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EMERGENCY CONDITION OF THE OPERATION OF A NON-SYMMETRIC TUNDISH

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The aim of the research was to analyze the influence of the flow behavior of liquid steel in a three-strand, asymmetric tundish when not all outlet openings are working. This problem was solved through physical modeling. The tests were carried out with the use of the water model of the continuous casting (CC) machine equipped with an asymmetrical, three-strand tundish model, made on a reducing scale. Modelling research concerned casting 110 x 110 mm square ingots. The obtained results of visualization tests and resistance time distribution (RTD) characteristics (F type) allowed to determine the method of mixing the steel (changes in mixing intensity were estimated) for the analyzed experimental variants.

Keywords: steel, continuous casting, tundish, physical modelling, RTD curves

INTRODUCTION

The technology of continuous casting of steel is a very complicated process and has a multi-stage character. At each of these stages, there are phenomena affecting the efficiency of the process, both in terms of its productivity and the quality of the obtained continuous billets. These phenomena are related to each other by close cause and effect relationships. One of the basic stages of the discussed technology, apart from the crystallization process in the primary and secondary zones, is the process of flowing and mixing liquid steel in a tundish. The nature of this flow directly affects the thermodynamic conditions of the solidification process in its further stages [1]. Therefore, it requires special attention, which is reflected in wide research interest in many centers around the world [2-6].

The determination of the method of flow and mixing of liquid steel in a tundish under industrial conditions is greatly limited for important reasons. Therefore, modeling is a common method of determining this character. The basic parameters determining the method of flow and mixing of liquid steel in a tundish are the areas of individual flow zones, which can be determined on the basis of the process visualization, the minimum time for the marker to reach individual outlets and the minimum mixing time (changes in mixing intensity) understood as the time between the change of the marker concentration achieved through the system in the range of 0,2 ÷ 0,8 dimensionless concentration [7]. The last two parameters were determined on the basis of the analysis of RTD curves obtained during model tests [8-10].

These test methods can also be used to determine the changes in the liquid steel flow in the tundish during emergencies. In such situations, it is usually necessary to cut one or more strands and continue pouring until it is completed as quickly and safely as possible. However, accident procedures must be strictly defined. Model tests allow for safe identification of the consequences of an accident on the flow of liquid steel in a tundish and development of the required rules of conduct in such situations. Such principles are of particular importance in the case of using asymmetric tundish in the CC machine (continuous casting machine), which due to their design constitute a major operational challenge.

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PROBLEM DESCRIPTION

The analyzed object is an asymmetric three-strand continuous casting tundish (CC tundish). It is a model corresponding to an industrial device with a nominal capacity of 10 Mg. Due to the characteristic dimensions of the real object, for the tundish model a linear reducing scale S_L = 1:2 = 0,5 was adopted. The geometry of the tundish model along with the basic dimensions are shown in Figure 1.

The research was carried out using the physical model of the CC machine with a segment structure. Individual structural elements belong to the main and auxiliary segments. The rules of similarity are met only in the main segment (tundish model) [11]. The remaining segments play the role of supporting elements, enabling the fulfillment of the necessary conditions in the main segment. The model is described in detail in [7,12]. The view of the CC machine model equipped with the tested tundish is shown in Figure 2.

The physical model of the device for continuous steel casting is intended for visualization tests and thanks to the installed conductometers it enables the determination of RTD curves. Water is used as the modeling fluid. The

Table 1 **Various variants and conditions of the tests**

Variant number	Outlet closed		
	Outlet 1	Outlet 2	Outlet 3
A			
B	**x**		
C		**x**	
D			**x**

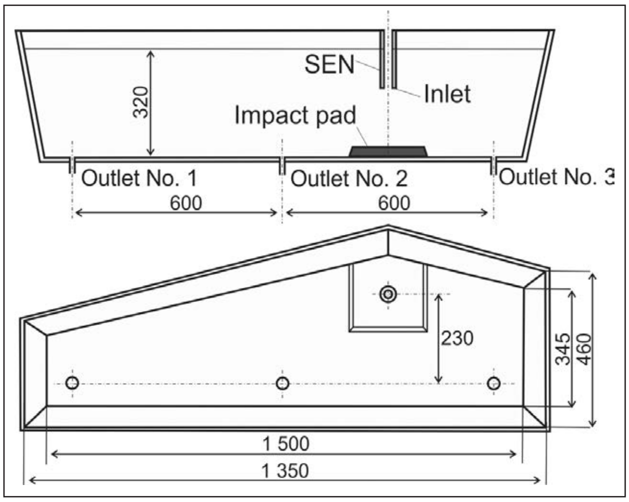

Figure 1 Geometry of the studied tundish model, dimensions / mm

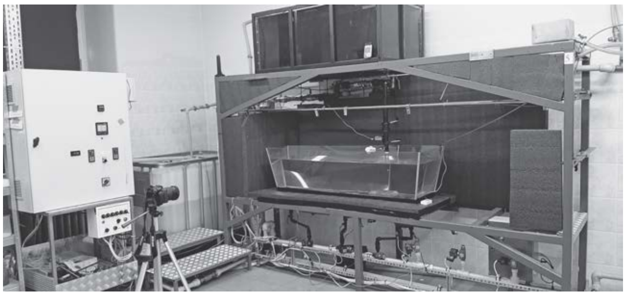

Figure 2 View of the model of continuous steel casting device

dominant criterion for the similarity of the tundish model to the industrial device is the Froude number (Fr) [13].

The tests were carried out with the assumption, that in real conditions the cross-section of the continuously cast ingots is 100 x 100 mm at the linear casting speed V_{cas} = 2,8 m/min. Therefore, after conversion, the water flow rate in the model was 16,1 l/min.

The research used the method of Heaviside signal stimulation in the intlet of the tundish. After reaching the assumed water level in the tundish model and the flow stabilization in accordance with the developed similarity conditions, the tank with clean water was closed, and the tank with marker ($KMnO_4$ and NaCl solution) was opened. The marker was therefore applied throughout the entire measurement period.

The most common response to an emergency in a CC machine (device) is to cut one or more strands. This influences the hydrodynamic conditions of the tundish. Therefore, the experiments were carried out for 4 variants of active outlets configuration. Table 1 describes the different cases studied in the present work.

Variant A refers to the case when all the outlets are open whereas Variant B to Variant D deals with the cases when outlet No. 1, outlet No. 2 and outlet No. 3 are closed respectively as shown by a tick mark against the respective outlet. These three variants illustrate the effect of closing far outlets (No. 1) or near outlets (No. 2 or 3) on flow behavior inside the tundish.

RESULTS AND DISCUSSION

The analysis of the research results was divided into two groups: qualitative and quantitative.

Qualitative research is flow and mixing analysis (process visualization). Figure 3 illustrate selected results of the flow visualization for individual variants of the experiment. The illustrations show the steps reflecting the dynamics of the marker dispersion ($KMnO_4$ aqueous solution) in the physical model of the tundish.

On the basis of the research of visualization of the liquid flow through the tundish model (Figure 3), the formation of a turbulent flow zone in its inlet area was observed. This zone includes outlets No. 2 and 3. This phenomenon is unfavorable from the point of view of refining capacity. On the other hand, it favors its quick homogenization. The consequence of such a nature of the flow in this area is a relatively short time of reaching the outlets covered by the marker.

After approx. 10 seconds of the experiment, a dispersed plug flow zone will be created towards the outlet No. 1, with a clearly shaped front. However, as its sliding velocity decreased in the area above outlet No. 1, there was a tendency to form a dead zone. The time it takes for the marker to reach outlet No. 1 is much longer than for other outlets, which is undesirable and may lead to failure. The described hydrodynamic state is characteristic for an asymmetrical tundish of this type, and is essentially similar in all variants of the experiment. Minor but significant differences from the point of view of the emergency casting process can be more accurately assessed by analyzing the results of quantitative tests.

The quantitative analysis was performed on the basis of the obtained F-type RTD curves. Appropriate conversions were performed to obtain F-type RTD curves [14, 15].

Dimensionless characteristics of the mixing time (F curve) for the analyzed cases are shown in Figure 4.

When analyzing the curves shown in Figure 4, it can be seen that for outlets No. 2 and 3 the characteristics are similar to each other, especially the time it takes to reach the outlets. In the case of outlet No. 1, the time for the marker to reach the outlet is much longer. The nature of the curve growth also differs from the others, some disturbances in the flow are observed, visualized by the fluctuations in the curve. This regularity is independent of the considered variant of the experiment.

This phenomenon is unfavorable from the point of view of the stability of the tundish operation and causes

Table 2 **Changes of mixing intensity (Δt)**

Variant	Δt /s			
	Outlet 1	Outlet 2	Outlet 3	Average
A	1,23	1,15	1,06	1,16
B	x	1,25	1,12	1,19
C	1,16	x	1,08	1,12
D	1,31	1,20	x	1,26

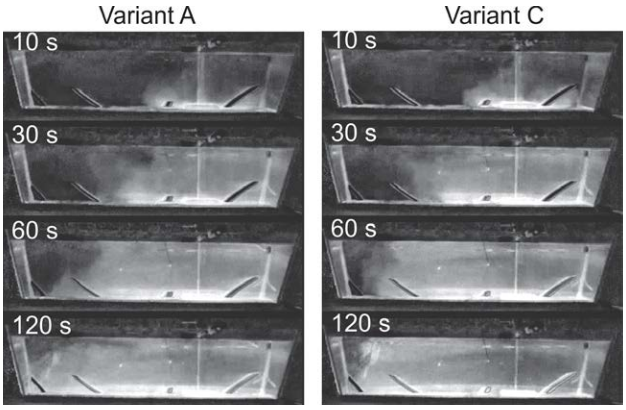

Figure 3 Results of visualization for the variant A and C

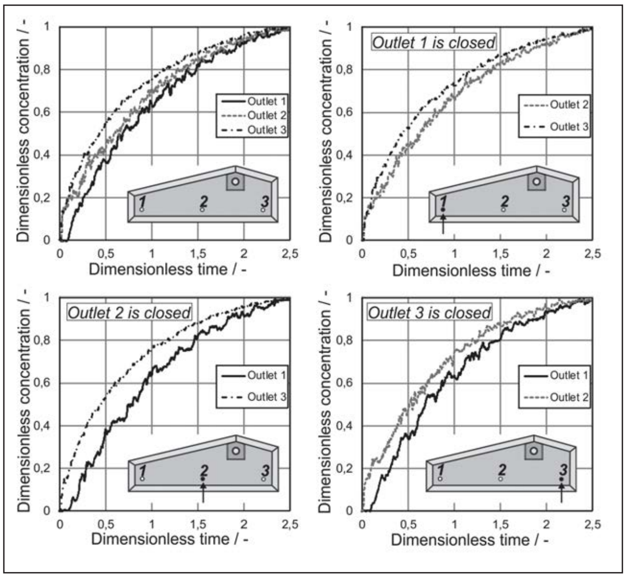

Figure 4 Dimensionless mixing time characteristic (the F curve)

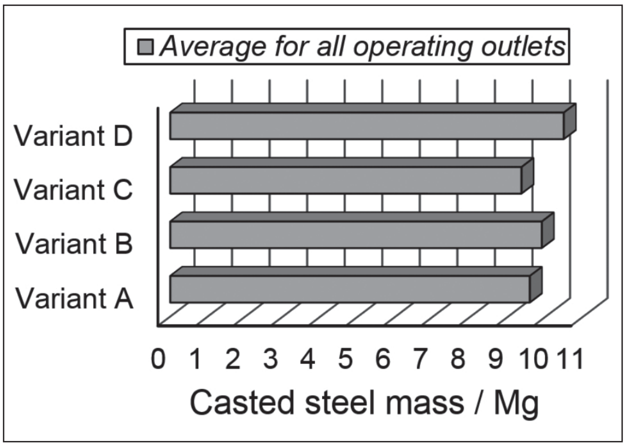

Figure 5 Mass of the cast steel

the occurrence of chemical and temperature heterogeneity of the liquid steel introduced into the individual moulds. At the same time, it is not conducive to the self-refining processes of cast steel, which does not guarantee the required metallurgical purity of the cast ingots.

Assuming that the value 0 on the axis of ordinates of the presented curves (Figure 4) represents the current grade of cast steel, the value (Δt - changes in mixing intensity) can be determined. This value is assumed for a dimensionless concentration ranging from 0,2 to 0,8. The smallest Δt values, the better the mixing condition. Table 2 shows the results of steel mixing intensity.

The analysis of the values in Table 2 confirms the previous observations from the F curves of the unfavorable phenomenon in terms of steel mixing for the A variant (the range of Δt for outlets No. 2 and 3 differs from outlet No. 1).

For the analyzed variants B and D, there is an increase in Δt for individual outlets (also for the mean value of Δt) compared to variant A. However, for variant C (outlet No. 3 is closed), increase of Δt in for outlet No. 3 is seen, while for outlet 1 a significant decrease, compared to variant A. At the same time, the mean value Δt does not decrease significantly compared to variant A.

Knowing the range of Δt for the analyzed variants, it is easy to determine the mass of cast steel that differs in chemical composition and material properties expected for the planned steel grade. It should be mentioned that under the conditions of steel plant, there are very rarely cast steel grades that differ significantly in their chemical composition in one sequence. Usually the same steel grade or grades with a very similar chemical composition are cast. The analyzed case is an extreme case when two grades of steel with significantly different chemical compositions were cast on the CC machine.

The calculated amount of cast steel is shown in Figure 5.

Figure 5 shows graphically the amount of steel corresponding to the average Δt for the analyzed variants.

Comparing the obtained masses of cast steel (ingots), it can be seen that for variant C the mass of cast steel is slightly lower than for variant A (when all outlets are working). On the other hand, for variants B and D, the mass of cast steel increases during variant A.

The presented diagram shows that the most advantageous variant, due to failure of one of the outlets (strand of the CC machine), is variant C.

SUMMARY AND CONCLUSIONS

The physical modeling technique was used to develop the flow characteristics of the CC tundish. The conducted experiments provided valuable information on the emergency operating conditions of the tundish. The most common causes of failure are phenomena related to dirty outlets, mold failure, etc. This usually results in an emergency shutdown of the outlet and a possible continuation of the casting through the remaining active outlets.

The obtained results may be helpful in predicting the flow and mixing of molten steel following emergency operation.

Analysis of the presented results of research for water model tundish, allows to state:

- For all analyzed variants, there is a significant difference between the time of liquid steel reaching the outlet No. 1 and the outlets No. 2 and 3. This is due to the characteristic asymmetrical structure of the tundish.
- For all analyzed variants, the presence of dead flow zones in the area of outlet No. 1 was found. This adversely affects the stability of the tundish operation and causes chemical and temperature heterogeneity of the liquid steel introduced into the individual moulds.
- In the tested tundish (variant A, when all the outlets are operational), there are unfavorable phenomena in the scope of mixing and steel flow (the range of Δt for outlets No. 2 and 3 differs from the outlets No. 1).
- For variants B and D, there is an increase in Δt for individual outlets (at the same time for the average value of Δt) in competition with variant A.
- For variant C (outlet No. 2 is closed), there is a slight decrease for the mean value of Δt.
- From the point of view of the weight of cast steel, variant C is the best solution.

To sum up, it should be stated that the obtained test results show a very significant problem of the necessity to modernize the tundish interior (installation with a flow control device). The enclosure of the tundish workspace should be conducive to the equalization of the Δt range and the times to reach the individual tundish outlets. This modernization should be preceded by a series of model tests.

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Note: The responsible for English language is P. Pieprzyca, Katowice, Poland