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THE INFLUENCE OF SLENDERNESS OF CERAMIC FILTERS ON THE EFFICIENCY OF STEEL REFINING

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The results presented in this paper are the next planned stage of research on the process of steel refining from dispersoid non-metallic phase by means of its filtration. The acquired results of macro and microstructure anlyzes, as well as steel cleanliness before and after the filtration process, reflect the course of the research and attest that it can be an effective and cheap method of refining it from non-metallic inclusions. Presented results confirm that the slenderness of a filter has a significant impact on the effectiveness of the steel filtration process. Products of deoxidation have been identified on the filtration surface of ceramic filters.

Keywords: steel C70D, filtration, ceramic filter, refining, non-metallic inclusions.

INTRODUCTION

The topic of this publication is in line with the modern direction of steel metallurgy development, preferring steelmaking technologies (or their components) ensuring the production of steel with high metallurgical purity, the so-called „clean-steel”. At the present, the most frequently used ceramic filters in metallurgy are foam filters. They are used for the filtration of non-ferrous metals, cast iron or small amounts of steel (up to several dozen kilograms). In a number of publications, the phenomenon of foam filters destruction as a result of strong erosion at the temperature of steel casting (around 1 873 K) can be observed. As an example, the results of many authors’ works may be presented, e.g. Solarek J. [1] or Dudczing S. [2], where the authors present the damage to the ceramic material of the filter, which is destroyed as a result of strong erosion, generating further contamination of the metal bath. The research presented in subsequent publications and the results obtained are a continuation of a series of experiments, the authors of which, over the last several decades have tried to get to know and develop the mechanisms of the filtration process in the most optimal way possible. Examples include Bažan J. and Bužek Z. Their subsequent publications provide more information [3]. The authors present preliminary research with very promising results. There are others working on the filtration process at the time however. Hamada K., Ali S., Mutharasan R. and Apelian D. are conducting their research correspondingly. At the same time, other research centers are conducting research on experiments on a semi-industrial and industrial scale. At the beginning of the nineties, Mamcini J. and Stel J. or Xintian L. with co-authors presented the results of semi-industrial studies of the filtering process of low-carbon steel during continuous casting with alumina (Al_2O_3), corundum-quartz ($Al_2O_3{\cdot}SiO_2$) and limestone filters (CaO). Janiszewski K. in his works [4, 5] on the efficiency of the filtration process in laboratory and then industrial conditions in the technological line of the CC device also confirms that the use of ceramic filters can be an effective and cheap method of refining steel from the fine-dispersed non-metallic phase.

Recently, Wetzig T. et al. [6] proposed to use foam ceramic filters in the technological line of the CC device for filtration of steel in industrial conditions. These filters were used for the filtration process for a maximum of 30 minutes. How, then, would these filters be used in industrial conditions? Currently, interesting experiments on the steel refining process are also conducted by Chattopadhyay K. [7]. However, an article by Q. Wang [8] confirms the correctness of the approach of the reasearchers who also highlited the significant impact of filter slenderness on the efficiency of the process of steel filtration [5].

RESULTS OF LABORATORY RESEARCH TESTS OF THE STEEL FILTRATION PROCESS

Laboratory research works on steel filtration with ceramic filters were conducted in argon protective atmosphere with melts 12 kg in weight. In thirteen filtration experiments, steel grade C70D was tested, the chemical composition of which is shown in Table 1. Melts prior to filtration have been deoxidized with aluminium. Then the steel temperature in the furnace has been measured with Pt-Rh-Pt sensor and the melts have been filtrated. The melt filtration times, being the times

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of casting operations, have amounted in the range of 8 to 10 seconds. The steel liquidus temperature has been determined according to formula: T_L= 1 535 – 70 (% C) – 5 (% Mn) – 12 (% Si) – 30 (% P) – 25 (% S) – 80 (% O). The casting speed has been 0.098 m/s, argon flow rate ~ 300 l/min, the chamber has been filled with argon 15 minutes before the start of the steel casting and filtration process. The multi-hole ceramic filter used for steel filtration, manufactured by the company of Keramtech s.r.o. Žacleř (Czech Republic), has been made on the base of mullite ($3Al_2O_3 \cdot 2SiO_2$). The filters used have had equal orifice numbers 19, diameters of $8,1 \times 10^{-6}$ m and the total filtrating surface of $5\ 802 \times 10^{-6}$ m^2 for S_F1 filter slenderness ratio, $11\ 604 \times 10^{-6}$ m^2 for S_F2 filter slenderness ratio and $17\ 406 \times 10^{-6}$ m^2 for S_F3 correspondingly.

Table 1 **Chemical composition steel C70D / wt. %**

Element	Element content
C	0,72
Mn	0,61
Si	0,23
P	0,13
S	0,020
Cr	0,02
Ni	0,02
Al	0,39
Mo	0,004

After steel solidification in the ingot-mould and the pouring gate, from each melt two samples of filtrated and non-filtrated steel, as well as of the filter depositing area, have been collected for investigation of the chemical composition, steel contamination with non-metallic inclusions and for identification of the inclusions adsorbed at the filter ceramic - solidified steel phase border (Figure 1). The chemical composition of samples of filtrated and non-filtrated steel has been determined with the emission spectroscopy method combined with spark excitation. The non-metallic inclusion content (surface-shares) and their dimensions have been determined with Leica's computerized image analyzer Leica Q500 MC on samples in the form of polished microsections zoomed 500 times. The inclusions have been investigated for one hundred of randomly selected fields of every sample. When determining the inclusion percentage, i.e. the area occupied by the inclusions in the surface of the observed microsection, the „area" option (expressed in mm^2) has been used, while the so called Feret's diameter option (expressed in mm) has been used for inclusion number determination. In the analyses of steel contamination with non-metallic inclusions, the so-called factor of surface-share variation and of the inclusions number has been used [4]. The border of phase division between filter ceramics and solidified steel together with adjoining areas has been examined with the X-ray microanalyses method by means of Noran Instrument's Hitachi S-3400N scanning electron microscope (SEM).

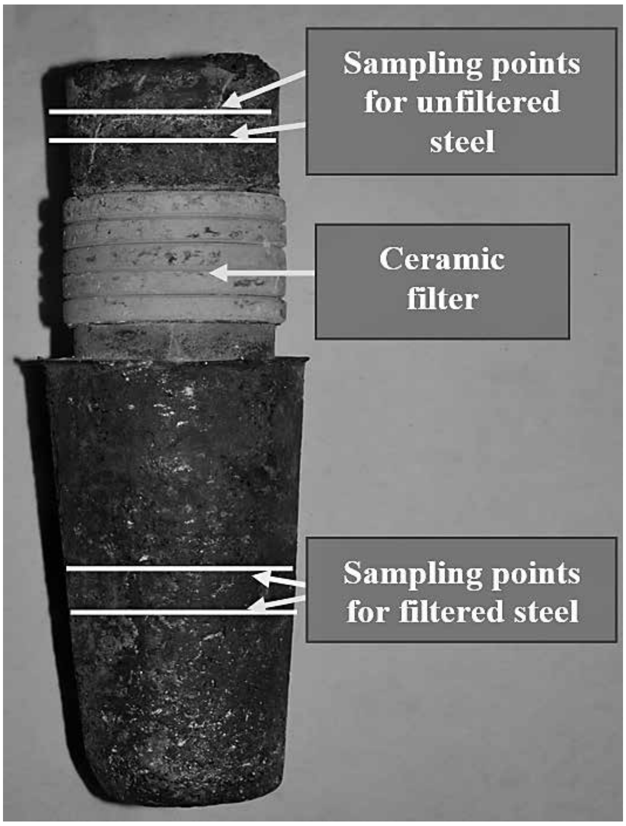

Figure 1 Places and method of sampling filtered steel.

The efficiency of steel filtration in protective argon atmosphere has been defined by variations in the superficial share of all non- metallic inclusions and the number of non-metallic inclusions in filtrated steel in comparison to non-filtrated one, in dependence on the filter slenderness ratio according to assumptions presented in the paper [8]. The results of examinations of the inclusion-steel surface ratio variations or – in other words – efficiency of steel filtration in argon atmosphere in twelve experimental melts (divided into sulphide and oxide inclusions) are, graphically illustrated in Figure 2.

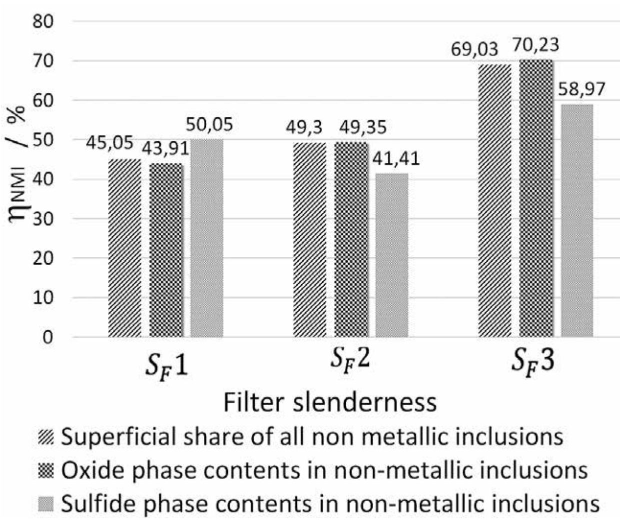

Figure 2 Efficiency of removing the non- metallic inclusions expressed as variation of η_{NMI} surface inclusion-steel ratio for all experimental melts in dependence on the filter slenderness.

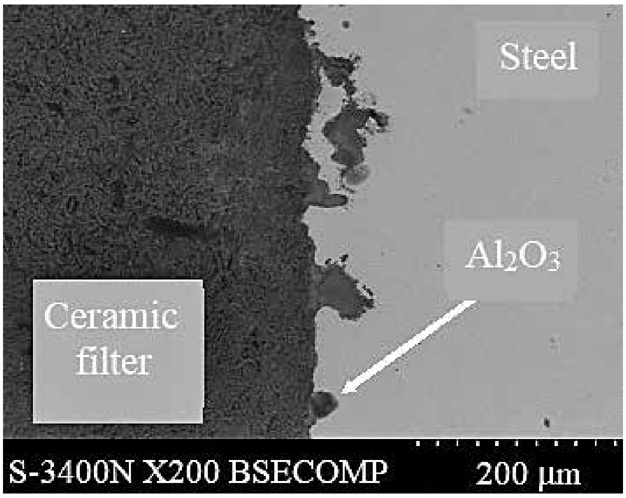

Figure 3 SEM of interface partition filters ceramic- filtration steel of head M-3

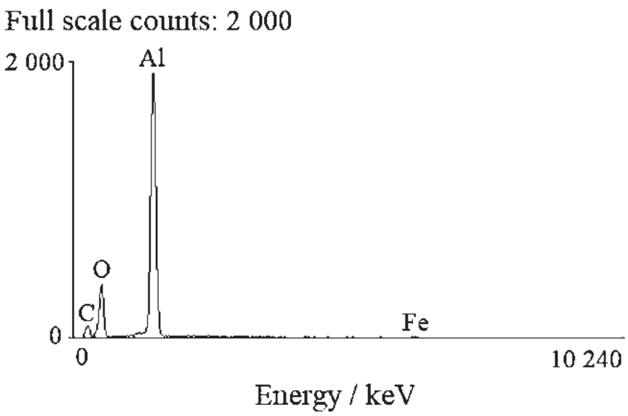

Figure 4 X-ray photograph of non- metallic inclusions chemical composition identified on the surface of a ceramic filter and in steel volume from melt – M-3.

Finally the inclusion-steel surface parameter of all non-metallic inclusions in steel after filtration has decreased correspondingly: for filter slenderness S_F1 h_{NMI} = 45,05 %, for filter slenderness S_F2 h_{NMI} = 49,3 % and for filter slenderness S_F3 h_{NMI} = 69,03 %. Number of non-metallic inclusions of smaller diameters – below 6,5 mm – has been decreased in different degree for particular melts and Feret diameter ranges.

Finally the number of all non-metallic inclusions in filtrated steel has decreased correspondingly: for S_F1 filter slenderness h_{NMI} = 8,31 %, for S_F2 h_{NMI} = 43,60 % and for S_F3 h_{NMI} = 46,49 %. Estimation of efficiency of liquid steel filtration process has also been made in regard to oxide inclusions. Observed variations in the inclusion-steel rates both for oxide and sulfide inclusions confirm that the process of steel filtration with use of multi-orifice ceramic filters is well-founded and efficient. Figure 3 shows 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 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 (Figure 3). A phase composition of the identified inclusions is confirmed with the X-ray photo in Figure 4.

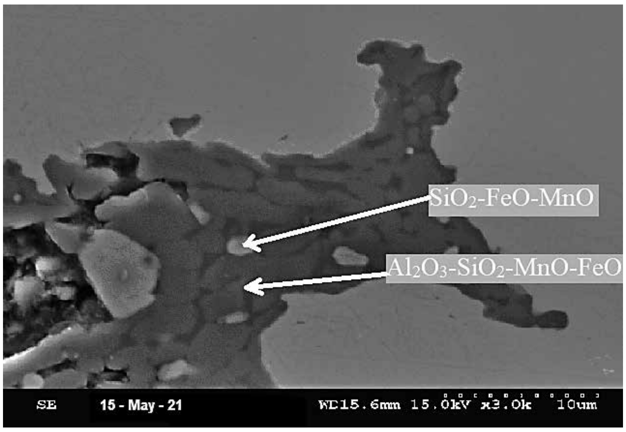

Figure 5 SEM of interface partition filters ceramic- filtration steel of head M-10

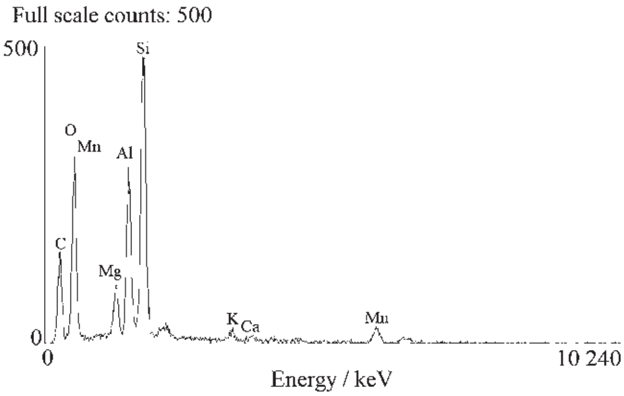

Figure 6 X-ray photograph of non-metallic inclusions chemical composition identified on the surface of a ceramic filter and in steel volume from melt – M-10.

The complex inclusions (probably liquid) contact in a different way with the ceramic filter surface during steel filtration of the melt M-10 (Figure 5): it can be seen that the filter ceramic is wetted by the clusters of complex inclusions composed of particles of Al_2O_3-SiO_2-MnO-FeO configuration.

Phase composition of the complex inclusions cluster corresponds to chemical composition of products of the used sedimentary method of steel melt deoxidation.

The shape of inclusions and the manner of contacting with the filtrating surface of the ceramic filter confirms the state of inclusions is liquid and the filter ceramic material is wetted in a high degree.

A phase composition of the identified inclusions is confirmed with the X-ray photo in Figure 6.

SUMMARY AND CONCLUSIONS

Based on the review carried out, the assessment of the available source publications as well as the obtained results of laboratory tests of processes of liquid steel filtration with multiple-orifice ceramic filters, it is possible to present the following conclusions:

- the steel cleaning effectiveness, as measured with average degree of the surface share variation, in relation to the whole range of inclusions, has decidedly increased and amounted respectively: h_{NMI} = 45,05 % filter slenderness (S_F1 – 1,67), h_{NMI} = 49,30 % for filter slenderness (S_F2 - 3,34) and), h_{NMI} = 69,03 % for filter slenderness (S_F3 - 8,36),
- the total variation degree of inclusion number has also increased and amounted respectively h_{NMI} = 8,31 % filter slenderness (S_F1 – 1,67), h_{NMI} = 43,60 % for filter slenderness (S_F2 - 3,34) and), h_{NMI} = 46,49 % for filter slenderness (S_F3 - 8,36),
- using this coefficient we obtain the possibility to compare the filtration effectiveness of different types of ceramic filters, not only for filters with cylindrical filtrating orifices, but also for other types, e.g. with orifices of rectangular section.

The purity of steel should be understood as reducing the content of not only harmful elements such as sulfur or phosphorus, but also the dispersoid non-metallic phase. The possibility of increasing the macro and micro-transparency of cast steel ingots due to the prospect of easily achieving economic benefits makes the steel filtration method a prospective one.

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Note: The responsible translator for English language is Marceli Janiszewski, Sosnowiec, Poland.