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CONTINUOUS STEEL CASTING: PRESENT POSITION AND FUTURE PROSPECTS

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CONTENTS

1. Types of plant for continuous steel casting

In spite of the differences of opinion which still exist on certain economic problems involved in the substitution of continuous casting for conventional casting methods, the continuous casting process has now received official recognition as an effective method of production in many countries throughout the world.

According to published figures, there are now about 60 industrial, semi-industrial and experimental plants in operation in 22 different countries; and about 30 more plants are under construction.

Although the first experiments in continuous casting were started before the Second World War, it was not until the period 1945-50 that large-scale experiments were undertaken in a number of European countries and the United States of America.

Initial research was carried out on experimental semi-continuous casting plants; and by the early 1950's this had already produced the necessary data for designing and building larger semi-industrial and industrial plants for casting steel in vertical moulds from which the billet is continuously extracted.

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Between the middle 1950's and the present day continuous casting has come to be used on an industrial scale in the USSR, the United Kingdom, the Federal Republic of Germany, France, Austria, Japan, Czechoslovakia, Spain, Mexico, Brazil, the Polish People's Republic, Peru and the United Arab Republic.

According to figures published by Concast about 2 million tons of steel were produced by the continuous casting method in 1962, and about half of this total was produced in the Soviet Union.

The equipment most commonly used is the vertical plant which has considerable technical and economic advantages in that it possesses none of the unsatisfactory features associated with inclined and horizontal systems such as continuous contact between the billet and one of the mould walls, asymmetry in the structure of the billet, and a large surface of metal in the mould.

Depending on the actual conditions prevailing in individual works, the plants are installed in different positions in relation to the floor level of the shop.

Some advantages and drawbacks are associated with both the main positions - the above ground position in which the entire plant is situated above floor level, and the underground position when the greater part of the equipment is located in underground pits, and only the pouring platform is raised slightly above floor level.

In the USSR and other countries plants of both types - "tower" and underground - hav been operating successfully for a number of years.

With the latest continuous casting plant it is now possible to produce square carbon steel and steel alloy billets from 50 x 50 mm to 300 x 300 mm in size and slabs up to 200 x 1500 mm in size from ladles of up to 150-300 tons capacity.

In recent years there have been reports of new design solutions for individual parts of the equipment and for the plants as a whole, including arrangements for bending the billet in the vertical plane as it is extracted, and for pouring the steel into moulds placed in radial formation; and these have made it possible to reduce the height of the plant considerably and improve its efficiency indicators still further.

2. Main components of continuous casting plant

(a) Ladle

Two different types of ladle are used - the stopper-type for pouring very heavy heats, and the tea-pot type for heats of less than 30 tons (though tea-pot ladles are used for pouring 90-ton heats at the Appleby-Frodingham works).

The difference in the types of ladle used for different purposes is due to the fact that the temperature of the metal falls rapidly when small quantities of steel are poured from stoppor-type ladles; there is a risk of the metal solidifying in the tundish and the flow of metal is difficult to regulate.

When tea-pot ladles with lids are used, it is easier to obtain a higher temperature before casting; and it is also possible to keep the metal hot during the casting process with heaters fitted in the lid.

On the other hand, when the metal is poured from tea-pot ladles, it is drawn off from underneath the slag and therefore contains a larger proportion of non-metallic inclusions.

As the metal solidifies more quickly in the mould, slag inclusions do not have time to float to the surface; and continuous casting therefore calls for higher metal purity standards. The content of non-metallic inclusions can be reduced to a minimum by ensuring that the charge is of the right quality, that the correct technique (rimming and deoxidation regimes) is used for preparing the heat, that the refractory linings used are highly resistant and that the metal is protected from secondary oxidation when it is being tapped from the furnace, poured into the tundish and thence into the mould.

(b) The tundishes (which distribute the metal to each mould, facilitate the removal of slag particles and reduce the hydrostatic pressure when the metal is poured from the ladle) are also of two kinds. One is fitted with a stopper, and the other with measuring cups.

Before casting, the lining of the tundish is heated to a temperature of 1200°-1300°, and the measuring cups are also heated by portable heaters.

In the USSR extensive use is made of tundishes fitted with stoppers. The advantage of this type lies in the fact that there is no need for additional nozzles for drawing off the first pourings of metal and slag.

The tundish lining consists of two layers - one the re-inforcement and the other the lining proper. The re-inforcement layer is made of a refractory material with a low thermal conductivity, and the lining proper of standard refractory clay brick. Good results have been obtained from experiments in lining lids and tundishes by padding them with plastic refractory materials.

The reliability of the stoppers can be increased by cooling the stems with compressed air and using suitable refractory material for the plugs and cups.

Satisfactory results have been obtained with a system in which the metal is poured through double-layer cups the working piece (insert) being made of a wear-resistant material and the outer cup of refractory clay.

Cups made of zircon or high-alumina refractories may be recommended for casting rimming steel.

For killed steel deoxidized with aluminium, zircon and bi-ceramic cups with a clay-graphite protective layer may be relied upon to produce satisfactory results.

Standard clay-lined cups and cups with zircon inserts may be used for casting transformer steel.

(c) The moulds are made of copper and copper alloys which have a high thermal conductivity.

For casting small sections the normal practice is to use seamless moulds enclosed in a steel casing with cooling water circulating inside the walls.

For large and medium sections, it is more common to use thick-walled sectional moulds with channels for the cooling water to circulate. The working surfaces of these moulds may be planed again and again to remove the faults which always arise in the course of operation; and this gives them a longer lifetime, sometimes as much as 20,000 to 30,000 tons of steel cast.

The length of the moulds used in plants in different countries varies within a wide range from 500-800 mm to 1000-1500 mm.

Long experience has shown that moulds should have an "inverse conical" shape, - i.e. with the dimensions smaller towards the bottom. The dimensions should be reduced by an absolute figure of 1% of the width of each side, and the reduction does not depend on the length of the mould.

The "inverse conical" shape gives the mould better heat reduction qualities and reduces the risk of longitudinal heat cracks forming on the sides and edges of the billet.

To reduce the amount of friction and eliminate the risk of the crust sticking to the mould walls, one solution is to use various types of lubricant such as organic oils, paraffin, the waste products of the fats and oils industry and mineral oils. Another method is to keep the mould vibrating by mounting it on springs or moving it up and down. In the latter case, it will move downwards at the same speed as the billet or slightly faster, and then return to its original position at three times this speed.

The reasons why the crust sticks to - or "hangs" on - the mould walls are: (a) faults in the working surfaces of the mould walls at the point where the crust touches them (300-400 mm from the top); (b) gaps in the joins between the walls, and the leakage of metal into them; (c) deflection of the mould from its vertical axis as it moves; (d) displacement of the axis of the mould in relation to that of the plant as a whole; (e) faulty lubrication of the walls; (f) particles of steel attaching themselves to the mould walls when the cooling rate of the latter is reduced; (g) poor quality of the metal.

Experience has shown that pure copper is not the only substance which can be used for making the moulds. Moulds with working walls of copper with an admixture of chromium, which makes them tougher, have produced satisfactory results in terms both of longer lifetime and the quality of the transformer steel slabs produced.

(d) Secondary cooling systems. This consists of a number of jets which spray water round the billet, and also of guide rollers which prevent the billet from bulging.

Bulging and warping (bending) of the billet occur for a number of reasons including: insufficient intensity and unevenness in the cooling of the sides, particularly the narrow ones; incorrect distribution of the water in the secondary cooling area; insufficient stiffness of the rollers supporting the steel bar in the secondary cooling area, or too high a casting speed with the result that the liquid phase in the centre of the billet lasts until it has passed below the secondary cooling area.

As the quality of the billet and the presence or absence of internal cracks depends to a large extent on secondary cooling, many countries are undertaking intensive research to discover the best possible designs for jets and supporting systems, and the best cooling systems for steels of different grades.

As a result of this research the equipment is being simplified, production and repair costs are being reduced and the cooling water is being used to better purpose.

(e) Pinch-roller housing. This usually houses one or two pairs of rollers (though multi-roller systems are occasionally used when the billet enters the housing with the core still liquid; in this case the specific pressure of the rollers on the billet must be reduced to prevent the formation of cracks due to uneven temperature changes).

The rollers are driven by electric motors with mechanical or hydraulic transmission.

(f) Separation. The billets are usually separated in even lengths with gas cutters which move downwards at the same speed as the billet itself. On plants where the billet is bent on extraction it is usually separated in the horizontal plane, and sometimes even by hand.

For separating small sections some plants are equipped with hydraulic shears instead of the oxy-acetylene cutters.

Other efficient methods of separating the billets are now being developed. These include sliding shears, explosion methods, etc.

(g) On plants where the billet is not bent on extraction, the equipment for delivering the steel bars consists of tilter-baskets, roller conveyors or inclined elevators in the case of underground or semi-underground plant.

3. Main parameters of the continuous casting process, and quality of the billets produced

Continuous casting plants can produce a wide variety of steels, in terms both of cross-section and quality.

The least suitable section, as regards the formation of internal and external cracks and flaws in the centre of the billet due to shrinkage and liquation, is the round section.

Square sections are not so tough as round ones, as there is always some "give" in their sides, and the risk of internal cracks is somewhat reduced. As regards structural flaws due to shrinkage and liquation, the square section is no better than the round one.

Rectangular sections (slabs) are less liable to internal cracking, as the broader sides offer less resistance to the shrinkage of the inner layers. Flaws due to shrinkage and liquation usually appear along the longer axis of the section. High output figures can be achieved in casting rectangular sections but, as the width of the slab is increased there is a greater risk of longitudinal heat cracks on the broader sides.

The main technical parameters which determine the quality of continuously cast billets are the temperature of the metal at the time of casting, the casting speed and the cooling conditions when the billet is in the mould and after it leaves it.

The metal hardening conditions and the duration of the casting process mean that quality requirements for the hot steel are much higher.

When the metal is under-heated, it is difficult to cast the whole heat. The billet will have an unsatisfactory surface, with wrinkles and scabs. Frequent burning of the ladle and tundish cups complicates the casting process and adversely affects the quality of the steel.

When the metal is overheated, the linings of the furnace and ladles are heavily scoured, the proportion of slag in the moulds increases and the casting speed has to be reduced considerably to prevent the metal dropping right through the mould when the outer crust of the billet is so thin. There is also a greater risk of internal and external cracks, the stoppers do not function properly, the gas saturation of the steel is increased and the quality of the billet is impaired.

If the metal is cast at the right temperature, these difficulties do not arise and the quality of the metal produced is completely satisfactory; and it is therefore essential to discover the optimum temperature for each grade of steel, bearing in mind that the temperature of the metal will drop between the furnace and the tundish.

When the temperature of the steel and the casting speed are increased, the surface quality of the billet is improved but there is an additional risk of internal cracks and porosity along the axis. For continuous casting, therefore the temperature should not be more than 15-30^{0} C higher than that adopted for normal casting, though allowance should be made for the fact that the duration of the process is longer.

High casting speeds are valuable from the point of view of output and the quality of the billet surface. But speeds are restricted both by the height of the plant and by requirements regarding the structure of the steel produced. The optimum casting speed should therefore be selected in the light of the section and dimensions of the billet and the grade of steel used.

On existing industrial and semi-industrial plant the casting speed varies within a fairly wide range from 0.25 to 15 m/min, but in actual practice there is little difference between optimum casting speeds. When the speed is reduced, the tundish cups tend to block up and a crust forms on the surface of the metal in the moulds. When the speed is too high, there is a risk of the metal dropping right through the mould, or bulging above the pinch-rollers.

The highest speeds can be achieved in casting small sections. According to published figures, the Barrow Steel Works, Barrow, uses speeds ranging from 5.6 to 14.5 m/min in casting 50 x 50 mm billets, although the optimum speed appears to be about 9-10 m/min.

On the plant operated by the Sumitomo Metal Industries, Osaka, the maximum speed attained in casting 90 x 90 mm squares from carbon, stainless and spring steels is 6 m/min.

Casting speeds on plants at Ibbse (Austria), San Adrian (Spain) and Eskilstuna (Sweden) range from 3 to 4.5m/min.

For wide slabs, casting speeds have to be reduced considerably. On a plant at Hikari (Japan) which produces carbon and stainless steel slabs of 115 x 1030 mm and 150 x 1200 mm the steel is cast at speeds of up to 2 m/min.

On a plant in Dillingen (Federal Republic of Germany) low carbon rimming and killed steels are cast in 200 x 1020 and 200 x 1500 mm slabs at a rate of 0.7 m/min. Approximately the same speeds are used in large plants in the USSR.

The quality of the continuously cast billet depends to a large extent both on proper control of the stream of metal flowing into the moulds and on the chemical composition of the steel.

Even with optimum temperatures and casting speeds, it is essential to avoid any splashing of metal which may occur when the lower rim of the tundish is cracked or pitted, when the amount of metal poured is too small for the section of the tundish channel, or when the level of the metal in the tundish is too low and pressure is inadequate.

When wide slabs are being cast the back-flow of the stream of metal in the middle of the mould washes away the crust of the billet at the thinnest point (the middle of the broader side), and this causes longitudinal cracks to form.

If the stream of metal is deflected to a point one third of the width of the mould from the narrow side, the proportion of rejects due to longitudinal cracks can be greatly reduced.

The main elements which affect the formation of longitudinal cracks in medium-carbon steels are carbon and sulphur. If the carbon content of the steel is high, the sulphur content has to be correspondingly reduced. In the case of 150 x 770 mm slabs, for instance, no cracks were observed in steels with a carbon content of 0.14% and a sulphur content of less than 0.028%.

The quality of the inside of the billet is greatly affected by the rate and evenness of cooling after it leaves the mould, - i.e. in the secondary cooling area.

If the surface of the billet is cooled too rapidly, serious thermal stresses are set up and internal cracks form in the layer of solid metal nearest to the solidification front. Some of the cracks are filled by hot metal enriched with liquates. Cracks of this kind occur most frequently in medium-carbon killed steels.

Carbon steels, low alloy, austenitic and even dynamo and transformer steels are less liable to this type of flaw.

Research and practical experience suggest that the optimum water consumption for the continuous casting of rectangular billets (slabs) from carbon and low alloy steels is 1 litre per kg of steel.

For square and round sections which are more liable to crack, the cooling rate has to be reduced to 0.5 l/kg.

Dynamo, transformer and austenitic chrome-nickel steels require a higher cooling rate than carbon and low alloy steels.

The quality of billets produced by the continuous casting system depends to a great extent on the length of the secondary cooling area, - i.e. the distance between the mould and the pinch-rollers. In experiments carried out in the Soviet Union in the early stages of continuous casting it was discovered that, when a billet with a liquid core was subject to comparatively slight reduction by the pinch-rollers, it was liable to produce internal cracks which were filled by liquates. Accordingly one of the main problems which has to be solved in designing new equipment is how to ensure that the billet is completely solidified when it enters the rollers.

If all the technical requirements for heating and pouring the metal are complied with, the structure and quality of continuously cast billets are not inferior - in many cases they are in fact superior - to those of billets cast by conventional methods.

Continuously cast billets have a better surface texture, and labour expenditure on the removal of surface defects is lower.

The continuously cast billet has a finer grain structure, and is therefore more suitable both for hot and cold deformation. It has been demonstrated by research that hot-rolled sheets of transformer steel produced from continuously cast slabs have magnetic properties as good as those produced from billets of the conventional type, and their plasticity (number of folds) is 50% to 100% better*/. This makes it possible to increase the silicon content of the steel and reduce wattage losses.

*/ V.F. Andreyev, Stal, No. 2, 1963.

One striking feature of the continuously cast billet is the uniformity of its chemical composition and the consistency of its mechanical properties both longitudinally and in cross-section, but porosity at the centre of the billet is more developed, particularly in the case of square sections. In carbon and low alloy steels, however, this porosity may be easily corrected by rolling after a 4- to 6-fold reduction.

4. Technical and economic advantages of continuous casting

Continuous casting has a number of economic, technical and operational advantages over the normal casting process.

It helps to increase labour productivity, improve working conditions and reduce the costs of the steel-making and rolling processes.

It completely eliminates the consumption of pans, bottom plates, bogies and other steel-making equipment, and does away with the operation of transporting the billets to a special section for stripping. The consequent reduction in the labour force employed cuts conversion costs per ton of steel by 5-16%.

The Jones and Laughlin Co. estimates that the cost of semi-finished steel produced by the continuous casting method is about 7% lower than with conventional facilities. According to Concast the reduction will vary according to plant layout, grades of steel, annual tonnage, heat capacity, and the design of the continuous casting facility.*/

One considerable economic advantage of rolling continuously cast billets is that there is no need for top and bottom trimming, which accounts for 12-25% of the volume of conventional billets. The continuously cast billet is much longer than those produced by conventional methods, and this means that wastage as a result of trimming and cutting amounts to only 3-5%. This figure can be further reduced by increasing the amount of metal poured in a single run.

It has been demonstrated both by practical experience in the operation of existing plants and by economic calculations that, while the yield of serviceable steel produced by the normal method is 85-86%, it is as high as 94-98% with the continuous

*/ Steel, Vol. 151, no. 12, September 17 1962, pp.86-91.

casting process. In other words, in rolling continuously cast billets of killed steel the yield is increased by 8-13%. With rimming steel the yield is increased by 3-4%.

Another factor to be taken into consideration is the reduction in costs achieved by doing away with the re-heating and blooming processes required for billets produced by the conventional method.

Nearly all the operations in continuous casting plants lend themselves to mechanization and automation, and this makes it possible to release a considerable proportion of the labour force for other purposes. Economists have estimated that the reduction in the number of operators required means that wages payable per ton of metal can be cut by about 10%.

One characteristic feature of the continuous casting process is that it is highly efficient both for large iron and steel works and for smaller works with an annual output of 50,000-250,000 tons of steel: in other words the advantages of large-scale production (and of large billets) no longer apply to the same extent.

Continuous casting makes it possible both to do away with the blooming mill (and thus reduce the number of rolling operations and cut down capital outlays and operating costs) and to supplement the work of the blooming mill when output from the steel-making shop and the finished mills is running ahead of blooming mill capacity. Another advantage of continuous casting is that steel production can be increased without enlarging the area of the casting shop.

Metal produced from any kind of plant is suitable for continuous casting, but the best results are obtained with converter or electric furnace steel.

The continuous casting process can produce small and large sections of almost any grade of steel.

Many continuous casting specialists believe that this process is particularly promising for the production of alloyed and high-alloy steels where the economic effects of the higher yield are much greater than in the case of carbon steels, though the possibility of producing large masses of carbon steel by this method should not be overlooked. Other specialists take the opposite view that the future of continuous casting depends on the success which plants of this type can achieve in producing carbon steels.

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The extent to which continuous casting plants are likely to be used in the iron and steel industry depends on the possibilities of increasing output. At one plant in the Soviet Union it has been calculated that, by increasing the casting speed by 0.1m/min and reducing the time taken to prepare the equipment by 30 minutes, productive capacity can be increased by about 30%.

One decisive way of increasing output is to cast the steel in multi-strand moulds or to use multi-strand plants.

In short, the present position regarding continuous casting may be summed up by saying that the process has moved out of the experimental stage into the wider arena of industrial steel production in many countries throughout the world; and that in these countries it is bringing about radical changes in the technique of iron and steel production, and raising the steel-working and casting processes to a new and higher level of industrial development.

5. Prospects for the development of continuous casting

The results already obtained from continuous casting plant fully warrant a further extensive application of this advanced process, and its development will be continued both by the installation of new plants in existing works and by the construction of new plants.

It is quite clear from experience gained at the Novolipetsk plant which was the first in the world to operate without chill pans and blooming, and from the results obtained at works in a number of other countries, that it is now possible to move on to the next stage in the development of this process and to build large works based on steel-making shops equipped with continuous casting plant without any blooming or slabbing mills.

The continuous casting plants which will replace the blooming and slabbing mills in large works will radically change the whole organisation of production, the location of the main workshops and the arrangements for transport within the works.

Calculations made by Gipromez (USSR)[a] indicate that, in a works producing 3,200,000 tons of rolled sheet steel, metal consumption can be reduced by 700,000 tons by using continuous casting instead of slabbing. The metal consumption factor per ton of rolled steel will be 1090 kg. compared with 1310 kg. by the conventional method.

The total area of the rolling shop can be reduced from 117,000 to 86,000 m^2 and the area required for the works as a whole can be reduced by 60 hectares.

The length of railway lines required will be reduced by 14 kilometres. The number of workers employed in the steel-making and rolling shops will be reduced by 180, and labour productivity will be 19% higher than with conventional facilities.

The effects of continuous casting are particularly striking when the process is used in conjunction with oxygen converters. Satisfactory synchronisation of the converter process with that of the continuous casting plant is guaranteed by the regularity of oxygen converters.

It seems possible too to cast a number of heats in one plant without a break in the process; and this reduces preparation time, and increases the productivity efficiency of the plant.

In the USSR, the Federal Republic of Germany and Japan plants for the continuous casting of slabs 1200-1500 mm wide are already in operation; and data obtained from experiments and production practice show that it is technically possible to cast slabs up to 1800-2000 mm wide and square sections of 350 mm and more.

The development of industrial production of billets of these sizes is paving the way for the complete replacement of the conventional casting process by continuous casting.

The ultimate success of continuous casting depends largely on the extent to which the process can be automated, and research is being undertaken to produce automatic devices for regulating the casting process. These consist of systems to regulate the level of the metal in the tundish and the mould, both of them being subject to a single control.

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[a] G.V. Vitin, Stal, No.1, 1960.

The function of these systems is not only to measure the level of the metal in the tundish and the mould with the necessary accuracy, but also to keep the levels within prescribed limits.

The level is regulated by control devices operating on the stoppers of the ladle and the tundish respectively.

All countries are now giving serious attention to the problem increasing the output, and reducing the number, weight and cost of continuous casting plant.

One promising development seems to be the production of plants with multi-strand moulds, and also of multi-strand plants, in which heats of great weight can be successfully cast in small and large sections. At the same time, tundishes are being simplified, and the operation of the refractory vessels and stoppers improved.

One way of reducing the height of the plants is to arrange for the billets to be bent from the vertical to the horizontal position. It has already been demonstrated that billets up to 200 mm wide can be bent in this way. With greater widths of up to 300-350 mm, the bending radius has to be increased to 9-10 m or more; and, as the billet cannot be bent until the outer crust is sufficiently thick and hard, this creates additional difficulties when casting speeds and the grades of steel cast are varied.

In the search for other means of reducing the height of plants, tests are being made of equipment with a radial mould or with a rectilinear mould inclined at an angle. But these methods have not yet been developed to a sufficient extent for it to be possible to indicate specific uses to which this type of equipment should be put and the billet sizes and grades of steel suitable for casting in it. There are in fact some particular features about the solidification of steel along the axis of a billet lying at an angle which make it impossible always to obtain a billet of the required quality.

It should be remembered, too, that if the height of the plant is reduced, considerably more room is required for all the ancillary equipment; and the technical and economic efficiency of reduced-height plants can only be determined in the light of actual conditions existing in a given workshop. It is often advisable to cut down the total space used to a minimum by placing more of the equipment below or above ground level. How effective these methods will be and how widely they will be used, only the future will show.

The successes achieved in continuous casting have paved the way for the development of a combined continuous casting and rolling process which, it is hoped, will constitute the nucleus of the steel-making works of the future.

The advantages of this are that the duration of the production process for finished steel would be reduced, the yield would be increased (less trimmings and other waste), capital outlays would be reduced, labour expenditure would also be reduced (elimination of several technical transport and auxiliary operations) and better possibilities would be offered for complete mechanisation and automation of the entire process.

The main obstacle to the solution of this problem is that continuous casting and rolling are carried out at different speeds. In a vertical continuous casting plant, for instance, a 300x300 mm square section will move at a speed of 0.6 m/min, and the output of a single strand is 25 tons per hour. But the speed required for rolling billets of this size in the first stand of a continuous rolling mill is 18 m/min, and output is 730 tons per hour. Thus the output of a single-strand plant is one twenty-fifth or one thirtieth of that of the rolling mill. For 200x1000 mm slabs, the output of a single-strand plant is one eighth or one tenth of that of a thin-sheet rolling mill.1/

Other difficult problems are how to synchronise the operation of the plant and the rolling mill, how to maintain an even temperature at the separation point, etc.

When continuous casting and rolling are run together into a single process, the billet has to be of high quality as it is difficult to check and eliminate faults when the billet is moving continuously forward into the rolling mill. Accordingly one of the main problems of this combined process is how to produce a continuously cast billet with no surface and internal flaws which have to be removed before rolling.

For producing large- and medium- section rolled steel it is possible to use multi-strand vertical continuous casting plants in conjunction with channel-type heaters for heating the billets and the rolling mill and keeping them at an even temperature.

Continuous casting plants are suitable for the incorporation of additional features such as preliminary vacuumisation, arrangements for protecting the flow of

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1/ I.N. Golikov, O.G. Kuzalevsky, Izvestiya AN SSSR, OTN, No. 5, 1962.

metal from secondary oxidation with inert and reduction gases (Nitrogen, argon, propane, etc.) treatment of the metal with synthetic slags, etc., all of which considerably improve the quality of the billet.

In short, continuous casting is a basic process; and, if it is extensively applied in the near future, it should encourage the construction of works with automatic oxygen-blown furnaces and automatic continuous casting combined with the rolling process. It should in fact bring about a revolutionary change in the technique of iron and steel production.

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