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FLOW AND MIXING OF LIQUID STEEL IN MULTI-STRAND TUNDISH DELTA TYPE – PHYSICAL MODELLING

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The article presents the results of liquid steel flow and mixing in tundish when applying different equipment to modernize the tundish working zone. The six-strand continuous casting tundish of a trough-type was studied. Such tundish is an object with geometry adjusted to the conditions of particular CC machine, which is installed in one of a polish steel plant. The problems suggested in research were solved basing on physical model experiment.

Key words: tundish, continuous casting, physical modeling, flow control devices.

INTRODUCTION

Essential influence on the casted strands quality has the way of liquid steel flow and mixing in the tundish. It is mainly dependent on the hydrodynamic phenomena occurring in the working zone of the tundish. Correct flow of the liquid steel trough the tundish of CC machine should be characterized by the right proportion of well mixed flow areas to dispersed plug flow area and also the minimal share of dead flows [1]. Area of well mixed flow should ensure the maximal chemical and temperature homogenization of the liquid steel in the whole working zone of the tundish. The area of dispersed plug flow makes the nonmetallic inclusions easy to pass into the slag. To determine the proportion of mentioned flow areas in industrial conditions is very difficult, sometimes even impossible.

Therefore, the understanding and identification of the flow structure has fundamental meaning. Appropriately regulated movement of the liquid steel can improve the pattern of liquid steel flow in the tundish [1-3]. Because of this different flow control devices are applied in the working zone of a tundish, such or baffles, baffles with notches, dams and turbulence inhibitors. Frequently such equipment is implemented by the elements that actively affected the liquid metal, e.g. gas curtains and/or ceramic filters [4-6].

They essentially influence on the forming the hydrodynamic conditions of the liquid steel flow. They are translated into the individual (for each type of the tundish) view of flow structure, temperature distribution and steel mixing conditions.

Physical modelling has become one of the most convenient methods for determining the character of the hydrodynamic phenomena in the working zone of the tundish. Such modelling is commonly used in problems connected with analysis of metallurgical aggregates [7-10].

WATER MODEL RESEARCH

Six-strand delta type tundish with nominal capacity of 24 Mg was under study. Steel is poured into the tundish through a ceramic shroud positioned in the device's plane of symmetry. Figure 1 presents the scheme of the studied tundish, whereas Table 1 shows dimensions of the model made at 1:3 scale.

Figure 2 presents the different models of turbulence inhibitors (TI), A - used now in the studied tundish, whereas B and C are the proposed variants of TI. The physical model of CC machine (on which the research was conducted) has character of water segmental model. In such type of models the rules of similarity are ful-

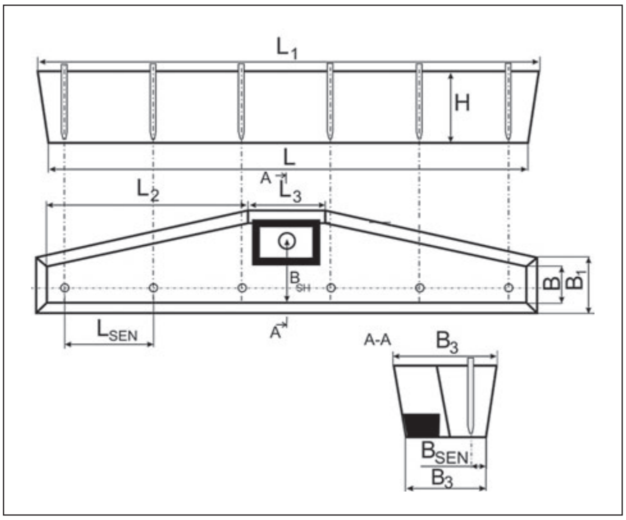

Figure 1 Schematic view of the tundish

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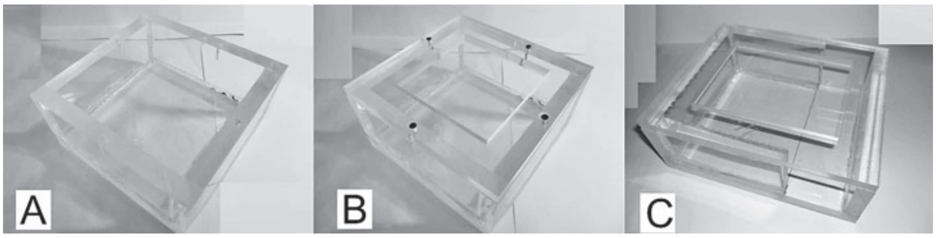

Figure 2 Different variants of TI studied in the present work

Table 1 **Dimensions of the tundish water model at 1:3 scale**

Parametr	Symbol	Unit	Tundish
			Water model at 1:3 scale
Volume of tundish at filling level H	V	m^3	0,126
Filling level (steady-state casting)	H	m	0,267
Tundish length	L	m	1,800
	L_1	m	1,880
	L_2	m	0,756
	L_3	m	0,228
Tundish width	B	m	0,137
	B_1	m	0,223
	B_2	m	0,342
	B_3	m	0,387
SEN position	L_{SEN}	m	0,333
	B_{SEN}	m	0,057
Shroud position	B_{SH}	m	0,220

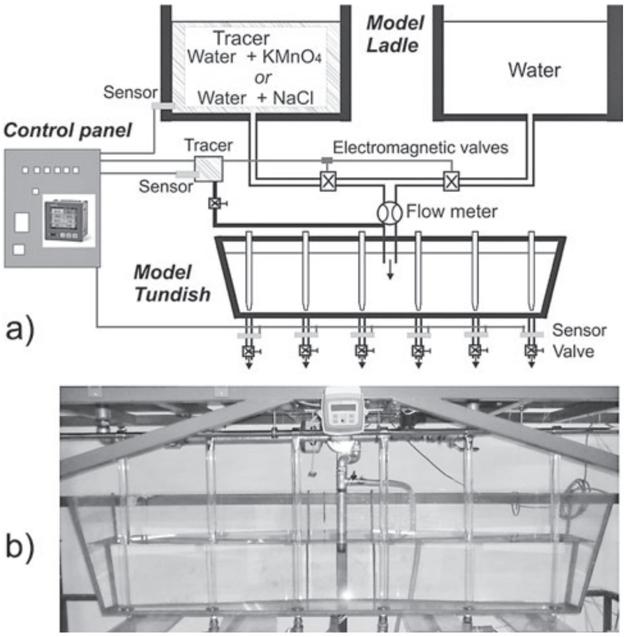

Figure 3 a) The schematic view of the test stand and b) tundish model

filled in the main segment, whereas the other segments (models of main ladles, hydraulic installation) play role of supportive elements. Main segment of the model is such constructive element in which occur phenomena important especially taking into account the expected results of the experiment.

Water was used as a modelling factor. Figure 3 shows the scheme of test stand and the view of the tundish model. The Froude number (Fr) is the dominating criterion of the similarity of the model to the industrial aggregate.

Research carried out in the physical model of CC machine has visualization character. Through to the installed equipment there is also possible to resident distribution curves (RTD). The research was conducted assuming that in real condition the cross-section of cast strands is 130 x 130 mm. Flow rate of water in the model was 14,65 l· min^{-1}.

In the research the Heaviside method (step function method) at the outlet was used. When the appropriate level of water in the model was obtained and the flow was stabilized according to the assumed similarity conditions, the tank with pure water was closed, whereas the tank with tracer (water solution of $KMnO_4$) was opened. Tracer was introduced in such way in the whole measuring time. The experiment was registered by system of digital cameras placed in different planes.

THE RESULTS OF MODEL TESTS

Obtained results in the form of film were specially treated using the computer. As a result the pictures shown in the Figures 4 to 6 were obtained.

Basing on the results obtained during research for variant A (turbulence inhibitor without the support flange) it was stated, in that the inlet area of the tundish with is rebound from the bottom of the inhibitor and directed into the mirror of liquid. The observation of water free surface gives information, that there is no excessive sloshing of liquid in the tank (in other case there will be danger of breaking the slag continuity). The size and range of interaction of created area of well mixed flow enable the sufficient mixing of liquid and creating the area of dispersed plug flow in the channel part of the tundish. Only in the area of terminal outlets the tendency to creating small areas of dead flow was observed.

Applying of the support flange in the variant B turbulence inhibitor caused considerable decrease of modelling liquid flux dynamics in the tundish model. Because of that the size and range of well mixed flow area, were limited. As a consequence there is no proper forming of dispersed plug flow area because of too small kinetics of liquid flow through the channel size of tundish (see Figure 5 e and f). In that variant, the ten-

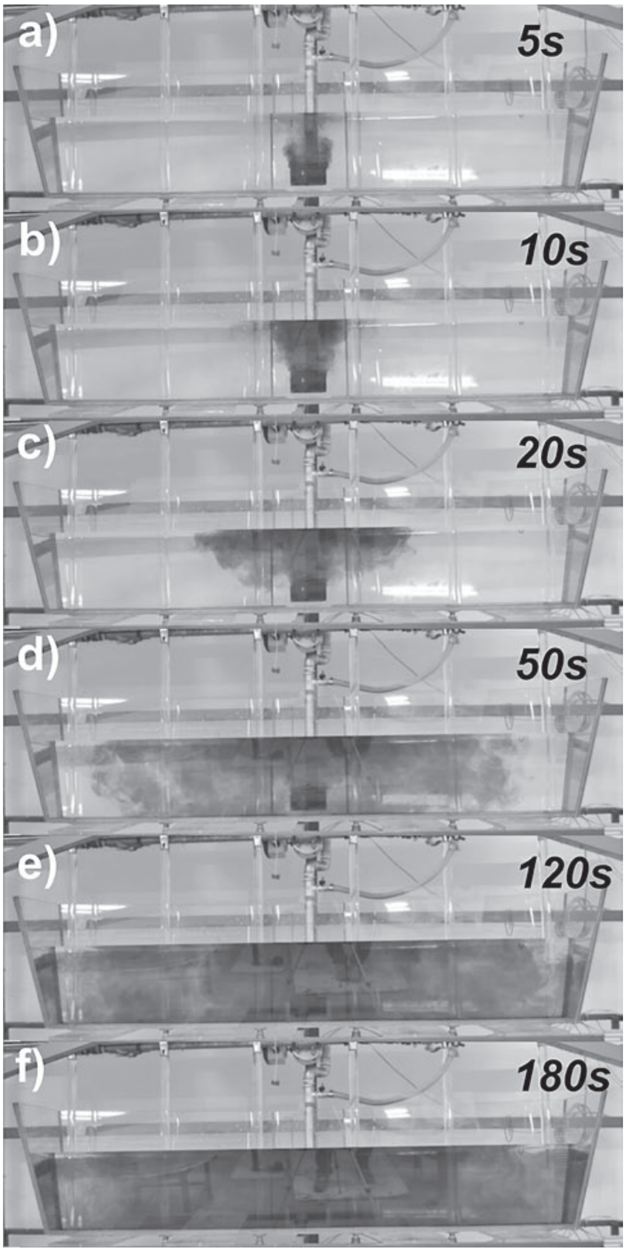

Figure 4 The results of model tests - tundish with TI (A)

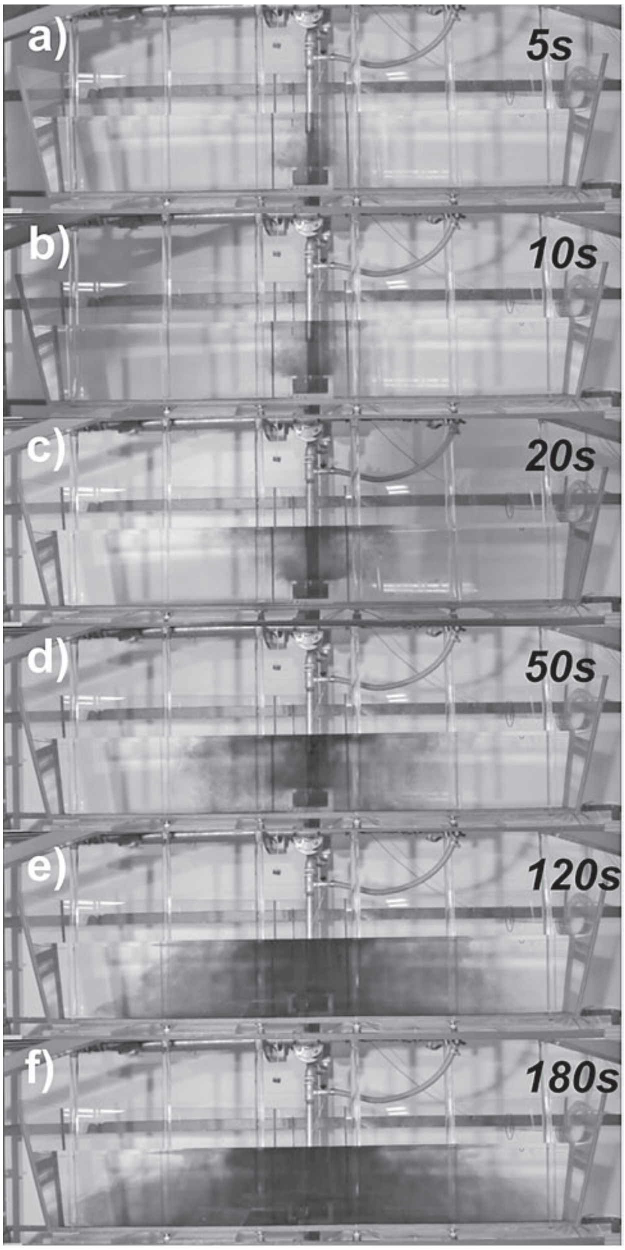

Figure 5 The results of model tests - tundish with TI (B)

dency to creating big areas of dead flow in the terminal outlets was also observed.

This situation was unfortunately not changed by using the turbulence inhibitor applied additionally with notches in its sidewalls (variant C). During the research the range of well mixed flow area was not sufficient. The range of dispersed plug flow area was increased. Its kinetics, however, does not ensure the uniform supplying of the liquid to the particular outlets and cause creating in their areas dead zones.

Additionally the unfavorably phenomenon of rinsing inlet plugs No 3 and 4 by the flow flux coming out from side notches. This can cause their excessive consumption during the sequence casting and also the secondary impurity of steel by endogenous non metallic inclusions.

A corresponding schematic top-view of flow pattern in the tundish is also depicted in Figure 7.

CONCLUSIONS

Although different defects can be observed in the strands casted obtained by continuously (they are caused by incorrect choice of technological parameters of the process), their quality from the metallurgical point of view is much higher than ingot obtained by a traditional casting. In the method of steel continuous casting it is possible to influence the solidification and crystallization process of liquid steel through the correct choice of technological parameters of the process (temperature of casting steel, cooling parameters in both: primary and secondary zones, linear casting speed, electromagnetic mixing). The important problem that influences also the quality of obtained products is the way of liquid steel flow in the tundish working zone. Applying different kinds of flow control devices gives possibility to control and structure of a flow. In industry

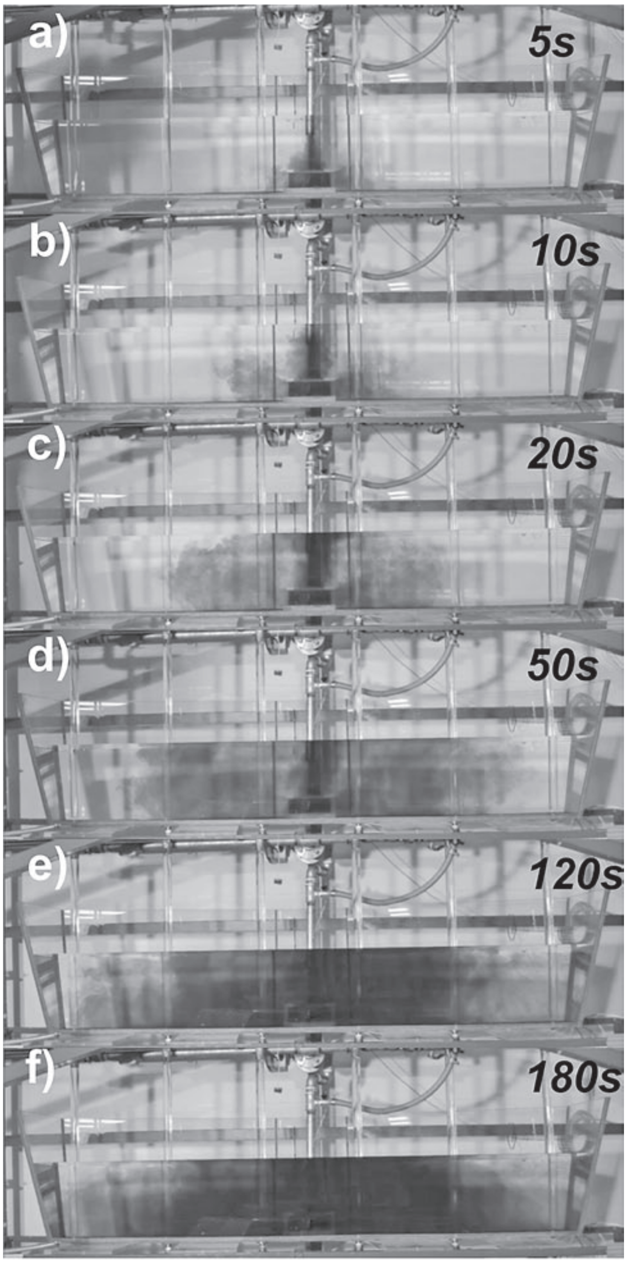

Figure 6 The results of model tests - tundish with TI (C)

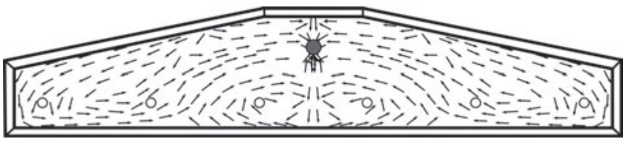

Figure 7 Schematic view of flow pattern in the tundish (0,5 H)

one of the mostly used solution is turbulence inhibitor. Such equipment is installed in the tundish under the incomer steel flux. The main task of turbulence inhibitor is to dampen the energy coming from the flux to limit the turbulence in the inlet area. As a result, the obtained flow is more uniform, the speed profile is lower and the part of dispersed plug flow is higher.

Basing on the conducted research it was stated that the efficient applying of turbulence inhibitors in industry is possible only when their construction is appropriately fitting to the particular constructive solutions of the specific tundish. Applying turbulence inhibitors B and C type worsened the conditions of steel flow and mixing in the tundish; that means such solutions could be eliminated from the industrial application.

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