K. JANISZEWSKI

ISSN 0543-5846
METABK 63(3-4) 337-340 (2024)
UDC – UDK 669.15.71.26.24:669.13-658.281:661.31-542.6.002.64=111

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

Received – Primljeno: 2023-12-23
Accepted – Prihvaćeno: 2024-02-25
Original Scientific Paper – Izvorni znanstveni rad

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 Al_2O_3 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 (Al_2O_3), corundum-quartz ($Al_2O_3 \cdot SiO_2$) 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

K. Janiszewski, (krystian.janiszewski@polsl.pl) Silesian University of Technology, Department of Metallurgy and Recycling, Katowice, Poland.

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 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).

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

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) S_F – 1,67 and Alcor S.A. S_F – 1,74 has been made on the base of mullite ($3Al_2O_3{\cdot}2SiO_2$).

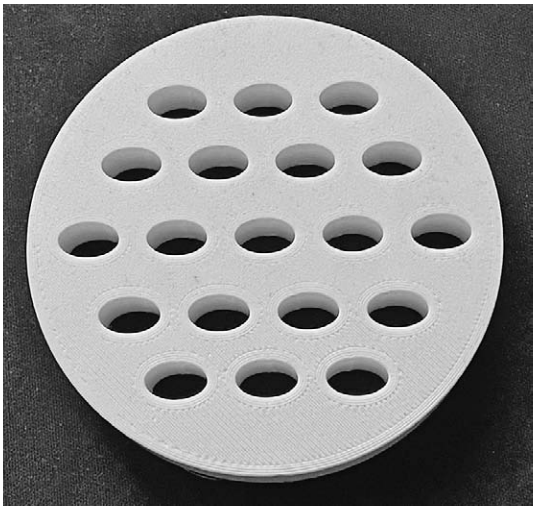

Figure 1 Multi-hole ceramic filter used for testing.

The filters used have had equal orifice numbers 19, and the total filtrating surface of 5 802×10^{-6} m^2 for filter slenderness ratio S_F - 1,67 and 5 821×10^{-6} m^2 for filter slenderness ratio S_F - 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.

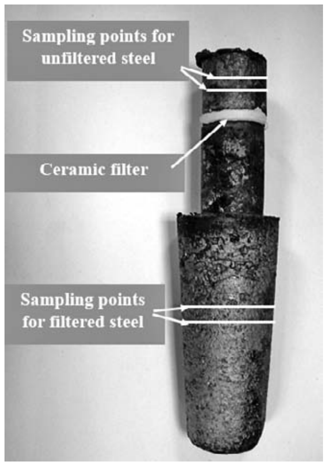

Figure 2 Places and method of sampling filtered steel.

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 [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_F1,67 h_{NMI} = 45,05 %, for filter slenderness ratio S_F 1,74 h_{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_{NMI} = 8,31 %, for filter slenderness ratio S_F – 1,74 h_{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.

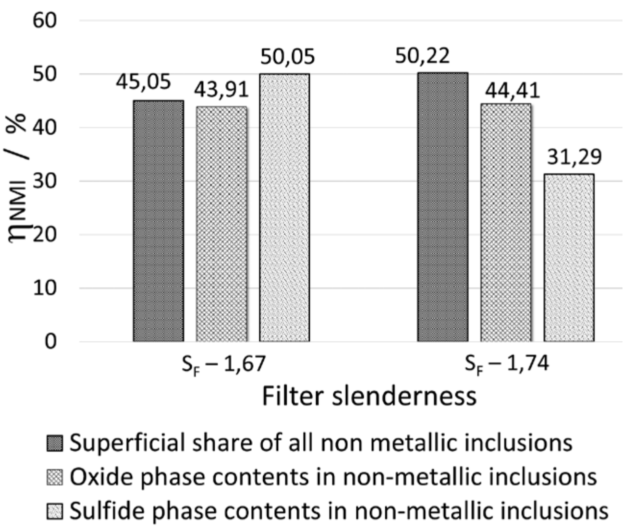

Figure 3 Efficiency of removing the non- metallic inclusions expressed as variation of η_{NMI} surface inclusion-steel ratio for all experimental melts in dependence on the filter slenderness.

Figure 4 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 for slenderness ratio S_F - 1,74.

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 4). A phase composition of the identified inclusions is confirmed with the X-ray photo in Figure 5. Phase composition of the complex inclusions cluster corresponds to chemical composition of products of the used sedimentary method of steel melt deoxidation.

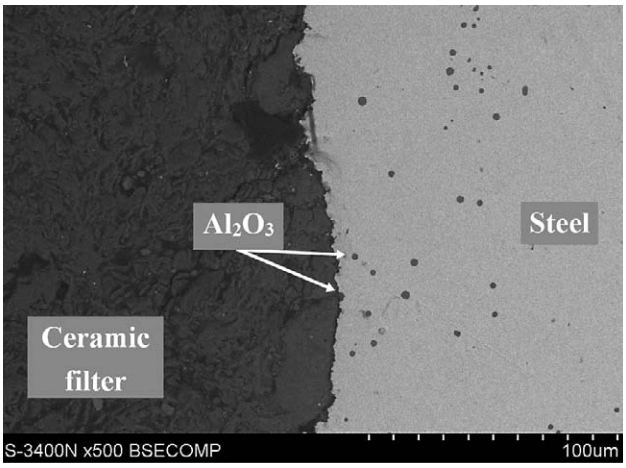

Figure 4 SEM of interface partition filters ceramic- filtration steel of head M-3

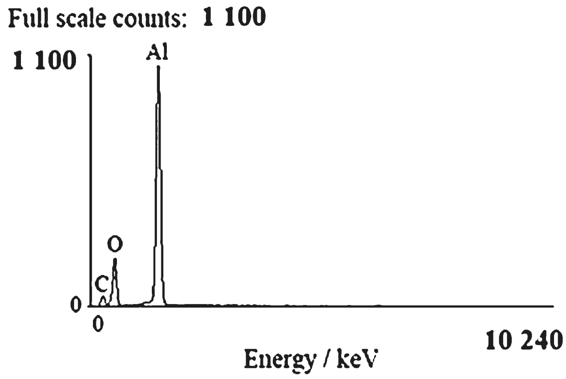

Figure 5 X-ray photograph of non- metallic inclusions chemical composition identified on the surface of a ceramic filter and in steel volume from melt – M-3.

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_{NMI} = 45,05 % and for the new filter design with slenderness ratio S_F – 1,74 h_{NMI} = 50,22 %.
- the total variation degree of inclusion number has also increased and amounted respectively h_{NMI} = 8,31 % filter slenderness ratio (S_F1 – 1,67), h_{NMI} = 38,45 % for filter slenderness ratio (S_F2 – 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.

Acknowledgements

The research was carried out as part of the research work 11/020/BK_23/0104.

REFERENCES

[1] Mancini J., Stel J., Tundish metallurgy: a combined Irsid und Hoogovens research. Revue de Metallurgie-CIT 89 (1992) 3, 269–277.

[2] Xintian L., Yaoke Z., Baolus S., Weiming J., Flow behaviour and filtration of steel melt in continous casting tundish, Ironmaking and Steelmaking 19 (1992) 3, 221–225.

[3] J. Solarek. Ductile behavior of fine-grained, carbon-bonded materials at elevated temperatures. Carbon 122 (2017), 141-149.

[4] Ali S., Apelian D. Refining of an aluminum and steel bath with the use of multi-cell squeezed ceramic filters Can. Metall. Quart 24 (1985) 4, 311–318.

[5] H. Barati, M. Wu, A. Kharicha, and A. Ludwig. Calculation accuracy and efficiency of a transient model for submerged entry nozzle clogging. Metallurgical and materials transactions B. 50B (2019) 6, 1428-1443 doi.org/10.1007/s11663-019-01551

[6] Bažan J., Bužek Z, Roučka J., Strańsky K., Lev P. O mechanizmu filtrace tvarne lipiny ceditkovymi a penovymi filtry. Conference materials of the 7th International Scientific Conference „Iron and Steelmaking", Mala Lučivna, 23-25.09.1998, 168–171, Slovakia.

[7] J. Bažan, Z. Bužek, R. Bužek, K. Strańsky, Z. Kudliński. Wyniki badań filtracji ciekłej stali, Hutnik – Wiadomości Hutnicze 66 (1999) 4, 163–168.

[8] C. Yuan et al. Effect of Rare-Earth Oxides Containing Refractories on the Cleanliness of Al-Killed Steels. Steel Research International 94 (2023) 12, DOI: 10.1002/srin.202300389

[9] T. Wetzig et al. Development and testing of carbon-bonded alumina foam filters for continuous casting of steel. Ceramics International 44 (2018), 15, 18143-18155 DOI: 10.1016/j.ceramint. 2018.07.022.

[10] K. Chattopadhyay et al. Effect of Physical State of Non-Metallic Inclusions on the Accumulation Within Magnesia-Stabilized Zirconia Foam Filters. AISTech 2019 — Proceedings of the Iron & Steel Technology Conference, 6–9 May 2019, Pittsburgh, Pa., USA, 1029-1040 DOI 10.1000.377.106

[11] Q. Wang, Y. Liu, A. Huang, et al. CFD Investigation of Effect of Multi-hole Ceramic Filter on Inclusion Removal in a Two-Strand Tundish. Metall Mater Trans *B* 51, 276–292 (2020). doi.org/10.1007/s11663-01901736-4

[12] K. Janiszewski. The slenderness ratio of the filter used in the process of liquid steel filtration as the additional parameter of the filter form. Steel Research International, 84 (2013) 3, 288-296, DOI: 10.1002/srin. 201200077.

[13] K. Janiszewski: Industrial application of liquid steel filtration out of dispersed nonmetallic phase in the continuous casting machine, Metalurgija 52 (2013) 1, 71-74.

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