INFLUENCE OF STEEL FILTRATION ON REDUCTION OF CLOGGING OF IMMERSED NOZZLES IN CONTINUOUS STEEL CASTING INSTALLATIONS

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Abstract

Despite the development of steel making technologies a significant portion of deoxygenation reactions products remain in the molten metal until the time of casting. These ration products are referred to as non-metallic inclusions and their dimensions lower than 30 μm. Years of research, both in laboratory and in industrial environment, showed that these type of inclusions can be removed using multi-holed ceramic filters. Additionally, filters can, when used in continuous steel casting installations, reduce the risk of clogging of tundish nozzles. Clogging is frequent problem during casting of steel deoxidized with aluminium. In this situation the outlet may act like ceramic filter when non-metallic inclusions are deposited on its edge. In effect, this results in the need for early termination of the casting process. The internal diameter of nozzles is from 3 to $4.5 \cdot 10^{-2}$ m (for the experiments presented in this publication). The problem with this issue was raised by other researchers [1, 2]. Paper presents the results of studies on this phenomenon.

Keywords: Steel, tundish, ceramic filter, continuous casting, nozzle

1. INTRODUCTION

It is evident from the hitherto existing experience [3-11] that the conventional out-of-furnace steel treatment (especially that which is deoxidized by depositing, e.g. with use of aluminium) does not usually guarante high levels of the metallurgical purity. Including non-metallic inclusions with a size of less than 30 μm. Furthermore, the presence in liquid steel of non-metallic inclusions of Al_2O_3 type throws into confusion the process of continuous casting due to the phenomenon of covering the ladle discharge nozzles by a layer of such inclusions. According to judgements presented by many research centres [7, 12] the steel filtration with use of multi-hole ceramic filters can be the efficient and cost-effective method of removing the non-metallic inclusions from liquid steel. The experimental results obtained hitherto in the laboratory and field indicate the substantial reduction in content of non-metallic inclusions and damaging impurities in liquid steel [9]. Differences, however, exist in levels of efficiency of this steel refining method, depending on local filtration conditions. The reason for such differences can be found in the phenomenon of secondary oxidation of liquid steel by the atmospheric oxygen. The positive results obtained in the laboratory-scale research have become the base to undertake the trials to filtrate liquid steel in industrial conditions. A series of model investigations [13-15] has been carried out, and then, after obtaining the positive results, a series of industrial-scale melts of steel has been produced [16-18]. The results of industrial research recently presented by Bulkowski, and others [19]. However, it is difficult to relate to them because they were cast only one melting capacity of 30 Mg. The goal of the research carried out, the results of which are presented here, has been to prove the possible extent of the solid non-metallic inclusion removal from liquid steel through the steel filtration by means of multi-hole ceramic filters. These inclusions most frequently throw into confusion the process of continuous casting d inclusion deposits formed on the walls of the submersion-type nozzles, which gradually reduce the nozzle cross-section (which cause nozzle accretion). The aim of the research carried out has been to prove that the liquid steel filtration is a cheap and efficient additional processing stage, separating the non-metallic inclusions, which in case of the conventional casting technology could remain in the cast steel bodies.

Modeling research (physical and numerical) are commonly used for analyzing and knowing better the phenomena that occurring in tundish applied in metallurgy of steel [13, 15].

2. THE HITHERTO OBTAINED RESULTS OF THE RESEARCH OF LIQUID STEEL FILTRATION IN THE INDUSTRIAL ENVIRONMENT

Xintian et al. [20] presents the results of trials of industrial investigations of the process of filtration of low-carbon steel in the continuous casting environment by means of filters based on corundum (Al_2O_3), quartz and corundum ($Al_2O_3 \cdot SiO_2$) and limestone (CaO). The filters in form of panels 150 mm thick with the filtrating orifices 50mm in diameter have been placed in the tundish of CC machine. The filters, prior to start the steel casting, have been preheated to the temperature of 800-1000 ^oC (1073-1273 K). The following quantities of steel have been casted during the experiment: 280 Mg through the corundum filter, 350 Mg through the quartz and corundum filter and 350 Mg through the limestone filter, each at the velocity of 0.80 - 1.05 m/min and to the flat ingot moulds of (210-250) x 1300 mm cross-section. The effectiveness of the process of filtration has been determined as variation in the average relative content of non-metallic inclusions in samples of liquid steel collected in the tundish upstream and downstream of the filter. The best results have been obtained for the corundum filter, for which a reduction in the total relative content of non-metallic inclusions (η_{MeO}) has amounted 63.63% (49.26% of Al_2O_3 inclusions and 41.17 % of SiO_2 inclusions). The steel filtration with use of limestone filters has been of lower effectiveness: the total relative content of non-metallic inclusions has decreased in the best instance only 42.11 % with, at the same time, highest decrease in SiO_2 inclusions of 83.68%. It is worth to pay attention to the investigation of the process of filtration of the low-carbon liquid steel ($C \leq 0.12$ %) carried out in the industrial environment of the converter plant of the Metallurgical Works in Novolipetsk, Russia (Novolipetsk Steel) [10]. The sieve filter made of corundum has been placed in one of the partition of the tundish of 22 Mg capacity of the dual channel CC machine. The number and dimensions of the filtrating orifices have been differentiated so (diameters 7.20 and 40 mm and lengths of 40, 150 and 200 mm) that the wide range of filtrating surfaces has been obtained. Prior to start the steel casting the filters (partition) have been preheated to the temperature of 1000-1100 °C (1273-1373 K). The steel casting velocity during the investigations carried out, has amounted 0.8-1.2 m/min. In liquid steel samples (collected in the tundish) the decrease has been stated in oxygen content of 23 and 34%, while in the samples collected from the concast slabs (experimental slabs and comparative ones) the non-metallic inclusion content has been analysed. In each instance the content of non-metallic inclusions has been of lower value for the filtrated steel.

Mancini J. and Stel J. [17] have presented the results their industrial investigations of the process of filtration of liquid steel, which correlate to the most extent with our methods presented here. It comprises the method of filter installation in the tundish, as well as assessment of steel pollution with solid non-metallic inclusions. However the lack of adequate preheating of the tundish with the ceramic filter installed has led to the result that most of trials have been terminated unsuccessfully (the filters have broken).

3. RESULTS OF INDUSTRIAL INVESTIGATIONS OF STEEL FILTRATION

Frequent problems with casting sequence of high aluminium steel ending prematurely were the basis for preparation and execution of series of experiments concerning steel filtering, which now has a chance to become permanent technological operation. Until recently, this process was sought only to increase the metallurgical purity of steel. Metallurgical purity is very important element steelmaking process, unfortunately a few steel mills with regular buyers seemed to ignore the issue. However, problems encountered during continuous casting of steel with high aluminium content renewed the interest and encouraged further research.

The tundish nozzles (**Figure 1**) were identified as a site where the steel “froze” and stem the flow of liquid metal. This was caused by the deposition of the non-metallic impurities on the walls of the nozzles. When the casting sequence was aborted the samples of the material in the nozzles were taken and cut axially to analyse the inner surface (**Figure 2**). Analysis confirmed the previous assumptions. It was proven that the non-metallic phase adsorbed on the nozzle surface (**Figure 3**) leads to a reduction in the flow and consequently was the cause of emergency shutdown of the casting process.

a)

b)

Figure 1 Nozzles: a) before the casting process, a) after the casting process

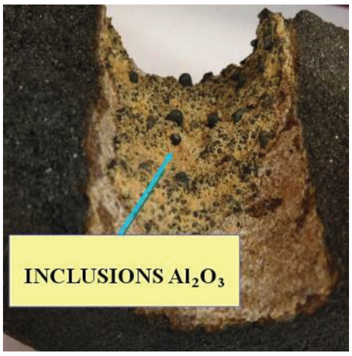

Figure 2 Non-metallic phase identified on the walls of tundish nozzles

Analysis using the scanning microscope show that the phase adsorbed on the nozzle walls, which lowered the steel flow and consequently led to plugging of the nozzle, is a non-metallic inclusion of Al_2O_3 type (**Figure 3**). Diffraction patterns in **Figure 4** confirm its chemical composition. It was proven, that in specific conditions the nozzles behave like ceramic filters and the significant length of the nozzles is also crucial. It correlates with previous research on the influence of filter channel slenderness on the effectiveness of filtration process in which the new slenderness parameter S_F was introduced as a tool for filter evaluation [21]. Collected research data were the basis for preparation and execution of series of industrial scale experiments using multi-holed ceramic filters. The experiments have been prepared and then carried out in the steel plant of one of the Metallurgical Works belonging to the Polish Steel Plants (now ArcellorMittal Steel - MCOS-1, **Figure 5 -** a) before the filtration, b) after filtration). The filter used, in form of a barrier, has been made with 26 orifices of 60 mm diameter and filtrating surface of 80 8236 mm^2. In contrast to experiments presented to date in international literature, the volume of filtered steel was significantly larger.

Three experiments were carried out - sequences of 10, 5, 3 and 3 melts of 330 Mg steel each. First experiments was treated as a pilot in order to verify the hydrodynamics of steel flow in the tundish, the behaviour of the ceramic filters and assess the macrostructure of CC heats. Sampling did not take to determine the effectiveness of the filtration process. Ten A700 rail steel melts of 330 Mg were poured in sequential system. Combined mass of poured steel was 3300 Mg. Because of the earlier concerns about the risk of failure the low aluminium steel grade was selected for the first experiment. Low aluminium eliminated the risk of „plugging" the filter holes. Positive result and failure-free run of the first experiment enabled carrying out the next melts in the planned cycle. Second experiment of steel filtering in the tundish of CC device concerned the sequence of three melts of 34 GJ steel, 330 Mg each. During filtering, the samples of unfiltered and filtered steel were taken from respective halves of the tundish to check the total oxygen content. The third experiment on steel filtering in industrial conditions concerned the sequence of five melts of SE03-u steel, as before 330 Mg of steel per melt. Combined mass of melted steel in this sequence was 1650 Mg. The fourth experiment on steel filtering in industrial conditions concerned the sequence of five melts of C45R/1 steel, as before 330 Mg of steel per melt. Combined mass of melted steel in this sequence was 990 Mg. The filter has been manufactured by Alcor S.A. company of Krzeszowice, Poland, and has been made of mullite-based body. Prior to start of the steel casting process the multi-hole ceramic filters installed has been pre-heated together with the tundish to the temperature of 1250 °C (1523 K).

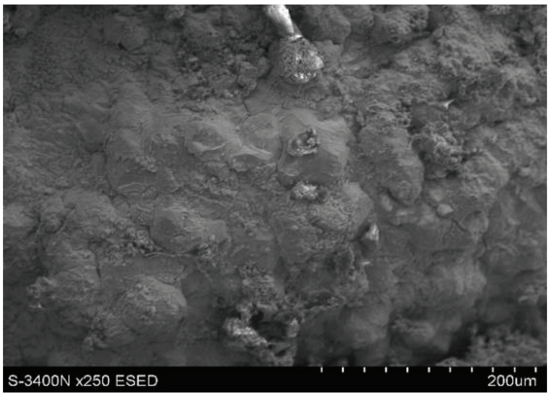

Figure 3 Scanning pictures a non-metallic phase absorbed on the surface of the ceramic

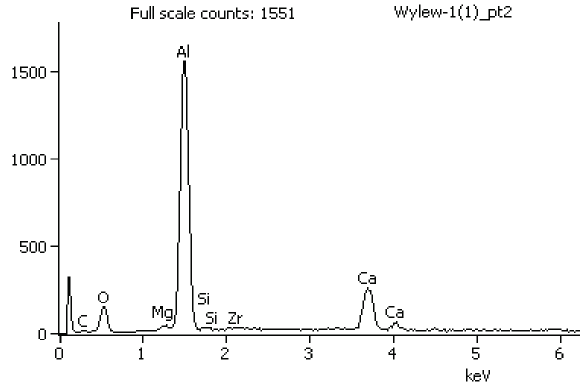

Figure 4 X-ray photograph of non metallic inclusions chemical composition identified on the surface of a nozzle

a) *b*)

Figure 5 The tundish of the ceramic filter: a) before the filtration, b) after filtration

In every experimental melt listed in **Table 1** the decrease of the inclusion surface-share in the filtrated steel in comparison with the non-filtrated steel was observed.

Table 1 Average surface-share of all non-metallic inclusions in the filtrated and non-filtrated steel of the experimental melts related to intervals of the inclusion size according to Feret diameters

Test No	Symbol of the melt	Superficial share of all non metallic inclusions		Superficial share of the inclusions with the diameter F_x = 0.5 - 2.5 μm		Superficial share of the inclusions with the diameter F_x = 2.6 - 6.5 μm		Superficial share of the inclusions with the diameter F_x = 6.6 - 15.5 μm		Superficial share of the inclusions with the diameter F_x = 15.6 - 30 μm	
		Superficial, %	η_{NMI}, %	Superficial, %	η_{NMI}, %	Superficial, %	η_{NMI}, %	Superficial, %	η_{NMI}, %	Superficial, %	η_{NMI}, %
2	M-1	$\frac{0.107}{0.08}$	**25.2**	$\frac{0.02}{0.01}$	**50.0**	$\frac{0.039}{0.035}$	**10.3**	$\frac{0.039}{0.027}$	**30.8**	$\frac{0.009}{0.011}$	**- 22.2**
	M-2	$\frac{0.15}{0.11}$	**26.7**	$\frac{0.014}{0.016}$	**-14.3**	$\frac{0.069}{0.044}$	**36.2**	$\frac{0.045}{0.049}$	**- 8.9**	$\frac{0.021}{0.004}$	**81.0**
	M-3	$\frac{0.149}{0.10}$	**32.9**	$\frac{0.015}{0.016}$	**- 6.8**	$\frac{0.051}{0.046}$	**9.8**	$\frac{0.048}{0.031}$	**35.4**	$\frac{0.035}{0.005}$	**85.7**

3	M-1	0.120 / 0.117	2.5	0.017 / 0.018	- 5.9	0.057 / 0.048	15.8	0.044 / 0.040	9.1	0.002 / 0.011	- 45.0
	M-2	0.103 / 0.101	1.9	0.020 / 0.021	- 5.0	0.050 / 0.040	20.0	0.023 / 0.032	- 39.1	0.010 / 0.008	20.0
	M-3	0.174 / 0.120	31.0	0.033 / 0.016	51.5	0.098 / 0.061	37.8	0.034 / 0.040	- 17.7	0.009 / 0.003	66.7
	M-4	0.146 / 0.135	7.5	0.018 / 0.015	16.7	0.047 / 0.054	- 14.9	0.054 / 0.057	- 5.6	0.027 / 0.009	66.7
	M-5	0.136 / 0.099	27.2	0.009 / 0.013	-44.4	0.046 / 0.037	19.6	0.051 / 0.045	11.8	0.03 / 0.004	86.7

4. SUMMARY AND CONCLUSIONS

The presented results are a summary of many years of research carried out by the author on the subject of refining liquid steel from dispersed non-metallic phase - commonly referred to as non-metallic inclusions. Based on the source material analysis, theoretical considerations, results of laboratory tests and experiments carried out in industrial conditions the following conclusions can be formulated:

- Results of experiments carried out in industrial conditions confirmed that installing multi-holed ceramic filters in the tundish of CC device as a permanent construction elements in the working area of the tundish results in reduction of the number of non-metallic inclusions (average of 20 %) during pouring. It especially concerns the inclusions of dimensions below 30 μm.
- Presented results of industrial experiments are, as of now, unique (in the world scale) because of the large volume of steel that was processed in the sequential system - **990 Mg** (three melts of 330 Mg) during first experiment and **1650 Mg** (five melts of 330 Mg) during the second experiment.
- The filtration process now brings double benefit. Steelmakers which offer steel with increased metallurgical quality (the share of non-metallic impurities measuring less than 40 μm) can expand their client base. In addition, the filtering extends the operating time of the tundish nozzles and allows casting of at least 300 Mg of steel.

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