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DO4726

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.146/45
3 May 1973

ORIGINAL: ENGLISH

Third Interregional Symposium
on the Iron and Steel Industry, 3d
Brasilia, Brazil, 14 - 21 October 1973

Agenda item 6

SOME ASPECTS OF SMALL-SCALE CONTINUOUS CASTING PLANTS[1/]

by

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id.73-2747

SUMMARY

The combination of electric arc furnace and continuous casting machine is now acknowledged to be a typical pattern for steel-making in steel plants which produce steel bar, wire rod, and small sections with production capacities not exceeding 500,000 tons per year.

This paper attempts to explain the situation of the continuous casting process as applied in the small-scale plants from the economic and technical viewpoints.

Before the continuous casting process was applied in practice, it was generally held that bottom-poured round ingots were the cheapest semi-finished steel products. However, since continuous casting was introduced, it has been acknowledged that cast billets are cheaper than ingots by 886 yen/t and that working conditions are improved, although the machine is rather complicated and requires skilful operators who have been trained for a long period. There is still a danger of interruptions to operations resulting from improper operating practices.

In order to increase yield and productivity and to reduce production costs, the application of in-line reduction mills, automatic operation of the casting machine, high-speed casting, and sequence casting should be considered.

Another problem to be investigated in the future is the improvement of the steel-making process, bearing in mind that price of scrap, which constitutes one-third of the production costs, is always variable.

INTRODUCTION

The economic production of steel has always been one of the most important questions for steel plants and it is becoming increasingly urgent at the present time. Some companies attempt to construct large-scale integrated steelworks, seeking the cost reduction offered by mass production, whilst others select the so-called "mini steel plant", which derives local advantages in terms of the transportation of products and raw materials. There have been many papers published, covering the economic and technological analysis of the mini steel plant. Taking these theoretical analyses into account, this paper tries to establish the productivity and production cost of the continuous casting process based on our own experience and on data furnished by the users of continuous casting machines in Japan, since this process has a great influence on the cost of steel-making in mini steel plants.

THE PRESENT STATUS OF CONTINUOUS CASTING

1. Comparison of continuous casting with bottom-poured ingot casting.

1.1 Product quality

There is no substantial difference between continuously cast billets and bottom-poured ingots, since both have as-cast structures. The continuously cast billet has a typical macrostructure with a thin chilled structure with, 3 - 5 mm under the skin, a dendrite structure growing toward the centre of billet and centre porosity. This pattern is caused by the intensive cooling in the mould and spray sone that is a characteristic of the continuous casting process. Since this typical structure is more marked in smaller billets, continuously cast billets were largely unacceptable for rolling into small bars etc. until optimum reduction ratio for such structures had been investigated.

Before the continuous casting process was in practical operation, it was said that bottom-poured round ingots for rolling into wire rod or small sections in a roughing mill and finishing mill were the cheapest semi-finished product, and bottom pouring was the most common process in the melting shops of small-scale steel plants. However, the continuous casting machine is nowadays acknowledged to be a more economical way of producing billets than bottom pouring. A brief comparison of the two processes and a study of existing continuous casting machines are reported in the present paper.

1.2 Steel-making process.

There is a slight difference in the steel-making process, depending on whether the steel is to be supplied to a continuous casting machine or to a bottom-pouring system, i.e.,

(1) The tapping temperature for steel to be supplied to the continuous casting machine is about 50 - 70° higher than that for bottom pouring, since there is a heat loss in the tundish located between the ladle and the mould, and so a slightly longer refining time is necessary.

The steel-making cost is thus increased by 3 - 4%.

(2) In order to minimize the detrimental effect of sulphur in the continuously cast billet, which is sensitive to cracking while being cooled, and to minimize heat loss from the top after tapping, excess limestone to maintain a high basicity is usually charged to the furnace, resulting in additional expense. Since sulphur has a strong affinity with manganese to form MnS, the ratio of manganese to sulphur in continuously cast steel is relatively high compared with steel for bottom-pouring.
The cost of making slag for continuously cast steel is 8-10% higher.

(3) Aluminium added to steel to control grain size and to deoxide it is liable to clog the tundish nozzle. The amount of aluminium charged in the continuously cast steel is kept as low as possible, to avoid dogging of the nozzle.

(4) Since the casting time for continuous casting is longer than that for bottom-pouring, a higher grade of refractory material must be used for the stopper head and sleeves. Longer casting time also causes erosion of the refractories at the slag line. The cost of ladle refractories for continuous casting is 2-5 times that for ingot casting.

(5) Bottom-poured ingot casting always restricts the steel volume that can be tapped from the furnace, since the number of ingot moulds in the casting pit determines the product capacity. On the other hand, the continuous casting machine can accept extra steel from the furnace and empty the full ladle.

1.3 Yield

(1) Yield of bottom-pouring ingot casting
The principal loss in this process comes from the runner, pouring gate, and hot top and it is estimated at 2.7 - 2.8% in the case of casting 120 - 140 mm sq. ingots.

(2) Yield of continuous casting
The crop and tail loss and the scale loss in the cooling zone are inevitable. In addition to these losses, the statistically estimated loss has to be considered.

Breakouts, over-casts, and tundish nozzle blockages are the main factors that interrupt the casting operation and influence the yield.

1) The inevitable loss can be detailed as follows:

   (a) Crop and tail loss: 1 - 2%

   (b) Scale loss in spray-cooling zone: 0.3~0.4%

   (c) Scale loss in air-cooling zone: 0.4~0.5%

2) The statistical loss can be calculated as follows: The probability of operational disturbance in certain works is quoted in Table 3.

   In order to achieve the highest yield, complete casting to empty the ladle is the most effective method. If it is assumed that the disturbance ratio influences the yield directly (i.e. this ratio indicates the loss due to disturbance per strand), the ratio on multi-strand machines can be expressed by the mathematical method of probability.

Table 3. Disturbance Ratio (per cent)

Works	Ladle trouble	Tundish disturbance	Break-outs and overcasts	Wrong operation and machine troubles	Total
A	0.60	1.45	1.1	3.07	6.22
B	0.80	1.9	1.4	3.4	7.5
C	0.18	4.57	0.48	0.56	5.79
D	2.61	1.49	1.31	3.30	8.71
E	0.41	2.5	1.0	2.86	6.5
F	1.0	4.4	1.0	2.6	9.0
G	0.27	1.42	3.23	4.58	9.5
Average	0.800	2.533	1.360	2.910	7.603

$$\text{Disturbance Ratio} = \frac{\text{Number of disturbances}}{\text{Number of casts x number of strands}} \times 100$$

$$\text{Ladle Disturbance Ratio} = \frac{\text{Number of ladle disturbances}}{\text{Number of casts}} \times 100$$

If any one strand is stopped by a disturbance and the steel produced is not accepted for the caster, the loss from the stoppage is expressed as follows [x = probability] :

	1-strand machine:	x	0.068
	2-strand machine:	x^2	0.00462
*)	3-strand machine:	$x^2 (3-2x)$	0.0132
**)	4-strand machine:	$x^3 (4-3x)$	0.0252

Substituting ***) 0.068 for "x" by an average from Table 3, the loss due to stoppage of casting is shown in the above table.

Continuously cast billets help to improve rolling yield because the cutting length is so accurate that cropping loss is greatly reduced and the quality of the billet is so uniform that pipe and seam, which are often seen in bottom-poured ingots, are eliminated. The improvement of yield in continuously cast billets is as follows:

Works	Casting size	No. of strand	Furnace	Improvement of yield (%)		
				as-cast	as-rolled	Total
F	100 mm	4	60 ton E.F.	2.8	2	4.8
D	90 mm	2	25 ton E.F.	3.2	1.7	4.9

*) On the basis that the machine can empty the ladle using two out of the three strands:

$$_3C_2\, x x^2 (1 - x) + x^3$$

**) On the basis that the machine can empty the ladle using three out of the four strands:

$$_4C_2 x^2 (1 - x)^2 + {_4C_3} (1 - x) + x^4$$

***) Subtract 0.008 from 0.076 in Table 1.

1.4 Productivity of the rolling mill.

(1) Sub-standard ingots contaminated by slag, refractories, etc. often stoppages of rolling work due to breakdowns.

Breakdown occurred on average 3 - 4 times in 2,000 ingots in works "D". However, the continuously cast billet reduced disturbances for this cause to less than half.

(2) The taper on ingots is essential to facilitate stripping; however, the continuously cast billet is straight enough for the passes of the roughing train to be bypassed. In a plant where 13 mmø, 16 mmø, 19 mmø, 25 mmø, and 32 mmø bars are being rolled from 100 mm billets, an improvement in productivity of up to 20% has been attained.

1.5 Consumable material

(1) Mould

Ingot moulds for bottom-pouring are compared with moulds for continuous casting.

The consumption of ingot moulds is about 10 kg per ton of product of about 140 mm sq. ingot. For the continuous casting of 100 - 150 mm billets, a tubular mould of pure copper is usually used. The life of the latter is mainly limited by the deformation and scratches on it. A well maintained mould can last for 200 charges or 3000 ton of casting steel, with several repairs.

(2) Tundish lining and nozzle.

The refractory material for lining the tundish is of fireclay or siliceous bricks, the same as for the ladle.

Every 20 casts, on average, a complete reline is necessary, after several repairs with bricks or castable refractories. The tundish nozzle must be heat- and wear-resistant, to keep the stream steady during casting.

It is normal to use the so-called zircon nozzle, which contains about 60% ZrO_2 for the tundish nozzle, unless the manganese content in the steel exceeds 1%.

(3) Fuel.

Preheating of the tundish lining is essential in order to distribute the steel without clogging of the nozzles. Fuel consumption will be 1.0 - 1.5 per ton of steel. The preheating time is around two hours.

(4) Electric power

The continuous casting machine uses electric power for mould oscillation, withdrawal and straightening of the billet, discharging the billet, etc.

Excluding the cooling-water cleaning system for the continuous casting machine, electric power consumption will be 6 - 8 KWh per ton of steel.

(5) Cooling water.

The continuous casting machine needs a great deal of cooling water to solidify and cool the steel in the mould and the spray cooling zone and to cool the machine internally. To conserve water, it is usually circulated through a water cleaning plant, where it is cooled and contamination such as scale from the billet in the spray cooling zone is separated in a settling basin.

Oil is also skimmed up by the oil skimmer or removed by an oil fence.

The water loss in a circuit is mainly caused by vapour in the spray cooling zone and drift from the cooling tower.

The water losses can be detailed as follows:

	Water volume ratio	Cause of loss	Loss in per cent to each line	Loss in per cent to total water
Mould cooling	0.8	Overflow	0.2	0.16
Machine cooling		Drift from cooling tower	3.0	2.4
Spray cooling	0.2	Overflow	0.4	0.08
		Drift from cooling tower	3.0	0.6
		Vapour	5.0	1.0
Total	1.0			4.24%

A water volume equivalent to about 4.[illegible]4% of the total circulation has to be supplemented in a main water basin.

(6) <u>Others.</u>

In order to maintain the machine, lubrication oil, grease, and hydraulic oil are topped up periodically.

Further, several thermocouples to measure the steel temperature in the ladle and tundish are used in daily operations.

These additional items cost about 100¥ (0.37 US$) per ton of steel.

1.6 Product Cost.

The estimated cost of processing wire rod or small section is compared in <u>Table 4</u> for the bottom poured ingot process and continuous billet casting.

1.7 Maintenance manpower.

The continuous casting machine comprises so many mechanical components that maintenance is the most important factor in keeping the machine in operation.

Typical manpower requirements for the maintenance of continuous casting machines are shown in <u>Table 5</u>.

Table 4. Cost Comparisons

Condition:

Steel-making furnace	:	50 t E.F.
No. of charges per day	:	13
Casting size	:	130 mm sq.
No. of strands	:	4
Product	:	Reinforcing bar

Item		Bottom pouring ingot casting	Continuous casting	Remarks
1. Electric power for steel-making	KWH/t	530	550	
	¥/t	2,041	2,118	(3.85¥/KW.H)
	(US$/t)	(7.6)	(7.9)	
2. Limestone	kg/t	7.3	15.0	
	¥/t	39	80	
	(US$/t)	(0.144)	(0.296)	
3. Aluminium	kg/t	0.4	0.1	
	¥/t	75	19	
	(US$/t)	(0.278)	(0.705)	
4. Ladle lining	¥/t	130	333	
	(US$/t)	(0.48)	(1.23)	
5. Ladle stopper	¥/t	89	55	
	(US$/t)	(0.33)	(0.204)	
6. Mould	¥/t	430	31	
	(US$/t)	1.6	(0.115)	

Item		Bottom pouring ingot casting	Continuous casting	Remarks
7. Lubricating oil	¥/t	[illegible]	-	
	(US$/t)	(0.148)		
8. Mould lubricant	l/t		0.125	
	¥/t	-	15	
	(US$/t)		(0.05)	
9. Basic brick	¥/t	754	-	
	(US$/t)	(2.8)		
10. Tundish lining	kg/t	-	4.0	
	¥/t	-	120	
	(US$/t)		(0.445)	
11. Tundish nozzle	¥/t		48	
	(US$/t)		(0.178)	
12. Dummy bar head	¥/t		47	
	(US$/t)		(0.174)	
13. Fuel oil	l/t	-	1.6	
	¥/t		16	
	(US$/t)		(0.059)	
14. Electric power to drive machine	kWh/t	-	6.42	
	¥/t	-	25	
	(US$/t)		(0.093)	
15. Cooling water	m^3/t	-	13.0	
	¥/t	-	5	
	(US$/t)		(0.185)	

Item		Bottom pouring ingot casting	Continuous casting	Remarks
16. Consumables	W/t	-	100	
	(US$/t)		(0.37)	
17. Yield improvement	W/t		-300	
	(US$/t)		(-1.11)	

Table 5 - Man-hours for maintenance of continuous casting machine.

Details of machine:

Ladle capacity	30 tons
Number of strands	2
Working days per month	25
Number of castings per day	8
Casting size	120 mm square

Item	Man-hours: Total necessary man-hours	Man-hours: Man/hour per charge	Standard number of persons	Remarks
1. Ladle refractory lining	120	4.8	4	Brick life: 25 charges
2. Tundish refractory lining	21	1.2	3	Brick life: 18 charges
3. Repair of tundish	1	0.5	1	Repaired each time
4. Replacement of tundish nozzle	1	0.5	1	Replaced each time
5. Regular replacement of mould	2	0.01	2	Replaced every 200 charges
6. Replacement of shear blade	1.5	0.0075	2	Replaced every month
7. Build-up of shear blade	3	0.015	1	
8. Repair at time of breakout				
(1) Replacement of mould	0.5	0.005	2	Breakout occurrence rate: 1%
(2) Adjustment of mould	4	0.04	2	
(3) Replacement of roller apron	4	0.04	4	
(4) Adjustment of roller apron	8	0.08	2	
9. Periodical inspection				
(1) Cleaning of filter for air, water, pressure oil, etc.				
(2) Inspection of hydraulic equipment	35	0.36	5	Inspected every 2 weeks
(3) Supply of lubricating oil				
(4) Removal of scale				
(5) Inspection of electric equipment				
Total	201 man-hour	7.5575 man-hr/charge		

2. Sise of continuous casting machine in relation to output

The capacity of the continuous casting machine depends on the number of oasts and strands. They are so determined as to meet the requirement of the product size.

2.1 Casting size and casting capacity.

Casting capacity is defined as the rate of molten steel poured into a certain size of mould. This rate is limited by not only the cooling effect in the mould but also by the casting size. The casting speed corresponding to the casting size is obtained experimentally, as shown in Fig. 3. The casting rate is, however, increased for larger casting sizes.

2.2 Casting size and product size.

Casting size is determined so as to be large enough to be rolled down to product size. Thus, the minimum reduction ratio for the product has to be investigated. Nowadays, there are many reports (1) about the practical reduction ratio. These may be summarized as follows: The ratio 7 ~ 8 is adequate to eliminate centre porosity.

For steel plants making reinforcing bar less than 30 mmø, a billet section smaller than 100 mm is preferable from the point of minimizing the reduction ratio in the rolling mill.

2.3 Limit actions on casting size.

To reduce rolling and to give hig productivity, a mall section billet will meet this objective; however, the smaller the casting size, the more difficult the casting operation becomes.

The casting speed is assumed to be inversely proportional to the square of the casting size, when the casting rate is kept constant. In fact, the casting speed can not be increased as might be expected.

This is mainly due to the casting technique, since it is difficult for the casting operator to control the steel level in the mould so as to counteract variations in the higher casting-speed range for small casting sizes.

Trouble such as breakouts and overcasts are apt to occur frequently with increase in casting speed. Nevertheless, the use of a smaller tundish nozzle to restrict the casting speed causes nozzle clogging.

In practice, an 80 mm sq. billet is the minimum size to permit an increase in casting speed economically, and nozzle diameters smaller than 13 mm lead to severe nozzle clogging and result in a decrease in the productivity of the machine.

The irregular and divergent steel stream from the tundish disturbs the even and symmetrical solidification in the mould as well as in the spray cooling zone.

If the steel stream is always brought to the centre of the mould by means of, for example, a stream centring device, complete casting until the tundish becomes empty is possible in spite of an irregular stream at the casting end.

[illegible].4 Number of strands.

The number of strands in the continuous casting machine has to be calculated so that the casting time does not exceed the heat cycle of the furnace and the steel temperature does not drop down to the lower limit.

The steel temperature drop in the tundish is due to the steel retention time and its holding capacity. In order to minimise heat loss in the tundish, the steel retention time should not exceed 10 min.

A multi-strand tundish, which requires a long and slender container, makes it difficult to distribute the steel to each nozzle. The temperature gradient is naturally greater in the longitudinal direction.

A six-strand machine is the maximum that can be cast with a single tundish; double tundishes can be used to minimize the temperature gradient.

From the view-point of maintenance costs, more strands mean higher cost per product tonnage rate.

On the other hand, a single strand machine has so little flexibility that its operation can be stopped by minor troubles.

3. <u>Future trends</u>

As mentioned before, the continuous casting process has an advantage in that the product yield is improved owing to reduction in steel loss, etc.

Starting with this advantage, the remaining problems then require to be solved, with the object of:

(1) Increasing product yield:

(2) Increasing productivity;

(3) Reducing product cost.

Some methods of doing so are given below:

3.1 In-line reduction mill.

The process in which a somewhat larger cast strand is rolled to the required size after the withdrawal roll unit is known as in-line reduction.

This process gives the following advantages:

(1) The casting operation itself becomes easier owing to the larger mould size.

(2) The casting rate per strand is increased, permitting the use of a machine with a minimum number of strands.

(3) Billets smaller than 80 mm sq can be delivered.
Our tests show that a 110 mm sq mould can provide stock for reduction to 80 mm sq billet in two mill passes.

(4) The work of changing casting sizes on the machine is eliminated, so that the machine running rate is improved.
For works where billets are made in small quantities for one size but in many sizes, the down time for stopping the machine and changing the casting size is minimized.

(5) Rolling at a temperature between the solidification point and about 1,250°C helps to close up the centre porosity and improves the central structure.
As-cast, the billet is as sound as the rolled product.
Our tests showed that rolling billets with a liquid core (i.e. rolling before complete solidification) was not practical because it was too difficult to control the crater depth.

Rolling to size with an in-line reduction mill has the above-mentioned advantages; however, its economic advantages must also be compared. Whether a single breakdown pass can be comparable with an in-line mill installed on each strand is the key point. The essential factors in designing an in-line mill are:

a) A compact design, for installation in a narrow space (normally smaller than 1.5 m for billets up to 150 mm sq.)

b) A low roll speed to synchronize with the casting speed.

c) A high torque to roll down the billet.

For example, the in-line reduction mill can have the following characteristics:

Mould size	Reduced billet size	Roll speed (r.p.m)	Torque (kg-m)
120 mm sq	80 x 125	1.85	12,000
	85 x 85	2.30	9,000

3.2 Automatic operation

On existing continuous casting machines, the principal function under the control of human operations is the control of the steel volume poured and the withdrawal speed, i.e. the time-volume control system.

Such control work requires skill and training on one part of the operations; however, they can be replaced by an automatic control system. For example, an automatic steel level control system makes it possible to reduce the number of casting operators, and they only have to concentrate on removing the slag on the meniscus. Since training costs are mainly spent on casting operators, a reliable control system can help considerably to reduce production costs. Nowadays, two strands can be managed by one operator.

3.3 High speed.

Since the casting rate is increased in proportion to the casting speed, machines tend towards those with casting speeds. In this case, the quality of the product is more important than the machine capacity.

The discussion about the optimum machine type for high casting speeds has not yet ended; however, as the curved-mould machine is popular at present, the strain rate as well as the integrated strain when bending or straightening the product is the factor necessary to eliminate billet defects when the casting speed is increased.

As the higher casting speed causes a deep crater in the billet, non-metallic inclusion, segregation, and central porosity become more significant.

The target speed we are aiming is shown in Fig. 1.

3.4 Sequence casting.

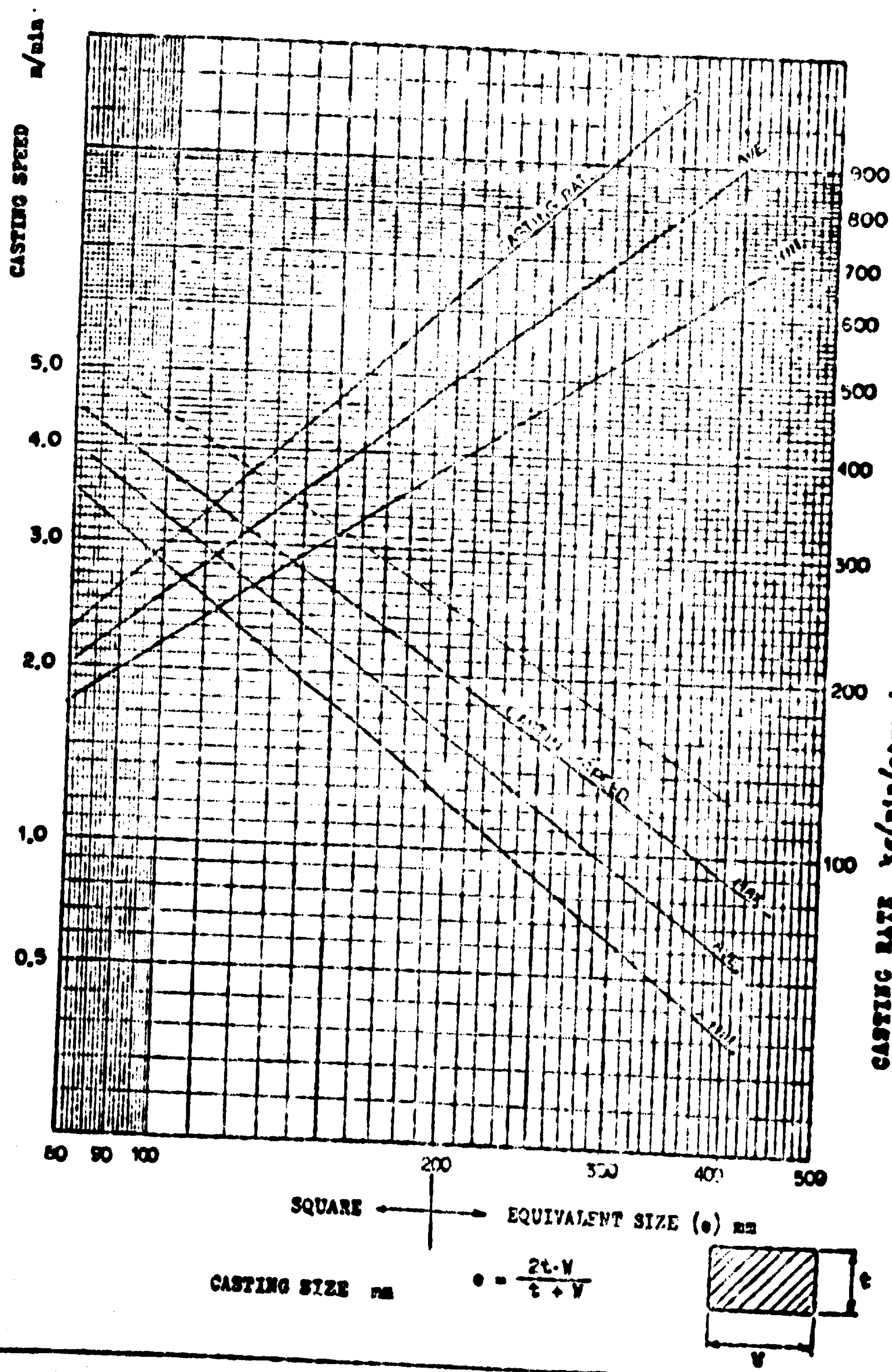
If the working rate of the continuous casting machine is expressed by the ratio of actual casting time to total working time, the working rate is about 50% in ordinary operation, in which 60 min. casting work and 60 min. preparation work are repeated for each cast. This value is very small compared with that of a rolling mill, which works at about 80%.

Because improvement in working rate is achieved by shortening or eliminating the preparation time, it has become common to adopt the so-called sequence or series casting process, in which casting continues with the substitution of new ladles before the tundish becomes empty.

Fig. 2 shows that the working rate is improved by adopting sequence casting. It contributes to the improvement in yield and also in production costs, since the loss from head and tail crops, residual steel in tundish, etc. is minimized, the tundish nozzle does not have to be changed, and the tundish need not be preheated.

Fig. 1

CASTING RATE AND CASTING SPEED



4. Conclusions.

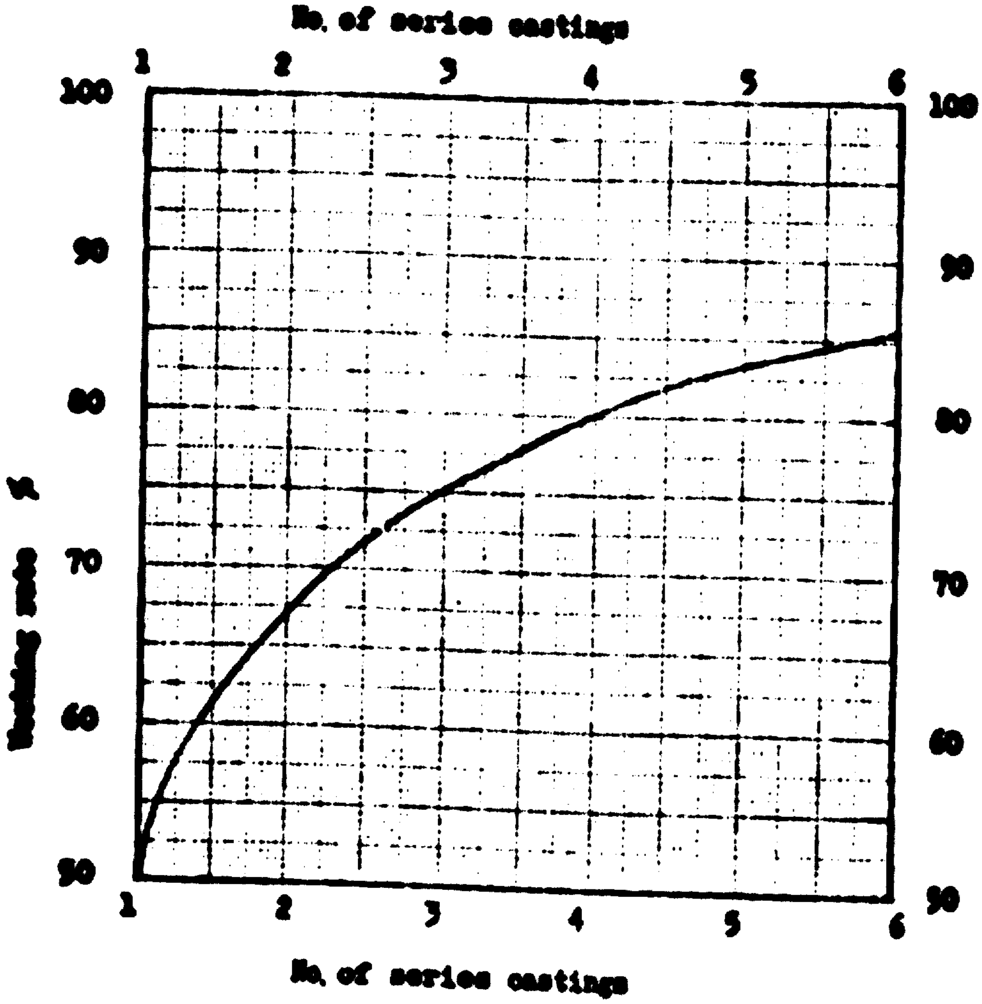
In view of the fact that continuous casting gives higher yields and lower product costs and makes it possible to produce small-section billets of uniform quality, it has been accepted in the steel plants in price of the bottom-pouring ingot casting process. However, when compared with the electric arc furnace or the rolling mill, the continuous casting machine still has disadvantages, such as:

1) The ratio of disturbances to production due to bad operation is higher.
2) The success of the operation lies in the skill of the operators.
3) Productivity is relatively low.

In the near future, the continuous casting machine equipped with an automatic control system and an in-line reduction mill will overcome these disadvantages and establish an unassailable position in steel plants.

. 2 NO. OF SERIES CASTINGS - WORKING RATE

Based on 60 min. casting and 60 min. preparation.



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1. For example,

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