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ISSN 0543-5846
METABK 61(2) 291-294 (2022)
UDC – UDK 669.18:669.184:621.642:621.74.04-531.76:628.11.086.5=111

INFLUENCE OF CASTING RATE ON THE MIXING PROCESS OF STEEL IN NON-SYMMETRIC TUNDISH

Received – Primljeno: 2021-06-11
Accepted – Prihvaćeno: 2021-09-30
Original Scientific Paper – Izvorni znanstveni rad

The article presents the results of research aimed at determining the nature of changes in the mixing of liquid steel in asymmetrical tundish due to the increase in casting speed and the possibility of limiting the use of Flow Control Devices (FCD). The tests were carried out on the water model of the Continuous Steel Casting (CSC) device equipped with the tundish model. Four variants of casting speed were analyzed. The analysis of the obtained results was divided into two stages: qualitative analysis of flow and mixing (visualization process) and quantitative analysis of flow and mixing (by analysis of mixing curves - Residence Time Distribution (RTD) type F).

Keywords: tundish, steel flow, mixing time, casting rate, water model

INTRODUCTION

The main task of the multi-strand tundish is to provide favourable conditions for the homogenization of the liquid steel, in terms of chemical and temperature, before introducing it into the moulds [1]. This is important from the point of view of the mechanism of formation of the primary structure of solidifying ingots in individual strands of the device. The aim is to achieve a state where the thermodynamic solidification conditions in all strands are as similar to each other as possible [2]. This is of particular importance in the case of asymmetrical tundishes [3], where such conditions are very difficult to achieve. A common method for achieving this goal is to use flow control devices [3-12] in the workspace of the tundish. Often, however, due to the specific structure of such tundishes, they do not meet the required expectations. Moreover, they can be a source of undesirable contamination of liquid steel with exogenous non-metallic inclusions (NMI). This is of particular importance in view of the current high market requirements with regard to the metallurgical purity of steel.

The need to increase the efficiency of equipment for continuous casting of steel is the reason for introducing innovative solutions in the design of moulds. These solutions make it possible to significantly increase the casting speed without adversely affecting the quality of the continuous cast ingots. Increasing the casting speed also results in changes in the mixing mechanism of the liquid steel in the tundish workspace. The article presents the results of model research of these changes and their use to eliminate the need for application of flow control devices.

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MATERIALS AND METHODS

The object of the research was asymmetric, three-strand continuous casting tundish. The nominal tundish capacity is 10 Mg. The working level of steel is about 0,64 m. The steel is poured into the tundish through the ceramic cover. Such tundish is used for casting square and round ingots. The scheme of tundish along with the symbols of the most important dimensions are shown in

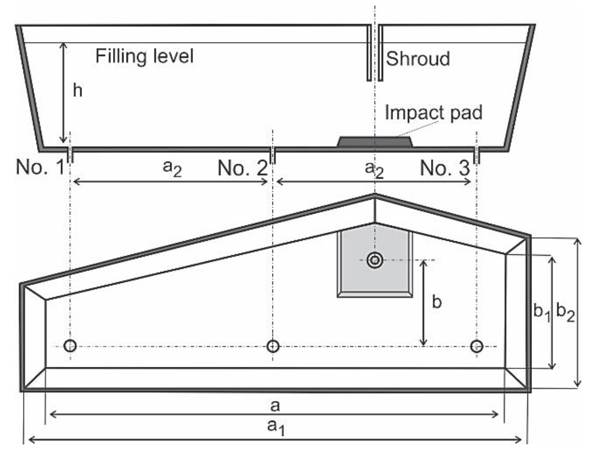

Figure 1 Scheme of the investigated tundish with designations of selected dimensions

Table 1 **Design data for the industrial and the model tundish**

Parameter	Symbol	Tundish	
		Industrial	Model 1:2
Height / m	h	0,640	0,320
Length / m	a	2,700	1,350
	a_1	3,000	1,500
	a_2	1,200	0,600
Width / m	b	0,460	0,230
	b_1	0,690	0,345
	b_2	0,920	0,460

Table 2 **Variants of the experiments**

Var. No.	Industrial			Model 1:2	
	Cross-section of the cast ingots	Casting velocity	Volumetric flow (inlet)		
		/m/min	/ m^3/s	/ m^3/s	/ l/min
A	100 x 100	2,5	0,0014	$2,4 \cdot 10^{-4}$	14,4
B		3	0,0016	$2,9 \cdot 10^{-4}$	17,3
C		3,5	0,0019	$3,4 \cdot 10^{-4}$	20,1
D		4	0,0022	$3,8 \cdot 10^{-4}$	23,0
AT		2,5	0,0014	$2,4 \cdot 10^{-4}$	14,4

Figure 1, the dimensions of the industrial tundish and its model are given in Table 1.

The tests were carried out on the water model of the CSC device equipped with the tundish model. The tundish model is made on a reducing linear scale S_L = 1: 2 = 0,5 in accordance with the requirements of the theory of geometric, dynamic and kinematic similarity [13]. The dominant criterion for the similarity of the tundish model to an industrial device is the Froude number (Fr) [13]. The model is described in detail in [14].

The conducted tests were qualitative (flow visualization) and quantitative (mixing curves measurements). In both kind of studies, a method of step signal forcing on the tundish inlet was used. The tracer in the qualitative tests was the aqueous solution of $KMnO_4$, whereas in quantitative research, an aqueous NaCl solution with a known concentration.

In the case of qualitative studies, continuous recording of the course of the experiment was performed using a high-resolution video camera. The recorded video material allowed for the analysis of colour changes in the model liquid, which is the criterion for assessing the course of the CSC process. On the other hand, in quantitative research, the signals constituting the basis for drawing mixing curves are generated by conductometers. The conductometers were installed on the outlets of the tundish model. The recorded signals from the measuring sensors were further processed in order to draw the mixing curves.

The aim of the research was to determine the nature of changes in the mixing of liquid steel in the tundish as a result of increasing the casting speed and to reduce the need to use flow control devices. Therefore, an adequate research program presented in Table 2 was developed. The A-D variants are without the development of the tundish workspace. In contrast, a turbulence inhibitor was used in the AT variant.

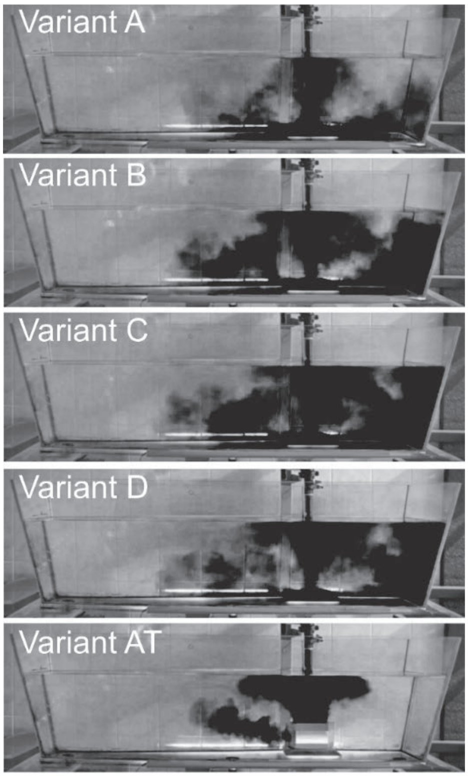

Figure 2 Tracer flow in tundish model for time 20 s

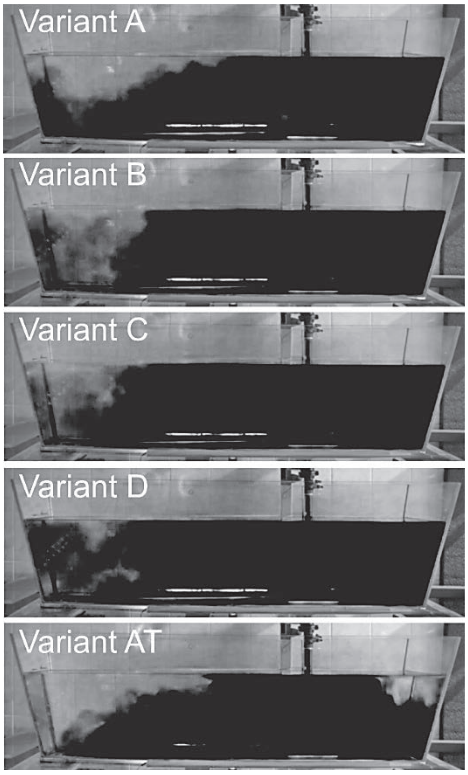

Figure 3 Tracer flow in tundish model for time 80 s

RESULTS AND DISCUSSION

Figures 2 and 3 illustrate selected results of the visualization of the flow in successive steps of the passage of time. The presented figures show the stages reflecting the dynamics of dispersion of the applied tracer in the tundish.

Analyzing the results of the research (Figures 2 and 3), the expected expansion of the turbulent flow zone of the model liquid in tundish is noted, due to an increase in the value of its flux. The effect of this phenomenon is a significant reduction of dead zones. The plug (laminar) flow zone is also limited. The expansion of the turbulent flow zone has a positive effect on the process of homogenization of the liquid steel in a tundish. This is conducive to obtaining similar thermodynamic conditions in individual moulds. However, this required ef-

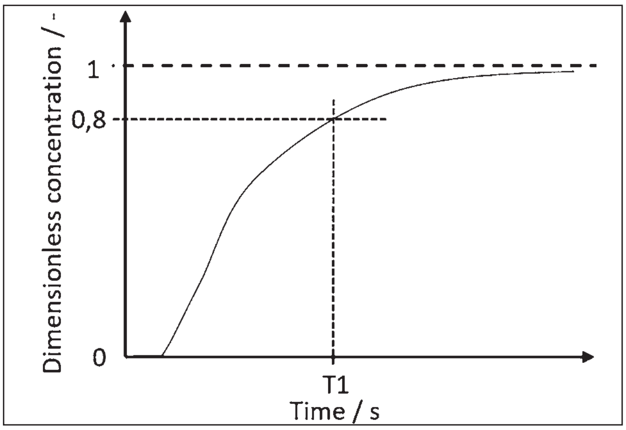

Figure 4 The method of determining the time constant T1

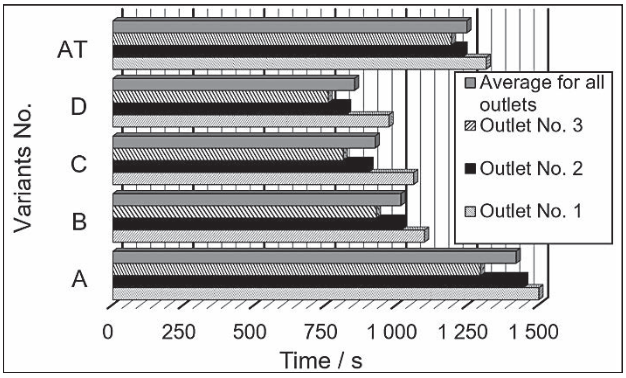

Figure 5 Values of time constants T1 for individual variants of the experiment

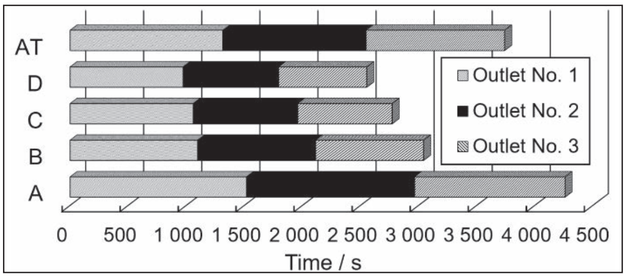

Figure 6 Comparison of the T1 constants in individual outlets and their average value

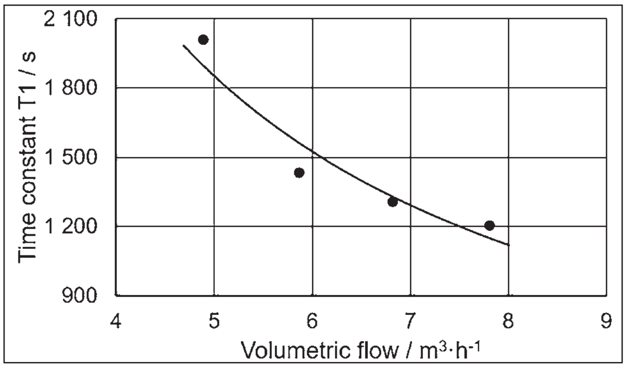

Figure 7 Change of the constant value of T1 as a function of casting velocity

fect is achieved at the expense of a slight limitation of the plug flow zones, which may adversely affect the possibilities of refining liquid steel with NMI. The effects of this phenomenon can be reduced by appropriate preparation of steel for casting during ladle processing.

The results of the visualization of changes in the mixing of the model liquid as a result of increasing the value of its flux were also compared with the applied technique of flow control with the use of turbulence inhibitor. This comparison allows us to state that the rational increase of the casting speed enables for resignation from ceramic flow control devices while ensuring the required homogenization of the liquid steel in the tundish. Such an operation also reduces the risk of secondary contamination of the liquid steel with endogenous NMI.

The quantitative analysis was performed on the basis of the obtained mixing curves. In order to facilitate their direct comparison, appropriate conversions were made to transform the me-asured electrical conductivity into dimensionless tracer concentration. On the other hand, time was converted into real values in accordance with the relationships described in the paper [15].

The time constant T1 was adopted as the criterion for assessing the mixing intensity of the model liquid reflecting the kinetics of the homogenization of the liquid steel in the tundish. This constant determines the duration of the mixing process for individual outlets and the entire tundish according to the developed mathematical model, with the steel mixing coefficient equal to 0,8 (80%). The method of determining this criterion in a graphic form is presented in Figure 4.

The analysis of the obtained results consisted in comparing the values of the T1 time constants for individual outlets in subsequent variants of the experiment. The average value of this constant was also determined for each variant of the casting speed. The results are presented graphically in Figure 5.

A significant reduction in the mixing time of the model liquid in the tundish workspace was observed as a result of increasing the casting speed.

From the point of view of industrial practice, it is also important to obtain similar thermodynamic solidification conditions for liquid steel in individual strands of the device, as well as to shorten the differences in the value of the time constant T1 between individual outlets. This parameter is illustrated in Figure 6.

After the tests, it should be stated that also this process parameter changes favourably with increasing casting speed.

As in the case of visualization, the possibility of replacing traditional flow control devices by increasing the casting speed was also found during quantitative research. Such a statement justifies the observed trend of changes in the method of mixing of the model liquid, caused by an increase in the casting speed, analogous to the effects obtained during the application of flow control devices (FCD).

In order to generalize the obtained test results, their further parameterization was performed to determine the mathematical dependence of the influence of increasing the casting speed on the reduction of the value of the time constant T1. Such characteristics is presented in Figure 7.

The determined characteristics allows for the formulation of a general empirical equation describing the change in the value of the time constant T1 under the influence of the change of the casting speed. This equation takes the form:

$$T1 = 10353 \cdot Q_o^{1,069} \quad (1)$$

where: Q_o – volumetric flow of steel from ladle to tundish / m^3/h.

It should be noted, however, that while the reduction of the time constant T1 has a positive effect on the homogenization of liquid steel in tundish, it worsens the conditions for its refining from fine NMI. Therefore, the proper selection of the casting speed for specific steel grades should be the result of a reasonable compromise between these two parameters of casting.

CONCLUSIONS

Based on the research and analysis of the results, the following conclusions can be drawn:

- The casting speed affects the flow pattern and the intensity of mixing of the liquid steel in the tundish.
- The reduction of the unfavourable dead flow zones is proportional to the increase in the casting speed.
- Increasing the casting speed has a beneficial effect on the mixing process of the liquid steel in tundish, and consequently on its homogenization.
- Improvement of the homogenization conditions of liquid steel in tundish favours the equalization of thermodynamic conditions of its solidification in individual moulds, which is of particular importance when using non-symmetrical tundish.
- As a result of increasing the casting speed, the plug (laminar) flow zone is limited. This may result in a reduction in the efficiency of micro-refining of liquid steel. This problem should be taken into account during ladle treatment process of steel.
- The rational increase in casting speed allows the abandonment of ceramic FCDs while ensuring the required homogenization of the liquid steel in tundish. This fact minimizes the phenomenon described in the earlier conclusion.

Acknowledgements

This article was partially supported by Silesian University of Technology as a part of Statutory Research BK-230/RM2/2021 (11/020/BK_21/0080).

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Note: The responsible for English language is P. Pieprzyca.