INVESTIGATION OF OPTIMAL TRANSIENT CONDITIONS IN T-SHAPE TUNDISH DURING STEEL INTERMIXING

[1]Lukáš FOGARAŠ, [1]Branislav BUĽKO, [1]Peter DEMETER, [1]Slavomír HUBATKA, [1]Jaroslav DEMETER, [1]Peter ŠMIGURA, [1]Martina HRUBOVČÁKOVÁ

[1]Institute of metallurgy, Faculty of materials, Metallurgy and Recycling Department of Metallurgy, Technical University of Košice, Košice, Slovakia, EU, lukas.fogaras@tuke.sk

https://doi.org/10.37904/metal.2023.4631

Abstract

The presented research was focused to optimize the conditions in a T-shaped three-strand tundish to minimize the intermix zone during steel casting. The intermix zone occurs when different steel grades are cast in a single sequence without interruptions or restarts, resulting in mixing of old and new steel grades in the tundish and the continuous cast billet. To achieve maximum steel casting efficiency, the conditions of the tundish were optimized to minimize the intermix zone. The study is focused on investigating the starting height of the steel level in the tundish before opening the pouring ladle and the duration of the steel level in the tundish after opening the pouring ladle for a specific time period. The SimCont physical model was utilized to realize the research.

Keywords: Steel, F-curves, tundish, intermix, transient casting

1. INTRODUCTION

Nowadays, continuous casting is extremely conditioned by sequences of different steel grades that produce a large amount of intermixed steel. Due to customer requirements, steel producers are forced to deliver a few conti-casts of high-specialized steels, so the number of castings handling steels of dissimilar grades has been significantly increased in recent years. As a consequence, manufacturers are particularly concerned with the development of practical methods to know exactly where the mixed regions begin and end, in order to make a precise classification of the steel grade that has been produced and avoid further downgrading [1-2]. Hence, the tundish is forced to work under variable conditions, increasing the transient states, and the desirable homogenization is compromised due to the production requirements. Obviously, steel producers need to know exactly the location of mixed regions, optimizing the casting sequences to minimize the costs associated with intermixing different molten steels from different ladles [3]. The intermixed zone originates during a sequence casting when the various steel grades are cast in a single sequence, without the interruption of the casting, and without consecutive restarts. This casting technology causes a mixing of the old and new steel grades in the tundish, and in the continuous cast billet it creates so called the intermixed zone [4-5].

The aim of this research is to find the optimal conditions in a T-shaped three-strand tundish that provide the shortest possible intermix zone during steel casting. The research was carried out on a physical model of a T-shaped three-strand tundish SiMConT, which is part of the Laboratory of simulation of flow processes at the Institute of Metallurgy joint ŽP VVC, s.r.o. [6]. The main parameters under investigation will be the starting height of the steel level in the tundish before opening the pouring ladle and the duration of the steel level in the tundish for a certain period of time after opening the pouring ladle. By optimizing these parameters in combination with the results of the previous researches, we should theoretically be able to achieve intermix connections as short as possible [1-4].

2. MATERIALS AND METHODS

The investigation of the optimal conditions for the shortest intermix during the casting process was realized on a water model of a tundish, located in a research laboratory at the Technical University of Košice, Faculty of Materials, Metallurgy and Recycling, at the Institute of Metallurgy. The physical water model of the tundish is an exact replica of the internal volume of a real tundish (RT), in a scale of 1:2. Total volume of tundish is 0.019 m^3.

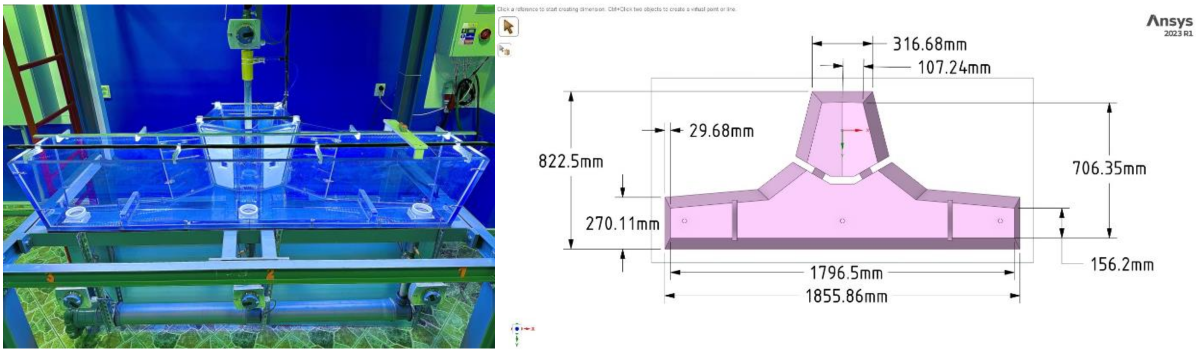

Figure 1 On the left, a physical water model of a tundish, on the right, the geometric dimensions of the water model.

The water model was used as a substitute for liquid steel in the study. The kinematic viscosity of steel at 1600 °C and water at 20 °C is very similar. The kinematic viscosity of steel at a temperature of 1600 °C is $0.913 \cdot 10^{-6}$ m^2/s and that of water at room temperature 20°C is $1 \cdot 1^{-6}$ m^2/s. Sensors are placed at the inlet and outlet to monitor the change in conductivity of the water. Higher conductivity is achieved by adding salt, in this case KCl, to the water. For visual effect, $KMnO_4$ is added to the water to give it a purple color. This allows for visual observation of the flow of steel, mixing of two melts, and so on. The scale of the model is 1:2, which means that each dimension of the model is half that of the real tundish. Therefore, the desired volume of steel in the actual tundish needs to be divided, and since these are 3D objects, they need to be divided by 8, i.e., 2^3. At the outset, it was important to determine how many times faster the process would be on the model than on the real tundish. This ratio was calculated using the formula:

$$M_\tau = M^{1/2} = 1/2^{1/2} = 0.7071 \qquad \frac{1}{0.7071} = 1.41423 \tag{1}$$

"M_τ" represents the time dependence between the tundish model and real tundish. "M" represents the scale ratio of the model to the actual object, and from the calculations provided, it follows that the speeds achieved on the water model will be 1.4142 times shorter than on the real tundish. Four measurements (V1-V4) were performed under different conditions listed in **Table 1**.

Each measurement lasted for 10 minutes. The measurements were taken with different settings based on the initial level of the model or the possible duration of the initial level for a certain period of time. Since it is an unsteady regime of mixing of melts, the result of this data will be graphical representations of F-curves.

Table 1 Individual conditions of the tundish for simulations V1-V4

	Steel level START (mm)	Steel level END (mm)	Weight of liquid steel (RT) (t)	Duration (RT) (s)	Duration (model) (s)	Weight of liquid steel END (t)
V1	170	300	5.15	0	0	10.1
V2	170	300	5.15	360	260	10.1
V3	250	300	8	0	0	10.1
V4	250	300	8	360	260	10.1

The lengths of individual intermix zones for different configurations were evaluated using two criteria: the 80/20 criterion and the 90/10 criterion. Using these criteria, it was possible to determine the shortest intermixing times and evaluate which experimental setup resulted in the shortest transition time, and to assess the most advantageous conditions to solve the intermix problems. The individual criteria indicate the imaginary start and end of the transition region, the difference of which gives us the length of the transition region itself. Based on these results, various optimization options were compared.

All measured values were converted to dimensionless concentration values ranging from 0 to 1. The 80/20 criterion represents values at dimensionless concentrations of 0.2 and 0.8, while the 90/10 criterion represents values at dimensionless concentrations of 0.1 and 0.9. Based on the parameters of the most common casting format at real conditions and the above-mentioned speed conversion, the resulting F-curve values in the model were converted to mass parameters for the real tundish, for better understanding and comparison of the results see **Tables 2-11**. During the measurement, the physical model of the tundish had the same setup as the real tundish.

3. RESULTS AND DISCUSSION

In the following graphs presented in **Figure 2**, the results of measurements V1-V4, according to the conditions in **Table 1**, are displayed in the form of F-curves, which are evaluated based on the 80/20 criterion. Each graph in **Figure 2** also corresponds to numerical values of times on the model in the form of a table for individual casting strands (CS) and their differences, which indicate specific lengths of transition areas based on the 80/20 evaluation criterion. **Tables 2-6** shows numerical expressions of F-curve graphical results recalculated to the mass values of the real tundish, based on the above-mentioned parameters, for easier comparison of the results of different settings of the tundish. **Table 6** displays the overall evaluation of the lengths of intermix zones for measurements V1-V4 for individual CS, and also shows the percentage differences in the weights of the intermix conti-cast for measurements V2-V4 compared to V1 (highlighted column in the table), whose values were the best according to the 80/20 evaluation criterion.

Evaluation criterion 80/20:

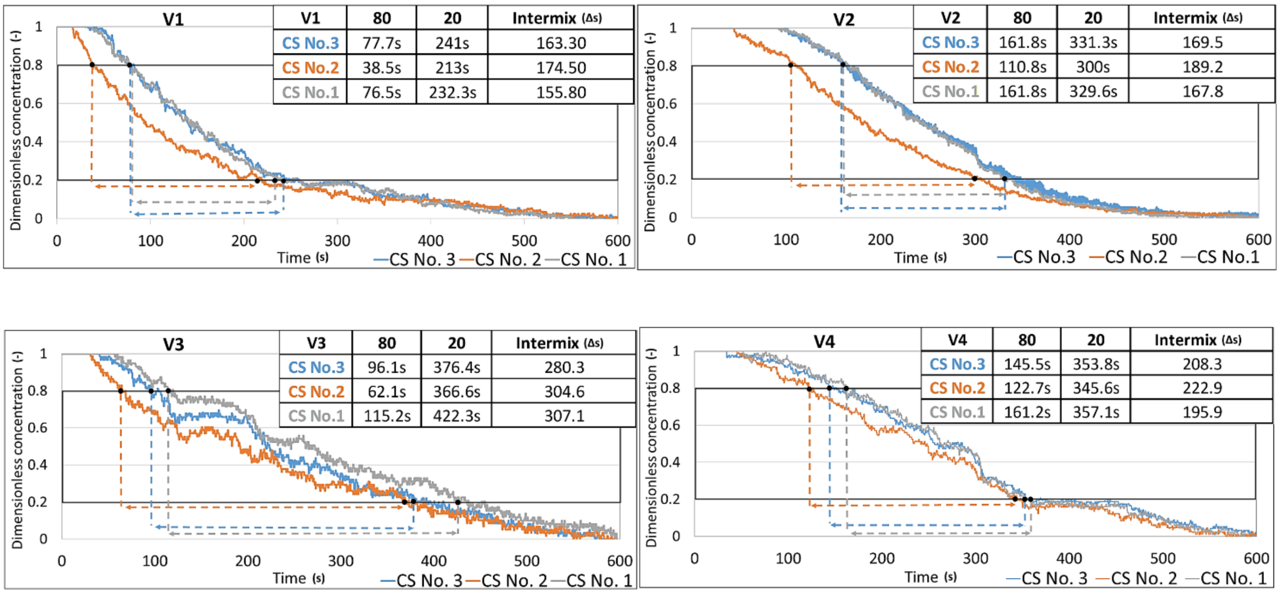

Figure 2 Graphical evaluation of the results of measurements V1-V4 in the form of F-curves using the 80/20 criterion

Table 2 Numerical results of F-curves (V1), 80/20

V1	80	20	Intermix (Δt)
CS No.3	0.581 (t)	1.801 (t)	1.220
CS No.2	0.288 (t)	1.592 (t)	1.304
CS No.1	0.572 (t)	1.736 (t)	1.164
SUM CS No.1-3			**3.688 (t)**

Table 3 Numerical results of F-curves (V2), 80/20

V2	80	20	Intermix (Δt)
CS No.3	1.209 (t)	2.475 (t)	1.266
CS No.2	0.828 (t)	2.242 (t)	1.414
CS No.1	1.209 (t)	2.463 (t)	1.254
SUM CS No.1-3			**3.934 (t)**

Table 4 Numerical results of F-curves (V3), 80/20

V3	80	20	Intermix (Δt)
CS No.3	0.718 (t)	2.812 (t)	2.094
CS No.2	0.464 (t)	2.739 (t)	2.275
CS No.1	0.861 (t)	3.155 (t)	2.295
SUM CS No.1-3			**6.664 (t)**

Table 5 Numerical results of F-curves (V4), 80/20

V4	80	20	Intermix (Δt)
CS No.3	1.087 (t)	2.644 (t)	1.556
CS No.2	0.917 (t)	2.582 (t)	1.665
CS No.1	1.204 (t)	2.668 (t)	1.464
SUM CS No.1-3			**4.685 (t)**

Table 6 Overall comparison of the resulting intermix zones for measurements V1-V4 for individual casting strands, 80/20 criterion

	Intermix - V1	Intermix - V2	Intermix – V3	Intermix – V4
CS No.3	**1.220 (t)**	1.266 (t) / ↑**3.8%**	2.094 (t) / ↑**87%**	1.556 (t) / ↑**39%**
CS No.2	**1.304 (t)**	1.414 (t) / ↑**20.6%**	2.275 (t) / ↑**94%**	1.665 (t) / ↑**42%**
CS No.1	**1.164 (t)**	1.254 (t) / ↑**7.7%**	2.295 (t) / ↑**97%**	1.464 (t) / ↑**26%**

During the first two measurements, V1-V2, the initial level of the tundish was set to 5 tons, whereas for the last two measurements, it was set to 8 tons. In real operating conditions at a steel plant, the minimum level of steel in the tundish is typically 5 tons. If the level of steel falls below this level during the opening of the main casting ladle, various timing issues may occur, and the 5-ton level in the tundish allows for a quick response to prevent the interruption of the casting process. For the second case, the level of the ladle was set to 8 tons, as this is the actual level of the ladle from the closing of one casting ladle to the opening of the next.

Based on the measured values, it can be inferred that reducing the level of steel in the tundish to a certain value before pouring new steel grades from the ladle into the tundish significantly and unequivocally shortens the intermix zone for this type of tundish on all three casting strands. In contrast to measurements V3 and V4, where the initial level in the tundish was 8t, it has been demonstrated that increasing the level in the tundish before starting a new sequence has a negative impact on shortening the intermix zones. For V2 and V4 measurements, the steel levels in the tundish were left at a level at which the main pouring spout was open with the new steel grade for a period of 4 minutes. When comparing the resulting values of measurements V1 and V2, it can be demonstrated that maintaining the steel level in the tundish at the initial level in this case has no positive effect on the length of the transition zones.

Evaluation criterion 90/10:

The evaluation of measurements according to the 90/10 criterion was carried out analogously to the first evaluation by the 80/20 criterion. **Figure 2** presents the graphical results of the measurements in the form of F-curves for the 90/10 criterion. The recalculated mass parameters for the real tundish based on the evaluated durations of the intermix zones **Table 7-11** were also selected as the final comparative parameter. In the case of the 90/10 criterion, it was confirmed that increasing the initial level of steel in the tundish to 8t, as in measurements V3-V4 prior to pouring a new steel grade, has a negative impact on the length of the intermix **Table 7-11**. Therefore, it can be inferred that reducing the level of steel in a specific type of tundish to 5t before pouring a new steel grade from the ladle significantly shortens the transition regions on all three strands.

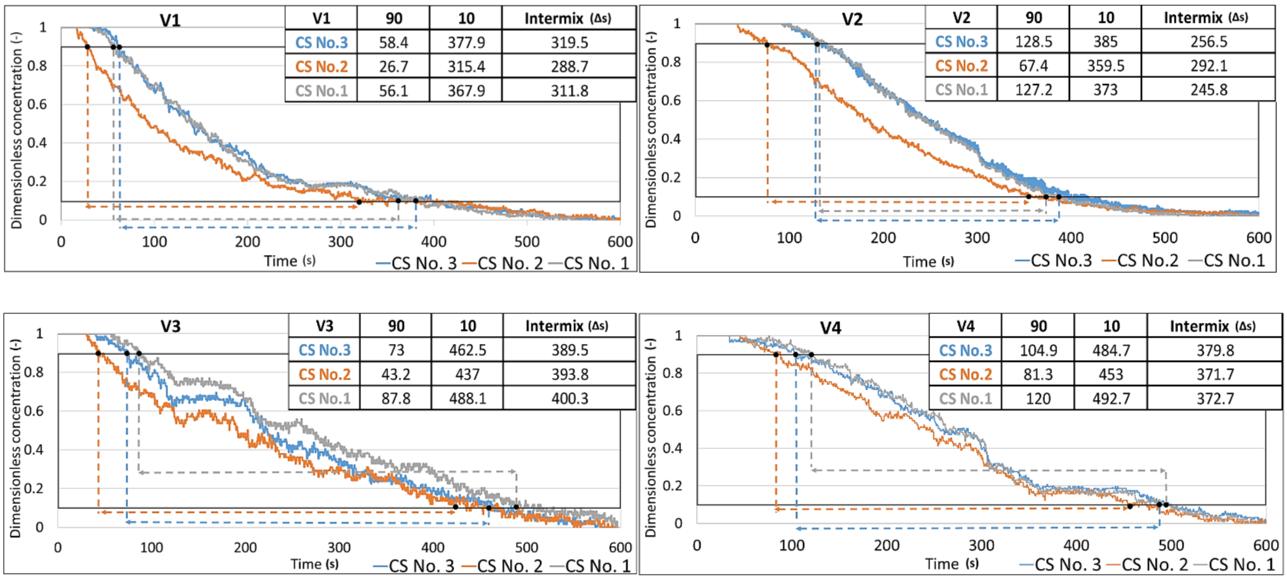

Figure 3 Graphical evaluation of the results of measurements V1-V4 in the form of F-curves using the 80/20 criterion

Table 7 Numerical results of F-curves (V1), 90/10

V1	90	10	Intermix (Δt)
CS No.3	0.436 (t)	2.824 (t)	2.387
CS No.2	0.199 (t)	2.357 (t)	2.157
CS No.1	0.419 (t)	2.749 (t)	2.330
SUM CS No.1-3			6.874 (t)

Table 8 Numerical results of F-curves (V2), 90/10

V2	90	10	Intermix (Δt)
CS No.3	0.960 (t)	2.877 (t)	1.917
CS No.2	0.504 (t)	2.686 (t)	2.183
CS No.1	0.950 (t)	2.87 (t)	1.837
SUM CS No.1-3			5.936 (t)

Table 9 Numerical results of F-curves (V3), 90/10

V3	90	10	Intermix (Δt)
CS No.3	0.545 (t)	3.456 (t)	2.910
CS No.2	0.323 (t)	3.265 (t)	2.942
CS No.1	0.656 (t)	3.647 (t)	2.991
SUM CS No.1-3			8.844 (t)

Table 10 Numerical results of F-curves (V4), 90/10

V4	90	10	Intermix (Δt)
CS No.3	0.784 (t)	3.622 (t)	2.838
CS No.2	0.607 (t)	3.385 (t)	2.777
CS No.1	0.897 (t)	3.681 (t)	2.785
SUM CS No.1-3			8.400 (t)

Table 11 provides an overall evaluation of the lengths of intermixes measured in V1-V4 trials for each of the casting strand. It also displays the percentage differences in the weights of the intermixes measured in V1, V3, and V4 relative to V2 (highlighted column in the table) which yielded the best results under the 90/10 comparison criterion. The most significant differences in measurements between V1 and V2 were observed for CS No.3 and 1, while CS No.2 achieved a nearly identical result. As V2 measurements obtained the best overall results for intermix zones under the 90/10 criterion, it can be concluded that, in this case, maintaining the level of liquid steel in the intermediate ladle before initiating a new sequence had a positive effect.

Table 11 Overall comparison of the resulting intermix zones for measurements V1-V4 for individual casting strands, 90/10 criterion

	Intermix – V1	Intermix – V2	Intermix – V3	Intermix – V4
CS No.3	2.387 (t) / ↑**25%**	**1.917 (t)**	2.910 (t) / ↑**52%**	2.838 (t) / ↑**48%**
CS No.2	2.157 (t) / ↓**1.2%**	**2.183 (t)**	2.942 (t) / ↑**35%**	2.777 (t) / ↑**27%**
CS No.1	2.330 (t) / ↑**27%**	**1.837 (t)**	2.991 (t) / ↑**63%**	2.785 (t) / ↑**52%**

When comparing all measurements, the significant differences between V1, V2, and V3, V4 measurements are immediately noticeable. The initial level of the ladle was 5 tons for the first two measurements, and 8 tons for the latter two. The results indicate that a lower level of steel in the ladle upon opening the main casting vessel unequivocally and significantly shortens the intermix in all three casting strands. The difference between the results is around 800 kg of steel, which, for three streams, represents a difference of almost 2.5 tons disadvantageous to the latter two measurements. Regarding the endurance of steel level in the ladle after starting the casting of a new sequence, the results suggest that the V1 measurement according to the 80/20 criterion, where the endurance of steel level did not significantly affect the intermix length, could be applicable for steel grades which are connected during the casting sequences with a closer range of their chemical composition, where the chemical composition of two steel grades is close or overlapping. The graph shows that the 80/20 criterion has a steeper slope, which theoretically suggests a substantially shorter intermix zone than in the case of the 90/10 criterion. Consequently, the result of the V2 measurement according to the 90/10 criterion, where the endurance of steel level had a positive effect on intermix, could be applicable for steel grades whose range of chemical composition is wider.

4. CONCLUSION

Based on the results of this study, it can be concluded that a significant and clear reduction in the length of the intermix zone occurs when the level of steel in the tundish is lowered upon opening the main casting ladle, regardless of the evaluation criterion used. This is confirmed by the results of realized simulations. With regard to the holding of the steel level in the tundish, it was found that such holding can be beneficial in individual cases, as demonstrated by the configuration V2 in the case of the 90/10 criterion, where the optimal conditions for achieving the shortest intermixing time were achieved with a lowered steel level and a holding time of 260 seconds, in contrast to the 80/20 criterion, where a holding time of 260 seconds did not have a significant effect on improving the transitional zone. From these results, it can be inferred that there is likely no universal tundish configuration for achieving the shortest transitional zone. These findings will be validated in the following phases of this study through verification in a real production environment and exploration of an alternative physical prototype of the tundish using identical parameters.

ACKNOWLEDGEMENTS

This research work was performed under the grant project no. 1/0212/21 and was financially supported by VEGA ME SR AND SAS

REFERENCES

[1] HUANG, X., THOMAS, B.G. Intermixing model of continuous casting during a grade transition. *Metallurgical and Materials Transactions B*. 1996, vol. 27, pp. 617-632.

[2] CHATTOPADHYAY, K., ISAC, M., GUTHRIE, R.I.L. Physical and mathematical modelling of steelmaking tundishoperations: A review of the last decade (1999-2009). *ISIJ International*. 2010, vol. 50, pp. 331-348. ISSN 0915-1559.

[3] MICHALEK, K., TKADLECKOVA, M., SOCHA, L., GRYC, K., SATERNUS, M., PIEPRZYCA, J., MERDER, T. Physical Modelling of Degassing Process by Blowing of Inert Gas. *Archives of metallurgy and materials*. 2018, vol. 63, pp. 987-992.

[4] TKADLECKOVA, M., VALEK, L., SOCHA, L., SATERNUS, M., PIEPRZYCA, J., MERDER, T., MICHALEK, K., KOVAC, M. Study of solidification of continuously cast steel round billets using numerical modelling. *Archives of metallurgy and materials*. 2016, vol. 61, pp. 221-226. Available from: http://doi.org/10.1515/amm-2016-0041.

[5] TKADLECKOVA, M., MICHALEK, K., STROUHALOVA, M., SVIZELOVA, J., SATERNUS, M., PIEPRZYCA, J., MERDER, T. Evaluation of Approaches of Numerical Modelling of Solidification of Continuously Cast Steel Billets. *Archives of metallurgy and materials*. 2018, vol. 63, pp. 1003-1008. Available from: http://doi.org/ 10.24425/122435.

[6] BUĽKO, B., DEMETER, P. *Laboratory of simulation of flow processes*. [Online]. 2017. [viewed: 2023-05-08]. Available from: https://ohaz.umet.fmmr.tuke.sk/lspp/index_en.html.