HOT TOPS FOR STEEL INGOTS - THEIR DEVELOPMENTS AS INFLUENCED BY SOLIDIFICATION PATTERNS

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This paper is concerned with hot tops for steel ingots, an area in which Foseco has been actively involved for many years. After defining the need for hot tops, the historical development is reviewed, highlighting the major steps taken in the development of the two hot top components - sideliner and top cover, in particular the impact made by the introduction of lightweight expandable PROFAX (R) sideliners and successive generations of anti-piping compounds. It next examines current developments, in particular superlightweight exothermic sideliners, and anti-piping compounds in board form. Also included in this section is a review of the ancillary testing techniques used in the development of these new products - these techniques including a computer model for predicting ingot solidification profiles. Finally the future course of hot topping practice is considered highlighting those areas in which further developments are anticipated.

THE NEED FOR HOT TOPS

Shrinkage of steel during the ingot casting process is the reason why hot tops are needed. This is illustrated in Figs 1a-1b which, although a much simplified generalisation, do demonstrate the marked contrast between using an insulated head and taking no account of shrinkage.

A more accurate picture of the effect of a hot top and of changes within its constituents - sideliner and top cover - can be obtained by considering heat flow vectors within the ingot head.

Any principal heat flow may be represented by a vector in the direction of the loss concerned and of length proportional to its magnitude. Consider the losses in two dimensions for a central vertical plane equidistant from opposite mould faces. The major heat flow will be that from the head into the body of the ingot. Heat losses through the sideliner and top cover are also significant. These heat losses may be resolved into a single heat flow vector and the solidification front may be assumed to be normal to this resultant. Diagram 2a illustrates the case of a poor sideliner and poor top cover. The resultant heat flow tends to the horizontal and hence the advancing solidification front tends to the vertical and a deep shrinkage cavity (or pipe) will result. Diagram 2b shows the transition from the situation illustrated in 2a to the use of a good sideliner and good top cover. (Clearly consideration of the time/dimension effects of ingot solidification will result in some modification of the final solidified head contour, as illustrated in the lower part of the diagram, but this will still reflect the direction the resultant heat flow takes).

In theory, of course, by reducing the sideliner and, top cover losses to zero we would obtain a vertical resultant, hence a horizontal solidification front and a perfectly flat ingot top. Though impractical, this ideal sets a goal to aim for. Let us now look at how far the art has progressed and how much further it can be expected to go.

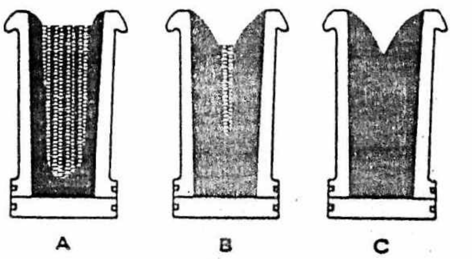

Fig.1a Solidification of a wide end up ingot without hot top

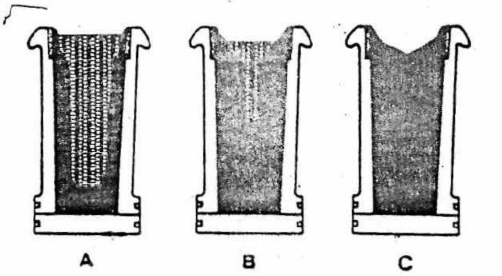

Fig.1b Solidification of a wide end up ingot with hot top

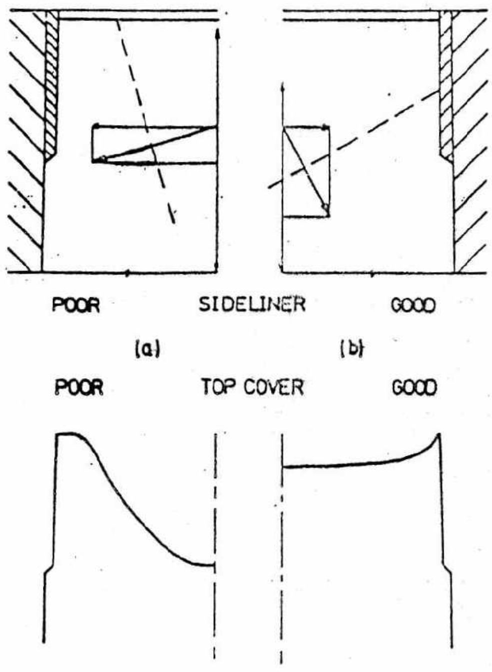

Fig.2 Vector heat flow diagram

HISTORICAL DEVELOPMENT OF THE HOT TOP

There has been a certain inter-dependence between the development of sideliners and of the other hot top component, top cover, but before looking at the development of the total hot top, major development in each of these component areas will first be considered.

Sideliner Development

A hot top sideliner made by knocking the bottom out of a crucible was, it is reported, used in Austria as long ago as 1870(1). Most early feeder heads either extended the mould by placing on it a heavy frame lined with refractory bricks or recessed the top of the mould in order to insert refractory bricks. Fig.3 illustrates the likely feed pattern associated with these materials and also highlights a further associated problem - hanger cracks. A superimposed unit seldom mated accurately with the mould top and hence liquid steel frequently penetrated the gap and formed solid fins which were strong enough to suspend the ingot as it shrank away from the mould. This resulted in so-called 'hanger cracks' penetrating into the ingot body.

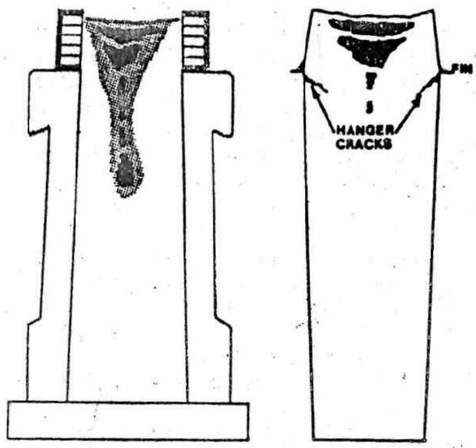

Fig.3 Use of traditional feeder heads illustrating hanger crack problem

Although pre-heating went some way towards overcoming the high 'chilling' effect of the massive brick lined heads, it was by no means the complete answer. A logical way to reduce the heat demand of a sideliner was to use exothermic materials. A generation of such materials succeeded the brick tops, and, particularly in the context of small ingots, made considerable improvements in ingot feed patterns. However, good though the insulation of the burnt out residue of these materials was in comparison to earlier materials, exothermics did not prove to be the complete answer for all ingots, particularly those of long solidification times.

In 1958 a process was invented which revolutionised the art of sideliner production. This process enabled low density fibre/particulate refractory composites to be manufactured, giving birth to Foseco's well known range of PROFAX sideliners.

PROFAX sideliners were low in density (compared to all earlier materials), which meant a reduced heat demand and improved insulation; it also meant far greater ease of handling. The skeletal structure was quite unlike that of the earlier massive rammed or pressed materials (2). The high efficiency and expandable nature of these sideliners has allowed great flexibility in the design of ingot hot tops. A selection of head designs is illustrated in Figs. 4(a)-4(d).

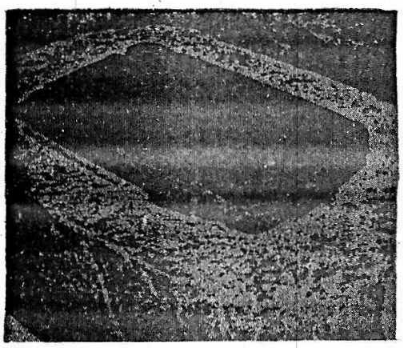

Fig.4a Eight piece PROFAX sideliner assembly

Fig.4b Assembly set down in ingot mould

During the relatively short life of the lightweight expandable sideliner title, there has been a continuous evolution of head designs and of composition - the complete removal of asbestos being but one example.

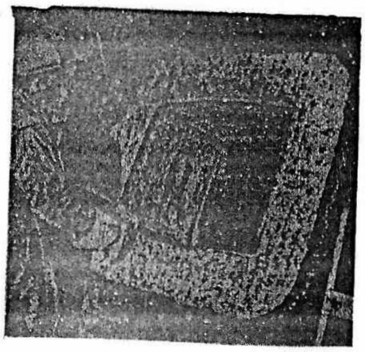

Fig.4c Use in superimposed head box

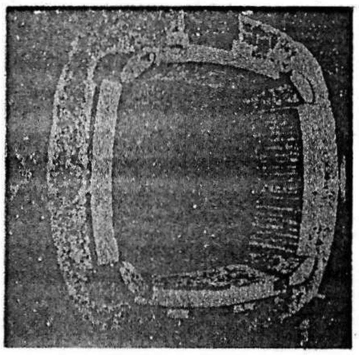

Fig.4d Use in slotted mould

Top Cover Development

The heat loss from the tops of the ingots which are not covered is considerable (possibly 25-30%) (3), hence a top cover is as important as a sideliner.

In the earliest days of hot topping, materials such as straw were used to cover the ingot tops. Later, top surface losses were drastically reduced by the use of a covering layer of vermiculite (4).

The use of 'anti-piping compounds' (or APC's) as hot topping aids in the steel industry began in the early 1950's. These are powder compositions possessing an exothermic component which, by rapidly raising the product's temperature, ensures low initial heat demand or chilling. On cessation of the exothermic reaction an insulating residue remains.

i. First stage APC's were tailored to combat the price structure of topping with vermiculite. They were, relatively speaking, dense low efficiency materials, usually based upon secondary raw materials.

ii. The second generation of APC's incorporated prime raw materials and crusting spinel forming ingredients. In relative terms these materials were still dense.

iii. A third generation of products emerged with the introduction of lightweight fillers into the composition. This achieved a reduction in density and an improvement in insulating performance.

iv. These lightweight products were themselves overtaken with the advent of expanding products. This fourth generation of products expand during the exothermic reaction to give a lightweight residue better in insulation performance than any of the previous generations of APC's.

Foseco has developed an apparatus - AMITEC® for assessing the thermal performance of topping materials. More will be said about this apparatus later, but at this stage AMITEC curves are used in Fig.5 to illustrate the continued improvement in thermal performance resulting from the successive APC generations.

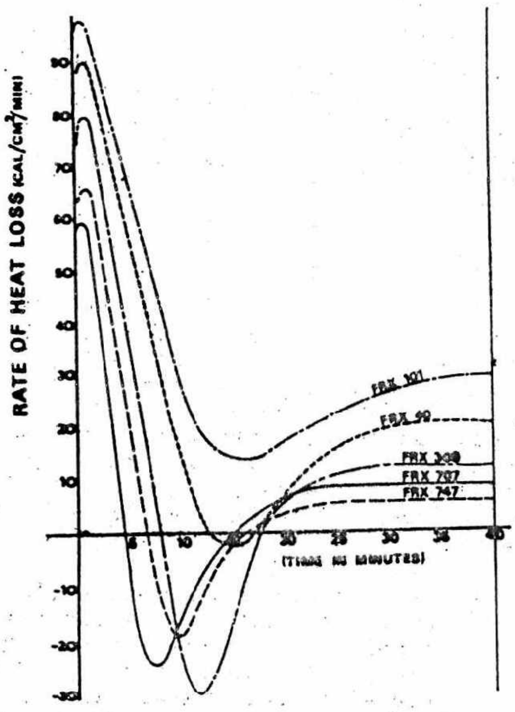

Fig.5 AMITEC curves of successive APC generations

The Total Hot Top

As stated earlier, there has been a certain interdependence between the development of sideliners and that of top covers (sideliner improvements necessitating an improvement in APC and vice-versa). Fig.6 puts the development of the total hot top in perspective by relating the various product improvements to top crop reductions, and the effects associated with the major steps outlined earlier are evident.

Equally it has been implicit throughout this historical review that there has been a continuous process of product development and improvement. This is reflected in the last step of diagram 6 - New Developments - and it is to this area that we now turn.

NEW DEVELOPMENTS

Since the mid 1970's an upsurge of developments has taken place in the sideliner area because:-

i) Interest has always been shown by steelplant personnel in reducing top crops further to give more saleable steel yield. Motivation has increased for the following reasons:

a) to be more competitive with the continuous casting route.

b) to reduce energy consumption per tonne of steel products.

c) to improve profits.

These have been accompanied by the added requirements to satisfy increasing environmental pressure against the use of potentially hazardous constituents (e.g. respirable dusts) in products.

ii) The improved performance and cost effectiveness of the latest generation of lightweight expanding APC's in particular has led to the realisation that top cover performance was no longer the limiting factor in hot top performance and that further significant improvements would be more likely to ensue from improvements in sideliner properties and performance.

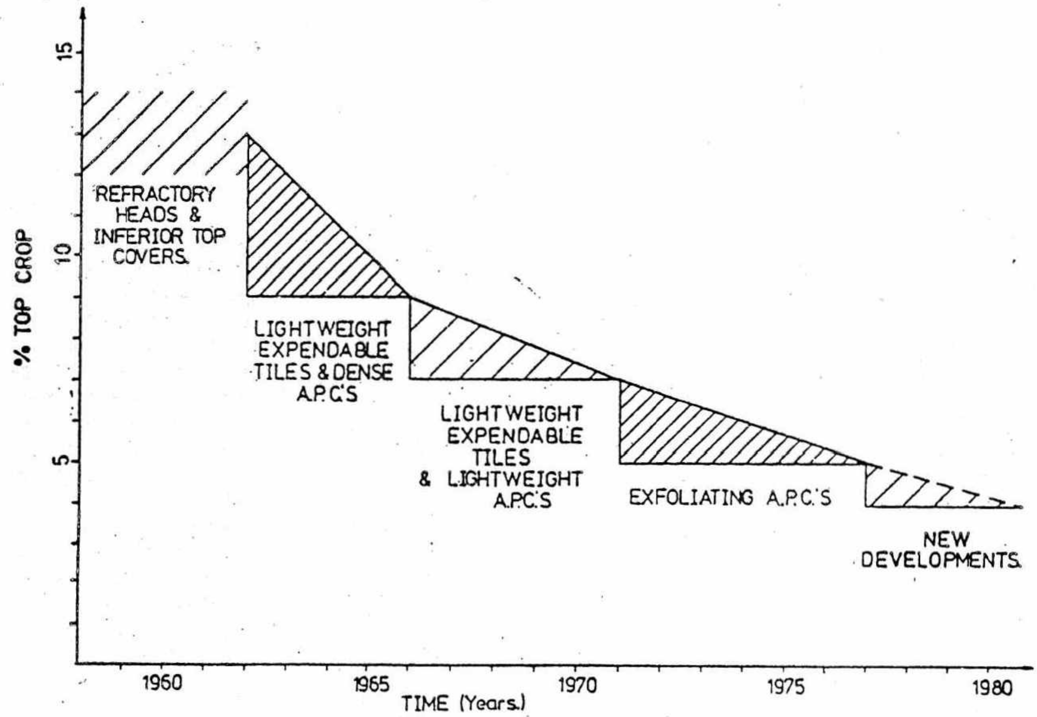

Fig.6 Development of the total hot top

The earlier theoretical consideration of vector heat losses serves to substantiate the view that further improvements in sideliner performance will lead to lower top crop requirements (and hence higher product yields) by providing flatter feed profiles.

Improvements have been achieved by moving to superlightweight products but before discussing these, the sophisticated assessment methods used to arrive at these products are considered first.

Ancillary Product Assessment Tools

In order that new developments might progress on rational grounds it was necessary for efficient and effective means of assessing product properties and performance to be devised. Foseco have developed and adopted the following three basic systems for measuring the relative thermal performance of current and developed heading systems materials and applying them to individual steelplant casting situations.

AMITEC

It was obvious in the early 1960's that there was a requirement for an instrument capable of providing information on the comparative thermal performance of sideliner and top cover products. The AMITEC instrument was therefore developed by Foseco and adopted as a product development and quality control device.

The instrument (Fig.7) comprises an insulated furnace heated by electrical elements. A silicon carbide test plate is fitted in the upper surface to accept specimens of 230 x 230 mm boards or loose powder. The test plate is maintained at a constant temperature (generally 1420 ± 2°C) by use of a high precision optical pyrometer focussed on the bottom surface of the plate. The instrument meters the electric input required to maintain this constant temperature and this input is plotted continuously during the test after correction for 'background' losses to give an accurate measure of heat flow into and through the material under test which may be an insulator or exothermic type. In addition to temperature, other standard

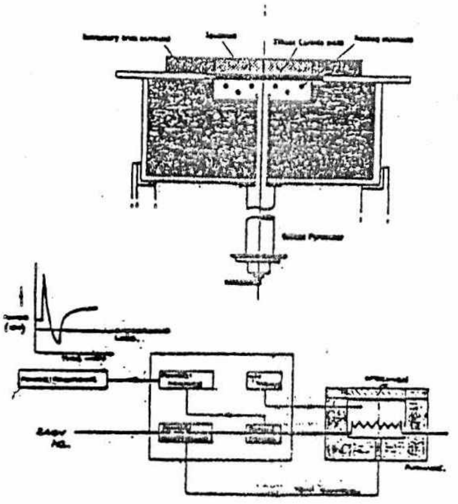

Fig.7 Schematic diagram of AMITEC apparatus

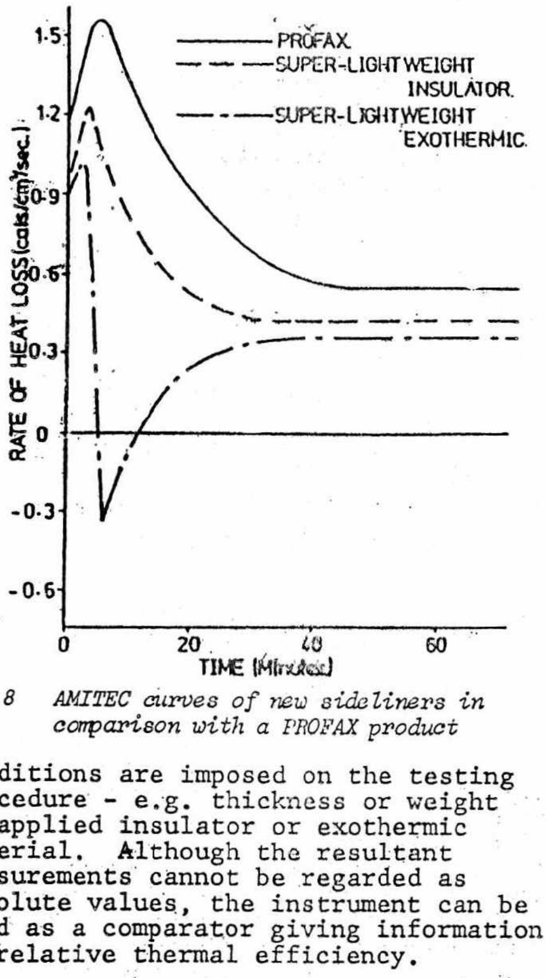

Fig.8 AMITEC curves of new sideliners in comparison with a PROFAX product

conditions are imposed on the testing procedure - e.g. thickness or weight of applied insulator or exothermic material. Although the resultant measurements cannot be regarded as absolute values, the instrument can be used as a comparator giving information on relative thermal efficiency.

Typical heat flow curves obtained from the AMITEC apparatus for both exothermics and insulators are illustrated in Fig.8. This graph illustrates:

a. the chilling effect of the sample, and quantities;

b. the insulating properties of the sample, and

c. the duration and nature of any exothermic reaction.

For the exothermic material there is an initial chilling effect as the product is applied, followed by a rapid reduction in heat flow through the silicon carbide plate as the exothermic reaction proceeds. In the example shown the reaction is sufficiently intense to reverse the heat flow through the plate - finally reaching a minimum heat flow situation giving an indication of the intensity of the exothermic reaction. As the reaction subsides, the heat flow through the combustion product residue increases to reach a steady state situation (referred to as the Final Insulation Value) and this gives a measure of the insulation performance of the product in practice. Product performance requirements differ for various ingot mould configurations - for large slab ingots the final insulation properties of products are of prime importance whereas for very small ingots (with shorter solidification times) the chilling effect of products becomes increasingly significant. An example here is the previously mentioned use of exothermics for small ingot applications.

Although the AMITEC test is the initial screening procedure adopted by Foseco for new products, it is recognised that the values given by this test are only strictly valid if the products tested maintain similar levels of integrity throughout the casting practice, i.e. there should be no (or comparable degrees of) compression or reaction of products in contact with molten steel. The test also fails to indicate whether there is any significant deterioration in performance of the material between the AMITEC test temperature of 1420°C and normal steel casting temperatures.

Steelpour Performance Ranking Test

As a means of assessing sideliner and top cover performance in contact with liquid steel a foundry steelpour test has been developed. This test compares the performance of materials in terms of:

i ii iii

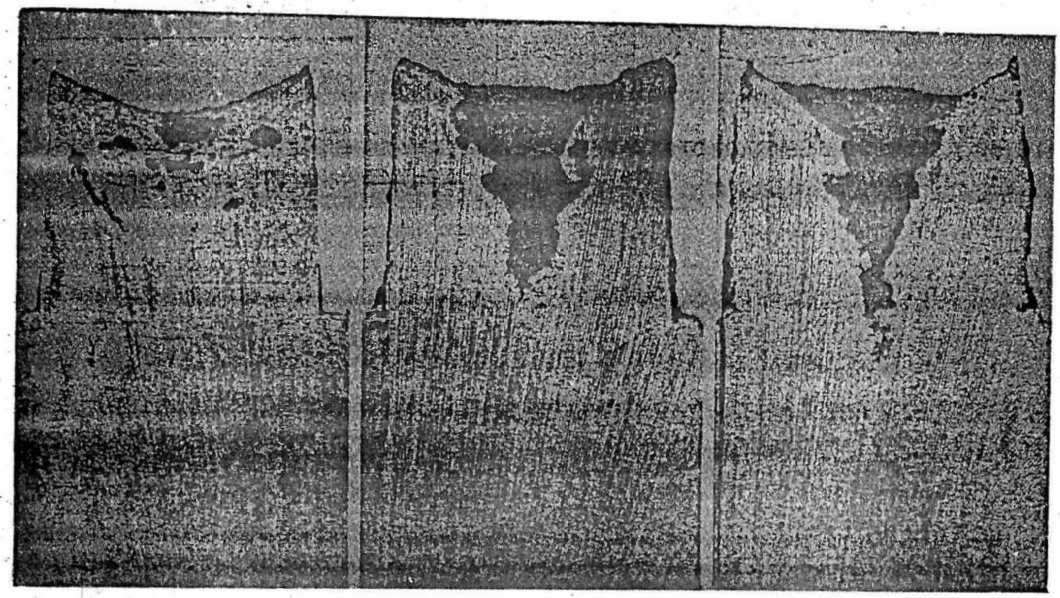

Fig.9 Sideliner evaluation by casting test

i. Thermal performance - effect on piping profiles and

ii. sideliner compressibility/ penetration/reaction with molten steel.

In the test 180kg ingots are cast in a silicate set sand mould headed with the sideliner under test and topped with the relevant APC. Test conditions can be established in order to study the individual performance of sideliner, APC, or the total heading system.

The use of a sand mould slows the steel solidification rate in the ingot body thereby giving conditions more like those found in larger cast iron ingot moulds. Heat flow conditions through sideliners can also be studied by inserting thermocouples in the sand mould behind the sideliner. The cast ingot produced is sectioned vertically through its mid section and measurements made of pipe depth, beneath-pipe segregation, sideliner compression etc.

Fig.9 shows the relative performance of three sideliners in this test for:

i. A super-lightweight exothermic board.

ii. A super-lightweight insulating board.

iii. A conventional insulator (of the PROFAX type referred to previously).

Computer Aided Mathematical Model Study

Many attempts have been made to predict mathematically the optimum feeder head shape and volume for any given ingot or vice-versa to predict the ingot feed and primary segregation profiles for a given heading system. Foseco has developed such a computer aided Mathematical Model. In this system account is taken of the thermal efficiency of the hot top materials, the ingot configuration, steel quality and casting conditions.

The main parameters used in the study include:

Mould Height.

Internal top dimensions of mould.

Internal bottom dimensions of mould.

Mould wall thickness.

Height of sideliners in contact with steel.

Thickness of sideliners.

Thermal properties of sideliners.

Application rate of anti-piping compound.

Thermal properties of anti-piping compound.

Contraction co-efficient of steel quality.

Superheat/latent heat of steel.

Teeming rate and height.

A computer prediction is then made of the expected feed profile. Conversely the process can give recommendations of size and and APC's to particular sideliners and APC's to achieve specified ingot piping and primary segregation conditions.

The model basically employs cylindrical geometry and calculates by three stages.

STAGE 1

The volume of the ingot under consideration is calculated, together with the total volume of contraction which will occur during the casting and solidification stage. Factors involved at this stage include the dimensions of the mould, casting speed, steel composition, casting temperature etc.

STAGE 2

Here heat transmission data (as measured by AMITEC) for the APC and sideliner is used to determine heat loss vectors in the feeder head. This calculation employs the dimensions of the ingot and mould (including mould wall thickness) as well as the thermal properties of the heading materials, size of the head etc. Chilling and exothermic factors of sideliners and APC's are also incorporated here.

STAGE 3

The predicted solidification profile is obtained by relating values of the heat loss vectors at various points within the ingot head to the calculated volume contraction. Solidification profiles are automatically computed on the basis that the liquid/solid solidification front proceeds at right angles to the heat flow at that instant.

At all stages in its development, predictions were confirmed with values obtained in steelplants, any necessary modifications being incorporated in the model.

Fig - 10 and 11 show respectively a typical computer print-out of an ingot feed profile and a typical comparison between predicted and measured feed profiles. Although still undergoing a process of refinement there is now sufficient confidence in the model for Foseco personnel to make increasing use of it - particularly to minimise the requirement for costly steelplant trials.

Present Developments

Sideliners

Recognition has been made of the known superior insulation properties of lightweight products and two basic product forms have been developed:

1. Super-lightweight insulators of density approximately half that of conventional insulators such as PROFAX.

ii. Super-lightweight exothermic products with densities similar to (i).

These products have the added advantage of satisfying more stringent environmental requirements.

Earlier exothermic products were dense and, although the initial chilling effect of liquid steel coming in contact with the sideliner was offset by the heat from the exothermic reaction, the steady state insulation properties of the final residue were very much inferior to those of conventional insulators such as PROFAX - hence their unsuitability for applications other than small ingots.

With the new super-lightweight products.

i. Heat capacity is lower and there is therefore less tendency to chill the liquid metal on contact.

ii. The exothermic reaction (where present) further offsets any chilling tendency.

iii. The most important difference from earlier exothermic products

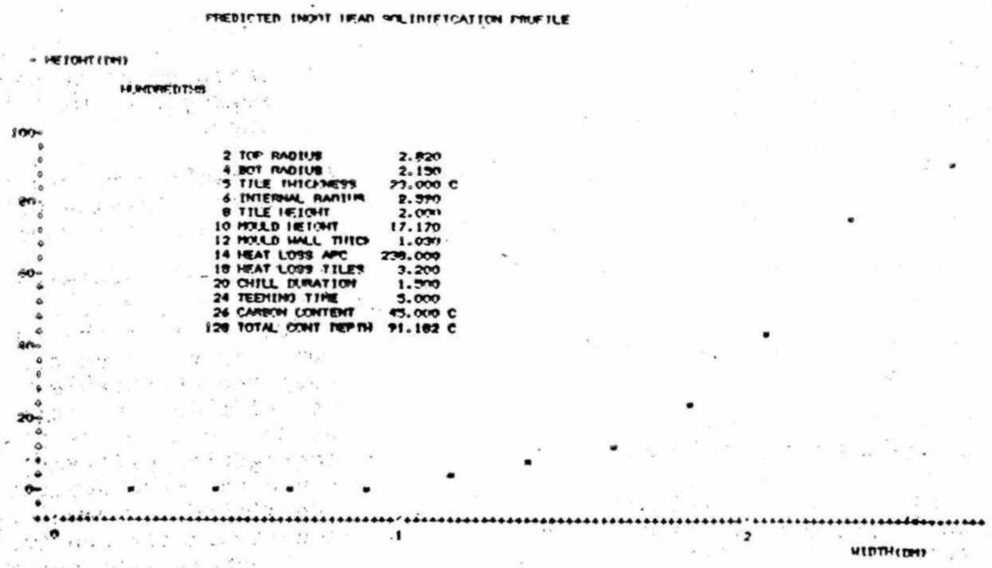

Fig.10 Typical print out using computer model

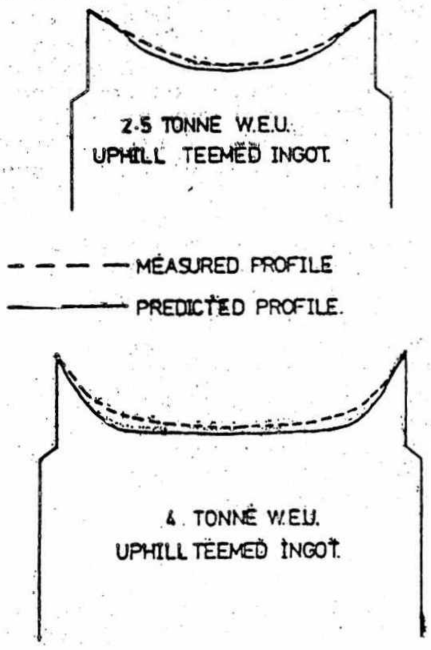

Fig.11 Comparison of computer predictions with actual ingot profiles

is that the exothermic reaction together with the low density produces a super-lightweight strong residue with insulating properties considerably better than those of conventional sideliners. Although no exothermic reaction takes place with the super-lightweight insulator, judicious selection of constituent ingredients ensures that a highly insulating tile residue is again produced.

Fig.8 compares AMITEC curves typical of these products with that of a conventional PROFAX type. It can be seen that the heat requirements of both the super-lightweight insulator and exothermic sideliners are considerably lower than conventional PROFAX clearly indicating the potential for yield improvement even for very large ingots by providing a better insulated hot top.

The benefits resulting from the adoption of these new products are demonstrated by the following case histories:

i. In North America adoption of the super-lightweight exothermic approach for large slab ingots not only enabled the steelplant to eliminate asbestos and other hazardous respirable dusts from its casting bay environment but also significantly improved pipe and segregation patterns. This removed problems previously encountered with joining of primary and secondary pipe regions. All the above was achieved at lower feeder head volumes - an additional benefit.

The new products also improved feeding of "tall" ingots with height: breadth aspect ratios greater than 4:1 - previously difficult to feed satisfactorily.

Benefits

a) Hazardous dusts removed.

b) Ingot yield improvement.

c) Reduced feeder head volume.

d) Improved feeding of "tall' ingots.

e) Removal of primary/secondary pipe problems.

ii. In Europe, studies have been made on 0.8/0.85%C and other high carbon steels. Here comparison was made of the segregation patterns of WEU uphill teemed ingots headed with conventional PROFAX type sideliners and NEU direct teemed ingots headed with the new super-lightweight exothermic sideliners. Steelplant personnel prefer to use NEU moulds for ease of ingot stripping and mould handling and would be attracted additionally by a direct teeming practice if this were possible . Ingots concerned were 5-7 tonnes in weight.

With conventional PROFAX type heads, secondary segregation patterns from the NEU ingot configuration give unacceptably high local carbon levels - contrasting with the more uniform segregation behaviour found beneath primary pipe in WEU casting.

Adoption of the super-lightweight exothermic approach with direct teeming in NEU moulds led to a considerable improvement in segregation behaviour, giving performance levels more like those of the WEU uphill teemed system. Although the new sideliners did not fully satisfy all requirements, it was shown that most relevant customer specifications could be met without necessarily resorting to the uphill teemed MEU ingot practice.

Benefits

a) Improvement in secondary segregation with NEU ingots.

b) Extention of use of NEU direct teeming practice for higher carbon steels.

iii. A number of steelplant trials have been conducted in Europe to demonstrate the improvements in pipe and segregation patterns obtainable with the new sideliner materials. To study properly the pipe and segregation patterns, billet top crops were separated, identified and sectioned longitudinally and transversely. Accurate measurements were made of visible pipe depth. Segregation (of carbon and sulphur) was determined by extensively drilling the sections for chemical analysis. Sulphur segregation was also studied by sulphur printing the sections at various points. Results typical of those found are shown in Fig.12 where the magnitude of the possible yield gains (from a piping viewpoint) are immediately apparent. As expected, segregation patterns have shown similar degrees of improvement from which has been demonstrated potential yield savings of up to 3% by adopting the super-lightweight insulating or exothermic sideliners.

Benefits

a) Lower top crop requirements - hence yield gains.

b) Improvement in segregation patterns.

Two other advantages are found with the new materials:

i. The ultra light-weight of the products lends itself to handling ease and is therefore attractive to casting bay personnel.

ii. The improved performance of these sideliners enables lower head volumes to be considered -

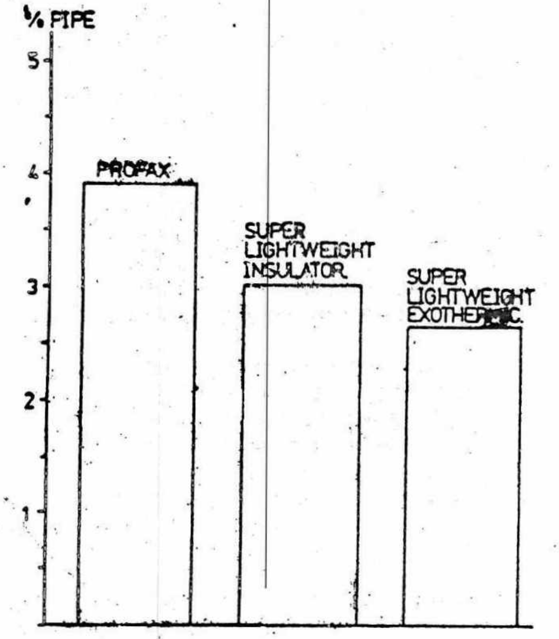

Fig.12 Reduction in pipe levels achieved with new sideliner systems

and therefore lower tile insert depth. This gives the advantage of more molten metal solidifying in contact with the mould wall - improving steel ingot surface quality.

The superior properties of the exothermic sideliner have been achieved by the use of expensive fuels and light-weight refractory constituents. For this reason the product is likely to find application principally where the steel-maker can make use of the extra yield accruing, or with more expensive steel grades.

Anti-piping Compounds

Such considerable improvements in anti-piping compounds have taken place during the last fifteen years that greater returns were expected to be achieved by improvements in sideliner performance. Recent developments with APC's have therefore concentrated on responding to steelplant environmental and handling requirements.

APC's are now supplied in board from (KALTOP ®). KALTOP boards overcome some of the deficiencies found in practice with powder APC's which are summarised below:

Disadvantages of Powdered APC's

1. High wastage.
2. Inconsistent cover - dependence on flowability.
3. Dusty - convection currents - fumes.
4. Labour intensive.
5. Untidy teeming area.

Advantages of Kaltop Boards

1. More effective use of material- no waste.
2. Consistent and uniform cover.
3. Dust-free with low fume emission.
4. Less labour intensive and safer to use.
5. Tidier teeming platform.

KALTOP boards are particularly attractive when used with uphill teeming practice since they can be pre-set in the moulds at the same time as the side-liner boards. This removes the normal steelplant difficulty of applying a consistent APC cover to those moulds farthest away from the teeming platform.

The use of KALTOP boards is not however confined to uphill teeming practice; it is also being used successfully in a number of direct teemed ingot applications.

FUTURE DEVELOPMENTS

Hot topping practice has progressed a long way in the last 20 years and although the impact of continuous casting on conventional ingot practice will increasingly be felt, there is still considerable scope for steel yield improvement by the ingot route. Developments are seen in the following areas:

i. Materials

Further evolution of the material developments discussed earlier are possible and yet further generations of sideliner types are already envisaged, e.g. use of raw materials outside the confines imposed by present manufacturing techniques.

ii. Ancillary Tools

Further sophistication of the development tools discussed earlier will play an increasing role in future developments, e.g. increasing convergence of the AMITEC and casting test assessment techniques.

iii. Head Geometry

A potential yield improvement of ~2% is possible, at least in theory, with suitably shaped heads.

Failure of earlier attempts to improve yields by this route was probably due to contemporary sideliner and top cover performance. With ever improving hot top performance the potential for success by head shaping should increase.

iv. Application/Ease of Handling

Application and ease of handling of heading systems will assume increasing importance in line with a general tendency in the steelplant to easier and/or more automated handling systems.

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