STEEL FILTRATION USING MULTI-HOLE CERAMIC FILTERS WITH AN INNOVATIVE DESIGN

The research results presented in the article constitute the next stage of a planned series of experiments on the process of refining steel from a dispersive non-metallic phase by its filtration method. The paper presents the results of experiments carried out using an innovative design of multi-hole ceramic filters, the filter holes of which have an elliptical shape. Analyses of the macro and microstructure and purity of the steel before and after the filtration process reflect the course of the research and confirm that this can be an effective and cheap method of its refining from non-metallic inclusions. The results presented are the first of their kind in the world and confirm that the shape of the filter holes of multi-hole ceramic filters may have a significant impact on the efficiency of the steel filtration process. The non-metallic phase identified at the ceramic filter-steel interface corresponds to the reaction products of the deoxidation of aluminum steel.

Key words: steel C70D, continuous casting, ceramic filter, refining, non-metallic inclusions.

INTRODUCTION

The metallurgical purity of steel is not only about the impurities it contains, such as sulfur or phosphorus. The content of non-metallic inclusions also plays an important role. Especially fine inclusions, which can disorganize further technological processes. The experience of numerous researchers [1-4] shows that conventional post-furnace processing of steel (especially that deoxidized by the sedimentary method, e.g. using aluminum) does not guarantee its high metallurgical purity. Moreover, this method generates a large number of fine non-metallic inclusions of the Al2O3 type in the liquid steel and introduces disorganization in the process of continuous steel casting due to the phenomenon of the nozzles from the tundish becoming overgrown with them [5]. 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 (Al2O3), corundum-quartz (Al2O3∙SiO2) and limestone filters (CaO) [1, 2]. Over the last several decades, many experiments have been carried out, the authors of which presented theoretical assumptions of phenomena occurring during the steel filtration process (mechanism of retaining inclusions and clogging tundish nozzles) [4, 5]. The basics of the mechanism for retaining solid and liquid non-metallic inclusions were also presented [6, 7]. Possibilities of refractory tundish lining supporting the steel refining process are also being considered. After reaching the walls, the inclusions would stop there [8]. Recently, research results have been presented, the authors of which would like to apply foam filters to the steel filtration process in industrial conditions, e.g. Wetzig T. et al. [9]. These publications show that the filters were used in the filtration process for a maximum of 30 minutes. So how would they perform in industrial conditions? What is more, the results of previous research have shown that at temperatures above 1 823 K foam filters are destroyed, which generates further non-metallic inclusions in the furnace bath [7]. Currently, interesting experiments on the steel refining process are also conducted by Chattopadhyay K. [10]. However, the article by Q. Wang [11] confirms the validity of the approach of researchers, who also drew attention to the significant impact of not only the type of filter but also its slenderness on the efficiency of the liquid steel filtration process [5, 12]. The results of industrial research using multi-hole filters [13] confirmed that this method can become an effective and cheap way to remove non-metallic inclusions at the last stage of the steel casting process using a continuous casting device and steel cast traditionally using the siphon method. In this study, an attempt was made to verify the influence of the shape of the filtration holes of multi-hole ceramic filters on the effectiveness of the steel refining process by filtration.

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 aluminum. 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 of casting operations, have amounted in the range of 8 to 10 seconds. The steel liquidus temperature has been determined according to formula: TL = 1 535 – 70 (% C) – 5 (% Mn) – 12 (% Si) – 30 (% P) – 25 (% S) – 80 (% O).

Table 1 Chemical composition steel C70D / wt. %

<table>
<thead>
<tr>
<th>Element</th>
<th>Element content</th>
</tr>
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<tbody>
<tr>
<td>C</td>
<td>0.72</td>
</tr>
<tr>
<td>Mn</td>
<td>0.61</td>
</tr>
<tr>
<td>Si</td>
<td>0.23</td>
</tr>
<tr>
<td>P</td>
<td>0.13</td>
</tr>
<tr>
<td>S</td>
<td>0.020</td>
</tr>
<tr>
<td>Cr</td>
<td>0.02</td>
</tr>
<tr>
<td>Ni</td>
<td>0.02</td>
</tr>
<tr>
<td>Al</td>
<td>0.39</td>
</tr>
<tr>
<td>Mo</td>
<td>0.004</td>
</tr>
</tbody>
</table>

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)SF – 1,67 and Alcor S.A. SF – 1,74 has been made on the base of mullite (3Al₂O₃·2SiO₂).

The filters used have had equal orifice numbers 19, and the total filtrating surface of 5 802×10⁻⁶ m² for filter slenderness ratio SF – 1,67 and 5 821×10⁻⁶ m² for filter slenderness ratio SF – 1,74. A view of the ceramic filter used for testing is shown in Figure 1. 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 2). In total, three experimental melts were made using new ceramic filters (with an elliptical filter channel cross-section and S_F – 1,74 slenderness ratio) and the results were compared with five experiments for filters with a circular filter channel cross-section and S_F – 1,67 slenderness ratio.

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 mm²) 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 [12]. 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). 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 3. Finally, the inclusion-steel surface parameter of all non-metallic inclusions in steel after filtration has decreased correspondingly: for filter slenderness ratio $S_f - 1.67$ $h_{\text{NMI}} = 45.05\%$, for filter slenderness ratio $S_f - 1.74$ $h_{\text{NMI}} = 50.22\%$. 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 $S_f - 1.67$ filter slenderness ratio $h_{\text{NMI}} = 8.31\%$, for filter slenderness ratio $S_f - 1.74$ $h_{\text{NMI}} = 38.45\%$. 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.

**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 effectiveness of removing non-metallic inclusions, measured by the average degree of change in the surface share, in relation to all inclusions in the steel after filtration, was as follows: for the old filter with slenderness ratio $S_f - 1.67$ $h_{\text{NMI}} = 45.05\%$ and for the new filter design with slenderness ratio $S_f - 1.74$ $h_{\text{NMI}} = 50.22\%$.
- the total variation degree of inclusion number has also increased and amounted respectively $h_{\text{NMI}} = 8.31\%$ filter slenderness ratio $S_f = 1.67$, $h_{\text{NMI}} = 38.45\%$ for filter slenderness ratio $S_f = 1.74$.
- the introduction of a new factor - filter slenderness [5, 12] into the description of multi-hole ceramic filters used in experiments, now allows for comparison of the efficiency of the steel filtration process regardless of the shape of the filter holes. The conducted experiments are the first in the world in which elliptical filter channels were used.
The efficiency of the steel refining process using multi-hole ceramic filters with a new design increased by 10.30%.

The research presented in this paper constitutes the next stage in a planned, long-term series of experiments on the refining of steel from a dispersive non-metallic phase. Positive experimental results provide the basis for continued research and confirm that steel filtration may become a common technological element during the casting process in the near future.

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REFERENCES


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