation or machining. These components were previously made from steel bars or static iron castings. The steel was difficult to clean and de-burr after machining, whilst the static castings were subject to weeping under high pressure due to coarse graphite flakes and open structure.

The third area for bar usage in the hydraulic field is the production of various components for vane and piston pumps. The list of components includes pump rotors, gears, bodies, shafts, rams, bush, seals, plungers and idlers. All these components can be machined either from bars cut to individual lengths or, where the volume of operation makes it economically advantageous, from long length bar using automatic bar-turning machines.

It is hoped that this brief analysis of the advantages of grey iron produced by the continuous casting process will encourage users of conventional grey iron castings to investigate the alternative of this relatively new product. This applies particularly to design engineers in the general engineering industry where, unlike the situation in the more specialised hydraulic and glass industries, the use of continuously cast bars or shapes is still comparatively limited.

It is estimated that there are at present over 60 horizontal continuous casting machines for cast iron in operation throughout the world, most of them in Europe. Indications are that the European market is now more than adequately equipped to meet any foreseeable demands, particularly in England, where the process was first introduced, and in Germany, where it was developed to its present condition. The market for these machines and their products is still wide open, however, in the United States and, at the opposite end of the scale, in the developing countries.

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Ten years of cokeless melting

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INTRODUCTION

The cokeless cupola is now ten years old. The first melt took place on the 22nd July 1968 on a small experimental furnace. Continuous development over the next two and a half years enabled iron of satisfactory temperature and composition to be produced, when poured into moulds produced good castings which were then sold. One of the production conventional coke fired cupolas at Hayes Shell-Cast was converted during November 1970 and the first melt on this cokeless cupola took place on the 22nd December 1970. This cupola was originally fired with propane but in recent years was converted to light fuel oil. In excess of 25,000 tonnes of iron have been melted in this furnace and been poured into moulds to produce high quality grey and ductile iron castings. Hayes Shell-Cast are in the process of installing two new 7 tonne per hour cokeless cupolas in a completely new melting area. When these are commissioned both the original coke and the converted cupola will be removed.

Another 5 tonne per hour cokeless cupola fired with natural gas has now been operated successfully for nearly two years in Iran at the factory of Luleh Va Machinseri. This is a hot blast installation and the majority of the iron produced is ductile iron fired for spun pipes. Equipment necessary to convert a second of their cupolas has now been delivered, and the company has commissioned it in the near future. Also in Iran there is another cupola of approximately 4 tonne per hour capacity operated with natural gas, at the Iran Malleable Company where, as their name suggests, they produce malleable iron mainly for castings and other small work.

Another important installation is at Duker in West Germany where have built a completely new 10 tonne per hour capacity furnace operated with light fuel oil. Oxygen enrichment of the air has been incorporated so that tapping temperatures approaching 1500°C. are possible. A further 10 tonne per hour cupola is being operated at Widnes Foundry in England, where iron is used mainly for the production of large castings and metal temperatures of the order of 1450°C. are adequate. A second conversion at Widnes will be completed in the near future. A further oil fired cokeless cupola is to be installed at Nass Castings in Egypt later this year, having a capacity of approximately 4 tonnes per hour melting rate.

It can now be said that the cokeless cupola is being operated successfully in different countries under different conditions and it is not longer a technical curiosity but a proven production tool which foundrymen worldwide should consider when investigating new melting plant.