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Research Paper

EXPERIMENTAL INVESTIGATION OF INTER MIXING IN A TUNDISH-MOLD ARRANGEMENT

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A physical investigation has been carried out in which the inflow rate of the stream from ladle into the tundish is varied so that the level of steel in the tundish falls gradually. Once the steel level falls to certain depth below the top free surface, the inflow rate is further increased to maintain the original bath height of the tundish. Flow rate of steel into the tundish as well as the tundish bath height has been varied and the intermixed amount was calculated by using physical model of the tundish and water as the flowing medium. It was seen that decreasing the inflow rate of steel into the tundish decreases the inter mixed amount inmost of the cases. Intermixed amount was calculated both at the tundish outlet as well as at the mold outlet. This helps in knowing the contribution of mold intermixing to the overall intermixed amount formed.

Keywords: Intermixing, Tundish bath height, Watermodel

INTRODUCTION

During ladle change over process, there is mixing of the old and the new grade steel in the tundish producing intermixed grade steel whose composition falls between the composition of the old and the new grade steel. Depending upon the severity of the acceptable limits of steel users, the inter mixed grade steels are either treated as scrap materials or downgraded steels having less demand in the market. Hence it becomes the prime aim of the steel making companies to keep the amount of downgrade or intermixed steel to a minimum or if possible, completely avoid them (Kant *et al*., 2010; Muralikrishna*et al*., 2013; Thomas, 1997). The easiest practice adopted by the steel industry is to continue casting the different grades as a single sequence where a simple ladle change is involved. Although this method completely avoids losses in the productivity, it produces higher intermixed steel as compared to other methods. During ladle changeover operation, bath height of molten steel varies in tundish. This ladle changeover operation and change in bath height of molten steel in tundish have been a significant impact on intermixing phenomenon inside the tundish. Since the formation of these intermixed grades is dependent upon the flow configuration inside the tundish, it can be inferred that the

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parameters affecting the flow inside the tundish (casting and geometrical parameters) plays an important role in the formation of intermixed grade and their amount (Jha *et al*., 2002; Jha *et al.*, 2001). The casting parameters (such as the rate of inflow of steel from the new ladle into the tundish, bath height of liquid metal inside the tundish before the new ladle is opened) and geometrical parameters (shape of the tundish and use of flow modifiers in the tundish) affect the flow configuration inside the tundish and hence their effect on the formation of intermixed amount will be an interesting and useful observation for the steel industries.

In this physical modeling, molten metal in flow rate (from the new ladle) and different reduced tundish bath heights have been taken as casting parameters to investigate the pattern of intermixing phenomenon. The effort has been to know the coupled effect of inter mixing in tundish and mould simultaneously.

PHYSICAL DESCRIPTION

In the present work a boat shapes lab caster tundish has been considered for physical modeling. Geometric similarity has been maintained by keeping the dimensions of the model and prototype tundish in the same ratio and dynamic similarity is achieved by considering the inertial, viscous and gravitational forces. The fabricated tundish has been used for calculating intermixed amount from tundish of actual size which is 3 times the size of fabricated tundish in terms of linear dimensions. Water (at room temperature) and molten steel have equivalent kinematic viscosity; this makes advantage that water can be used as a medium to represent molten steel. Figure 1 shows detail dimensions of boat shape slab caster tundish with dam and mold. Tracer injections were done as continuous input to the tundish. Conductivity meter was used for recording concentration at outlets of tundish and mold. The time vs. concentration curve, known as F-curve, was used to compute the inter mixed amount arising because of mixing inside the tundish. The new grade composition coming out of the tundish outlet was treated as the incoming fluid to the mold and the composition coming out of the mold were further investigated. The effect of inflow rate to the tundish at different bath height of tundish has been investigated on both bare tundish and tundish with dam. Dam was used at the bottom of the tundish to see its effect on the intermixed amount. The fourteen cases which have been dealt with for bare tundish as well as tundish with dam are presented below in Table 1. While Case A to G deals with bare tundish, Case H to N deals with tundish with dam. When the first ladle gets emptied, the second ladle starts pouring into the tundish at different inflow rate of Q, Q/2 and Q/3 for the different cases mentioned in the Table 1 until the tundish bath height comes to the value shown under the H (m) value in the Table. When tundish bath height reached the minimum

Figure 1: Dimensions of Slab Caster Tundish

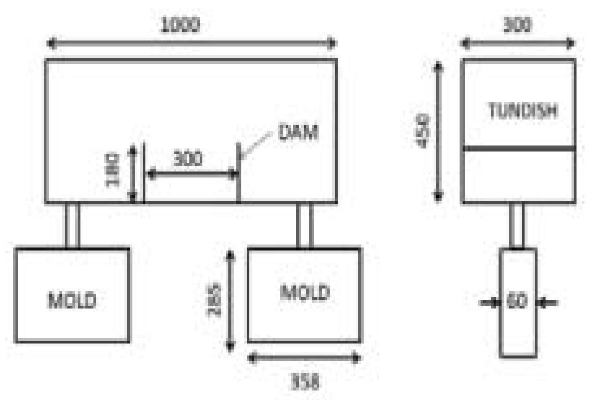


Table1: Experimentalcases with Different Conditions

Bare tundish (case)	Variation Inflow Rate* After Steady State	Tundish Bath Height Reach eq^n	Tundish with Dam (Case)
A	Q	h	H
B	1/2 of the Q	1/2 of h	I
C	1/2 of the Q	2/3 of h	J
D	1/2 of the Q	3/4 of h	K
E	1/3 of the Q	1/2 of h	L
F	1/3 of the Q	2/3 of h	M
G	1/3 of the Q	3/4 of h	N

Note: * Normal inflow rate is taken as 22 litres per minute which comes out to be velocity of 1.8 m/sec through the inlet of the tundish.

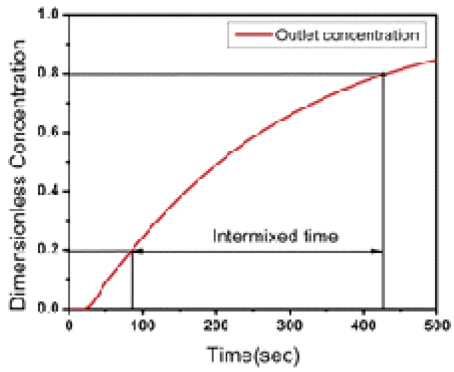
height of specific case, inflow rate was increased to original value Q. Assume that another new ladle was teeming in the tundish at that moment.

COMPUTATION OF INTERMIXED AMOUNT

The F-curve in Figure 2 depicts the temporal variation of the concentration of tracer (representing new grade steel) at outlet after the tracer was injected continuously through the inlet. The new grade concentration of steel can be found by the value of concentration at any point on the F-curve at any instant. The method of computation of intermixed amount for 20:80 (stringent-stringent) grade has also been depicted. The amount of steel flowing between times corresponding to concentration value of 20 % and 80 % respectively is represented as the intermixed amount, the unit has been considered in terms of seconds because the intermixed volume can be found by the product of intermixed time and the flow rate of steel through the particular outlet. The intermixed amount can be seen in this illustrated case of 20:80 grade specifications to be 320 s.

Figure 2(a): Diagram of Experimental Setup

Figure 2(b): Calculation of Intermixed Amount at the Outlet for 20:80 Grade Specifications



RESULTS AND DISCUSSION

Figures 3(a) and 3(b) show the F-curve at steady state conditions for bare tundish and tundish with dam respectively. The value of concentration (on y-axis) at a particular time is indicative of the concentration of new grade steel. It is seen that the concentration of new grade steel starts to appear through the tundish and the mold outlet only after certain time has elapsed. This is the time required by the tracer

Figure 3a: F-Curve of Bare Tundish and Mold (CASE-A)

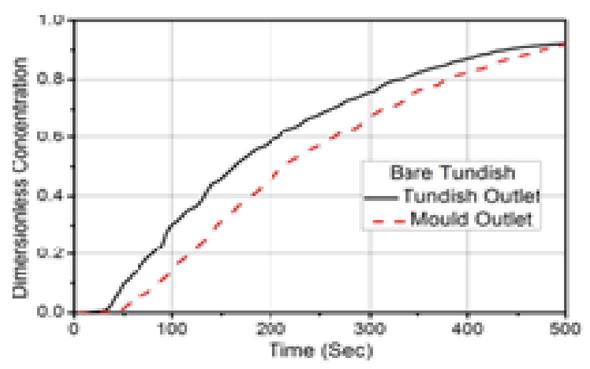
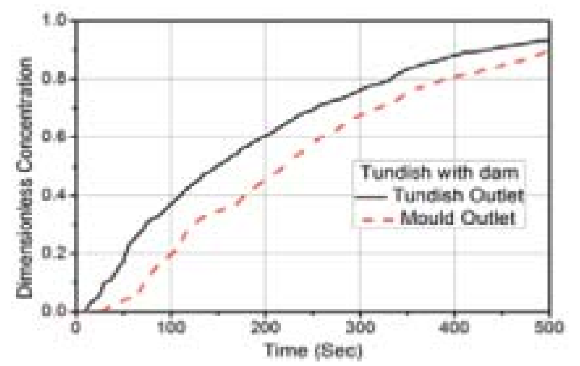


Figure 3b: F-Curve of Tundish-with-DAM and Mold (CASE-H)

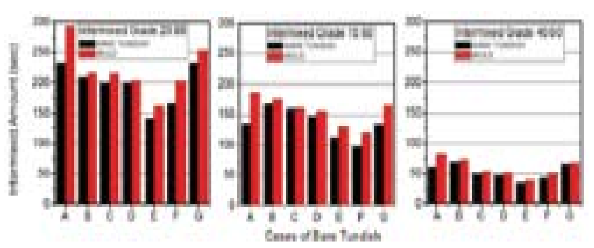


(new grade steel) to diffuse into the old grade steel and then the first appearance of the new grade steel is observed. It is clearly seen that the appearance at the mold outlet is seen further at a later time as compared to that at the tundish outlet because of the time taken by the fluid to pass through the mold and get intermixed in the mold. In Figure 3(b), the first appearance of the tracer (new grade steel) is observed at an earlier time for tundish with dam arrangement as compared to that for the bare tundish case. In this process, the old grade steel has some time to be driven out of the tundish outlet to the mold and less amount of old grade steel mixes with new grade steel to form intermixed grade. The rise of new grade steel (tracer) is seen to be fast in tundish with dam as compared to bare tundish. This means that the larger amount of old grade steel were driven off from the tundish and so less intermixed amount is likely to be formed. The amount of intermixed grade steel is calculated with the help of F-curve which is shown in Figures 3(a-b) for bare tundish and tundish with dam respectively.

COMPARATIVE ANALYSIS OF INTERMIXING IN TUNDISH AND MOLD

A quantitative analysis has been made to study the intermixing phenomenon in tundish with respect to two parameters i.e., variation in inflow rate and variation in reduced bath height. Figure 4 shows the bar graph of variations of intermixed amount in tundish for different cases. Intermixed amount in tundish has been calculated for three different grade specifications namely 10:60, 20:80 and 40:60. For all the three different grade specifications, 20:80 (a stringent-stringent grade specification) gives maximum intermixed amount whereas 40:60 (a lenient-lenient grade specification) gives minimum intermixed amount.

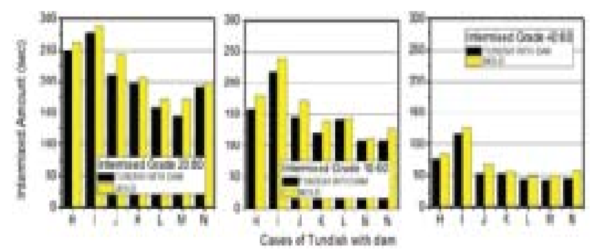
Figure 4: Comparative Bar Graph of IntermixedAmount in Bare TUNDISH Case



For all the seven cases of bare tundish, intermixed amount in mold and tundish has been calculated and shown. It can be seen that intermixed amount in mold is greater that for the tundish. This is indicative of the intermixing present in the mold, in addition to that in the tundish. It can be noticed that for case A (steady state operating condition) intermixed amount in mold and tundish are maximum as compared to all other cases of bare tundish. It is further seen that case E produces minimum intermixed amount, both at the tundish and the mold outlet for two of the three grade specifications, i.e. for 20:80 and 40:60 grade specification whereas case F shows the minimum intermixed amount for tundish and mold in case of 10:60 grade specification. The lesser value of intermixed amount for case E can be attributed to minimum inflow rate and minimum tundish bath height. Inflow rate was kept constant i.e. (1/3rd of Q) in the three cases E, F and G, however height was varied. It is found that in three cases E, F and G, intermixed amount has been increasing as the tundish bath height of fluid in tundish is being increased. These findings support the fact that intermixed amount is dependent upon reduced bath height of steel in tundish because of lowering the inflow rate into the tundish as compared to the steady state inflow rate value.

Figure 5 shows the similar bar graphs of variations in intermixed amount for tundish with dam. Intermixed amount for different grade specifications have been calculated. All seven cases for tundish with dam (H-N) have been computed and in each case, intermixed amount of mold and tundish are shown. Intermixed amount increases at the tundish as well as mold outlet for all the three grades as we change the case from H to I. From Figures 4 and 5, it is found that intermixing phenomenon is different due to incorporation of dam inside tundish. In a bare tundish, maximum intermixed amount is calculated in the case of A, while with the use of dam, case I produces maximum intermixed amount. It can be said that bare tundish produces larger intermixed amount at steady state operating conditions as compared to tundish with dam. Similarly, minimum intermixed amount has been calculated at case E and case M in bare tundish and tundish with dam respectively. It can be observed that intermixed amount has decreased from the cases I to case K, where inflow rate was kept constant and tundish bath height was varied. It further supports the evidential fact which was found earlier that intermixed quantity formed in tundish (with dam) is dependent on bath height of fluid in tundish. An increase in inflow rate of fluid in to the tundish seems to cause larger intermixed amount.

Figure 5 Comparative Bar Graph of Intermixed Amount in TUNDISH with DAM Case



Parametric Graphs

A steady state operating tundish has three variables viz. inflow rate, outflow rate and bath height of the tundish. One of the intent of this research work is to study the influence of inflow rate and tundish bath height over intermixed amount formed into tundish and mold. In addition to this, experiments were carried out on two configurations of tundish, in which one configuration is of bare tundish and other with dam. Figure 6 and 7 illustrate the effect of tundish inflow rate and bath height on the intermixed grade formed inside tundish and mold. These graphs are plotted for three different grade specifications viz.10:60 (Stringent-Lenient), 20:80 (Stringent -Stringent) and 40:60 (Lenient-Lenient). The graphs are plotted between tundish bath height versus intermixed amount calculated for tundish and mold. The straight line in graphs represents certain inflow rate to the tundish. Each illustrated point on the graph characterizes the intermixed amount formed at particular conditions. Following are the several inferences made from these graphs:

Figure 6: Effect of Inflow Rate and TUNDISH Bath Height on Intermixed Amount in a BARE TUNDISH. (A) For 20:80 Grade Specifications (B) For 10:60 Grade Specifications (C) For 40:60 Grade Specifications

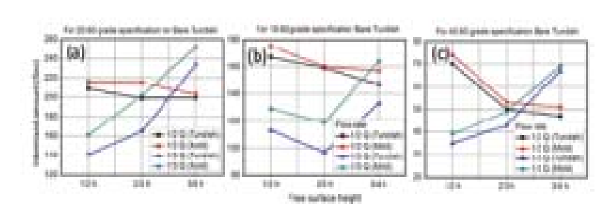
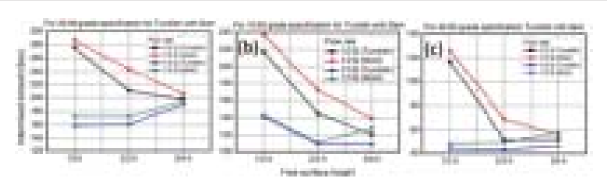


Figure 7: Effect of Inflow Rate and Tundish Bath Height on Intermixed Amount in a Tundish With Dam. (A) For20:80 Grade Specifications (B) For 10:60 Grade Specifications (C) For 40:60 Grade Specifications



i. It can be notice that due to variation of inflow rate and bath height of tundish, there is change in the formation of intermixed amount. The trend of variation of intermixed amount is followed by mold.

ii. It can be seen here that for ½ Q inflow rate, formation of intermixed grade decreases as tundish the tundish bath height increases.

iii. When inflow rate is decreased to 1/3rd Q, it is found that formation of intermixed amount rises with increase in tundish bath height except for one condition in Figure 7(b).

Furthermore, experiments were carried out on tundish with dam configuration (Figure 8) to understand the effect of tundish furniture on intermixed amount. On the basis of such, following observation can be made:

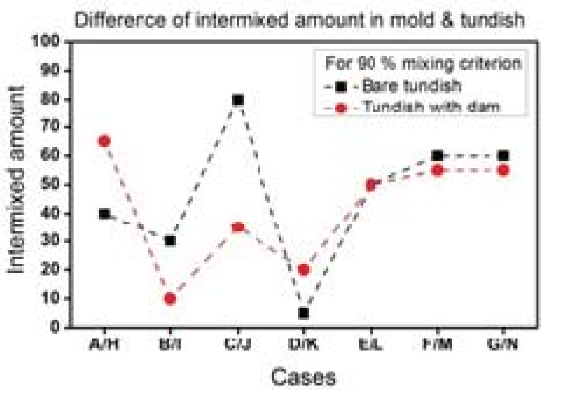
i. It can be noticed that at ½ Q inflow rate, formation of intermixed amount in tundish and mold decreases significantly with respect to increase in tundish bath height.

ii. At less inflow rate (1/3rd Q), It is found that due to addition of dam into the tundish, formation of intermixed grade is small. Also an increase in tundish bath height does make only a slight change in intermixed amount. This means, an addition of dam in the tundish restricts the formation of intermixed grade as compared to the bare tundish at low inflow rate (1/3rd Q).

DIFFERENCE OF INTER MIXED AMOUNT IN MOLD AND TUNDISH

The difference of intermixed amount formed in tundish and mold for each case has been shown in Figure 8. The amount of intermixed

Figure 8: A Comparison of Difference in Intermixed Amount in TUNDISH for all Cases



grade has been calculated when the concentration of the new grade fluid reaches 90% in the tundish and mold.

The following generalization can be made from this:

i. The formation of intermixed amount is more for case C/J while less formation of intermixed amount has been found for case D/K. It is apparent that inflow rate to the tundish is constant and due to increase in tundish bath height (from 2/3rd h to 3/4th height), formation of intermixed grade is less.

ii. At case E/L, F/M and G/N, when inflow rate to the tundish has been kept constant (i.e., 1/3rd Q), it is seen that formation of intermixed grade increased with respect to increase in tundish bath height.

iii. When tundish is operating on steady state i.e., case A/H, it is found that formation of intermixed grade increases due to insertion of dam in the tundish.

iv. It can be further inferred that formation of intermixed grade is more in the case of bare tundish as compared to tundish with dam configuration except for two cases (A/H and D/K).

CONCLUSION

The present study has been carried out to investigate the intermixing time in the boat shape slab caster tundish. The intermixed amount has been calculated for tundish with and without dam. Intermixing occurs in tundish as well as in mold. Hence in these physical investigations intermixed amount in mold has been calculated. A comparative bar graph has been illustrated for bare tundish and tundish with dam configuration, respectively. It has been observed that use of dam in the tundish increases the intermixed amount. The intermixed amount is seen to reduce once the inflow rate is reduced. Furthermore, the intermixed amount at the outlet of tundish is less as compared to that at the outlet of mold and there is significant amount of intermixing in mold of the boat shape slab caster tundish. A parametric relation among intermixing time, inflow rate and bath height of tundish has been illustrated. It is observed that inflow rate and tundish bath height has significant impact upon intermixed amount. An increase in inflow rate drastically increases intermixed amount for minimum bath height in both cases of tundish configuration. It is also found that the decrease in inflow rate and increase in tundish bath height causes larger intermixed amount in case of bare tundish while, tundish with dam does not show any significant change. In both configurations of tundish, it can be said that the formation intermixed amount are more for high inflow rate of new grade, as compared to the case when tundish bath height was minimum. In case of tundish with dam configuration, formation of intermixed amount due to change in inflow rate is about same at maximum tundish bath height.

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