Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 2, Issue 13; October-December, 2015 pp. 94-98

http://www.krishisanskriti.org/Publication.html

# Physical Investigation of Grade Mixing Phenomenon in Delta Shape Steel Making Tundish

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**Abstract—***The growing demands on quality in steel products have changed continuous casting process as an important step. Tundish, being an intermediate reservoir placed between the ladle and the mold in a continuous casting unit, receives the molten steel from the ladle and supplies continuously to the mold. A physical investigation on delta shaped billet caster tundish has been carried out to analyze the intermixing behavior. In present work, the inflow rate of the stream from ladle into the tundish was varied so that the level of steel in the tundish falls gradually. A tracer input has been made to monitor the concentrations at outlets of tundish and molds consecutively to obtain the F-curves. 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. The results obtained by two different physical models of billet caster tundish (bare tundish and tundish with dam) has been studied and effect of addition of tundish furniture has been discussed.*

**Keywords***: Tundish, continuous casting, mold, steelmaking*

## 1. INTRODUCTION

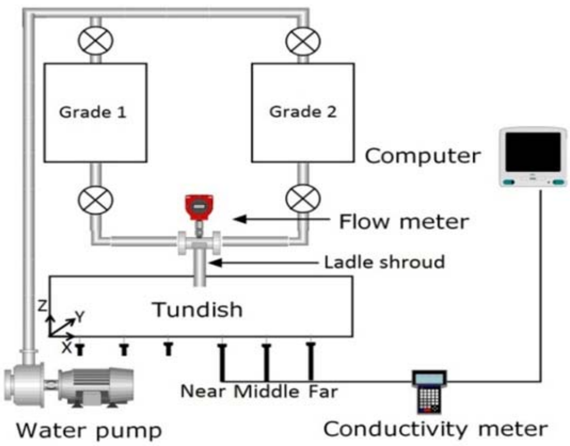
In the continuous casting of steel, the tundish is basically an intermediate vessel placed between the ladle and the mold so as to distribute and supply liquid steel to different molds at an approximately constant rate[1]. Thus significant efforts have been made by researchers around the globe to fully exploit and enhance the potential of continuous casting tundish as a molten steel refining vessel. Numerous experimental and theoretical studies have been carried out using both aqueous models and industrial units to investigate various transport phenomena of relevance to continuous casting tundish system[2]–[4]. A wide range of tundish geometries along with numerous designs of flow modifiers were applied to investigate grade intermixing phenomenon in tundish. Flow. To improve the efficiency of tundish different flow modifiers like Dam, Weir, Baffles, Swirling Chamber, Turbulence Inhibitors etc. were used[5], [6]. The results have shown that these flow modifiers significantly affect the fluid flow in tundish. The purpose of fluid flow optimization in the tundish is to reduce grade mixing[7], [8]. The flow modifier increases the mean residence time of the melt in tundish by having better fluid flow. In vast literatures available on grade mixing in tundish[9]–[12], there is lack of research work on grade mixing in mold combined with tundish. In present work, a physical investigation has been carried out on delta shape billet caster tundish, 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. Intermixed amount was calculated 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.

## 2. PHYSICAL DESCRIPTION

The high temperature of molten steel and the extremely corrosive environment in any steelmaking operation make experimentation on the real molten steel system very difficult. Therefore, water modeling is frequently used to study the fluid flow behavior in the molten metal system[13]. It allows visual observation of the flow patterns in a given system. It is also cheaper and more convenient to carry out flow visualization experiments on water models with advanced graphics packages for displaying flow, temperature and concentration profiles, water model will continue to be used since a very important use of a good water model is in validation of the mathematical model[14]. In fact, in most cases involving the modeling of the molten metal flows, water models are the convenient means of validating the mathematical model.

A good representation of actual fluid flow behavior inside tundish can be observed by using full scale model[15]. But in case of reduced scale water model experiments, there is need of kinematic and dynamic similarity between prototype tundish and model tundish.

A six strand, delta shape billet caster tundish is considered for the physical investigations. The geometrical description of the delta shape tundish used for the present study is shown in Fig. 1. Length of the long wall is 5800 mm and height of tundish is 872 mm. Upper span of the width of tundish is 1100 mm and lower span of width is 540 mm. Inlet dimension is 50X50 $mm^2$ and each six outlet dimension is 15X15 $mm^2$. In another case of investigations dam has been applied near inlet zone. Table 1 shows the different cases of experiments.




**(a)**

**(b)**

**Fig. 1(a) Schematic diagram of experimental setup and (b) reduced scale delta shape tundish**

**Table 1: Experimental cases with different conditions.**

| Bare Tundish (Case) | Variation in Inflow rate* after steady state | Tundish bath height reached | Tundish with Dam (Case) |
|---|---|---|---|
| A | Q | h | H |
| B | 1/2 of Q | 1/2 of h | I |
| C | 1/2 of Q | 2/3 of h | J |
| D | 1/2 of Q | 3/4 of h | K |
| E | 1/3 of Q | 1/2 of h | L |
| F | 1/3 of Q | 2/3 of h | M |
| G | 1/3 of Q | 3/4 of h | N |

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

### 2.1 Computational and Intermixed amount

F curve gives an idea of the nature of fluid flow with respect to casting of different grades of steel in consecutive heat in the same tundish. At the grade change the analysis of curve provides the extent of mixing length and at the ladle change, gives the information of how fast the flow return to steady state. The plot between the dimensionless concentration and dimensional less time is known as F curve. The F-curve in Fig. 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 sec [16].

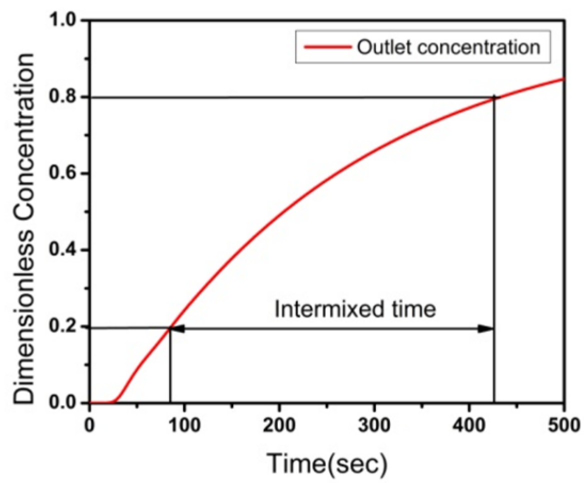



**Fig. 2: Calculation of intermixed amount at the outlet for 20:80 grade specifications.**

## 3. RESULTS AND DISCUSSIONS

Investigating the effect of parameters on minimizing the amount of intermixed grade steels is a very important for steel making units. In the present study, physical modeling and numerical investigation of formation of intermixed grade steels due to mixing in tundish as well as in the mold (coupled effect) has been carried out. The effect of casting parameters and the use of flow modifiers to minimize the amount of intermixed grade has been suggested for tundish and mold used in steel industries. Fig. 3 shows the calculated intermixed amount for 10:60 grade specification of steel at the near outlets of tundish and mold. This Fig. shows a comparative results on mixing behaviour of steel-making tundish, obtained through physical investigations on bare tundish and tundish with dam. It is seen that different cases have represented different amount of mixing time. It is found that intermixed amount is high for tundish with dam cases as compared to bare tundish. But in certain cases bare tundish has shown larger mixing time. In case of L and M cases in which velocity at inlet is constant and variation of water bath height is also similar to cases E and F, but due to addition of dam, it is found that larger intermixed amount at L and M cases. The fluid flow behaviour in bare tundish is different from a tundish having dam due to geometrical changes.

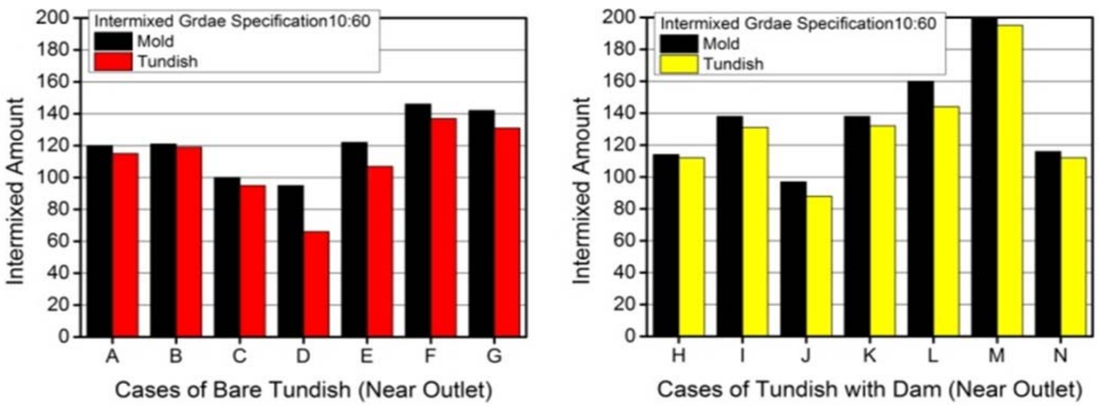



**Fig. 3: Intermixed amount calculated at near outlet**

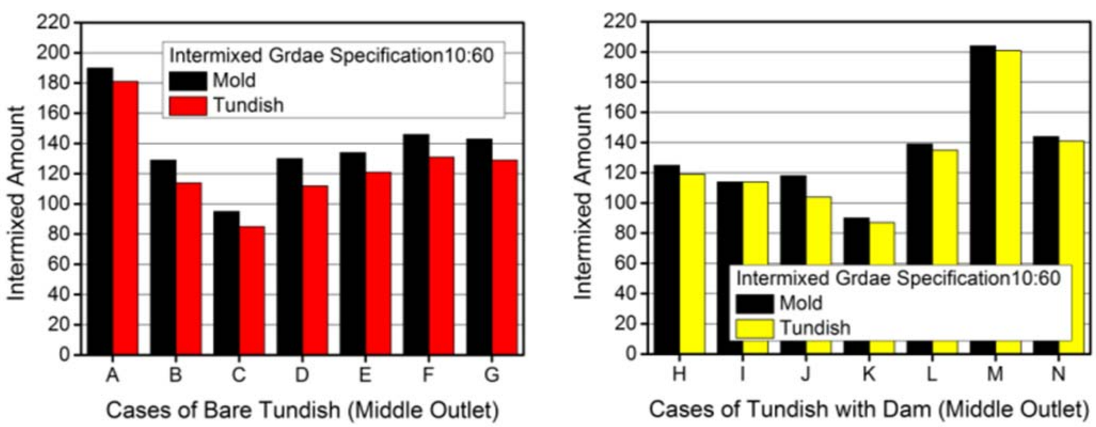



**Fig. 4: Intermixed amount calculated at middle outlet**

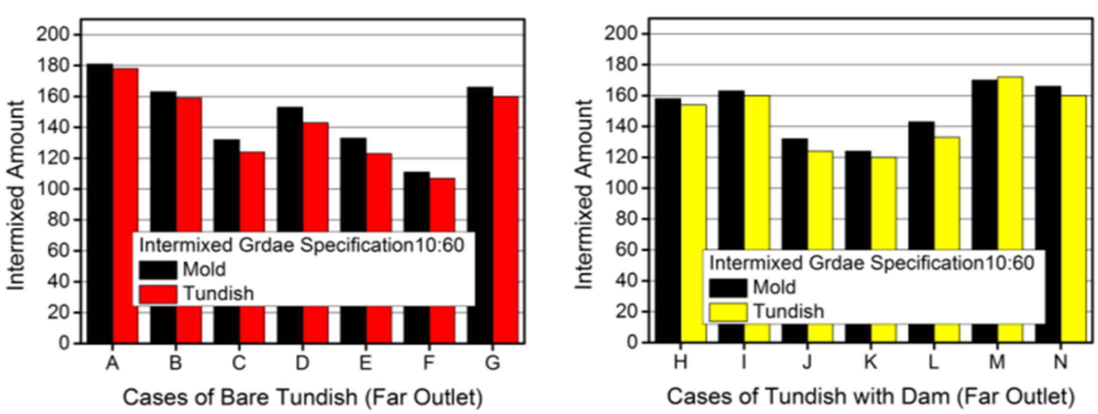



**Fig. 5: Intermixed amount calculated at far outlet**

The mixing behaviour of fluids in tundish highly depends upon shape and geometric parameters. So adding a dam near the inlet stream zone reduces the turbulent flow of incoming fluid plumes. In general, the fluid coming from submerged entry nozzle is diverted towards the longitudinal side of tundish. But adding tundish furniture like advance pouring box, dam, weirs etc. dramatically changes fluid flow behaviour. In present work, dam reduces the flow current moving towards the outlets and redirects incoming fluid towards top surface. This phenomenon enhances the chances of inclusions entrapment and minimizes the mixing time of different grades of steel.

Fig. 4 shows intermixed amount calculated at middle outlet of tundish and adjacent connected mold. Certainly the fluid flow behaviour at middle outlet is different from other two outlets. This figures compares the results of bare tundish and tundish equipped with dam. Fig. 4 shows intermixed amount calculated at middle outlet of tundish and adjacent connected mold. Certainly the fluid flow behaviour at middle outlet is different from other two outlets. This figures compares the results of bare tundish and tundish equipped with dam. It is seen that calculated intermixed amount is more at case as compared to case H. However case M shows a larger mixing behaviour as compared to case F of bare tundish. It can be also noted through the histograms that an addition of tundish furniture changes the overall mixing of tundish. Therefore, for optimal production of quality steel, a tundish must be designed accordance to mixing behaviour. As compared to near outlet graph, it is seen that middle outlet have larger mixing time with exception of few cases. Fig. 5 shows the intermixed amount calculated at far outlet of tundish. In general, fluid flow have less momentum and lesser mixing capability. Thus it is also seen that intermixed amount for all cases have higher mixing time as compared to other outlets. The use of flow modifiers or flow control devices like dams, weirs and baffles, which are physical obstacles placed in the path of the molten steel flowing in the tundish, has been extensive. The main aim of dam is to modify the fluid flow conditions so that the tundish can perform better in a fluid dynamical sense for metallurgical adjustments during the process of continuous casting. The formation of dead volumes in the lee ward sides of these flow control devices are believed to spoil the overall residence time and hence mixing in the tundish

## 4. CONCLUSION

In this study, physical modelling has been carried out to investigate the intermixing time in the delta shape billet caster tundish. The intermixed amount has been calculated for two physical models of tundish i.e., tundish with and without dam. This investigations also includes a calculation of grade mixing in molds adjacent to tundish outlets. A comparative histograms have been presented for bare tundish and tundish with dam configuration, respectively. From results it has been seen that intermixed amount increases due to addition of dam in tundish. 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

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