Recent experiences of continuous casting at Highveld Steel and Vanadium Corporation Limited

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SYNOPSIS

Vanadium slag production in the shaking ladles started in April 1968, steelmaking was begun in July 1968 and the first continuously cast blocks were produced soon after on the 29th July, 1968. Nominal monthly production of over 20 000 tons was reached in seven months and by December 1970 about 12 000 heats were cast and a monthly production of 35 000 tons has been achieved.

PLANT DESCRIPTION

The Plant was built by Demag Stranggiess-Technik GmbH, and is operated under a license agreement with SSG/ÖSIG according to the processes developed by Mannesmann and Böhler.

The continuous casting plant consists of three bow-type machines, joined by a common casting floor, 11 m above ground level. Figs. 1 and 2 show a plan view and a side elevation of the plant respectively. Machine 1 is a four strand machine casting 5½ and 8 in. square billets. The machine is equipped with vertically oscillating straight moulds; bending and bow-entry taking place shortly after the block emerges from the footrollers. The bow radius is 10 m. Machines 2 and 3 are identical and are two strand slab machines casting 22 × 12 in. and 22 × 10 in. blooms. The machines are equipped with curved copper plate moulds and the outer radius is 11.5 m.

A severe drawback of the present lay-out is the limited space available on the platform; too small to allow nozzle setting in tundishes, preheating of a larger number of tundishes at the same time and room to do smaller repair work on the spot.

Two semiportal casting cars which run the length of the casting floor are available.

EQUIPMENT

Steel Ladles

The steel ladles are bottom poured and stopper controlled.

Nozzles are conventional fireclay (1⅝ in. diameter). The stoppers are 2 in. solid rods with flange type ends with 6 in. sleeves and a 6¾ in. graphitic fireclay head.

No special sleeves are used in the slag line. The quality of locally manufactured sleeves has not consistently matched those of overseas manufacturers and has been the major cause for the greatest part of our stopper problems. Aircooled rods have been used, but there appeared to be no apparent advantage. Ladles are lined with 42 per cent and 60 per cent Alumina bricks. Comparison of the two types of refractories has shown a definite advantage and a cost saving when using the second type of R0,06/ton. Ladles are not preheated.

Tundishes

Tundishes are equipped with two or four nozzles as appropriate. The original design of tundish shape has proved a disadvantage in that the ratio of steel bath level to capacity is too great, resulting in excessive heat losses during casting. In addition the bath is shallow creating unfavourable stream conditions due to the low ferro-static head above the nozzle. Our intention is to go to a deeper tundish. This in turn will permit a greater range of control of the casting rate without the use of stoppers. The elimination of the inpouring spout will reduce damage to the lining during deskulling. Extensive effort has been expended to find a better way to line the tundish to improve life.

Recent experiments using normal sized fireclay bricks and applying a coating material (Chrome Magnesite) between casts seem to have eliminated steel penetration and made deskulling with only minor repairs to pouring pad and nozzle area possible. A considerable increase in tundish life is anticipated (see Table 1).

TABLE 1

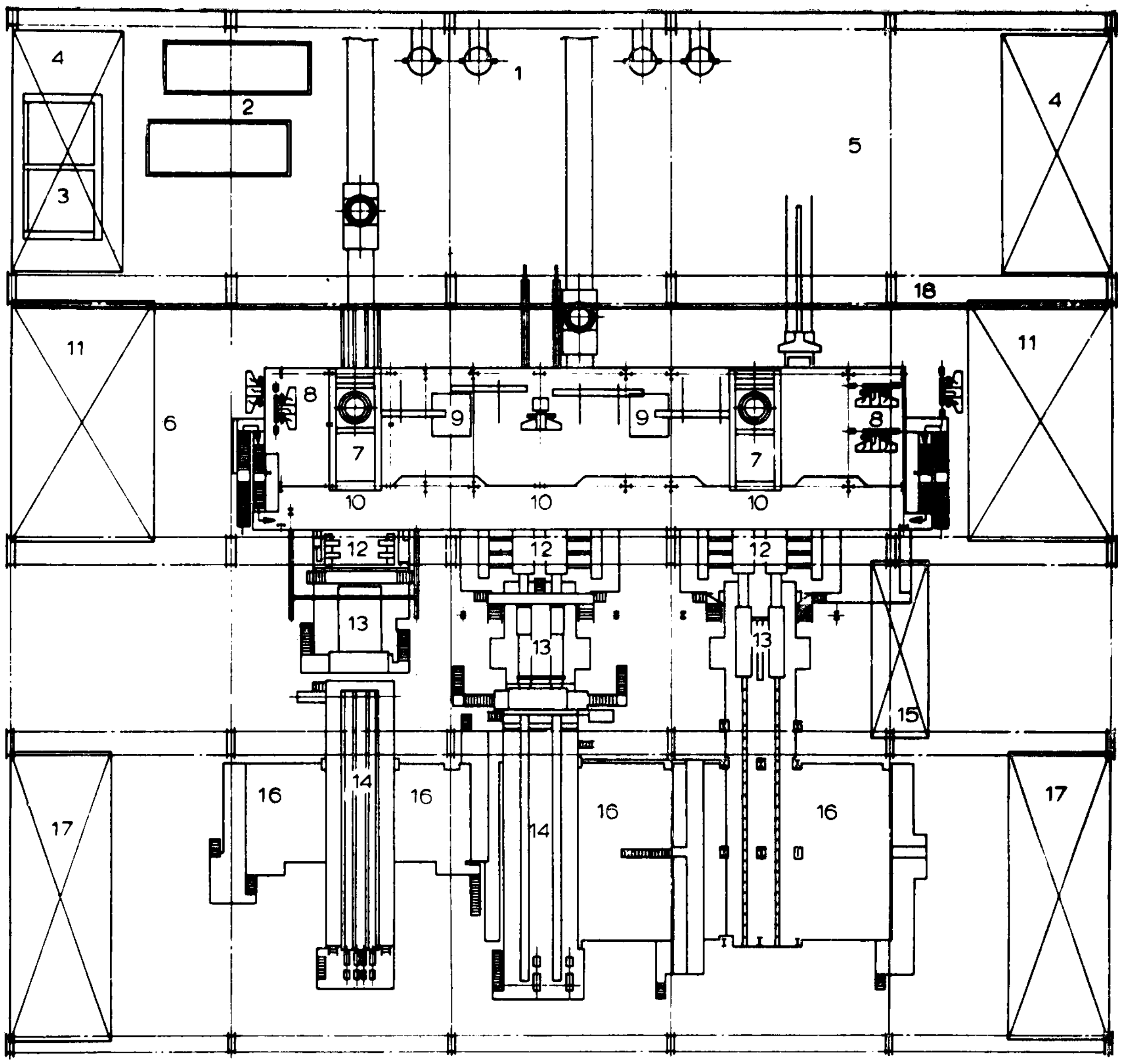
Shape of brick	Quality of brick	Coating	Saving R/Ton
Normal	42 per cent Alumina	None	—
Large	60 per cent Alumina	None	0,09
Normal	36 per cent Alumina	Cr-Mag.	0,12

Simplification of tundish shape should further reduce tundish costs. Since multiple sequence casting has become standard practice, all tundishes are equipped with high quality refractory nozzles (composite 80 per cent Al_2O_3 — insulating backing or Zirkon). Zirconium silicate nozzles have proved satisfactory with casting times extending to 6 hours. More difficulty was experienced in finding a suitable stopper to match the performance of the nozzles. A pressed single piece stopper manufactured from graphitic fireclay can be relied upon to withstand 4 consecutive casts and on one occasion has been used for 6 consecutive casts.

When stopper failure is experienced, an attempt is made to replace it by a new one, a procedure lasting up to 1½ minutes. Teeming arrests and at times ruptures and breakouts make this practice dangerous.

On the billet machine and eventually on all sections, casting without tundish stoppers is envisaged. The maintenance of the casting level in the mould will be achieved by speed changes and changes in the ferro-static head in the tundish.

At present, the limitation to prolonged sequence casting is our inability to change tundishes in a time



1 Casting ladle drying and preheat
2 Casting ladle wrecking, bricking, and repair
3 Steelmaking slag pit
4 30 ton ladle and tundish cranes
5 Tundish repair area
6 Emergency conventional casting area
7 Casting ladle car
8 Tundish preheat
9 Emergency ladles
10 Machines 1, 2, and 3
11 90 ton EOT cranes
12 Withdrawal and straightening
13 Cutting
14 Dummy bar ramp
15 10 ton maintenance crane
16 Cooling beds
17 30 ton EOT cranes
18 Main service tunnel

Fig. 1—Plan view of continuous casting plant.

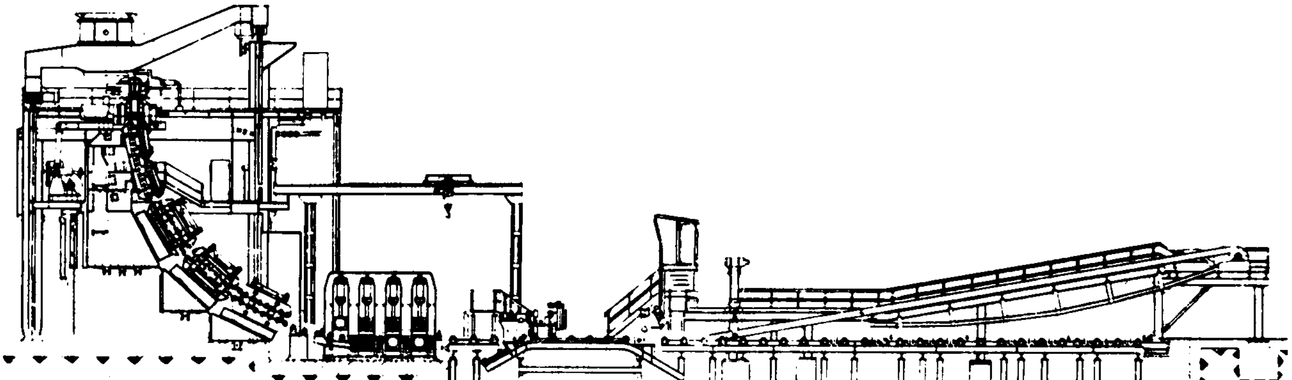


Fig. 2—Side elevation — machines 2 and 3.

interval short enough to avoid serious teeming arrests. Here we envisage the use of selfpropelled tundish cars, which will enable tundish switching in less than 1 minute.

Moulds

The moulds are of copper plate construction and oscillate with a sinusoidal motion.

Numerous problems were experienced with mould plate repair. The method of copper spraying of gouges and of complete surfaces was tried with limited success. There was a tendency for the spray to peel off after a very short life. Since little wear is experienced on plate surfaces, and severe damages and/or wear is generally localized (e.g. deformation in the vicinity of the joints and gouging due to mechanical damage) we are now using welding as a method of repair and better results have been achieved.

It is generally accepted that the opening of joints after some time of operation is inevitable when using a plate mould. This phenomenon however developed to such a serious problem on our $5\frac{1}{2} \times 5\frac{1}{2}$ and 8×8 in. moulds that mould life at present averages 30 heats on the $5\frac{1}{2} \times 5\frac{1}{2}$ moulds compared with 70 heats on the 22×12 in. moulds. Fig. 3 illustrates the poor performance of the billet moulds. We are considering the use of thin walled tube moulds for these sections. Shell shrinkage is partially compensated by the taper of the mould. The absolute value of the taper varies with dimensions (width and thickness) of the block. It is 1 per cent over the length of the mould. Since it is impossible to design a mould which will compensate exactly for the shrinkage under all conditions, a 1 per cent taper is believed to be a good optimum value. Therefore the strand shell usually lifts off the mould wall after 8 to 10 ins. and only partially contacts the wall below this as a result of ferro-static pressure. In our opinion the practice of increasing the mould length for higher casting speeds as advised by several authors achieves nothing else than to create a safeguard should bleeders or small breakouts occur.

Aprons and Secondary Cooling

The use of a straight mould with subsequent bending of the billet in the first part of the apron, as employed in the design of our four-strand machine is, in our opinion, an unfortunate arrangement. It has proved to have several disadvantages compared to the curved mould and footroller arrangement. Overcooling due to operational trouble can cause either strand sticking due to being unable to bend the billet or damage to the bending rolls and possibly the apron frame when the block is forced through. The removal of cold strands is complicated and extends repair times after breakouts. Furthermore we believe, the danger exists when casting crack-sensitive steel that cracking can occur near the solid-liquid interface.

Aprons and guide frames have in all cases been heavily overdesigned resulting in bulkiness with compli-

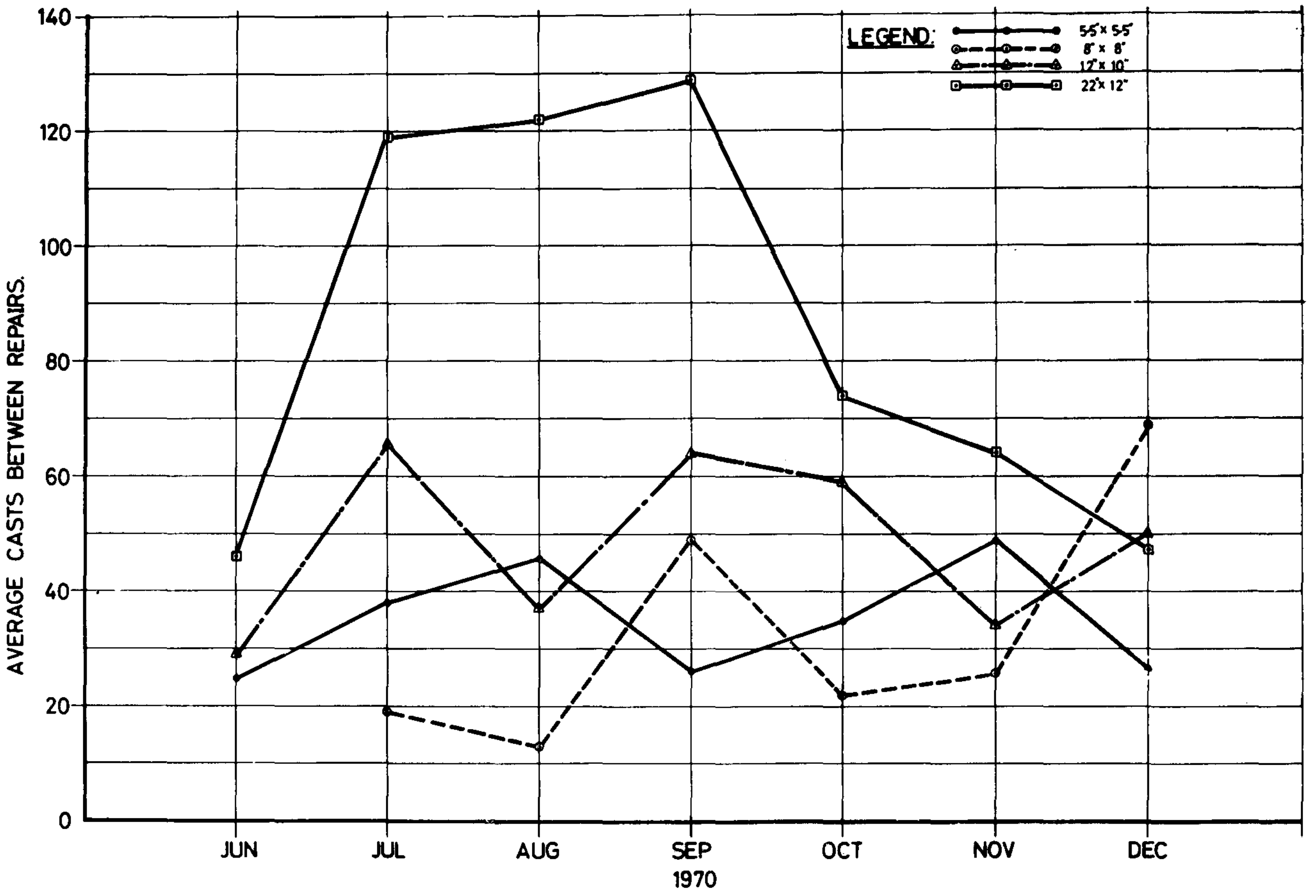


Fig. 3—Average mould life during second half of 1970.

cated and breakout-sensitive parts of machinery. A programme of drastic simplification, mainly consisting of removal of superfluous rollers has already been started with no signs of deterioration to block shape or quality.

One of our major trouble spots is the roller bearing design in aprons and guideframes. The bushes on both ends of the roller are cooled and lubricated by water. This water leaves the bearing on the block side, resulting, dependent on the setting, in severe overcooling of the block edges or in the other extreme, dry bearings. Adjustment is almost impossible.

Serious thought must be given to an entirely new type of roller and bearing design.

Cutting

High intensity oxygen-propane torches cut the blocks on the run; iron powder dispensation is provided for accelerated cutting. In the initial stages length measuring was done by means of a measuring roller, coupled to an initiator which signalled an electronic counting device. This in turn, when the pre-set length was reached, transmitted a signal to the equipment to commence the cutting operation. Due to the exposure of sensitive electronic equipment to heat, water and dirt, the maintenance required to keep the system operative was excessive. It was then decided to change to an infra-red sensitive photo-cell arrangement moving along a scale next to the block. The accuracy of cutting to length has improved remarkably to a value of $\pm\frac{1}{2}$ per cent.

OPERATION

Casting

It was realized soon after commissioning of the machines that casting of 22 × 12 in. sections was impossible with the use of rape seed oil alone, because of freezing of the liquid surface resulting in severe overlapping and at times transverse cracking.

We were therefore forced to make use of a layer of synthetic slag, added in the form of casting powder. We have experimented with 3 types:

(a) Highly fluid powders with a fusion temperature of up to 1 000 °C.
(b) Medium fluid powders with a fusion temperature between 1 000 and 1 250 °C.
(c) Viscous powders with a fusion temperature exceeding 1 250 °C.

We have found the medium fluid type powders best suited for the casting of our sections.

Chemical analyses can only act as a guide, since with varying analyses similar melting characteristics can be achieved (Table 2).

Regarding the usability of a casting powder, the practical performance of the powders in the mould is in our opinion of the greatest importance. The powder should spread readily on the casting level and should melt at the rate it is being consumed as a lubricant, on its downward flow between mould wall and block surface. Lower melting points result in the formation of sticky collars at the mould wall. Higher melting points result in the slag acting as an insulator only, so that oil must be used, and as the powder is not consumed it must at intervals be replaced increasing the risk of breakouts.

Since our tundish support design allows neither raising nor lowering of the tundish, casting with submerged nozzles is difficult. We have experimented both with vertical and horizontal outlet snorkels and will incorporate features on the tundish car to permit the trouble free use of submerged nozzles. A quiet casting level, no splashing, the avoidance of powder entrapment by the free-falling stream are some of a number of advantages of snorkel casting.

Cooling

In an attempt to raise the casting speeds a new look had to be taken at the secondary cooling. Since no adverse effects were found such as cracking or concavity we decided when casting structural grades to concentrate 50 per cent of the total spraywater below the mould. Increases in casting speeds of up to 50 per cent of previous speeds and as much as 100 per cent of the speeds recommended by the suppliers were achieved (Table 3).

TABLE 2

CASTING POWDERS, CHEMICAL ANALYSES AND MELTING POINTS

Powder make	CaO	SiO_2	Al_2O_3	MgO	Na_2O	K_2O	Na_2CO_3	CaF_2	FeO	Fe_2O_3	C	Melting point °C
A	31,4	29,2	10,3	3,8	2,1	0	—	2,5	2,8	3,1	4,7	1 220
	34,0	33,4	14,0	4,2	—	0	3,8	2,1	0,3	2,6	4,4	1 260
	17,0	39,0	17,4	3,3	5,6	0.6	—	16,2	—	3,8	1,1	1 150
	21,7	31,5	17,2	2,8	3,5	2.0	—	15,4	—	3,2	5,0	1 120
	18,8	37,7	16,1	2,5	9,0	0.4	12,4	1,0	—	—	1,0	905
B	32,0	30,0	11,2	3,3	2,9	2,0	—	7,1	4,2	—	5,0	1 130
	35,0	28,4	10,4	1,3	3,4	0,8	—	17,1	6,4	—	4,8	1 150
	31,0	30,1	12,4	2,5	3,6	2,1	—	6,5	5,1	—	4,9	1 140
C	39,4	28,6	5,0	1,2	1,7	0,6	—	10,8	3,2	—	—	1 180
	31,5	30,0	14,0	2,0	3,3	2,5	—	7,2	—	6,0	5,0	1 205
D	3,0	44,0	24,0	2,0	2,0	4,0	—	0	5,0	—	13,0	—
	4,6	40,0	20,2	1,3	3,0	0,8	5,1	9,1	5,3	7,3	—	1 235

All above powders were supplied as 'medium fluid powders'.

TABLE 3

CASTING DATA

Section mm × mm	Weight kg/m	Casting speed mm/min	Casting rate kg/min	Casting time min/1 000 kg	No. of strands	Primary cooling l/cm. circ.	Spec. Sec. cool l/kg	% of total at present
140 × 140	152	1 775	270	3,70	3	22,7	1,14	14,5
204 × 204	321	1 270	408	2,45	1	18,4	,87	7,9
305 × 254	605	1 015	615	1,63	3	18,8	,87	56,9
560 × 305	1 330	510	680	1,47	1	14,8	,59	20,7

Availability

The availability of a plant is measured by the frequency of breakdowns which affect production. Fig. 4 illustrates the ratio between trouble-free cast strands and the total number of strands attempted in a month. 23,32 per cent of the strands had to be discontinued because of some breakdown or other (curve 1).

The same figure shows the ratio of completely cast heats to the total number of heats. (Curve 2). At present 7,7 per cent of all ladles are not completely cast because of some breakdown, the casting plant (i.e. from tundish onwards) itself having a share of 2,9 per cent in this figure.

Analysis of these breakdowns led to the following division of faulty plant components.

(a) Ladle with stoppers and nozzles.
(b) Tundish with stoppers and nozzles.
(c) Mechanical and electrical faults on the casting machines (moulds, drives etc.).
(d) Mechanical and electrical faults on cutting and associated equipment.
(e) Breakouts.

Fig. 5 shows the frequency of breakdowns per month according to the above division. The number of strands started over the respective month is the reference value for all breakdowns.

Breakouts still cause tremendous headaches due to the influence they have on the smooth flow of continuous casting plant production. The breakout frequency lies at about 2,2 per cent at present. This unfavourable figure should be improved by the introduction of sub-

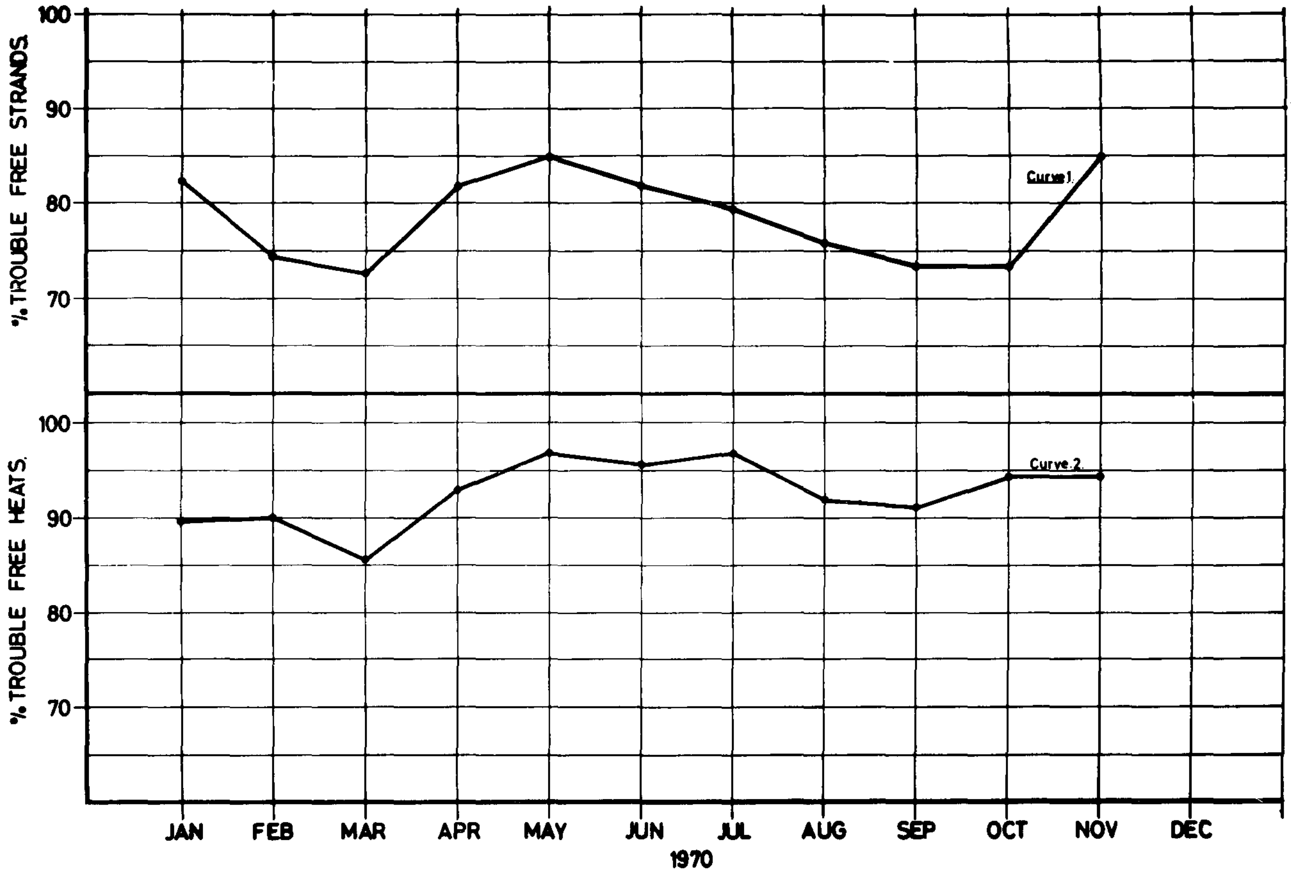


Fig. 4—Ratio of trouble free strands cast and trouble free heats cast.

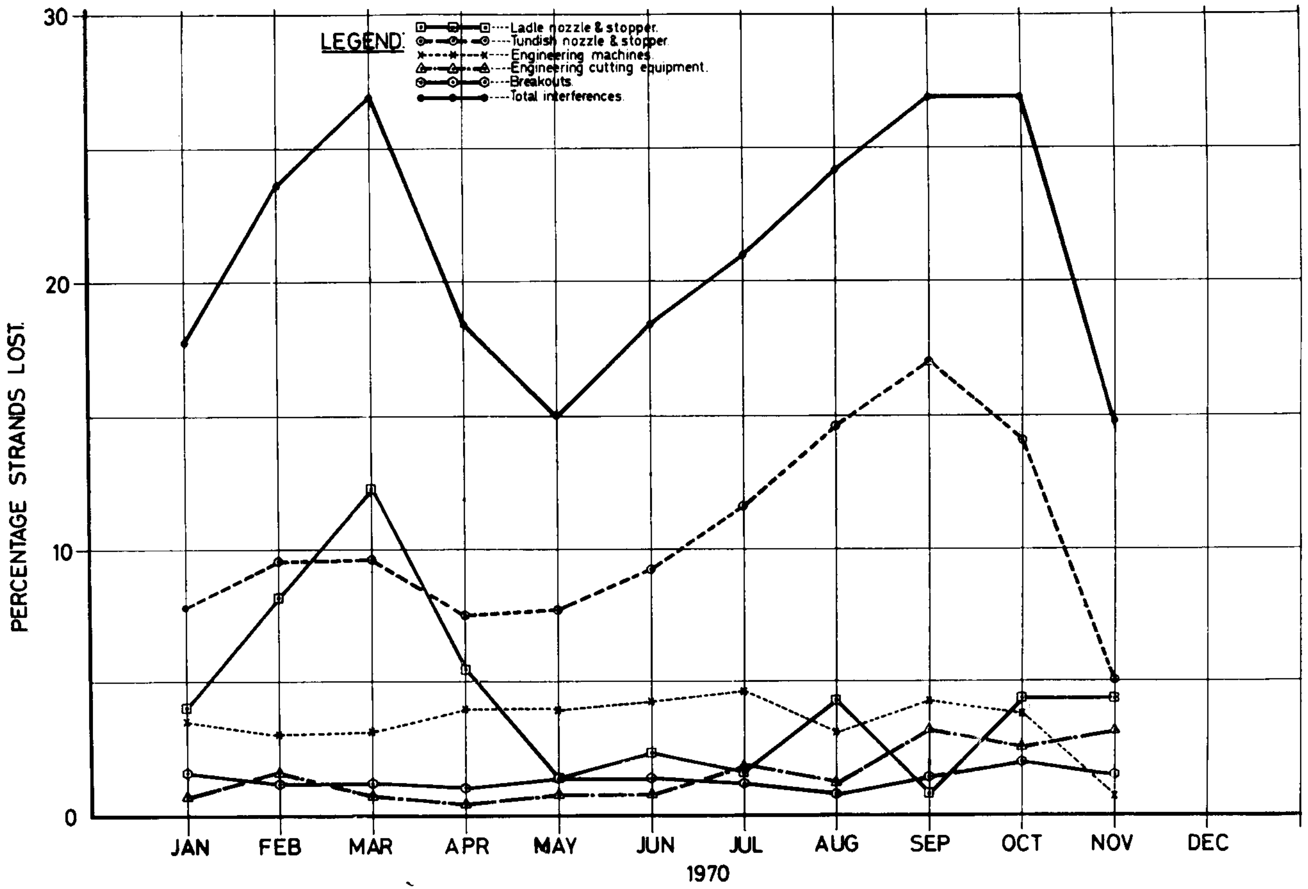


Fig. 5—Frequency of breakdowns during 1970.

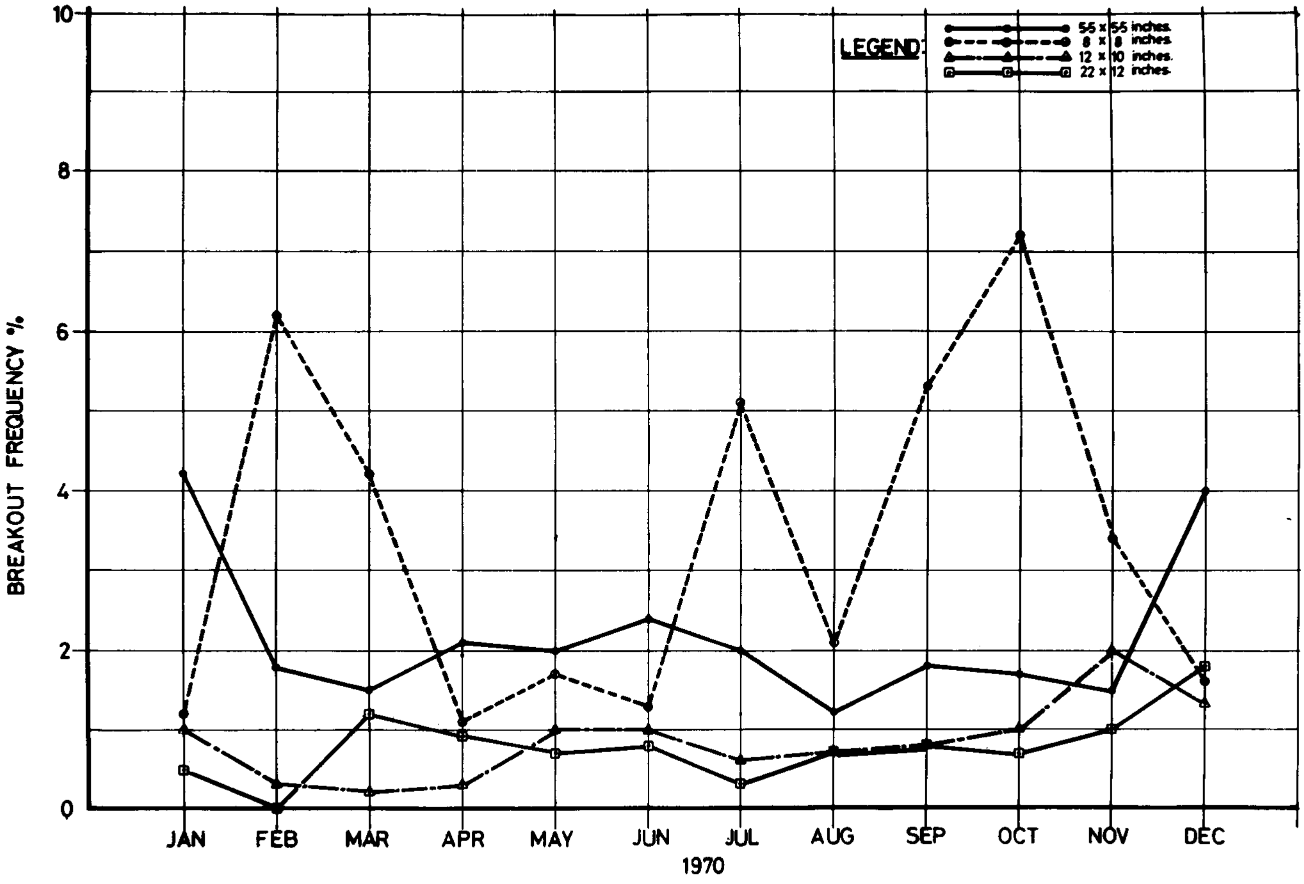


Fig. 6—Analysis of breakouts during 1970.

merged nozzles, introduction of tubular billet moulds and closer control of operations.

A breakdown of our breakout rate is shown in Fig. 6.

Development of Production and Yield

Fig. 7 is a quarterly production chart of the machines from the date of their commissioning up to 30.11.1970. The development of sequence casting is illustrated in Fig. 8.

At present 70 per cent of all casts are sequence cast. A record was established when six 70 ton ladles were cast through one tundish, 420 tons of steel were converted into blocks in 6 hours 1 minute. This may not be impressive by American or Japanese standards, but to effect substantial improvement in sequence casting, it is essential to have facilities for switching tundishes and an assurance of continual iron supplies to match the required rate of steelmaking.

A detailed analysis of our yield during November, 1970, is given in Table 4. The overall finished section yield is at present 87 per cent. All grades cast are killed steel as delivered to the machines. Although 95 per cent of the tonnage has been structural steel, rail quality heats have been cast. At one stage rail steels created a serious problem, each cast invariably resulting in a breakout. We believe the cause to lie in the lower solidification temperature and the greater range between liquidus and solidus temperatures. At the same mould cooling as for structural steels the thickness of solid shell at a fixed point below the casting level will be considerably less. Uneveness of mould plates, slight opening of the joints or insufficient lubrication could mean trouble-free casting of structural grades, but can cause serious trouble when casting rail steels.

Defects affecting quality

(*a*) *Rhomboidity*

Rhomboidity is defined as the difference between the diagonals of a bloom or billet and is divided into 4 degrees of severity on an arbitrary basis.

At present the percentage of blocks affected by rhomboidity of medium and extreme severity does not exceed 0,25 per cent. This percentage is diverted to products not affected by this characteristic.

The cause for rhomboid shapes can be found in uneven cooling or faulty bow alignment.

(*b*) *End-face cracking*

This terminology applies to diagonal, horizontal and vertical half-way cracks. The cracks are of intercrystalline nature and are usually caused by one of the following factors:

(1) Uneven spray-cooling,
(2) Inadequate roller support in the early stages,
(3) Misalignment of the bow.

Endface cracking is often associated with rhomboid distortion. The cracks can be present in

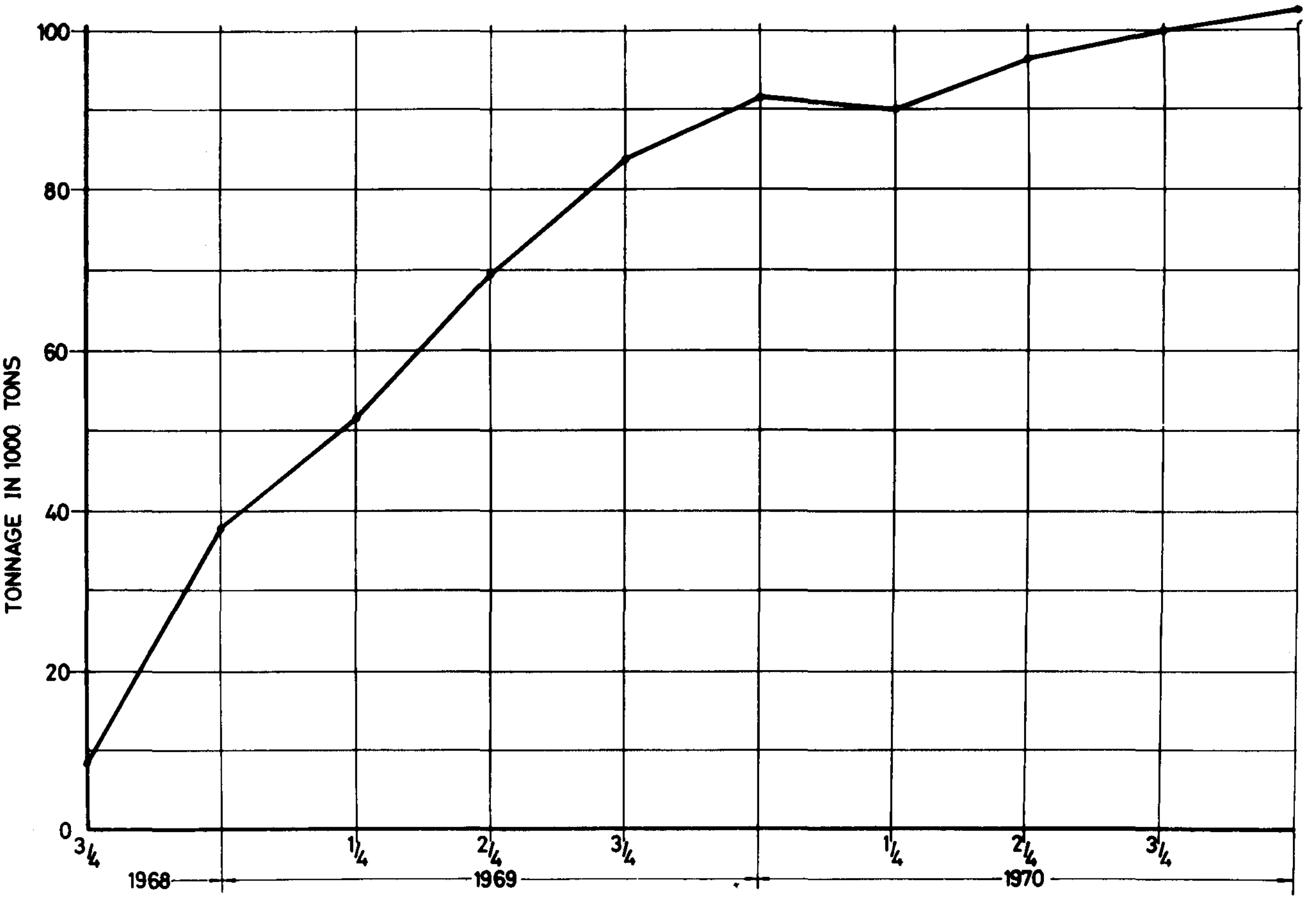


Fig. 7—Quarterly production chart since start-up.

TABLE 4

YIELD AND LOSSES OF CONTINUOUS CASTING MATERIAL FROM LIQUID LADLE STEEL TO FINISHED SECTIONS DURING NOVEMBER, 1970

CONTINUOUS CASTING

	ton/month	%
Total ladle steel	36 671	100,0
Tundish skull	1 202	3,3
Scale loss	—	—
Cutting loss	—	—
Other losses	—	—
Head tail loss	438	1,2
Blockyard loss	42	0,1
Wrong lengths, shorts etc.,	109	0,3
Total losses	1 791	4.9
Total blocks produced	34 880	95,2
Concast blocks despatched	6 957	—

	Tons per month			Percent		
	Billets	Sections	Rails	Billets	Sections	Rails
Blocks charged	11 194	15 443	1 286	100	100	100
Rolling losses:						
Scale	604	1 641	168	5,37	10,65	13,06
Cobbles						
Crops						
Rolling defect						
Steel loss	30	37	1	0,03	0,24	0,08
Prime material	10 587	13 765	1 117	94,6	89,13	86,06

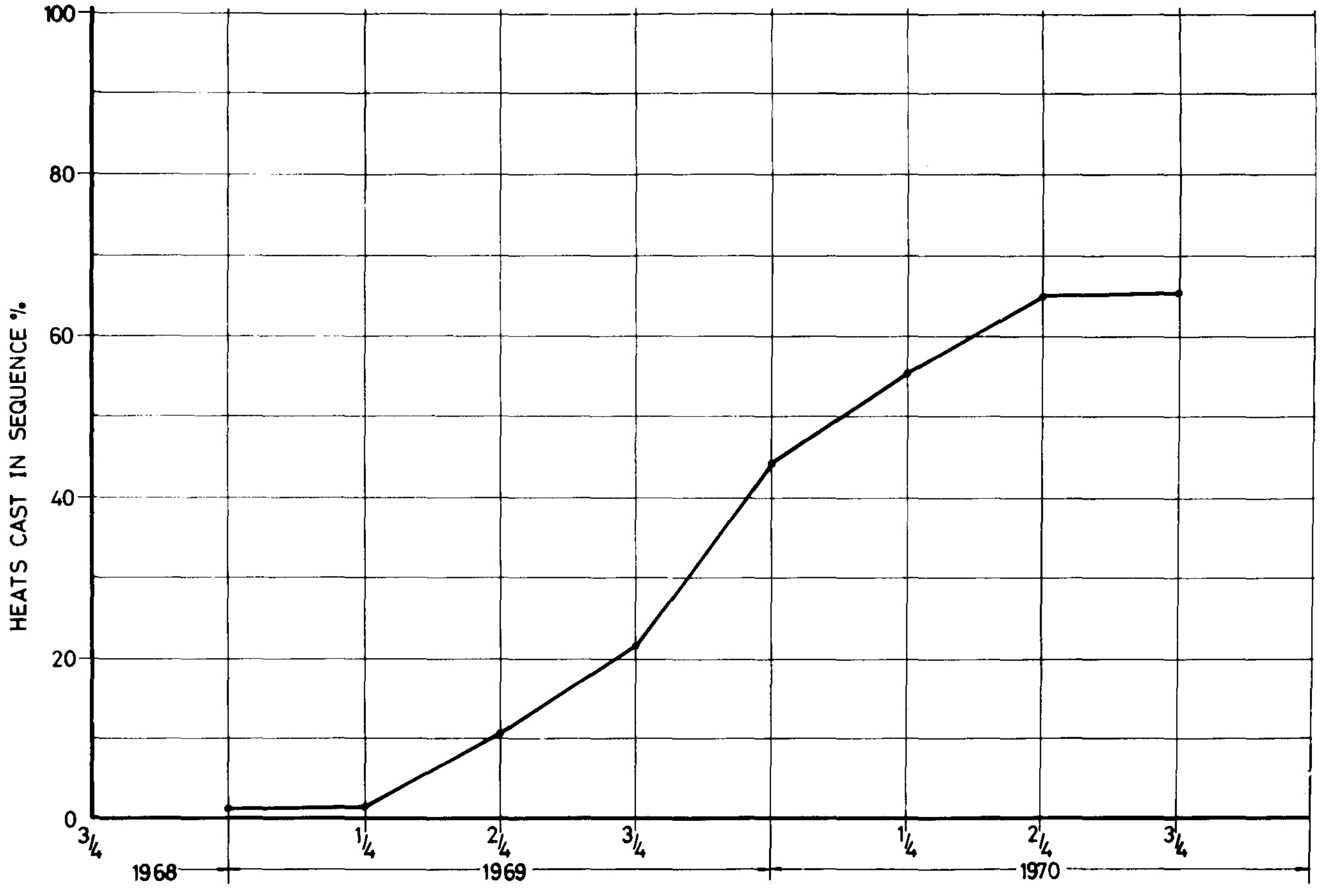


Fig. 8—Quarterly representation of the development of sequence casting at Highveld.

varying severities which are considered when allocating the blocks.

The finished product defects arising from end-face cracking can be aggravated by reheating practice and it is suspected that they are influenced by the Mn/S ratio.

(*c*) *Other defects*

Surface cracking such as longitudinal and transverse cracking on corners and faces poses no problem as the frequency is so low (.03 per cent).

(*d*) *Allocation of blocks*

Before being charged, casts are allocated to the various sections on the basis of estimated mechanical properties, Mn/S ratio, and block quality.

If the silicon content is below 0.15 per cent, blocks are subjected to a pinhole count and if necessary reallocated.

Mechanical properties of the sections rolled

No troubles have been experienced in meeting the mechanical properties in the specifications laid down for the products rolled.

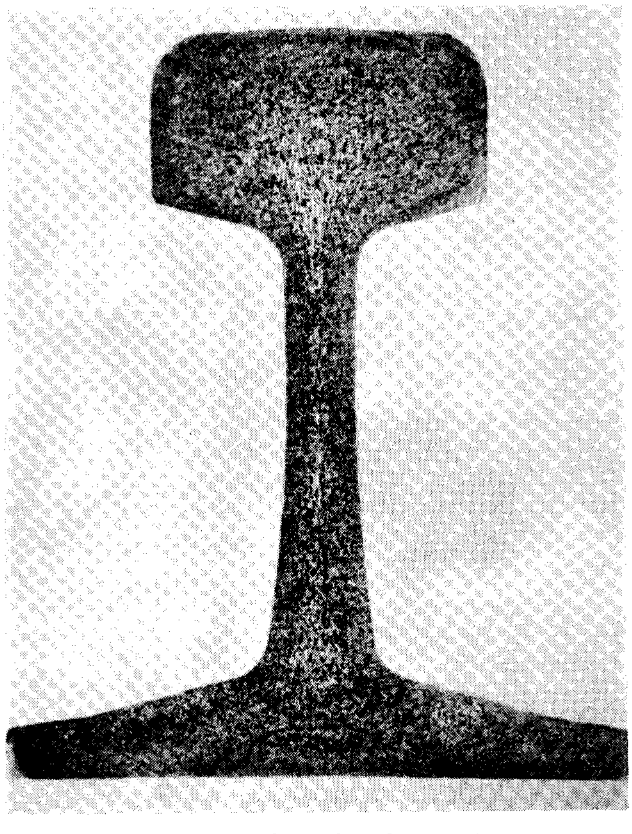


Fig. 9—Typical sulphur print of a 96 lb./yard rail.

The internal quality of rolled sections has been satisfactory. Fig. 9 shows a sulphur print from a typical 96 lb/yrd rail.

Chemical Properties of Cast Material

Throughout a cast the variation in analysis is negligible and is also extremely consistent across the section.

Average variation across section:

C	,025%
Si	,015%
S	,005%
P	,002%
Mn	,02%

CONCLUSIONS

In summarising our Continuous Casting Operation we believe that we have achieved a great deal in some areas such as quality and yield, but still have to improve the operation in other areas such as: Refractories, Engineering Maintenance and Operation Technique.

We at Highveld have a unique integrated operation, which makes steelmaking to some extent an unconventional operation. However, we can be proud of the yield of finished product from liquid steel. Taking into account all steel losses in the Steel Plant and Rolling Mill, we have achieved a yield of 87 per cent finished product from liquid steel. As can be seen from Table 3 the finished rolled product rejection due to steel defects is .15 per cent. This is achieved without scarfing or preconditioning of the cast blocks.

The other area where we have made significant progress is sequence casting. With the introduction of a number of modifications to the machines, continuous sequence casting can be made a standard practice.

Progress has to be made in standardizing and optimising of refractory quality, both in the ladle and tundish. Secondly, major simplification and modification programmes have to be made to reduce our maintenance costs and to improve the turnround of machines to meet availability necessary for future increased tonnages.

Thirdly, we need a more stable working force in order to improve the operational standards, which can only be achieved by training and experience.

Our aims are to maintain and improve both quality and yields and to concentrate on the weak areas mentioned above, which could improve our rather poor breakdown frequency and contribute substantially to reducing the conversion costs of the Continuous Casting Plant.