The Design of Continuous Casting Plants for India

M. N. Dastur
R. D. Lalkaka

WORLD steel producing capacity is being enlarged at an average rate of about 15 million ingot tons per year, requiring very substantial capital investments. The difficulties of financing such large investments, and their effects on production costs through heavy amortization charges, have led to extensive development work on new processes for iron and steel manufacture. The prospect of eliminating conventional stripper yards, soaking pits and blooming mills (which together may amount to about 10% of the cost of an integrated iron and steel plant) has created considerable engineering interest in the continuous casting of steel.

Continuous casting may be defined as teeming of liquid metal into a short mould with a "false bottom" through which the solidified "ingot" is continuously withdrawn. Currently, the process is only semi-continuous—the operation stops after each heat from the steelmaking unit has been cast. However, in order that the process may have wide commercial application, it should approach a continuous operation.

In the non-ferrous field, continuous casting processes such as the Asarco and Junghans process for copper and brass, and the Properzi and Hazelett processes for aluminium are being successfully used. Non-ferrous metals have been cast successfully because of their lower heat contents and pouring temperatures compared to steel. At the same time, their thermal conductivity is much higher which allows rapid dissipation of heat. An important difficulty in casting steel is its erosive effect on ladle and tundish refractories and moulds. Also, in order to make the process economic, steel must be cast in much larger tonnages than non-ferrous metals.

In the steel industry intensive work on continuous casting has taken place only during the last 10 years, although the earliest patent was taken out by Henry Bessemer almost 100 years ago. About 25 continuous casting plants are in operation today of which about half have operated commercially. However, only about six may be said to show the consistency and dependability required for economic operation. The installed plants include the Rossi-Junghans process at Welland (Atlas Steel) Canada, Watervliet (Allegheny Ludlum) in U.S.A., Sumitomo in Japan, Allevard in France, Barrow in England and Nyby Brut in Sweden; the Junghans process at Huckingen in Germany, Terni in Italy and Cail in France; the BISRA process at BISRA's own Sheffield laboratory, at Jessop in Sheffield, and Charleroi in Belgium; the Bohler process at Kapfenberg and Breitenfeld in Austria; the C.A.F.L. process in Unieux and Imphy in France; Babcock and Wilcox-Republic Steel plant at Beaver Falls, U.S.A.; and various installations, such as at Moscow (Novo Tula), Gorkil (Sormovo) and Stalingrad (Krasni, Octiyabar) in U.S.S.R. The Russians have made important technological advances and plan to produce by 1962 as much as 12 million tons of ingots (about 20% of their total output) utilising continuous casting[1]. 17 continuous casting machines are under installation in Russia of which three at the Voroshilovsk plant will cast 220 tons at a time[2].

In the following discussion the term continuous casting has at times been abbreviated to "con-cast" and the product of a continuous casting plant has been referred to as an "ingot" regardless of its cross-section, because of the cast structure.

The possible advantages of continuous casting

While dependable and consistent operation has only been partially attained the results to date have established that the product quality and yield by continuous casting are excellent. Further, lower capital and operating costs add to the attractiveness of the process. However, this is not to say that continuous casting will replace conventional methods—Blooming Mills will continue to be used for mass production of large steel tonnages. For outputs of 50,000 to 500,000 tons, continuous casting methods are likely to find increasing application.

Compared to ingot teeming, soaking and blooming, the advantages of continuous casting are in the following directions:

Quality

The difficulties of proper mould lubrication and mould cooling in order to effect clean separation of the mould at high withdrawal speeds, at times causes surface defects and corner cracks. Longitudinal

Dr. M. N. Dastur and Mr. R. D. Lalkaka, Metallurgical Engineers, M. N. Dastur and Company Private Ltd., Consulting Engineers, Calcutta.

cracks may also be experienced due to the ferrostatic pressure inside the ingot. The surface quality varies with the type of metal cast, and to a lesser extent with the casting speed.

The very rapid cooling rates required tend to give a coarse crystalline structure, and at times to entrap non-metallic inclusions. These can be minimised by proper design to tundish utilising high quality refractories. The inclusion counts of both conventional and con-cast ingots are similar except that in the latter the inclusions are more evenly distributed.

The high ferrostatic pressure of the liquid metal in the ingot column and the rapid cooling rate prevent the formation of gas bubbles. This prevents central porosity. The mechanical proportions of con-cast ingots are equivalent, and in some cases slightly better, than conventional ingots.

While special precautions are required to ensure good product quality, the existing plants report that the surface and internal characteristics of con-cast ingots are normally very satisfactory. At the Cail plant (France)[3,4] probably the largest con-cast plant in Europe outside Russia, con-cast ingots are reported to have more favourable grain size, more even distribution of segregations, and more homogeneous chemical composition. The application of a circular magnetic field at the top of the mould has been tried to give a more compact ingot core. Surface quality is excellent and no preparation is required before delivery to the rolling mill.

The Atlas plant (Canada)[5] which has successfully cast 35-ton heats in a single strand machine, reports good cleanliness in con-cast steels with negligible central porosity and evenly distributed inclusions. With austenitic stainless steels, minute gas holes below the surface were at times encountered, requiring additional grinding. Satisfactory quality has also been reported at the Russian plants[2,14] and other installations.

Yield

The yield (liquid steel to billet or slab) in the continuous casting process may be 94 to 97%. The losses are about 2·0% in ladle and tundish skulls, 1·0% in flame cutting, and top and bottom discards of 0·5 to 1·0 metre per strand amounting to 1 to 3% (depending on cross-section). The yield of semi-finished product for light section (75 mm sq., 100 mm sq.) is expected to be about 97% and for heavier sections (600 × 165 mm) about 94%.

In conventional casting methods, there is a pit loss of about 2% (more if bottom pouring is adopted) plus a top and bottom discard in rolling for each ingot amounting to about 15 to 20% for killed steel. Further, there is an oxidation loss in the soaking pit of about 2%. This gives an yield (liquid steel to slab) of about 80 to 85%.

The yield of liquid steel to semi-finished product may be 10 to 15% higher by continuous casting than by conventional methods.

Operating cost

In the opinion of operators at Cail (France)[3] continuous casting cost per ton ingot is of the same order as the cost by conventional ingot casting (excluding mould cost which for continuous casting is only one-tenth as much as conventional ingot moulds). However, when the cost of processing through the primary mill is added the overall cost of the semi-finished product by continuous casting is considerably lower. Under some conditions, such as manufacture of high-cost steels, the objective may be to eliminate the pouring-pit costs and continue to process the ingot through the primary mills.

The difference in operating cost between continuous casting and conventional process tends to increase as the annual output decreases. According to the cost study of hypothetical plants in Latin America[6] the operating cost (excluding interest and depreciation charges) by continuous casting have been estimated at about U.S. $ 3 per ton of ingot. To this must be added the fixed charges of U.S. $ 1·56 to U.S. $ 0·62 for plants of 50,000 tons and 320,000 tons per year respectively. For comparison,[7] the operating cost per ton by conventional blooming mill were reported to be about four times as much for capacities under 200,000 tons/year. Under U.S. conditions, operating costs were revised upwards to about U.S. $ 7 per ton (including fixed charges)[6a].

Capital cost

Morton and Savage[6] have estimated investment cost of a continuous casting plant for Latin America to range from about U.S. $ 12 per ton for annual output of 80,000 tons to about U.S. $ 7 for output of 300,000 tons. Cost of conventional facilities has been reported at U.S. $ 50 per ton for a 80,000-ton plant and U.S. $ 30 per ton for a 300,000-ton plant. According to Russian experience[2] the cost of conventional facilities is about double that of a continuous casting plant. The preliminary estimate in this study of a 50,000-ton per year plant under Indian conditions indicates that capital cost of conventional plant would be about 70% more than continuous casting.

Other possible advantages

Apart from the above major considerations, there may be other advantages such as less plant area required, which is significant when space is restricted ; lower processing time which reduces in-process inventory ; less arduous conditions for labour.

The disadvantage of the continuous casting process is that it is still in the development stage and dependable operations have yet to be attained in most installations. The casting of large tonnages requires complicated multi-strand machines which have not yet been developed. While the broad outlines of many of the existing plants have been reported[2-5, 8-17, 27, 28], the technical details of operation are seldom discussed.

The commercial profitability of the process is yet to be established. Many of the existing plants run intermittently. Casting failures are due to a variety of causes such as leaking stoppers and nozzles, inadequate or excessive metal temperatures, run-outs due to mechanical failures, failure of cutting or discharge equipment. However, the fundamental work that has been done[14, 18-25] and the success of the basic pilot plant operations encourage the expectation of wider application for this process.

Special significance for India

Apart from the general advantages, the continuous casting process has a special significance for India.

1. Dispersal of small steel-making units: The con-cast process is well suited for small tonnage plants from 50,000 to 500,000 tons per year capacity. This development enables the installation of small steel plants in various parts of India. This will also minimise freight charges on finished product distribution and help to decentralise a strategic industry.

Continuous casting is well suited for production of alloy steels and should be considered for the proposed alloy steel industry.

2. Simplicity of equipment manufacture: Compared to ingot stripping, soaking and blooming equipment, a continuous casting plant is essentially simple in design, and the bulk of the equipment required can be readily fabricated in the country. The foreign exchange component for a new installation would therefore be small.

As India does not have plants for the manufacture of heavy blooming mill equipment, there is likely to be less resistance to the introduction of new processes requiring new equipment.

3. Utilisation of existing capacity: India has a large re-rolling mill industry (estimated capacity 1·5 million tons per year on two shift basis) which is chronically short of its raw material. Continuous casting plants, in conjunction with electric steelmaking furnaces, can be set up in scrap-producing centres, such as Kanpur and Calcutta to supply billets for rolling to light and special sections utilising existing re-rolling facilities. The comparatively small investment required should enable three or four re-rollers to set up a con-cast plant of say 200,000 tons per year capacity on a co-operative basis. The billet production cost may well be lower than the cost of billets supplied by one of the large integrated steel plants after freight, etc. have been allowed.

Alternatively, if a steel foundry attached to an automobile or equipment manufacturing plant has surplus steel-making capacity, this can be utilised by installation of a con-cast plant to convert excess steel to saleable billets.

4. Lower capital investment: India has abundant raw materials for a large steel industry, but the financing of new installations is likely to put a severe strain on the economy. Under these circumstances new processes requiring less investment than conventional processes have a special significance. For instance, with further developments in the technology of new processes, the combination of small blast furnaces for iron-making, oxygen converters for steelmaking, and continuous casting machines in lieu of primary rolling, could reduce the cost of a medium-size installation (200,000–500,000 tons per year) to about 50 to 60% of the cost of a conventional blast furnace, open-hearth and primary mills plant. This means that for the equivalent investment, almost twice as much steelmaking capacity could be installed.

Continuous casting processes

Essentially, the sequence of operations in the various con-cast processes are similar—the main difference is in the design and functioning of the mould.

The con-cast machine is normally vertical, although inclined units have been tried in Russia. The mould may be stationary or moving, and the ingot withdrawal may be continuous or intermittent. In conventional teeming/stripping methods, the ingot is allowed to solidify sufficiently for one or two hours before being stripped from the mould. However, the continuously cast ingot must be stripped from the mould face at regular intervals within a few seconds after solidification starts. The skin has low strength, and has not yet shrunk significantly from the mould. The frictional force created tends to rupture the weak skin. Measurement of friction between ingot and various mould surfaces (polished brass, chromium or lead plated brass) showed lowest friction with a polished brass mould[23].

In order to avoid rupture of the ingot skin, the Junghan's process uses a reciprocating mould. The mould moves down at the same speed as the ingot for about 20 mm to 52 mm (at Barrow), then returns to original position at thrice this speed. There is no relative movement between mould and ingot for three-fourths of the duration, thus giving time for any rupture in the ingot skin to heal. For higher casting speeds, the "healing" time required, and consequently the mould stroke, are larger. At Barrow a mould stroke of 52 mm for speeds of 7 m/min (50 mm sq. ingot) and stroke of 20 mm for speeds of 2·5 m/min (150×50 mm slabs) are used. The above speeds and stroke lengths indicate that for plain carbon steels the time required for healing of a skin rupture is about 0·5 second.

The Babcock and Wilcox method of withdrawing the ingot intermittently from a stationary mould achieves the same purpose as the Junghan's system. Here also, for short periods there is no relative movement between ingot and mould. This gives time for any rupture of the ingot skin to heal.

The BISRA mould is mounted on springs in telescopic pillars. The mould tube (480 mm long) is made of copper surrounded by a water jacket. When the friction between ingot skin and mould increases, the mould moves vertically down on the springs for a short distance (max. 50 mm). By this time the ingot skin has chilled and shrunk away from the mould, releasing it to its normal position.

Rupture of the newly formed skin due to friction is thus avoided. The spring for mounting must be chosen so that its restoring force does not exceed the breaking strength of the ingot skin, for different ingot sizes and types.

The Bohler process at Kapfenburg and Breitenfeld in Austria adopted a well-lubricated stationary mould with lateral flexibility. The C.A.F.L. process at Unieux and Imphy uses a vibrating mould. The Goldobin machine in Russia [2,20] is an example of an inclined unit. This consists of two 8 m long conveyors, running parallel to each other, at inclination of 10% to the horizontal. Each conveyor carries cast-iron moulds which, when meshed, give a 150 mm square section. The conveyor speed is reported to be about 75 mm per sec and a cast of 10 tons is made in one operation. At the discharge-end the ingots are spray-cooled and bent to a horizontal. The uneven movement of the moulds and the larger meniscus in the mould have an adverse effect on ingot quality.

In another type of inclined machine at the Gorki plant, the mould is stationary and the ingot is withdrawn periodically so that the metal level rises and falls. However, the formation and breaking-up of an oxidised crust on the meniscus contaminates the ingot. The periodic rise and fall of metal prevent break-out due to spot-welds between ingot and moulds.

Factors affecting plant design

The design of the pouring facilities, heat exchange system, withdrawal speeds, cutting and discharge equipment for a continuous casting plant depend upon the type and quantity of steel delivered by the meltshop and the section, length and output of ingots required. Recent experience has pointed out the feasibility of designing for both—high casting speeds and multiple strands.

Structure and equipment

A vertical casting installation normally consists of a free-standing steel structure having five or more floors with a total height in excess of about 15 m (up to bottom of ladle). The installation may be above or below ground level. In most cases, it is partly above and partly below ground, depending on environment and circumstances. Salient characteristics of ten existing installations are given in Table I. The main plant features are as follows :

Top (Fifth) floor :

(*i*) Bottom-pour or tea-pot type ladle to deliver liquid steel to the con-cast machine.

(*ii*) Refractory-lined tundish to distribute the metal. The tundish is pre-heated (about 900 to 1,500°C) and also continually heated during the cast. Protective gas atmosphere may be used to avoid oxidation.

(*iii*) Hollow copper mould of reciprocating, spring-mounted or other design. Provision in the mould for water cooling and lubrication.

(*iv*) Dummy rod in mould to start the cast.

(*v*) Control cabin to regulate the operation.

(*vi*) Arrangement for emergency ladle in case of running ladle stopper or tundish nozzle, etc.

Fourth Floor

(*vii*) Guide rolls with spray cooling chamber for heat removal.

(*viii*) Machinery for reciprocating mould, if required.

Third Floor

(*ix*) Withdrawal rolls to remove ingot from mould. These rolls may also be reversible in order to set-up the dummy rods.

(*x*) Hoists to raise and lower the starter rods or ingot.

Second Floor

(*xi*) Oxy-acetylene burner to cut the ingot while in downward motion. The burner is synchronised to move with ingot for a short distance while cutting, and then return to original position at faster speed. Exhaust system for removing gas-cutting fumes.

(*xii*) At this platform a second control cabin may be necessary.

First (Pit) Floor

(*xiii*) Discharge cradle and conveyor system to remove ingot.

Other intermediate floors may be provided for the purpose of structural strength. A ladder for access to each floor, and a freight lift (for larger plants) are required. On the ground floor provision is required for preparation and storage of moulds, tundishes and dummy rods.

The liquid metal may be transferred to the casting platform by (1) the furnace tapping crane, if the con-cast machine is in the pit bay, (2) a high level crane, if the machine is in a tower in line with the pit, (3) by a ladle car, if the machine is wholly below ground level. In one of the existing installations, the metal is carried to the top of the tower by a skip arrangement, while in another the electric melting furnace is itself located at the high level of the casting floor. The majority of installations use bottom-pour ladles as it avoids specially designed tilting equipment, pre-heating of ladle top, and delivers cleaner steel.

The distance required between the fifth and third floors depends largely on the speed of casting and ingot section (see below). The distance between the pit and third floor depends on the required length of the cut ingot. In order to utilise maximum casting

Table I

Important features of some existing continuous casting plants

Location	Barrow (England)	Welland (Canada)	Duisberg-Huckingen (Germany)	Terni (Italy)	Denain (France)	Unieux (France)	Sheffield (England)	Sheffield (England)	Moscow (U.S.S.R.)	Gorkil (U.S.S.R.)
Company	Barrow Steel Works	Atlas Steel	Mannesman-Hutten-werken	Terni Societe*	Cail Steel Plant	C.A.F.L.	Wm. Jessop & Sons	BISRA Laboratory	Nova Tula Plant	Krasnoe Sormovo Plant
1. Process	Rossi-Junghans	Rossi-Junghans	Junghans	Junghans	Junghans	C.A.F.L.	BISRA	BISRA	TsNIICHM	TsNIICHM
2. Number of Strands	2	1	4	8	4	1 or 2	1	1	1	2
3. Ladle-Capacity (tons-approx.)	7½	35	35	60	35	Furnace (1½T) directly pours thru tundish	1½	½	10	50
4. Ladle	Lip-pour	Bottom pour	Bottom pour	Bottom pour	Lip-pour (Tea pot type)	—	Bottom pour	Bottom pour	Bottom pour	Bottom pour
5. Ladle-Preheat (Temp.-approx)	1540°C	760°C	N.A.	N.A.	950°C	N.A.	900°C	900°C	N.A.	N.A.
6. Time for emptying ladle (mins.-approx)	60	50	30	50	45	50	45	25	25	30
7. Mould	800 mm length, Reciprocating	500 mm length, Reciprocating	975 mm length, Reciprocating	Reciprocating Cu-mould	1000 mm length, Reciprocating	700 mm length, Vibrating	475 mm length, Spring suspension	475 mm length, Spring Suspension	1700 mm length, Oscillating	1700 mm length, Stationary
8. Lubricant	—	Rapeseed oil	Oil	Oil	Oil lubrication found unsuitable	N.A.	Rapeseed oil or water	Vegetable oil	Molten paraffin	N.A.
9. Cooling water for mould (GPM)	120-160	Varies up-to 250	N.A.	33 per strand	132-240 per strand	N.A.	150-250	250	800	800
10. Type of Steel Cast	Plain carbon & alloy steels (SiMn & high 'S')	Stainless and alloy steels	Tube steels	Carbon & alloy steels	Mild, alloy & silicon steels	Low alloy stainless & high speed steels	Stainless (18-4) & high speed steels (18-4-1)	Carbon, low alloy & 14% Cr. steels	Mild steels	Mild steels
11. Sections Cast (mm.)	50 mm. sq. 75 mm. sq. 150x50 mm.	155 mm. sq. 600 x 170 mm. 375 x 175 mm.	1000mm. round 300 ,, ,, 200 ,, ,,	110 mm. sq. 140 mm. sq.	240 mm. sq.	350 x 50 mm. 75 mm. round 60x75mm. oval	100 mm. sq.	100 mm. sq. 75 mm. sq. 220 x 45 mm.	150 x 500 mm.	175 x 420 mm.
12. Corresponding Casting speed (mm/min.)	5500mm/min. 3500 ,, ,, 2000 ,, ,,	1325mm./min. 1250 ,, ,, 1250 ,, ,,	100mm./min. 350 ,, ,, 325 ,, ,,	2500 mm./min. 2500 ,, ,,	575 mm./min	500 mm./min. 500 ,, ,, 500 ,, ,,	375 mm./min.	1100 mm/min. 1600 ,, ,, 1900 ,, ,,	800 mm/min.	850 mm/min.
13. Max. length of cut 'ingot' (metres)	9 m	5 m	4 m	3 m	1.6 m to suit furnace	N.A.	1.2 m	7 m	N.A.	N.A.
14. Height of installation (metres)	9.0 m Ingot bent horizontal before cut	9.5 m	16.5 m incl. 6.0 m depth of pit	18.0 incl. 4.8 m depth of pit	17 m from casting floor	10.0 m incl. 6 m depth of pit	11.5 m incl. 4.0 m depth of pit	10.5 m incl. 3 m depth of pit	22 m incl. 19 m depth of pit	16.8 m incl. 12 m depth of pit

N. A.=Not Available.

speeds and yet keep the structure at a reasonable height, the ingot may be bent to a horizontal position soon after solidification, instead of cutting to required length during its vertical descent.

Effect of casting speed and rate of heat removal

The most important factor affecting the design of a continuous casting plant is the maximum rate at which the ingot can be withdrawn. A low casting speed reduces the capacity of the casting machine and also has a bad effect on the quality of the ingot surface. Use of high casting speeds is limited by formation of cracks at billet corners or fissures in the core. Further, there is the risk of break-out in case the ingot skin has not reached a sufficient thickness and danger of run-out in case the ingot has not solidified through its entire cross-section at the cut-off point.

The speed of ingot withdrawal therefore affects (1) design of mould and the number of strands required (2) lubrication system (3) primary and secondary cooling, and (4) distance between mould and highest position of cut-off torch.

The depth of the liquid phase in the continuously cast ingot and the thickness of the ingot skin as it emerges from the mould depend largely on the rate at which heat is removed from the ingot. In a series of experimental casts two years ago by Inland Steel[24] on rimmed, killed and semi-killed low-carbon steels, the typical conditions for an aluminium-killed heat were as follows :

Section	...	$24 \times 5\frac{1}{2}$ in
Casting speed	...	40·8 in per min (1,280 lb steel per min)
Cooling water—mould	...	245 GPM
—sprays	...	965 GPM
Heat romoval by—mould	...	41,800 BTU/min
—sprays	...	385,000 ,,
Total		426,800 BTU/min

It was found that the rate of heat removal at the mould was mainly dependent on the casting rate, with heat removal of about 30,000 BTU/min for casting rate of 800 lb/min, increasing to about 48,000 BTU/min at casting rate of 1,600 lb/min. The calculated skin thickness of the emerging ingot decreased as the casting speed increased (thickness of about 0·48 in at casting rate of 800 lb/min to thickness of about 0·37 in at 1,600 lb/min). It was surmised from the investigation that best quality conditions were attained at speed under 1,400 lb/min (which corresponds to about 36 in/min for a $24 \times 6\frac{1}{2}$ in slab). The continuous casting process was not adopted by Inland Steel because the above speed limitation could not provide the large tonnage of slabs required using single-strand machines. Since then, the use of multi-strand units has developed to a point where it is possible to plan large tonnage con-cast plants.

In Russia[21,2] there has been considerable research work on the depth of the liquid phase and the solidification boundary of a continuously cast ingot. At Novo Tula two investigation methods have been used :

(*i*) Temperature measurement at the core of the solidifying ingot. A plot of temperatures shows a "kink" in the curve indicating the completion of crystallisation. For a 150 mm square ingot, the crystallisation time was 6 min and does not depend on speed of casting. Thus the depth of liquid phase (in metres) for this section is given by $L=6\,V$, where V is the casting speed (m/min).

(*ii*) Introduction of P^{32} isotope at 5 points along the central axis of the solidifying ingot. Contact radiograms of longitudinal and cross-sections of the ingot showed the boundary between solid and liquid phases at the time of isotope insertion. This method has also been investigated at the Bohler plant, Kapfenberg[25].

Using a 150 mm sq. mould in the Tula experiments, with casting speed of 315 mm/min the depth of liquid phase was found to be 1,900 mm and with a casting speed of 700 mm/min the required depth was 4,160 mm. These liquid depths are in agreement with those calculated by formula $L=6\,V$. The casting speed attained at Barrow of about 7 m/min for a 50 mm sq. ingot indicates that for this section the crystallisation time is only about 1·0 min, and the depth of liquid phase L, equals V.

Further, experiments were made with isotopes to determine skin thickness, which as discussed earlier, affects the casting speed. For an ingot 150×485 mm cast at a speed of 700 mm/min the skin thickness was found to be 43 mm on wide face and 34 mm on narrow face. This thickness was sufficient to prevent any break-out.

Heat-balance of ingots (150×500 mm) showed that when casting speed increased from 500 to 800 mm/min, total heat extracted from ingot increased from 308 to 333 cal/sec in the mould and from 442 to 555 cal/sec by secondary cooling. At the lower speed, heat removed by mould and secondary cooling was 50% of total heat, but with faster speed heat removed was only 30% (in each case balance of heat loss was by air cooling). Water consumption for secondary cooling of more than 6 litres/kgm did not improve heat extraction.

Casting speeds in existing plant

Coming to commercial application, casting speeds given in Table I are found to be operating satisfactorily. Projecting the results of the investigation by Jaicks et al[24] a casting rate of 1·3 m per min (120 tons per hour) for a $1,200 \times 165$ mm slab has been assumed to be feasible by Skelley and Easton[1]. The casting speed at Barrow of 5-7 m/min for 50 mm billet (max. speed attained 14 m/min) is well in excess of the prevalent practice. With improvement in technology it should be possible to attain high casting rates over a variety of casting conditions.

On the basis of an evaluation of casting rates in satisfactory operation today and anticipated technological advances, casting rates of up to 4·5 m/min for light sections (50 mm sq.) and 1·0 m/min for large slabs ($1,000 \times 165$ mm) are considered feasible. Table II gives the casting rate for various billets and slabs, the time and number of strands required to cast heats of 10 tons, 40 tons, 80 tons, and 240 tons.

With all other conditions remaining constant (type of steel, ingot shape, machine design, pouring temperatures, etc.) the rate of casting (tons/hr) varies linearly with the area of the section cast (Fig. 1). If the optimum casting rate for a particular section is exceeded, the quality suffers and there is danger of break-outs. On the other hand, at low casting rates there is the problem of cold-shuts and uneconomic outputs.

Duration of casting

Existing conditions of tundish refractories and drop of metal temperatures during casting place a limitation on the duration of the cast. Skelley and Easton[1] have assumed a one-hour casting and 30–40 min set-up time as a basis for design of a con-cast plant. Other workers have preferred cycles varying from one-hour cast and one-hour set-up to a 20–40 min cast, 5 min set-up. At Cail, on a commercial basis, they are casting for 45 minutes

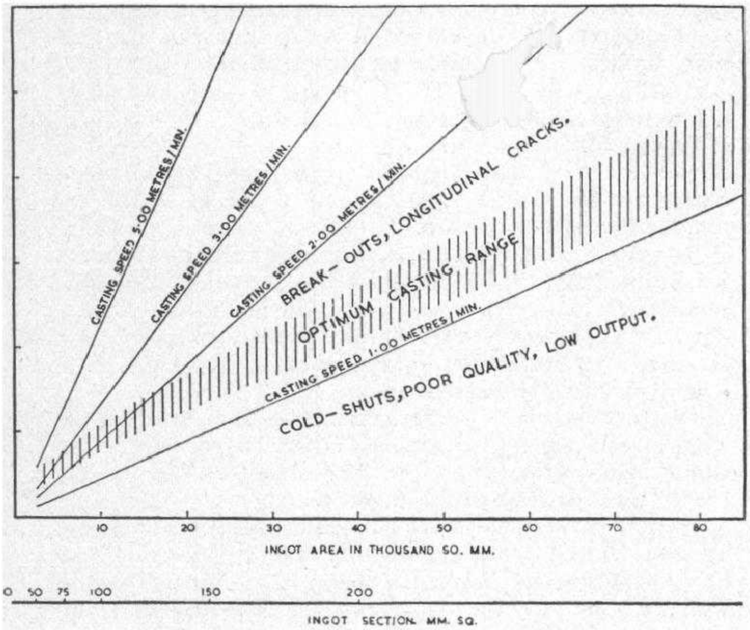

Fig. 1.
Optimum casting range for varying ingot section (Plain carbon steels)

with a 15 minutes down-time, while at Barrow casts of 2 hours have been made with a 7½-ton ladle in slow-running trials.

The number of strands required to cast different ladle tonnages is given in Fig. 2 on the basis of a casting time not exceeding 60 minutes.

Machine availability

Casting time of about 60 minutes with 20 minutes for clearing and setting up the machine gives a machine availability of 75%. However, this does not take into consideration the problem of synchronising the tapping of steelmaking unit with a readiness of the machine to start casting. This would depend upon the number of furnaces and the regularity of tapping. Even with balanced steelmaking and casting facilities, it would be reasonable to assume a waiting time after machine set-up of about 15 to 30 minutes. This would reduce the overall machine availability to about 55%. This figure would be higher for an oxygen converter or electric steel-furnace shop, lower for an open hearth shop.

For the design of large continuous casting plants it is essential that the machine cast for as long a

TABLE II

Number of strands and casting time required for various sections and ladle tonnages

(PLAIN CARBON STEELS)

'Ingot' Section (mm)	Casting Velocity (Metres per min)	Casting rate per strand (Tons per hr)	Metal Delivered Per Cast: 10 Tons		40 Tons		80 Tons		240 Tons	
			No. of strands reqd.	Casting time (Mins)	No. of strands reqd.	Casting time (Mins)	No. of strands reqd.	Casting time (Mins)	No. of strands reqd.	Casting time (Mins)
Squares										
50 x 50	4.50	5.05	2	59	8	59	—	—	—	—
75 x 75	3.00	7.60	2	40	8	40	—	—	—	—
100 x 100	2.30	10.35	1	58	4	58	8	58	—	—
150 x 150	1.70	17.20	1	35	3	47	5	56	14	60
200 x 200	1.50	27.00	—	—	2	44	3	59	10	53
Slabs										
200 x 75	2.00	13.50	1	45	4	45	6	60	18	60
400 x 75	1.50	20.30	1	30	2	60	4	60	12	60
600 x 165	1.25	55.60	—	—	1	43	2	43	5	52
1000 x 165	1.00	74.00	—	—	1	32	2	32	4	49

duration as possible with the minimum possible down-time. This requires the use of an intermediate holding furnace, superior refractories and a mechanically reliable con-cast machine. It is likely that future continuous casting plants can operate 3 shifts per day, 7 days a week, with machine availability approaching 75–85%. In the non-ferrous field, con-cast machines operate at availabilities of 90% and over.

Size of con-cast plants

The daily and annual productions to be expected at 50% and 80% machine availabilities are given in Table III.

TABLE III

Con-cast machine output at 50% and 80% utilisation

Ingot Section	Casting rate per strand Tons per hr.(1)	OUTPUT PER STRAND				Suitable Ladle capacity Tons	
		@ 50% machine utilization		@ 80% machine utilization			
		Tons per day	Tons per year(2)	Tons per day	Tons per year(2)	Single strand machine	Four strand machine
50 x 50 mm	5	60	18,000	96	28,800	4	18
100 x 100 mm	10	120	36,000	192	57,600	9	36
200 x 200 mm	27	324	97,200	518	155,400	24	100
200 x 75 mm	13	156	46,800	250	75,000	12	47
600 x 165 mm	55	660	198,000	1030	309,000	55	220
1000 x 165 mm	74	888	266,400	1420	426,000	66	260

(1) From Table 2.
(2) Three shift operation, 300 days per year

Obviously with multi-strand machines, the annual plant outputs would be higher. Assuming that two four-strand machines constitute a feasible initial size for a continuous casting installation, a plant of about one million tons/year capacity casting large slabs is possible. A production of 40,000 to 50,000 tons/year is considered the minimum economic tonnage for a con-cast plant. It is the experience of the Atlas plant[5] that with output of 6,000 tons/year 18-8 stainless steel, the casting cost is twice that with output of 30,000 tons/year.

Type of steel and size of ingot castable

A large variety of steels from low carbon to high alloy, are continuously castable in square, slab and round sections. The process is specially suitable for casting of special steel such as stainless steels, high speed steels, spring and free cutting steels. Plain carbon steels—both killed and rimming, are also cast successfully but present slightly greater difficulties due to their high freezing temperatures and low hot-strength.

Most of the work on continuous casting has been done on killed steels. Castings of rimming steels[24] requires slightly lower speeds, large quantities of water for secondary cooling, and rigid control on final deoxidation. Rimming steels—with their advantages of higher yields, better surface quality and saving in cost of deoxidising additions, constitute the bulk of low carbon hot and cold rolled sheets for pressed applications. Therefore continuous casting of rimming steel must be [illegible] developed in order that this process may have [illegible] commercial application.

Continuous ca[illegible] of small ingot sections (say, below 150 × 150 [illegible]) has n[illegible] favoured due to low outputs, diff[illegible] in dir[illegible]ng the hot metal stream i[illegible] small ingot, [illegible] the necessity of providing at least 4 : 1 reduction of ingot in order to remove the cast structure. However, squares as small as 50 × 50 mm have been cast successfully at Barrow. An interesting feature at Atlas Steels is that thin slab sections from the con-cast plant are fed directly to a Sendzimir planetary mill without intermediate processing. At Atlas 160 mm square sections are also extruded directly into seamless tube.

The tendency is towards casting medium and heavy squares and slabs. These may then be processed in conventional primary mills. The objective here is to secure cost savings in the ingot teeming and stripping operation, rather than in the forming operation. Slabs up to 800 mm wide are already being cast and it is likely that with experience, slabs of 1,250 mm × 200 mm will be cast in the near future. The range from 700 mm to 1,250 mm will cover the bulk of slab widths required for continuous strip mill operations.

The large variety of slab widths required by a strip mill poses the problem of an adjustable con-cast mould. Alternatively, moulds of various sizes could be kept and changed rapidly. This could be done at low-cost and with minimum down-time.

Although squares, rounds, rectangles and oval shapes have been cast, rectangular slabs have been shown most satisfactory results. For equivalent areas of different shapes, the casting speed for a slab is larger due to the larger surface area available for heat dissipation.

Machine location and height

As mentioned earlier, the height of the con-cast machine is determined by the depth of liquid steel at a given casting rate for a given section and the desired maximum length of ingot. For instance, an ingot 100 × 100 mm cast at a speed of about 2 m/min would require a length of about 8 m between the mould and the highest position of cut-off torch in order that the metal may have solidified through the entire cross-section before cut-off begins. To this must be added the length for which the cut-off torch travels with the ingot (say 2·5 m), the length of the ingot desired (say 3 m) and the ingot transfer equipment (say 1·5 m). Another 2 m must be allowed for the mould and tundish to give total machine height of about 17 m to the bottom of the ladle. The height required would be considerably reduced if the ingot could be bent to the horizontal before cutting.

The operating floor area required for a multi-strand machine would be about 15 m × 20 m.

The advantage of pit type construction to secure vertical height is that it would fit in under conventional pouring crane facilities and would therefore not require additional tall structural steelwork with a secondary ladle crane on a high runway. The Stalino 4-strand plant, which will be completed in Russia in March 1959, is housed in a concrete cylindrical pit of 25 m diameter and 22 m depth.

Under Indian conditions, where ground water table is normally high during monsoon periods, the pit type installation poses construction problems in overcoming the high hydrostatic pressures at depths of 10 m and over, and providing a water-proof pit.

The casting machine can be located in the pouring pit or in an extension in the same line as the pouring pit (Figs. 2 and 4). This is a desirable arrangement as it eliminates intermediate ladle transfer equipment thus delivering steel rapidly to the casting machine and resulting in high machine utilisation. Alternatively, the con-cast building may be located in a bay adjacent to the pouring pit and the metal transferred by a ladle car (Fig. 3).

In all cases the design and layout of the unit would depend upon environmental factors and the specific ingot requirements.

Choice of steelmaking process

The objective of further developments in continuous casting technology is, of course, to cast as continuously as possible over long periods from large ladle sizes through a holding furnace. Present technological limitations regarding casting duration favour a steelmaking process which will cast small heats at frequent intervals.

An oxygen converter shop casting heats of 30 to 70 tons in 40 minute cycles would fit this category. The largest oxygen converters in operation today produce over 70 tons per blow, for example at Imjuiden in Holland, Yawata and Nippen-Kokan in Japan. Two such converters (one operative, one stand-by) would produce about 700,000 tons per year. Fig. 4*a* indicates a possible arrangement of an oxygen converter-cum-continuous casting operation. In order to provide ample casting capacity to take care of disruptions in blowing schedules, two four-strand casting machines are provided for one operating converter. The con-cast plant is under the normal pouring bay and is supplied metal by the pouring crane. Provision for expansion of steelmaking and casting is made in the layout. The plant circulating scrap would be less here than by conventional ingot teeming-blooming and would be readily taken up by the converters. Therefore no auxiliary melting capacity would be required.

The pneumatic processes such as oxygen converter, Kaldo and Rotor, with their advantages of lawer capital and operating costs, could form an effective combination with continuous casting.

Electric furnace steelmaking also offers the possibility of making small and medium tonnages at an interval of about 3 to 5 hours per cycle. In this case one casting machine could handle the product of two furnaces. However, in order to have greater flexibility a machine per furnace may be provided. The majority of existing con-cast plants receive steel from electric furnaces.

Under conditions of low power cost and adequate scrap availability, the electric furnace can produce large tonnages of plain carbon steels competitively, with plant costing only 50–70% as much as a basic open hearth plant. However, in India with acute power shortage and a low current rate of scrap generation, only small electric furnace plants of 50,000 to 100,000-ton capacity can be contemplated.

In Fig. 2 a plant of 50,000 tons per year capacity is visualised consisting of two 10-ton furnaces with two single-strand con-cast machines. This is based on a 3-hour tapping cycle, 90% furnace availability, to cast ingots of 63×63 mm and over in cut lengths of about 3 m. A pit type casting machine is assumed to be accommodated in an existing pouring bay.

An alternative arrangement is shown in Fig. 3 wherein the metal is transferred by a ladle car to the con-cast bay which is alongside the pit. Here two larger electric furnaces of 20-ton capacity are assumed and the furnaces are elevated to tap into a separate pouring bay as in a conventional open hearth shop. The height, width, etc. of the building allows for the installation of larger, more efficient furnaces, if required in the future. Two double-strand casting machines are provided. The unit would cast 100 mm to 200 mm squares and slabs of 200 mm to 600 mm width. Based on a 3-hour average furnace cycle, the shop would produce 100,000 tons "ingots" per year. The capacity of the casting plant, at low machine utilisation of 50% is about 50 ton hr. of 200 mm sq. ingot. Additional steel melting capacity could be handled by the initial con-cast machines.

The bulk of the world's steel production comes from open-hearth furnaces, and therefore widespread commercial application of continuous casting will depend upon its integration with open-hearth steelmaking. Under present conditions, the large tonnages involved in modern open-hearth shops and the long, somewhat unpredictable tapping schedules present difficulties. However, the trend in Russia indicates that an open-hearth shop with a series of multi-strand casting machines is a workable proposition. In order to provide flexibility of operation one multi-strand casting machine would be required for about 4-5 furnaces.

Figure 4*b* shows a seven-furnace open-hearth shop with two four-strand casting machines located in the pouring bay. If the existing pouring bay does not possess the necessary width or height the con-cast machine may be located at one end of the bay under a new roof. Conventional ingot moulds would be required for the contingency that the heat is not suitable for continuous casting, or the con-cast machines are inoperative. The four-strand machine would cast 220-ton heats of $1{,}000 \times 165$ mm slab in about 45 minutes, with 20 minutes for machine set-up. The two machines between them would have to take about 12 to 14

*Fig. 2

heats per day, that is about one heat every 3·5 to 4·0 hours per machine. This would allow ample margin of 2·5 to 3·0 hours for any "bunching" of heats. In the study by Inland Steel on an existing 10-furnace open-hearth shop, the average waiting time after machine set-up was estimated at about one hour.

The shop defined above would produce 1,000,000 tons per year. An additional open hearth could be installed in future, without requiring any additional con-cast capacity.

Investment and Operating economics

To get an indication of the overall economics of a con-cast plant under Indian conditions, the electric furnace installation shown in Fig. 2 to produce 50,000 tons/year is compared with a conventional system teeming 150 × 150 mm, 1·25 m long, ingots from two 10-ton furnaces. These ingots are subsequently cogged to 63 × 63 mm billets in a 550 × 1,950 mm 3-high roughing mill to produce about 50,000 tons/year.

The main equipment items required by the two alternatives are listed below (Table IV) from the point that liquid steel is taken in bottom/pour ladles to the stage where the semi-finished product is delivered to a stock yard.

TABLE IV

Main plant items for conventional and con-cast installations

I. PLANT FOR CONVENTIONAL PROCESSING

A. Teeming facilities

(*i*) Pouring bay (20 m × 115 m) with two 20 T cranes, and teeming arrangements.

(*ii*) Ingot moulds, mould storage and preparation, and ingot stripping (Transfer to cogging mill by rail)

B. Rolling mill facilities

(*iii*) Mill bay (20 m × 80 m) with 35/10 T crane.

(*iv*) Motor-room, roll-turning shop, etc. (12m × 55m).

(*v*) Ingot storage bay (20 m × 80 m), 10/5 T crane and ingot heating furnace (20 m × 3 m inside).

(*vi*) 3-high 550 mm × 1,950 mm roughing mill with 1,000 h.p. motor reduction gear, pinion tilting and roller tables, cooling bed, electricals, and accessories.

(*vii*) Billet storage yard.

II. PLANT FOR CONTINUOUS CASTING

(*i*) Smaller pouring bay (20m × 70m) for emergency teeming, two 20 T cranes for casting.

(*ii*) Area for con-cast machine (20m × 20m).

(*iii*) Casting machine with moulds, controls, water system, runout conveyors and accessories.

(*iv*) Ingot cooling and stock yard (40m × 15m) with 5 T crane.

A preliminary cost estimate for the above alternatives is indicated below :

I. Preliminary capital cost estimate for conventional processing to 50,000, T/yr billets

A. Teeming facilities

		Capital cost Rs.
(*i*)	Pouring bay with two 20 T cranes and accessories ...	10,15,000
(*ii*)	Ingot moulds	1,00,000
(*iii*)	Contingencies and engineering @ 15% ...	1,67,000
	Total cost Rs.	12,82,000

B. Rolling mill facilities

(*i*)	Structures with foundations (including ingot and product storage yard) ...	10,00,000
(*ii*)	Ingot heating furnace ...	1,32,000
(*iii*)	Equipment — electrical and mechanical incl. maintenance shop, cranes, etc. ...	15,63,000
(*iv*)	Equipment foundations ...	1,12,000
(*v*)	Utilities ...	1,40,000
(*vi*)	Office ...	25,000
(*vii*)	Spares @ 10% ...	1,18,000
(*viii*)	Contingencies and engineering @ 15% ...	4,63,500
	Total cost Rs.	35,53,500
	Total cost by conventional process Rs.	48,35,500

II. Preliminary Capital cost estimate for continuous casting to 50,000 T/yr billets

		Capital cost Rs.
(*i*)	Pouring bay, con-cast bay and product storage bay with two 20 T and one 5 T cranes	11,50,000
(*ii*)	Equipment — electrical and mechanical, incl. con-cast machine, steel frame, maintenance shop, etc. ...	8,75,000
(*iii*)	Equipment foundations & pit	2,40,000
(*iv*)	Utilities ...	1,20,000
(*v*)	Office ...	25,000
(*vi*)	Spares @ 10% ...	87,000
(*vii*)	Contingencies and engineering @ 15% ...	3,74,500
	Total cost by continuous casting Rs.	28,71,500

The above figure may be compared[6] to the estimated cost of U.S. $770,000 (Rs. 36·6 lakhs) for an 80,000 tons/yr plant with one 4-strand con-cast machine. A 4-strand machine built at Cail in 1955 in an existing shop is reported to have cost about Rs. 10 lakhs. The single-strand machine at Atlas Steel is reported to have cost about Rs. 8 lakhs, of which the equipment amounting to 75 tons cost about Rs. 2·5 lakhs.

It must be pointed out that both the roughing mill and con-cast plants have ample (and almost equivalent) spare capacity, so that the cost per ton of future annual capacity would be lower in both cases.

The cost above metal for teeming and rolling in this plant is estimated as follows (Cost of laddle repair, etc., is common for both alternatives and is not considered below).

I. Preliminary cost above estimate for conventional process

A. Teeming

	Rs.	Rs.
Labour (Prodn., Supvr. and Maint.) ...	6·00	
Ingot moulds ...	13·00	
Misc. supplies ...	1·00	
Fixed charges @ 10% on Rs. 12·82 lakhs	25·60	45·60

B. Rolling

Labour (Prodn., Supvr. and Maint.) ...	9·00	
Power, water and other services ...	3·50	
Fuel oil	7·50	
Tools, lubricants and supplies, incld. rolls	11·50	
General plant expense	1·60	
Fixed charges @ 10% on Rs. 35·53 lakhs	71·00	104·10
Total cost above metal ...		149·70
(Say Rs. ...		150·00)

II. Preliminary cost above estimate for continuous casting

Labour (Prodn., Supvr. and Maint.) ...	6·00
Power, water and other services ...	2·60
Fuel oil (for tundish heating)	1·00
Refractories	1·50
Moulds and Lubricants	2·00
Tools and supplies	3·00
Fixed charges @ 10% on Rs. 28·71 lakhs ...	57·50
Total cost above metal Rs. ..	73·60

It is seen that excluding fixed charges the costs by continuous casting and conventional teeming are of the same order. However, when the higher fixed charges and the primary rolling costs are added, continuous casting shows a substantial advantage.

For both alternatives, the fixed charges are heavy due to the small initial plant size and large spare capacity. As plant size increases, the fixed charges (and the total cost above) would decrease rapidly. Furthermore, the wide margin between the two costs would diminish with large tonnage operations.

The above preliminary analysis does not take into consideration the savings as a result of better yields of the con-cast process. This in turn would require provision of 10 to 15% larger steelmaking capacity for the conventional process.

The continuous casting process, by virtue of its lower costs, higher yields, simplicity of plant design and ability to produce small steel tonnages, merits consideration for the large planned expansion of India's future steel capacity.

References

1 Skelley, H. E. and R. Easton, "Designing a Large Tonnage Continuous Casting Plant", Iron and Steel Engineer, May 1958,

2 Vavoisky, V. and P. K. Sen, "Continuous Casting of Steel", Transactions (10), Indian Institute of Metals, 1957.

3 Fievet, R., "Continuous Steel Casting in France", Journal of Metals—August and September 1957.

4 Thomas, P., "La Coulee Continue de l'Acier en France en 1958", Journees Internationales de Siderurgie, Juin 1958.

5 Olson, G. C., Continuous Casting at Atlas Steels Ltd.," Journees Internationales de Siderurgie, Juin 1958.

6 Savage, J., and J. S. Morton "The Replacement of Conventional Casting Bays, Soaking Pits and Blooming Mills by Continuous Casting", American Meeting of Experts on Steel Making and Transforming Industries—(ST/ECLA/CONF. 4/L. AIII-6) Sao Paulo, 1956.

6a Savage, J., and J. S. Morton "Economics of Continuous Casting in a Converter Steel Plant", Journal, of Metals—August and September 1957.

7 Schlesinger, K., "Selection and Economy of Equipment for Blooming Mills in View of the Growth of the Latin American Steel Market", Latin American Meeting of Experts on Steel Making and Transforming Industries (ST/ECLA/CONF./4/L. AIII.2) Sao Paulo.

8 Halliday, I. M. D., "Some Features of Continuous Castings at Barrow", Journees Internationales de Siderurgie, Juin 1958.

9 Fenton, G. and J. Pearson, "Continuous Casting on the B.I.S.R.A. Experimental Plant", Journees Internationales de Siderurgie, Juin 1958.

10 Barnhardt, L. R., G. E. Stock and W. U. Porter. "Continuous Casting at Atlas Steels Ltd.", Journal of Metals—August and September 1957.

11 Notes on Continuous Casting in Germany and Belgium, Journal of Metals—August and September 1957.

12 Continuous Casting of Steel Engineering, March 7, 1958.

13 Young, H. D., "Pioneering in New Developments in a Speciality Steel Mill", Paper read before the General Meeting of American Iron and Steel Institute at New York, May 25, 1955.

14 Boichenko, M S., V. S. Rutes and N. A. Nikolaev, "Development and Industrial Application of Continuous Casting of Steel", "STAL", Vol. 16, 1956 (No. 3818).

15 Harter, I., "Continuous Casting of Steel at Babcock and Wilcox Tube Co.", Journal of Metals, March 1951.

16 Waters, B. H. C., W. H. Pritchard, A. Braybrook and G. T. Harris, "Continuous Casting of High-Speed Steel", Journal of the Iron and Steel Institute, November 1958.

17 Zaeytydt, J., "La Coulee Continue au Centre National De Recherches Metallurgiques Section du Hainaut a Charleroi", Journees Internationales de Siderurgie, Juin 1958.

[18] Gegtyarev, L. G., "Economics of Continuous Casting of Steel", "STAL", Vol. 16, 1956 (No. 3819).
[19] Czikel, J., "Calculations About Continuous Casting", NEUE HUTTE, Vol. 1, 1956.
[20] Boichenko, M. S. and V. S. Rutes, "Continuous Casting of Steel", Liteinoe Proizvodstvo, 1956 (No. 3790).
[21] Sewell, R., "Russian Research on Continuous Casting of Steel", Iron and Coal Trades Review, February 15, 1957.
[22] Speith, K. G. and A. Bungeroth, "Observations on the Continuous Casting of Steel", Engenharia, Mineracao E. Metalurgia, Vol. XIX, No. 111, Janeiro—Fevereiro 1954.
[23] Savage, J. and W. H Pritchard, "The Problem of Rupture of the Billet in the Continuous Casting of Steel", Journal of the Iron and and Steel Institute, November 1954.
[24] Jaicks, F. G., L. E. Kraay and M. Tenenbaum, Continuous Casting of Three Types of Low Carbon Steel", Journal of Metals, August and September 1957.
[25] Krainer, H. and B. Tarmann, "New Experience in the Continuous Casting of Steel", Journal of the Iron and Steel Institute, October 1958.
[26] Brown, D. I., "Continuous Steel Casting Pilot Plant proves successful", The Iron Age, September 20, 1951.
[27] Morton, J. S., "Continuous Casting of Steel—Aims and Present-day Achievements," Iron and Coal Trade Review, April 8, 1958.
[28] Continuous Casting—Full Size Commercial Plant Installed in Canada, Iron and Steel, December 3, 1954.

DISCUSSIONS

Mr. B. S. Sharma, Mysore Iron and Steel Works: The subject of continuous casting is of considerable interest to me, as the process has been offered to the works with which I am associated. It was not seriously taken up mainly due to the costs involved. It was once thought that continuous casting was applicable only to special quality steels where the cost factor would be offset by the higher market price. The adoption of continuous casting is deferred till sufficient data are available to establish that the process can be economically taken up by small producers. The author has himself stated that there are at present 25 installations for the continuous casting of steel and only half the number are in commercial operation. This means that only about 12 are functioning on commercial basis and most probably all these are on commercial trials and have not yet established their works on sound lines. It has been further stated that the cost per ton of ingot is the same as that of the conventional cast ingot except for moulds which are 90% cheaper in case of continuous casting. While estimating the economics of this process, we should examine which items of costs have been taken into consideration.

I would request Mr. Lalkaka to let us know if the commercial plants so far established are really working on sound commercial basis and also to tell us which factors he has considered while estimating the cost of moulds.

Mr. R. D. Lalkaka. (Author): I quite agree with Mr. Sharma that the continuous casting process for steel cannot be said to have established itself commercially yet; and it would be correct to say that the plants referred to are being run on "commercial trial" rather that on continuous commercial operation. Most units run intermittently, and there are many mechanical problems to be ironed out. For each type of steel and section a certain amount of development work is required. At the Atlas Plant in Welland, Canada, the procedure is to allocate part of the saving between conventional and the continuous casting cost to a "development fund", because several million dollars have already been spent on the process.

It will still probably take a few years before one can consider continuous casting for a full-fledged commercial operation. This process has important possibilities and within the next two to three years one should hear a great deal more about it. At the present stage we should seriously consider installing a single-strand con-cast pilot plant in India. Small blast furnaces, side blown converters and continuous casting units would form a very economical combination for the installation of small and medium size plants of 50,000 to 500,000 tons/year capacity at different locations in India.

Regarding operating cost, a statement was made in the paper that according to operators at CAIL con-cast unit in France, teeming costs are of the same order as for conventional method excluding con-cast moulds which are considerably cheaper than the conventional ingot moulds. We have considered conventional processing in two parts: teeming costs which are mainly labour, ingot moulds, miscellaneous supplies and fixed charges; and cogging cost from ingot to billet including labour, utilities, fuel supplies and fixed charges. We estimate a figure of about Rs. 150 by this conventional processing. The operating cost by continuous casting is almost half of this amount. These calculations are only indicative.

Dr. E. G. Ramachandran, N.M.L. : It has been stated that a circular magnetic field is imposed when the molten steel is cooled. I would like to know how exactly steel at such a high temperature is affected by the imposition of this magnetic field and the mechanism of its action on the solidification of the material. Is this step taken only for steels or is it also true for any other material ?

Prof. C. Crussard, Director IRSID, France : The magnetic field helps in so far as it sets up Eddy currents and stirs the material. This effect is noticed in any similar type of material.

Mr. Manohar Singh, B.H.U., Varanasi : I would request some clarification on the technique used to lubricate the walls of the moulds when these are moving. I would also like to know if continuous casting of high speed steels is carried out anywhere in the world on an industrial scale, and if any special techniques are employed.

Mr. R. D. Lalkaka (Author) : For moving moulds the lubricant is added from the top ; in some cases, there is provision in the wall of the mould itself to introduce the lubricant at the same time as the metal is being cast. Rapeseed oil is commonly used.

With regard to the casting of high speed steels, it is being done, for instance, at the Bohler Plant in Austria, at Jessops in Sheffield, at Atlas in Canada, at C.A.F.L. in France and perhaps elsewhere as well. As stated earlier, each type of steel requires some development work before proper casting conditions can be established.

Mr. B. V. Somayajulu, N.M.L. : I would invite the author's comments on the minimum section thickness in continuous casting units. Can we cast sections less than 2" and if so, what special precautions are taken to avoid the rapid chilling of the casting. Is it necessary to exert any pull on the casting while it being drawn from the mould ?

Mr. R. D. Lalkaka (Author) : Sections below 2" are not recommended. Except the Barrow plant, there is no other unit casting down to 2" square. Normally it would be 4" or above ; the trend is to cast medium sizes and then process these through primay mills, taking advantage of reduction in teeming cast, rather than in primary rolling cost. In Russia, for example, large slabs are being cast and then processed through primary mills.

Regarding the second question, no pressure is needed on the "ingots" while it is drawn from the mould. A "dummy bar" is inserted to start the cast, and once the metal fills up to the top of the mould the bar is withdrawn mechanically. The bar is then detached and the ingot may move down by gravity. The ingot must descend at a controlled speed. No excessive downward force should be exerted as this would rupture the ingot skin.