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EFFECT OF THE STRUCTURAL PARAMETERS CHANGES IN THE MULTI-STRAND TUNDISH ON THE NON-METALLIC INCLUSIONS DISTRIBUTION AND SEPARATION

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The aim of presented studies was to investigate the fluid flow change and non-metallic inclusions removal changes due to tundish construction modifications. In presented study, numerical simulations were used. Numerical simulations are carried out with the finite-volume commercial code ANSYS Fluent. Steady-state casting conditions for the flow structure and the inclusions removal process are analysed.

Key words: continuous casting, tundish, non-metallic inclusions, numerical modelling

INTRODUCTION

The growing steel industry, requires use of progressive technologies. Their development and improvement is possible due to the use of advanced research techniques, enabling precise identification of phenomena and processes occurring in these technologies.

The growing importance of the tundish during the steel manufacture resulted in necessity for a better understanding of the processes occurring in it. The main issues that allow to understand the nature of these processes are related to the movement of liquid steel flowing through the tundish. The nature of this movement determines the manner of mixing of the steel in the tundish that affects the processes in terms of chemical and temperature homogenisation and non-metallic inclusion flotation [1].

The nature of the flow of liquid steel inside the tundish depends on many factors. First of all, its basic features are enforced by technological casting parameters (casting velocity, temperature of liquid steel during casting process) and the design parameters of the tundish (its shape, type, number of outflows).

The possibilities of forming the character of steel flow through the tundish based on these technological casting parameters are very limited. This is due to the fact that they are fixed at the planning level of casting technology. Therefore there is a need to be able to adjust and/or the formation of steel flow character in the tundish using other methods. The solution to this problem is the use of additional equipment called a tundish flow regulators. They are widely used in industry, and give a very good results in optimalization of the flow and mixing of steel in the tundish. Depending on the type of tundish, the shape of the working space and required change in the flow of liquid steel, an individual selection of flow controllers construction is needed.

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TUNDISH DESCRIPTION

The subject of this study is a CSC tundish operating in a Polish steel plant. This is a trough-type tundish with six nozzles and nominal capacity of 15 Mg. It is used for casting ingots intended for production of small cross-section rolled products. It is symmetrical with respect to its central cross-section. The basic refractory lining is made up of andalusite tiles, and the working layer is made up of a high-magnesite gunite mix. The tundish is equipped with an impact pad. The tundish used for sequence casting (more than ten heats).

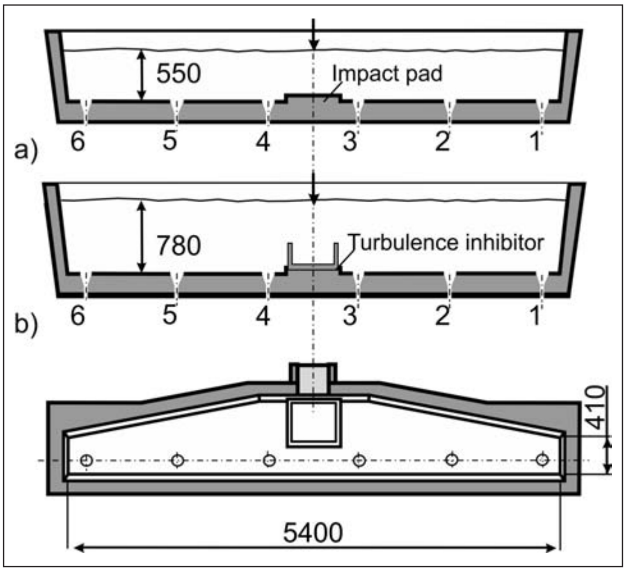

Figure 1 Different tundish configurations studied in present work a) 15Mg, b) 22 Mg

Changing market conditions to increase the purity of steel necessitated the need to rebuild the existing tundish. A simple action was to increase the height of the side walls of the tundish (without interfering with the continuous casting unit). This increased the level of liquid steel in the tundish from 0,55 m to 0,78 m, and thereby the capacity of the tundish from 15 Mg to 22 Mg (see Figure 1). In addition, a tundish (22Mg) is equipped with a flow control device – turbulence inhibitor.

The technological conditions of tundish operation, as used in numerical simulations, are given in Table 1. These relate to the actual casting square ingots with dimension of 160x160.

Table 1 **Parameters used in investigated tundishes**

Parameter	Value	
	Tundish 15 Mg	Tundish 22 Mg
Nominal capacity / Mg	15	22
Molten steel level / m	0,55	0,78
Shroud diameter / m	0,05	0,05
Number of tundish nozzles	6	6
Outlet diameter / m	0,017	0,017
Casting speed / m·min^{-1}	1,7	1,9

EXPERIMENTAL WORK

In order to identify the size of non-metallic inclusions, an industrial experiment was conducted. The study was carried out in industrial conditions for continuous steel casting (tundish 15 Mg) in one of the steel mills. Samples were taken from continuous ingots (Nos. 1, 2, 3). Steel grade for the experiment was steel BSt500S. The content of the major ingredients of the considered type of steel is shown in Table 2.

Table 2 **Chemical composition of the steel grade (BSt500S) / wt%**

	C	Mn	Si	P	S	Cr	Ni	Cu
min.	0,14	0,60	0,10	–	–	–	–	–
max.	0,18	0,70	0,15	0,04	0,04	0,3	0,3	0,4

The study of the size of non-metallic inclusion has been done on the metallographic samples using light microscope Nikon Eclipse Ma 200 that has a possibility of observation of the reflected light in the techniques of bright and dark field observation, the full scale of polarized light, as well as using Nomarski contrast. The range of possible use of magnification is 50 to 3 000 times. The microscope is connected to the computer with the software for data acquisition and NIS-Elements analysis.

Research has been done on the metallographic specimen samples. Three samples have been collected from each ingot. Figure 2 shows a view of the sample and place for taking the sample of continuous ingot.

NIS-Elements D software has been use for analysis of number of inclusions, that allows to perform investigations and archive data from the large area. Analysis of each of six areas using NIS-Elements D software was

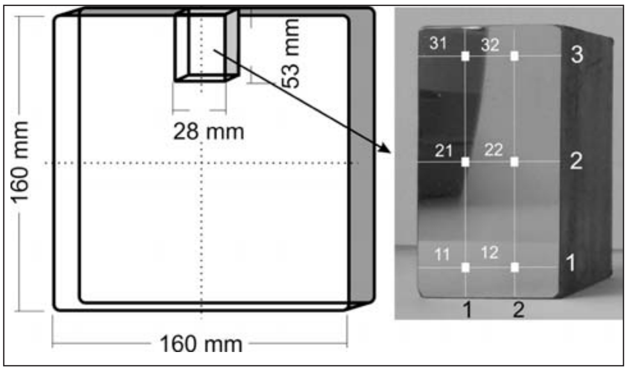

Figure 2 View of the sample and the place for taking the sample [2]

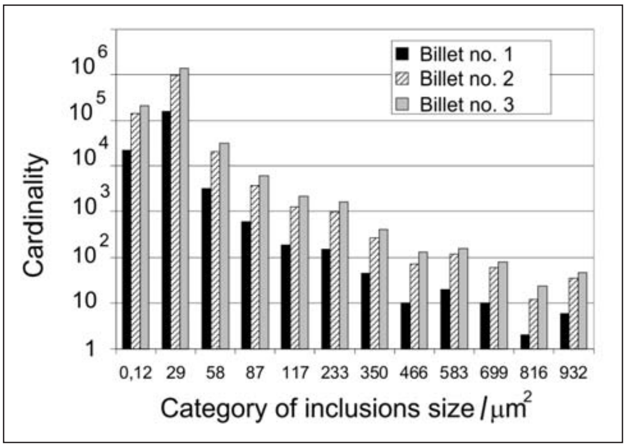

Figure 3 Size distribution of inclusions for tundish 15Mg [2]

based on the principle of separation based on the colour difference between inclusions and metal. This type of analysis could not be performed on the rough samples. Obtained statistical results are presented in Figure 3.

On the basis of data obtained from experimental determinations, shown in Figure 3, an appropriate range of non-metallic inclusions was chosen which has been implemented in the numerical code.

NUMERICAL MODEL

To construct the computational grid of the investigated tundish a commercial code Gambit was used. Computational grid was built with 300 000 control volumes. Numerical simulations of liquid steel flow field and distribution of non-metallic inclusions were performed using ANSYS Fluent commercial software. Mathematical model together with initial and boundary conditions used to calculate the flow field of liquid steel are given in details elsewhere [3-4]. To describe the turbulent flow field of steel, k-ε model [5] was used, it is commonly applied in solutions of engineering problems [6]. At the edge that corresponds to tundish inlet a boundary condition has been implemented based on the conditions presented in Table 1. The outflow rate from the tundish is calculated from the mass balance. The operating and boundary conditions of the mathematical model are based on the actual industrial data. Other pa-

Table 3 **Technological operating conditions of the tundishes used in simulations**

Parameter	Value	
	Tundish 15 Mg	Tundish 22 Mg
Inlet velocity / $m \cdot s^{-1}$	2,4	2,6
Inlet turbulence intensity / %	5	5
Inlet temperature / K	1 828	1 829
Density of molten steel / kg m^{-3}	6 947	6 945
Viscosity of molten steel / kg m^{-1} s^{-1}	$4{,}49 \cdot 10^{-3}$	
Specific heat / J kg^{-1} K^{-1}	830,8	
Thermal conductivity / W $m^{-1} \cdot K^{-1}$	40,5	

rameters used in numerical modelling are presented in Table 3.

The SIMPLEC algorithm was used in numerical simulations. During iteration, the convergence was assumed to reach a point where all the normalized residuals were smaller than 10^{-6}.

Trajectories of non-metallic inclusions were calculated based on the Lagrange method [7]. The method consists in solving the transport equation of non-metallic inclusions within a predetermined flow vector velocity field of steel, taking into account additional effects resulting from turbulent flow. In order to calculate non-metallic inclusions in the tundish it is necessary to supplement the system of equations for a differential equation describing the motion of particles in the liquid phase:

$$\frac{d\,u_{inc.}}{d\,t} = \frac{3\mu_{st.} C_D Re_p}{4\rho_{inc.} d_{inc.}^2}(u_{st.} - u_{inc.}) + \frac{g(\rho_{inc.} - \rho_{st.})}{\rho_{inc.}} + \\ + \frac{1}{2}\frac{\rho_{st.}}{\rho_{inc.}}\frac{d}{dt}(u_{st.} - u_{inc.}) + \frac{\rho_{st.}}{\rho_{inc.}}\frac{d\,u_{st.}}{d\,t} \quad (1)$$

where: $u_{inc.}$, $u_{st.}$ – inclusion or liquid steel velocity, $\rho_{inc.}$, $\rho_{st.}$ – inclusion or liquid steel density, $d_{inc.}$ – inclusion diameter, C_D – drag coefficient, Re_p – particle Reynolds number, g – gravitational constant, $\mu_{st.}$ – molecular viscosity of the liquid steel.

Boundary conditions used in the numerical model (non-metallic inclusions) are shown in Figure 4.

For such a model a modified boundary condition for non-metallic inclusions has been used, implemented at the liquid metal surface through the Users Defined Function (UDF) in ANSYS Fluent code.

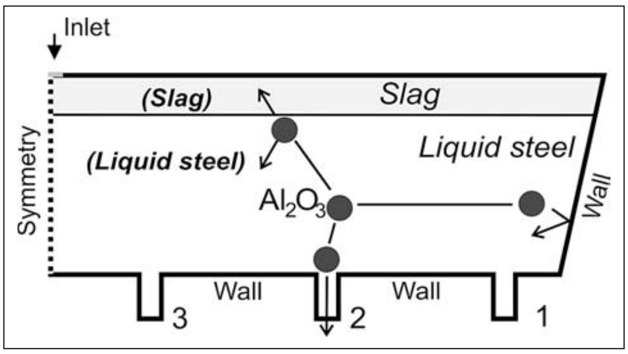

Figure 4 Boundary conditions for fluid and inclusions adapted in numerical calculations

TIt was assumed that non-metallic inclusions are spherical and released from the inlet surface with the same velocity as a fluid and their trajectories are calculated with discrete random walk model.

Based on the results of the decomposition of non-metallic inclusions obtained from tests made on samples of steel, the numerical simulations have been performed for the following groups of size: 1, 2, 5, 10, 20, 30 Mm. Adopted in the calculations inclusions are spherical bodies of density of 4 000 $kg \cdot m^{-3}$.

RESULTS

Non-metallic inclusions removal process is analysed based on numerical simulations. On pre-calculated flow field, trajectories of inclusions with specified sizes (1-30 μm) are tracked using Discrete Phase Model (DPM). Inclusions are released from the shroud (from the whole surface area). The separation rate of inclusions due to flotation can be calculated with the formula:

$$\beta = \frac{N_{in} - N_{out}}{N_{in}} \times 100\% \quad (2)$$

where N_{in} is the number of particles at the inlet of the tundish and N_{out} is the number of particles at the outlet of the tundish.

Presented results show conversed separation rate - the fraction of inclusions not separated at the surface but the fraction of inclusions leaving tundish with liquid steel – in general – and through specific outlets.

Figures 5-8 shows the results of inclusion flowing out through the nozzles, predicted numerically, for former tundish configuration and the tundish with higher capacity (22 Mg).

From Figure 5 it can be seen that higher tundish capacity effect in decreasing of bigger inclusions (size range 5-30 μm) leaving tundish. For smaller inclusions (1 and 2 μm), their quantity in molds increase – but this

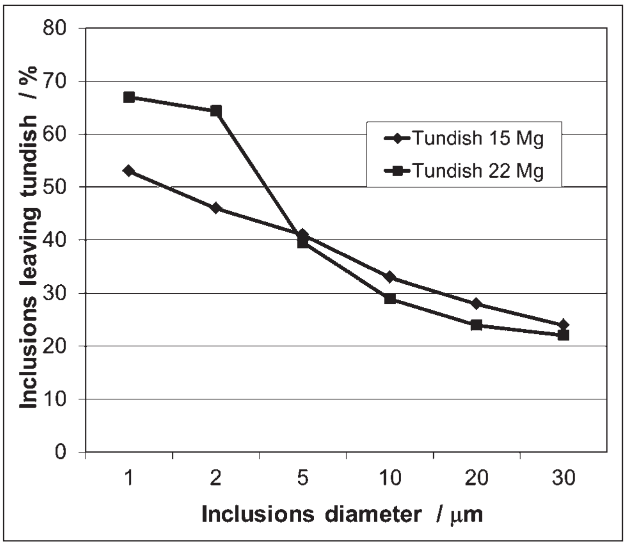

Figure 5 Inclusions flowing with liquid steel to the molds

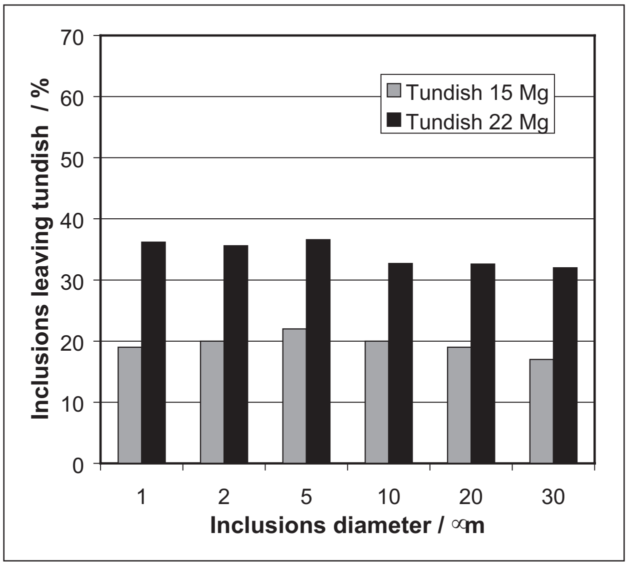

Figure 6 Inclusions flowing with liquid steel to the mold – outlet 1

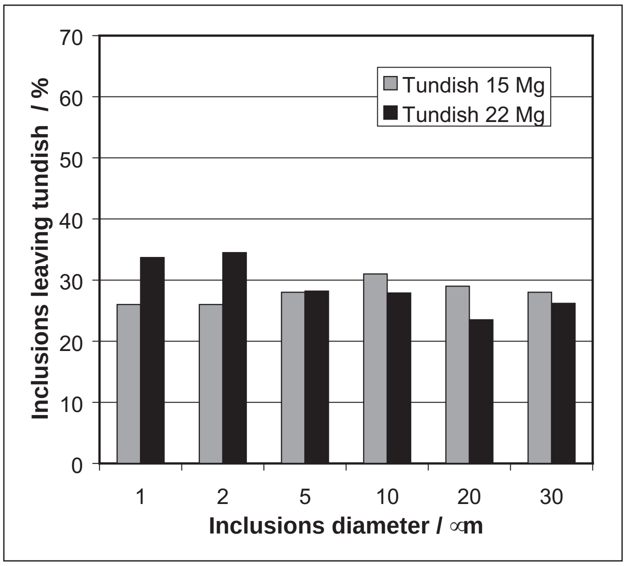

Figure 7 Inclusions flowing with liquid steel to the mold – outlet 2

phenomena can be caused by turbulence inhibitor. Similar results was obtained for tundish basic configuration (15 Mg) equipped with turbulence inhibitor [2].

Figures 6-8 show the influence of proposed tundish modification (extended capacity) on inclusions changes in steel leaving the tundish, depending on individual strands. Numerical simulation results performed for basic tundish configuration show evident differences in casted ingots quality (characterized by the number of inclusions) for internal (no. 3) and external (no. 1) nozzles. Together with increasing the capacity of the tundish and installing turbulence inhibitor, the differences are much lower and oscillate in a range of 30% for each of nozzles and inclusions diameters.

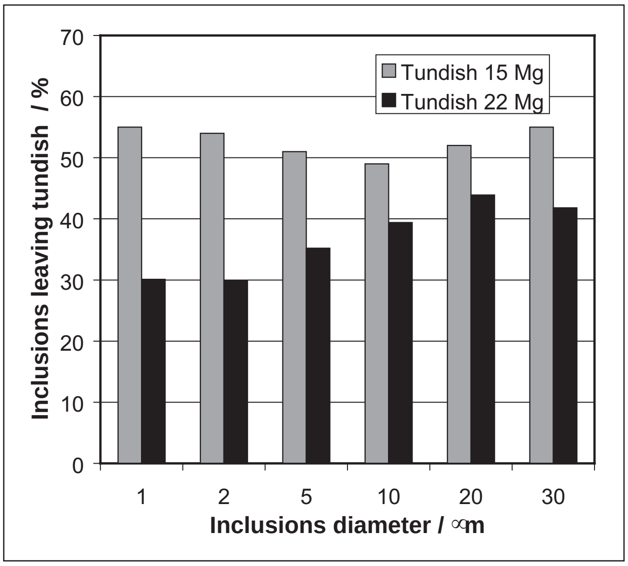

Figure 8 Inclusions flowing with liquid steel to the mold – outlet 3

CONCLUSIONS

Performed numerical investigations showed differences between numbers of inclusions leaving tundish through individual nozzles to casted ingots. For basic tundish configuration (15 Mg) one can observe the domination in the number of inclusions leaving tundish through the internal nozzle (outlet 3) and much less inclusions leaving tundish trough external nozzle (outlet 1).

Those differences can be decreased by both – increasing tundish capacity and installing a turbulence inhibitor.

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Note: The responsible translator for English language is P. Nowak, Czestochowa, Poland