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INDUSTRIAL APPLICATION OF LIQUID STEEL FILTRATION OUT OF DISPERSED NONMETALLIC PHASE IN THE CONTINUOUS CASTING MACHINE

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Preliminary Note – Prethodno priopćenje

Hitherto existing investigations concerning the ceramic filter use in the steel making processes (both of laboratory and industrial scale) have given good results. The obtained results of filtration (in the laboratory) have proved that this method may be used as an effective and cheap way of steel filtration from non-metallic inclusions. Placing filters in the tundish is the best location in consideration of limiting the possibility of secondary pollution of steel. Yet, the results presented in this paper, of an experiment prepared and carried out in the industrial environment, are the only positive results obtained, which are connected with so much quantities of liquid steel processed with use of the multi-hole ceramic filters.

Key words: steel, refining, tundish, ceramic filter, continuous casting (CC).

INTRODUCTION

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 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 [3–6]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 [6–9]. 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 [9]. The positive results obtained in the laboratory-scale research have bcecome the base to undertake the trials to filtrate liquid steel in industrial conditions. A series of model investigations has been carried out, and then, after obtaining the positive results, a series of industrial-scale melts of steel has been produced [10–13]. 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. 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.

INDUSTRIAL INVESTIGATIONS OF STEEL FILTRATION

The hitherto obtained results of the laboratory researches of liquid steel filtration by means of ceramic filters [10-13] have become the base for preparation and

Figure 1 Tundish of the CC machine provided with the ceramic filter

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implementation of the industrial application of the steel filtration process in the processing line of the continuous casting machine. Figure 1 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 808 236 mm^2. 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 ($\lambda = h/d$), the filter used in the experiment has been of slenderness ratio $\lambda = 3,10$ [14]. 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 (chemical composition steel: C- 0,340, Mn- 0,840, Si- 0,250, P- 0,025, S- 0,020, Al- 0,045), 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 Figure 2. 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 (1):

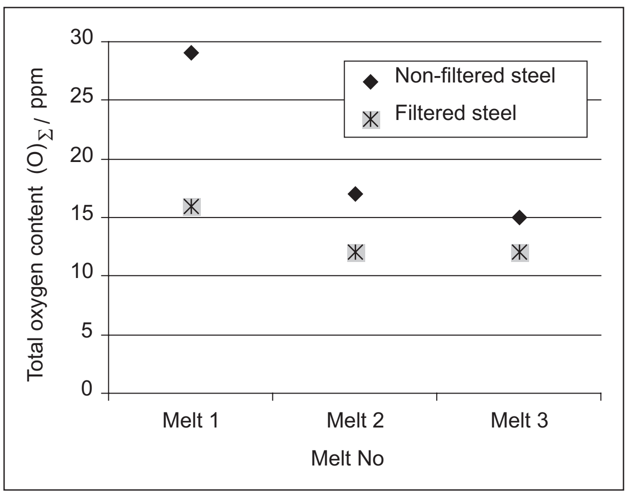

Figure 2 $(O)_T$ total oxygen content variation in each of the melt sequence - 34GJ steel

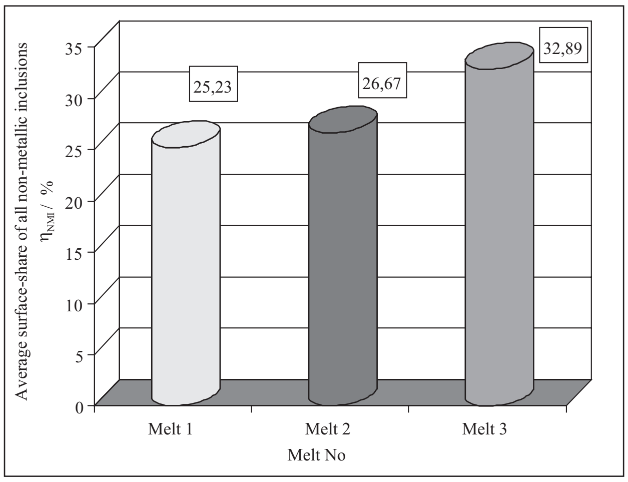

Figure 3 The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share η_{NMI} - 34GJ steel

$$\eta_{NMI} = \frac{x_p - x_k}{x_p} \cdot 100 \ \% \qquad (1)$$

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: 0,5-2,5 μm, 2,6-6,5 μm, 6,6-15 μm, 15,6-30 μm, what is shown in Figure 3. Figures 4–6 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 border of phase division between filter ceramics and solidified steel together with adjoining areas (after polishing the sample surface and deposition of thin film of gold) has been examined with the X-ray microanalyses method by means of Noran Instrument's Hitachi S-3500N scanning microscope. The highest level of the effectiveness of liquid steel filtration has been observed for inclusions in the 2,6 – 30,0 μm interval, what has been confirmed by the previously obtained experimental results [10, 13, 15].

The observed inclusions differ in shape and size. In the aluminium deoxidized melts (the second trial and the third trial) the single inclusions as well as irregular in shape the inclusions clusters of different configuration have been observed. They are built from non-metallic phase (Al_2O_3) produced during the deoxidizing process.

They consist of Al_2O_3 non-metallic phase, being the product of the deoxidizing process. In every experimental melt (excluding inclusions in M-3 melt - the third trial) the decrease of the inclusion surface-share in the filtrated steel in comparison with the non-filtrated steel was observed.

The highest degree in the surface-share decrease in relation to all inclusions was observed in M-1, M-2, and

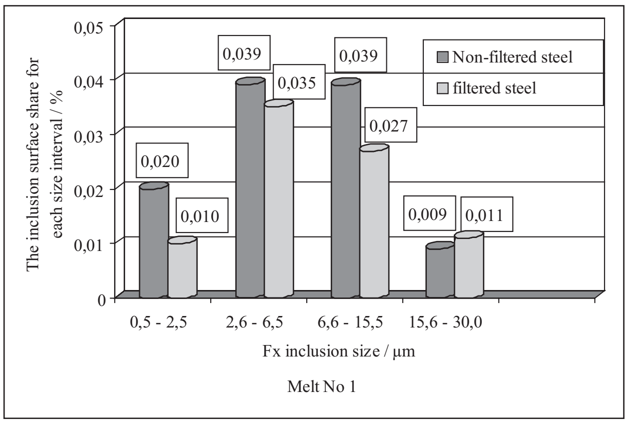

Figure 4 The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share η_{NMI}, with division into inclusion size intervals according to F_x Feret diameters melt no 1 - 34GJ steel

M-3 melts with parameters η_{NMI} equal to 25,23 %, 26,67 % and 32,89 % respectively (the second trial). Figure 3 illustrate this dependence for average η_{NMI} value calculated for every experimental melt. Increase of the non-metallic inclusions size (measured with diameter F_x)

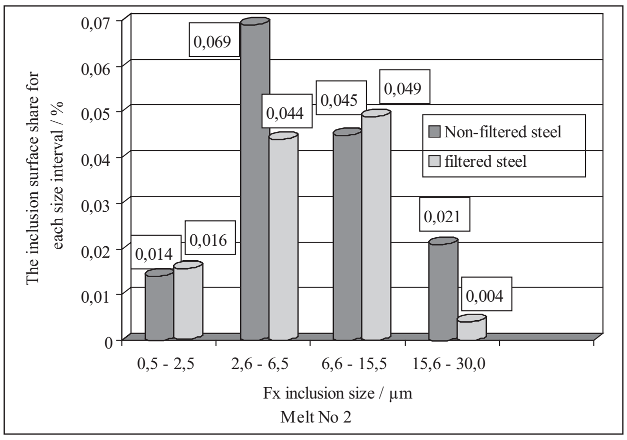

Figure 5 The effectiveness of removing non metallic inclusions as measured with the average rate of non-metallic inclusion superficial share η_{NMI}, with division into inclusion size intervals according to F_x Feret diameters melt no 2 - 34GJ steel

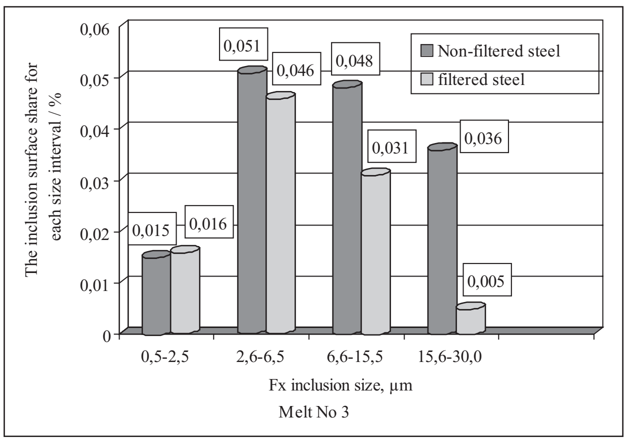

Figure 6 The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share η_{NMI}, with division into inclusion size intervals according to F_x Feret diameters melt no 3 - 34GJ steel

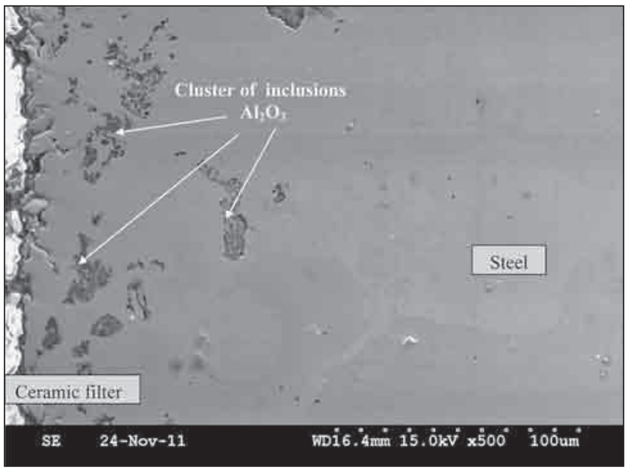

Figure 7 Scaning pictures of interface partition filters ceramic-filtration steel of head - 34GJ steel

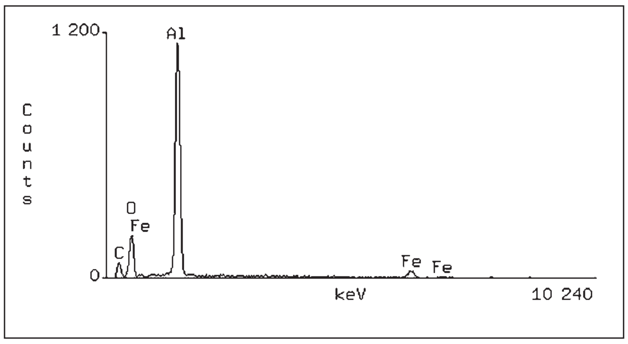

Figure 8 X-ray photograph of non metallic inclusions chemical composition identified on the surface of a ceramic filter and in steel volume from melt - 34GJ steel

causes increase in the number of inclusions removed during filtration, measured with η_{NMI}. Figure 7 show in a form of scanning pictures the results of investigation of the division border of the solidified steel – filter ceramic and the areas adjoining the border after filtration tests of steel (aluminium deoxidized) taken from the melt M-3 (the second trial) as an example. The solidified product of steel deoxidation in a form of Al_2O_3 have been identified on the ceramic filter surface and in the adjoining areas.

Character of a contact of Al_2O_3 inclusion particle (and clusters of this inclusions) with the filter ceramic surface excludes the chemical bounding and sintering of the contacting phases. Chemical composition of the identified products of steel deoxidation with aluminium is confirmed with the X-ray photo in Figure 8.

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 tundish, 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 η_{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 28,26 % for the second trial with the filter slenderness ratio $\lambda = 3,10$. 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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Note: The responsible translator for English language is Z. Kozyra, Katowice, Poland.