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J. PIEPRZYCA*,#, T. MERDER*, M. SATERNUS*

OPTIMIZATION OF SUBMERGED ENTRY NOZZLE DEPTH IN CC MOULD

OPTYMALIZACJA ZANURZENIA WYLEWU W KRYSTALIZATORZE COS

The way and speed of steel flux flowing into mould of continuous casting (CC) machine belong to the important parameters characterizing the steel continuous casting process. Such flux causes determined kinds of steel circulation, which together with simultaneous steel crystallization influence the creation of ingots primary structure and quality of its surface.

The article presents the results of modelling research which aim was to determine the optimal location of submerged entry nozzle in square moulds (130 x 130 mm and 160 x 160 mm) of CC machine. Such a research was carried out for two different grades of steel (low-carbon steel and high-carbon steel), which feature different parameters of casting.

Keywords: mould, nozzle, steel flow, physical modelling

Sposób i szybkość wpływania strumienia stali do krystalizatora urządzenia COS należą do ważnych, charakterystycznych parametrów procesu ciągłego odlewania stali. Wpływający strumień wywołuje, określonego rodzaju, cyrkulacje stali, co przy jednoczesnym jej krzepnięciu wpływa na proces tworzenia się struktury pierwotnej wlewków i jakość ich powierzchni.

W artykule przedstawiono wyniki badań modelowych określania optymalnego położenia wylewu zanurzeniowego w krystalizatorach kwadratowych COS 130 x 130 mm i 160 x 160 mm. Badania przeprowadzono dla dwóch gatunków stali nisko i wysokowęglowej, charakteryzujących się różnymi parametrami odlewania.

1. Introduction

Taking into account the size of cross-section area of the cast strands two methods of introducing the liquid steel to the mould are known. When such area is relatively small, the steel is introduced by the open flux to the mould. Such flux is protected against the negative affect of the air by applying the inert atmosphere (especially argon). The mineral oil is used as a lubricating agent, which is introduced on the friction area between the solidified layer of steel and the sidewalls of the mould. However, in majority of cases the process of introducing the steel into the mould is made by covered flux by means of submerged entry nozzles (SEN) [1,2]. These nozzles protect the steel flux from the negative influence of the air and also give possibilities to introduce it below the steel surface. This method allows to apply, in the continuous casting process, lubricant-insulating powders, which cover the steel surface, without danger decreasing steel purity by the powder. When casting the strands with square, rectangular or oval cross-section, the cylindrical submerged entry nozzles with through outlet are applied. To identify the character of the propagation of the liquid steel flux in the mould the modelling research (physical ones) can be done [3-5]. Such research together with numerical simulations is very popular in metallurgy of steel and non-ferrous metals [6-10], as it is not expensive and easy to carry out. The hydraulic model of the machine for continuous casting can be built according to the requirements of theorem of hydraulic modelling of natural phenomena, considering geometrical, dynamic and kinetic similarity of the model and a real object.

2. Experimental test stand

Hydraulic physical model of the CC mould is one of the segments of the complex model of the machine for steel continuous casting. It was made from transparent material (Plexiglas) basing on the rules coming from the similarity criteria. The dimensions of the studied industrial moulds (130x130 and 160x160) were taken into account when designing their models in the linear scale $S_L = 1$. There was also necessity to apply some simplifications. The action of electromagnetic stirrer and the oscillatory movement of the mould were not considered in the models. Geometry of the moulds does not take into account the changes of their cross-action dimensions considering the steel shrinkage during solidification of the skin and radius of moulds arc. Such simplifications do not essentially influence the quality of the model taking into account the expected results of the research. Fig. 1 presents the view of the designed test stand.

* SILESIAN UNIVERSITY OF TECHNOLOGY, INSTITUTE OF METALS TECHNOLOGY, 8 KRASINSKIEGO STR., 40-019 KATOWICE, POLAND
# Corresponding author: jacek.Pieprzyca@polsl.Pl

To control the flow of the fluid through the mould model, the system of automatic regulation was designed and installed. Such system ensures the repeatable condition of conducting experiments for different depths of the SEN location at the changing flow rate of modelling fluid. The regulation of submerged entry nozzle depth was obtained by means of mechanical controlling head.

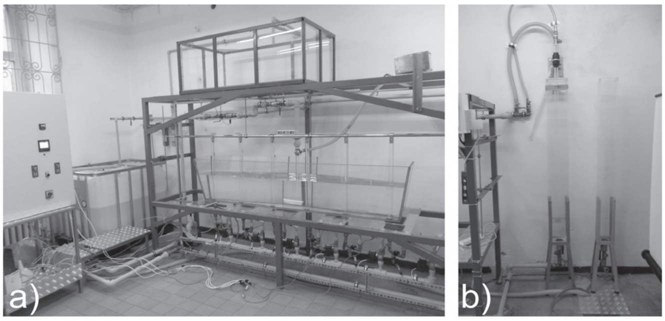

Fig. 1. Test stand for physical modelling of the CC machine: a) top segment – the model of the tundish (scale 1:3), b) main segment – the model of the moulds (scale 1:1)

3. Assumptions of the research

The aim of performed research, which has visualization character, was to determine the optimal depth of submerged entry nozzle in the mould of CC machine for the given casting speeds of the studied groups of steels. The grades of steel that were analyzed are the steels for cold deformation that is with the higher plasticity and the high-carbon steels for drawing and/or cold rolling. Table 1 shows the most important casting parameters for the analyzed steel groups [11].

TABLE 1

Parameters of casting for the analyzed groups of steel

Group of steel	Steel grade	Section of the cast strand, [mm]	Speed of casting, [m/min]	Average speed of casting, [m/min]
A	High carbon steels for drawing - rod for wires	130´130	2.6 – 2.9	2.7 – 2.8
			2.5 – 2.6	
			2.5 – 2.6	
			2.7 – 3.0	
B	Steels for cold upsetting and squeezing out – rod for bolts	160´160	1.8 – 2.0	1.8 – 1.9
			1.9 – 2.2	
			1.9 – 2.1	

Basing on the similarity theory [12] the parameters of experiment for the values presented in Table 1 were calculated, and Table 2 presents the results of such calculations. In the presented research the assumption was made that the level of mould filling should equal 85%. This is compatible with the industrial parameters of casting process – in that case the level of mould filling is changeable, depending on the different profiles of the mould and equals 80 to 85%.

Submerged entry nozzle in the mould according to the technological instruction should be submerged to the depth of 10 to 12 cm below the meniscus of a liquid steel. However, practically such submersion is from 8 to 12 cm. In case of a break-down there are cases when the entry nozzle could be submerged to 3 cm. Thus, for the research purposes, four different variants of submersion of the entry nozzle in the

TABLE 2

The calculated parameters of physical modelling experiment

Group of steel	Linear speed of casting, [m/min]	Section of the cast strand, [mm]	Volumetric flow (liquid steel), [m3/s]	Volumetric flow in model (water), [dm3/min]	Flow at the one nozzle in model (water), [dm3/min]
A	2.8	130´130	0.005137	308.26	51.4
B	1.9	160´160	0.005280	316.85	53

TABLE 3

The research program

Group of steel	Case	Cross-section of the mould, [mm]	The flow of water in the model, [dm3/min]	The distance of the nozzle from the upper edge of the mould, [mm]	Depth of the submerging the entry nozzle in the mould, [mm]
A	**AP1**	130´130	51.4	180	30
	AP2			230	80
	AP3			250	100
	AP4			270	120
B	**BP1**	160´160	53	180	30
	BP2			230	80
	BP3			250	100
	BP4			270	120

mould were assumed. Table 3 shows the assumed research program, whereas Fig. 2 shows it graphically.

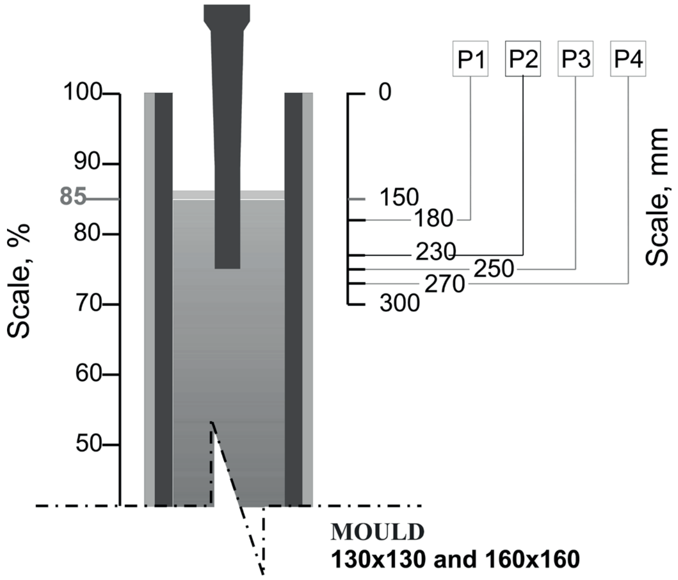

Fig. 2. Research program presented graphically

Research was carried out in the following way:

- The depth of submersion of the entry nozzle in the mould model was fixed on the needed level.
- Buffering tank was filled with water. This stage of experiment is significant taking into account the fulfilling kinetic condition of similarity. The flow rate of modelling fluid through the mould model is high, thus if the water was taken directly from the water-pipe network, the condition of similarity would be not fulfilled.
- The condition of modelling fluid flow through the mould model was fixed using the regulation system (the particular flow of modelling liquid is fixed for a given mould). After precise regulation of the liquid fluid flowing into the mould model the flow rate of water coming out from the mould model was fixed by means of the regulating valve. As a consequence the constant and precisely determined flow rate of modelling liquid through the mould model was obtained (the amount of liquid coming into the mould model equals the amount of modelling liquid coming out of the model); thus in the mould the constant level of water was maintained.
- When the system was stabilized (the needed kinetic condition of flow is settled) the tracer (water solution of $KMnO_4$) was introduced; to the modelling liquid, it enabled to observe the way of mixing the fluid in the mould model.
- The whole experiment was registered by the digital camera.
- After finishing the experiment, the water with tracer here, removed and the test was repeated in the same way as described above.
- The series of experiments were conducted for all variants assumed in the research program.

4. Results of modelling research

Results of research (recorded data) were treated in that way, that the film sequences containing appropriate needed amount of information were created. Then such sequences were

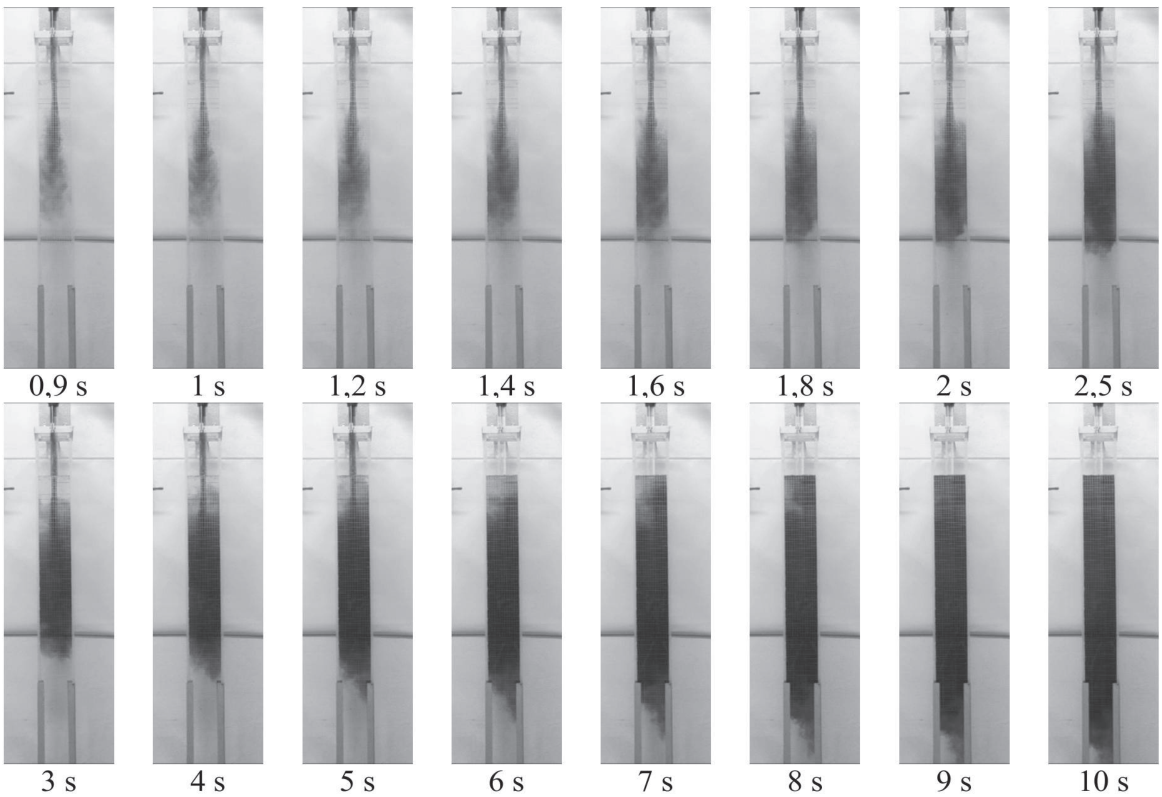

Fig. 3. Results of visualization for the variant AP2

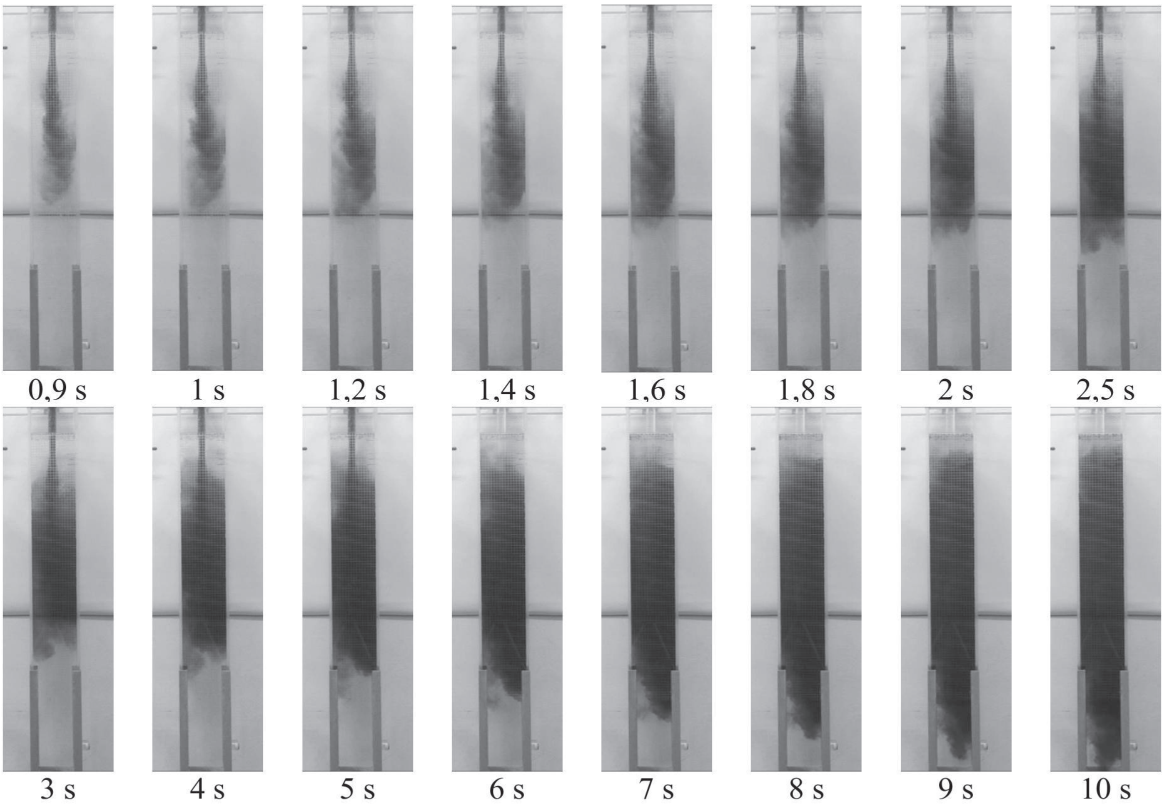

Fig. 4. Results of visualization for the variant BP4

divided into particular frames. From the material obtained in such a way the series of frames with identical time parameters for particular variants of experiments were chosen. After this, obtained frames were framed in such a way that optimal visualization of the conducted experiments was possible. Fig. 3 and 4 show the juxtaposition of chosen frames (from two series of research).

Obtained results were analyzed in the determined time interval. Taking into account the construction of the mould model, the carried out simulations were justified from the moment where the tracer was introduced into the system to the moment when the tracer reached the bottom of the mould model. In this range of time the results were compatible with the real conditions of steel circulation in CC mould. After this time the reflection of the modelling fluid from the mould bottom took place in the model (of course such bottom in the industrial conditions does not exist). So, analyzing the results of modelling after the mentioned time was pointless.

5. Conclusions

Analysis of the results of conducted research on the models of mould 130x130 and 160 x 160 mm can lead to the following conclusions:

- Taking into account the way of modelling the mixing process of fluid in the mould model, the level of submersion of the entry nozzle has a great importance. Applying the tubular type nozzles causes the creation of dead zones in the upper part of the mould. This unfavorable phenomena was clearly observed during the conducted research. Insufficient steel mixing in the upper part of the mould can cause many inner and surface defects of the casted strand; in the extreme cases even it can cause the serious disturbance of the continuous casting process operation.
- Analyzing the results of research it can be stated that the size of dead zone in the upper part of the mould depends on the level of submersion of the entry nozzle. When the surface of entry nozzle is placed further from the steel surface (variants AP4 and BP4), the dead zone is bigger. When the entry nozzle is less submerged the dead zone is smaller.
- However, there is the increase of dead zones in the upper part of mould with the increase of submersion of the entry nozzle; the process can be conducted under some conditions. The parameters of electromagnetic stirring of the upper part of the mould play the essential role in such case. The technique of process operation with high submersion can be strictly connected with simultaneous regulation of mixing parameters.
- In the second paragraph connected with the construction of the mould model it was mentioned that the research did not consider the influence of oscillatory movement nor the working of electromagnetic stirrers on the modelling fluid movement. Nevertheless, the conducted research enables to estimate some trends and determine the influence of such factors on the course of the casting process.

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