J. PIEPRZYCA, T. MERDER, M. SATERNUS, M. TKADLEČKOVÁ, J. CUPEK, J. WALEK
ISSN 0543-5846
METABK 63(1) 3-5 (2024)
UDC – UDK 699.18:669.184-621.642:621-47:620.193-621.72=111

MODELING RESEARCH ON LIMITATION OF TRANSITION ZONE DURING CONTINUOUS STEEL CASTING

Received – Primljeno: 2023-05-01
Accepted – Prihvaćeno: 2023-07-25
Original Scientific Paper – Izvorni znanstveni rad

The increase in market demand for small masses of special purpose steel forces its producers to use the technique of continuous casting with a transition zone. The article presents the results of model tests of limiting the range of the transition zone as a result of the use of an impact pad and changes in the volume of liquid steel in the tundish. A water physical model of a Continuous Steel Casting (CSC) device equipped with a two-outlets tundish was used for the research. The criterion for assessing the range of the transition zone was the value of the minimum time of complete mixing tome of the tracer in the modeling liquid, determined on the basis of the Residence Time Distribution (RTD) curves. Visualization techniques of the modeling liquid mixing process were used to identify hydrodynamic phenomena.

Key words: tundish, liquid steel flow, impact pad, transition zone, physical water model

INTRODUCTION

Currently, for economic and technological reasons, the process of continuous casting of steel is aimed at maximizing the length of the sequence. However, in the case of small orders in terms of the weight of a batch of steel, in order to optimally use the capabilities of the device, production plans provide for combining, for example, two types of steel with a similar chemical composition for casting in one sequence (without replacing tundish) [1- 2]. The advantage of this technique is that it avoids wasting time and energy to end the casting prematurely, prepare the equipment, replace the tundish, and start casting the next sequence. The disadvantage is the formation of the so-called transition zone. The transition zone is a mass of cast steel of undetermined chemical composition, which is formed when two types of cast steel are mixed. This process takes place in the CSC tundish and causes defects. Therefore, the basic problem to be solved in the case of using the casting technique with a transition zone is to limit the range of occurrence of this zone. This can be obtained by various methods. The most common of them are limiting the volume of liquid steel in the tundish and using the phenomenon of changing the viscosity of steel with temperature, and consequently changing the structure of the liquid steel flow from plug to layered [3-4]. The size of the transition zone is also affected by the design of the tundish and the flow regulators used. Therefore, a set of procedures for steel casting with a transition zone must be determined individually for each CSC device. Most often, for fundamental reasons, a series of experiments are performed using water physical models of the CSC device or numerical modeling programs [5-8].

J. Pieprzyca, T. Merder, M. Saternus: Silesian University of Technology, Faculty of Material Science, Katowice, Poland J. M. Tkadlečková, Cupek, J. Walek: VSB - Technical University of Ostrava, Ostrava, Czech Republic
Corresponding author: tomasz.merder@polsl.pl.

MATERIALS AND EXPERIMENTAL METHODS

The tests were carried out using a physical model of the CSC device. It is designed and built in accordance with the requirements of the theory of similarity [9-10]. This model has a segment structure. The main segment is a two-strand tundish model (see Figure 1), in which all conditions of kinematic and dynamic similarity have been met. This model is described in detail in [11,12]. The model of the tundish was made in 1:4 scale (volume of the model is 0,130 m^3). Tundish is characterized by a bottom lowered by 0,025 m in the area of outlets.

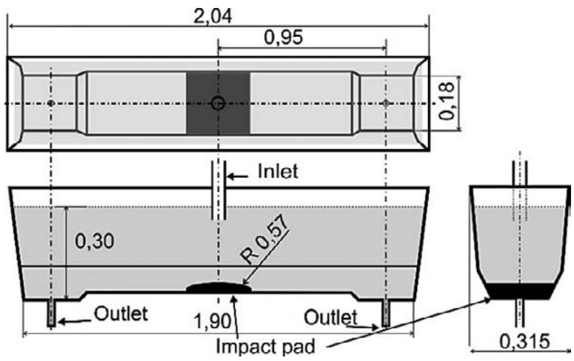

Figure 1 The geometric dimensions / m of the tundish

The tundish model is equipped with an impact pad (IP) described in detail in [13]. The designed impact pad is characterized by the fact that its working surface is a cross-section of a sphere. Therefore, unlike a flat surface, it is less sensitive to washing out. As a consequence, it favors the reduction of turbulence in the tundish inlet zone and the formation of exogenous non-metallic inclusions.

The dominant criterion for dynamic similarity was the Froude number [9,12]. The tests were carried out assuming that in real conditions the cross-section of cast continuous billets is 2 000 x 225 mm, at the linear casting speed V_{cas} = 0,6 m/min. Therefore, after calculation, the flow rate of the model liquid (water) in the model was 18,3 l/min.

In order to determine the F-type RTD curves (planned in the research program) and the visualization tests the step method of forcing the signal (Heaviside) on the inlet into the tundish model was used. An aqueous solution of $KMnO_4$ and NaCl was used as a tracer.

The aim of the conducted research was to determine the characteristic (curve) enabling easy prediction of the duration of the transition zone depending on the mass degree of filling the tundish with liquid steel.

To achieve this goal, the research was carried out in two stages. In the first stage, they had the form of visualization of the way of mixing the model liquid in the tundish model depending on the degree of its filling. The course of the experiments was recorded using video cameras. The obtained film material was analyzed in terms of determining the most favorable parameters of the experiments planned in the second stage. Based on the obtained visualization results, a plan of further research was developed, presented in Table 1.

Table 1 **Parameters adopted for model tests**

Variant of experim.	Mass of water in the model / Mg	Mass of steel in the tundish / Mg	Water flow rate / m^3/s	Steel flow rate / m^3/s
A1	0,121	60,0	0,0003	0,0098
A2	0,093	43,1		
A3	0,074	34,6		
A4	0,056	26,1		

In the second stage of the research, the RTD residence curves were determined. They were used to determine the minimum times of mixing the tracer in the model liquid as a function of the filling degree of the tundish model.

RESULTS AND DISCUSSION

Figures 2-3 show exemplary results of visualization of successive variants of the experiment in the form of images. These images were taken at equal time intervals for each variant, measured from the start of the experiment after 50 s (Figure 2) and 80 s (Figure 3), respectively.

The results of the visualization confirmed the expected shortening of the transition zone duration along with the lowering of the liquid level in the tundish model. However, their main purpose was to determine the safe range of liquid mass values of steel in tundish. As the time needed to replace the main ladle at the CSC station is approximately 4 minutes, the flow of liquid

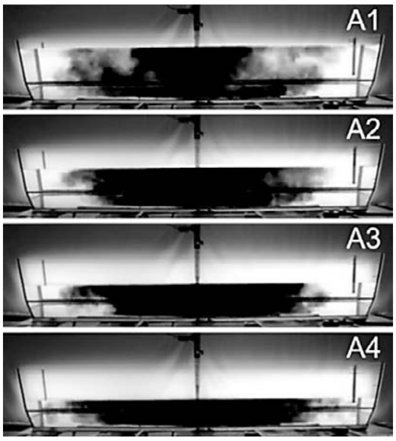

Figure 2 Visualization of the model liquid flow for the analyzed variants for 50 s

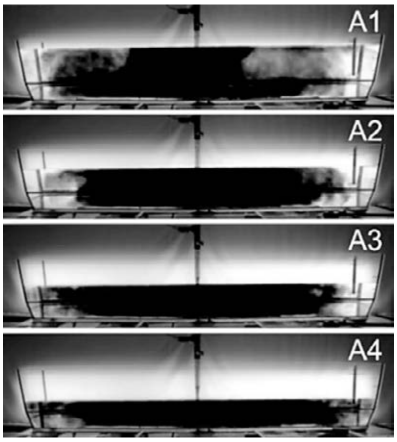

Figure 3 Visualization of the model liquid flow for the analyzed variants for 80 s

steel is approximately 4,2 Mg/min, and its nominal capacity is 60 Mg, the upper value of the tundish weight of steel was 43 Mg. The lower value was determined so as to minimize the risk of creating a vortex on the surface of the liquid steel mirror, and consequently the risk of slag being sucked into the mould. During the visualization, it was observed that the initiation of vortex formation takes place at a volume of approximately 57 liters of water in the tundish model. The mass of steel in

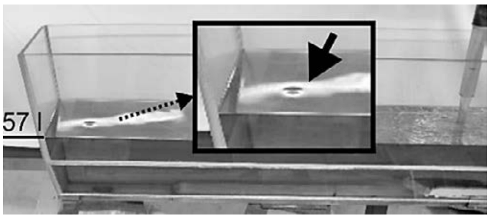

Figure 4 Initiation of the formation of a vortex

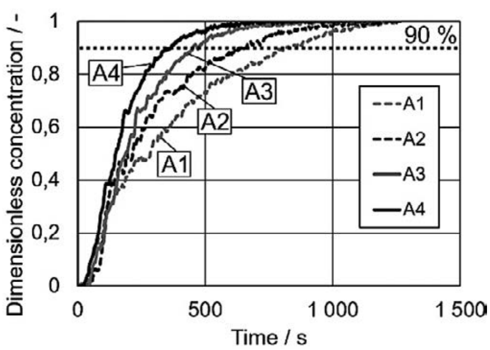

Figure 5 RTD curves for the analyzed variants

tundish is then approximately 26 Mg. In Figure 4 shows the observed vortex formation.

Figure 5 presents the developed F-type RTD plots for individual variants of the experiment. Appropriate conversions were made to obtain the curves [14, 15].

The values of the minimum mixing time were determined when the degree of mixing the tracer in the liquid reached 90 %. The test results are presented graphically in Figure 6.

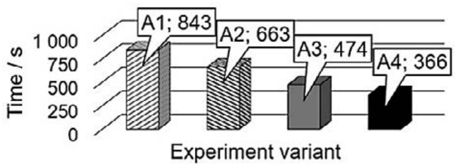

Figure 6 Values of the minimum mixing time for variants of the experiment

After converting the obtained results of model tests into real ones, the curve of the minimum duration of the transition zone was determined as a function of the degree of mass filling of the tested tundish with liquid steel. The curve is shown in Figure 7.

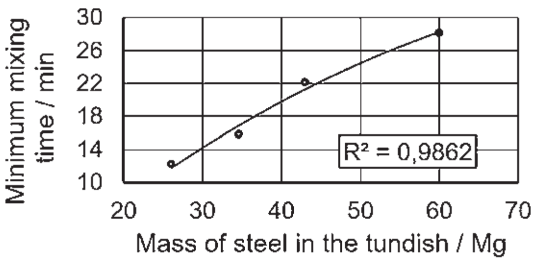

Figure 7 The minimum duration of the transition zone as a function of the degree of mass filling of the tundish with molten steel

The equation describing the mathematically determined curve has the form of a polynomial:

$$y = -0{,}0045x^2 + 0{,}8721x - 7{,}9044 \quad (1)$$

CONCLUSIONS

The tests carried out using the water model of the CSC device equipped with a two-strand tundish showed that the unfavorable phenomenon of the occurrence of the transition zone can be significantly reduced in industrial conditions by applying the results developed in the course of the research. This can be achieved by judiciously limiting the weight of the liquid steel in the tundish during this stage of the casting process. A useful tool in this case is the determined curve of the minimum duration of the transition zone as a function of the mass degree of filling the tundish with liquid steel. By introducing its equation into the algorithm of the process control system in the CSC device, it is possible to flexibly adjust the range of the transition zone.

Further work on limiting the range of the transition zone will take into account the phenomenon of changing the viscosity of steel with temperature, and consequently changing the flow structure of liquid steel from a plug to a layered one. This will further limit the range of occurrence of this unfavorable phenomenon.

Acknowledgements

The article was supported by Statutory Research 11/020/BK_23/0104 (BK-219/RM2/ 2023) of Silesian University of Technology.

The article was also created thanks to the Student Grant Competition of number SP2023/022 and the project No. CZ.02.1.01/0.0/0.0/17_049/0008399 from the EU and CR.

REFERENCES

[1] W.R. Irwing. Continuous casting of steel, Publishing of the Institute of Materials, London 1993.

[2] M. Zorzut, F. Vecchiet, N. Kapaj, A. Paderno. Tundish flow optimization and steel grade change prediction, BHM Berg und Hüttenmännische Monatshefte 152 (2007), 355-360.

[3] S. Song, Y. Sun, Y. Li, C. Zhuo. Effects of temperature and density on transition slab length during steel grade transition, TMS 2023: Materials Processing Fundamentals (2023) 227-240.

[4] M.I.H. Siddiqui, M. Kim. Two-phase numerical modeling of grade intermixing in a steelmaking tundish, Metals (2019) 9, 40, 1-14.

[5] J. Liu, P. Zhou, X. Zuo, D. Wu, D. Wu. Optimization of the liquid steel flow behavior in the tundish through water model experiment, numerical simulation and industrial trial, Metals (2022) 12 (9), 1480, 1-13.

[6] A. Cwudziński. Numerical and physical modelling of liquid steel active flow in tundish with subflux turbulence controller and dam, Steel Res. Int. 85 (2013) 5, 902-917.

[7] D.Y. Sheng. Design optimization of a single-strand tundish based on CFD-Taguchi-Grey relational analysis combined method, Metals (2020) 10, 1539, 1-22.

[8] J. Cloete, G. Akdogan, S. Bradshaw, D. Chibwe. Physical and numerical modelling of a four-strand steelmaking tundish using flow analysis of different configurations, J. S. Afr. Inst. Min. Met. (2015) 115, 355-362.

[9] K. Michalek. The use of physical modeling and numerical optimization for metallurgical processes, Publishing of the VSB, Ostrava 2001.

[10] L. Müller. Application of dimensional analysis in model research, Publishing of the PWN, Warszawa 1983.

[11] T. Merder, M. Warzecha, P. Warzecha, J. Pieprzyca, A. Hutny. Modeling research technique of nonmetallic inclusions distribution in liquid steel during its flow through the tundish water model, Steel Res. Int. 90 (2019) 7, 1-10.

[12] T. Merder. Numerical analysis of the liquid flow structure in the tundish with physical model verification, Archives of Metallurgy and Materials 63 (2018) 4, 1895-1901.

[13] J. Cupek, J. Pieprzyca, J. Walek, M. Saternus, M. Tkadlečková, T. Merder. Optimization of the steel flow in the two-strand tundish using different geometry of impact pad, Metalurgija 62 (2023) 2, 179-182.

[14] J. Jowsa. Engineering of ladle processes in metallurgy, Czestochowa University of Technology Publishing, Czestochowa 2008.

[15] J. Szekely, O.J. Illegbussi. The physical and mathematical modeling of tundish operations, Springer-Verlag, Berlin 1989.

Note: The responsible for English language is Paulina Pieprzyca, Cambridge, Great Britain