LIQUID STEEL FILTRATION IN THE PROCESS OF STEEL CASTING IN THE CC MACHINE

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Abstrakt

In the aspect of planning steel filtration process in an intermediate ladle of the CC device, a model testing of steel flow and mixing in an intermediate ladle with an equivalent constructional solution of multi-hole ceramic filter has been conducted. The results of these tests will make it possible to define the optimum filter construction and its position in the intermediate ladle. This research also presents the results of industrial tests of steel filtration with multi-hole ceramic filters, previously reduced with Al. The obtained results of filtration have proved that this method may be used as an effective and cheap way of steel filtration from non-metallic inclusions.

Key words: steel, refining, ceramic filter, solid non-metallic inclusions, continuous casting.

1. INTRODUCTION

Researches being carried out nowadays on metallurgical processes of steel making are focused on the final process stages due to the necessity to gain the high quality and high performance steel products in a cost-effective manner. Numerous works are being carried out in this area, which are primarily concerned with:

- Investigations of the hydro-dynamics of steel flow and steel blending within the system of the main ladle - tundish- CC machine’s crystallizer,
- Investigations of the liquid steel refining in the tundish of the CC machine.

It is evident from the hitherto existing experience [1, 2] that the conventional out-of-furnace steel treatment (especially that which is deoxidized by depositing, e.g. with use of aluminium) does not ensure high levels of the metallurgical purity. Furthermore, the presence in liquid steel of non-metallic inclusions of Al₂O₃ 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 [3–6] the steel filtration with use of multiple-orifice 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 [7–14]. 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 [4, 5, 7]. 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 has been carried out [8], and then, after obtaining the positive results, a series of industrial-scale melts of steel has been produced. 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 multiple-orifice ceramic filters. These inclusions most frequently throw into confusion the process of continuous casting and 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.
2. RESULTS OF MODEL INVESTIGATIONS OF THE PROCESS OF STEEL FILTRATION IN THE TUNDISH OF CC MACHINE

It is assumed in the theoretical considerations that in the process of filtration of non-metallic inclusions from liquid steel by means of multiple-orifice ceramic filters, the internal surface of the filter orifice is the „filtrating" surface. Soskov [15], taking into account the above mentioned dependencies, has proposed a simplified mechanism of filtration of non-metallic inclusions from liquid steel, comprising three stages:

- transportation of the non-metallic inclusion to the separating surface between liquid steel and ceramic filter material,
- passage of the non-metallic inclusion through the interphase borderline separating liquid steel from ceramic filter material,
- stop of the non-metallic inclusion on the ceramic filter filtrating surface.

It is difficult to indicate explicitly which of the above mentioned stages of such a mechanism of liquid steel filtration is responsible for the control over the filtrating process. In case of the laminar flow of steel through the filter orifices only the small part of non-metallic inclusions (located in the outermost layer of the steel stream) is able to reach contact with the interphase borderline between liquid steel and ceramic filter material, what can be seen in fig. 1. Instead in case of the turbulent flow there is a much higher likelihood of reaching contact with this borderline by the non-metallic inclusion. The process of passage of the non-metallic inclusion through the borderline between liquid steel and ceramic filter material is determined by the surface properties of contacting three phases (liquid steel – non-metallic inclusion – ceramic filter material). At the same time the probability of a non-metallic inclusion stop at the filtrating surface of the filter is by no means the function of many factors, including the process parameters of steel filtration (steel temperature and velocity of steel flow through the filter orifices) and the filter structural characteristics, and, first of all, the chemical composition and physical state of non-metallic inclusions: different ways of the non-metallic inclusion stop and differentiated efficiencies of the liquid steel filtration should be expected in case of solid and liquid non-metallic inclusions, the products of steel deoxidation by depositing. It is suggested here to assess the probability of the non-metallic inclusion stop at the filter surface in the flowing steel environment as based on the value of work of the inclusion adhesion to the ceramic filter material, which can be expressed by formula (1):

$$W_{A_{(LS)}}^{F-NMI} = W_{A_{(g)}}^{F-NMI} - \sigma_{LS} \left( \cos Q_{F-LS} + \cos Q_{NMI-LS} \right)$$  \hspace{1cm} (1)$$

where: $W_{A_{(g)}}^{F-NMI}$ is the work of adhesion of a non-metallic inclusion and the ceramic filter material in atmospheric environment, mN/m,

$Q_{F-LS}$ is the wetting angle of ceramic filter material in liquid steel, °,

$Q_{NMI-LS}$ is the wetting angle of non-metallic inclusion in liquid steel, °,

$\sigma_{LS}$ is the surface tension of liquid steel, mN/m.

Fig. 1. Distribution of current lines in the liquid stream.
It is not strictly evident from the formula (1) which of the physical states of the inclusion it refers to. In theory the adhesion phenomenon also exists between two solid phases, but it is however of insignificant importance in respect to the solid non-metallic inclusions in the environment of liquid steel filtration (spherical form, flat filtrating surface of the filter).

3. RESULTS OF INDUSTRIAL INVESTIGATIONS OF STEEL FILTRATION

The hitherto obtained results of the laboratory researches of liquid steel filtration by means of ceramic filters [9, 10, 14] have become the base for preparation and implementation of the industrial application of the steel filtration process in the processing line of the continuous casting machine. Fig. 2 presents the trough-type tundish prepared, in which a ceramic filter has been mounted. The filter used, in form of a barrier, has been made with 26 orifices of 60 mm diameter and filtrating surface of 31102 mm². The filtrating orifices have been of 165 mm in length. The filter has been manufactured by Alcor S.A. company of Krzeszowice, Poland, and has been made of mullite-based body. According to the term of the multiple-orifice ceramic filter slenderness ratio, proposed and brought into use by the author of this paper, calculated as a quotient of the filtrating orifice (channel) height (length) by the orifice (channel) width ((λ = h/d), the filter used in the experiment has been of slenderness ratio λ = 2.75 [16]. Ten (10) melts of A700 steel (rail steel), about 330 Mg each, have been in a sequential manner casted during the first trial of industrial steel filtration. After termination of the steel casting sequence the „wash-out” effect has been discovered in the filter central part. The initial assessment of the macroscopic structure of the continuous castings of the filtrated steel (not including the investigation of steel contamination with non-metallic inclusions) has proved good product quality. The first carried out industrial trial of steel filtration in the tundish of CC machine has not thrown the continuous casting process into any confusion and not proved the earlier apprehension of emergency risk. The second trial of industrial steel filtration, in the tundish of CC machine, comprise a sequence of three melts of 34 GJ steel, about 330 Mg in weight each. During the filtration process the samples of filtrated steel have been collected from one half of the ladle, while from the second, non-filtrated one the samples have been collected for analysis of total oxygen content. Results of the investigations carried out are presented in graphical form in fig. 3. The oxygen content analysis has been carried out with use of the Leco company’s method. Effectiveness of steel filtration has been evaluated as variation in the surface share of the non-metallic inclusions in filtrated steel versus the non-filtrated one according to the formula (2):

$$$$
\eta_{SMI} = \frac{x_k - x_p}{x_p} \cdot 100 \ %
$$$

where: \(x_p\) – inclusion surface share (or inclusion number) before filtration,

\(x_k\) – inclusion surface share (or inclusion number) after filtration,
with use of the following intervals of inclusion diameters according to Ferret: \(0.5 \div 2.5 \mu m\), \(2.6 \div 6.5 \mu m\), \(6.6 \div 15 \mu m\), \(15.6 \div 30 \mu m\), what is shown in fig. 4. Fig. 5 – 7 show the surface shares of the non-metallic inclusions in filtrated and non-filtrated steel for the experimental melts, correspondingly for each of the \(F_x\) Feret’s diameter intervals. The highest level of the effectiveness of liquid steel filtration has been observed for inclusions in the \(2.6 – 30 \mu m\) interval, what has been confirmed by the previously obtained experimental results [10, 13, 16].

**Fig. 4.** The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share \(\tau_{\text{NMI}}\).

**Fig. 5.** The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share \(\tau_{\text{NMI}}\), with division into inclusion size intervals according to \(F_x\) Feret diameters melt no 1.
**Fig. 6.** The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share $\eta_{\text{NMI}}$, with division into inclusion size intervals according to $F_x$ Feret diameters melt no 2.

**Fig. 7.** The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share $\eta_{\text{NMI}}$, with division into inclusion size intervals according to $F_x$ Feret diameters melt no 3.
4. Summary and conclusions

Based on the research carried out hitherto and the published results, a judgement should be made that liquid steel filtration with the ceramic filters can become in the nearest future the effective and cheap method of additional steel refining, in order to separate the non-metallic inclusions, as well as the permanent processing procedure in the continuous casting technology (for some types of steel). The model research has proved good liquid steel flow dynamics and steel mixing in the tundish provided with multiple-orifice filters in case of filter installation in the place of conventional overflow partitions. Placing the multiple-orifice filters in the position of conventional overflow partitions is the most beneficial filter location within the way of steel making process. The filtration trials carried out have not proved the earlier apprehension of emergency risk, have not thrown into confusion the continuous casting process and even have improved the liquid steel mixing dynamics in the intermittent ladle, as it has become evident after the model research. The filter washout effect discovered in its lower part (the first trial) should not be considered a surprise due to the fact that the quantity of liquid steel processed in each melt is about 330 Mg. The $\eta_{WN}$ effectiveness of non-metallic inclusions removal, as measured by the average extent of variation in the inclusion surface share in filtrated and non-filtrated steel, has amounted 34.21% for the second trial with the filter slenderness ratio $\lambda = 2.75$. There is a one more positive effect of use of the multiple-orifice ceramic filters, which is the increased time of the ladle nozzle service life. If part of the non-metallic inclusions is stopped at the level of the tundish then the nozzle service life is decidedly increased (the process of decrease in the nozzle cross section runs more slowly).

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