ISSN 0543-5846
METABK 61(3-4) 599-602 (2022)
UDC – UDK 669.18-66.067:666.7-542.6:66.061.002.6=111

# FILTRATION OF LIQUID UPHILL CASTED STEEL

Received – Primljeno: 2021-11-18
Accepted – Prihvaćeno: 2022-02-28
Original Scientific Paper – Izvorni znanstveni rad

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. Currently, the research has been focused on the process of casting steel using the traditional uphill method. This paper analyzes the prepared and conducted experiments on a semi-industrial scale with the use of multi-hole ceramic filters. 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.

*Key words*: steel filtration, ceramic filter, refining, uphill casted, results.

## INTRODUCTION

The subject matter 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 time, the most frequently used ceramic filters in metallurgy, of course metallurgy in a broad sense, of both iron and steel as well as non-ferrous metals, 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). Their use in the process of steel filtration in industrial conditions (during traditional or continuous casting of steel) carries the risk of failure due to hindered flow of liquid metal or its contamination due to damage to the filter. In a number of publications, the phenomenon of foam filters destruction as a result of strong erosion at the temperature of steel casting (around 1873 K) can be observed. As an example, the results of may authors' works may be presented, e.g. Solarek J. [1] or Dudczing S., where the work's 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. [3]. Their subsequent publications provide more information [4]. 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. [5, 6] 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. [7] or Xintian L. with co-authors [8] 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). Later on, the employees of IMŻ Gliwice conducted experiments on a semi-industrial scale; Bulkowski L., Galisz U. and others [9]. Unfortunately, in their publications, there are no specific research results which significantly detracts from the outcome of a very interesting experiment. It is possible that the research results could not be published. In order to get to know them, it is necessary to examine the research report, which is an unpublished material [10]. Janiszewski K. in his works [11, 12] on the efficiency of the filtration process in laboratory and then industrial conditions [13] 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. [14] proposed to use foam ceramic filters in the technological line of the CC device for filtration of steel in industrial conditions. These filters made by the method according to the invention [15] would be used for the filtration process for a maximum of 30 minutes. How, then, the authors of the work would like to use them in industrial conditions? The results of the work are to be known soon, as the next stage is to be experiments on a semi-industrial scale. Currently, interesting experiments on the steel refining process are also conducted by Chattopadhyay K. [16].

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## STEEL FILTRATION IN SEMI-INDUSTRIAL CONDITIONS

The positive results of the experiments, prepared and carried out in laboratory and then industrial conditions in the technological line of the equipment for continuous casting of steel (CC) gave the basis for the continuation of research on the steel process in industrial conditions. Another planned cycle of experiments was the application of the method of filtration of steel from the dispersion non-metallic phase as an additional refining treatment during its casting using the traditional method – uphill casting. The experiments were conducted in the steel mill Alchemia S.A. During the first filtration experiment, steel of the P250GH grade was given, the chemical composition of which is shown in Table 1. The total weight of the filtered steel was 1,3 Mg. For filtering the steel, a multi-hole mullite ($3Al_2O_3 \times 2SiO_2$) ceramic filter by Keramtech s.r.o. Žacleř, No. 202, made of ceramic material with the trade name RK-5 was used.

The used filter had a number of 27 holes (diameter $9,2 \times 10^{-3}$ m) and two small holes (diameter $5,2 \times 10^{-3}$ m) and the total filtration area was $9\,594 \times 10^{-6}$ m$^2$.

Table 1 **Chemical composition steel P250GH / wt. %**

| Element | Min | Max |
|---|---|---|
| C | 0,18 | 0,23 |
| Mn | 0,30 | 0,90 |
| Si | - | 0,40 |
| P | - | 0,025 |
| S | - | 0,015 |
| Cr | - | 0,30 |
| Ni | - | 0,30 |
| Al(c) | 0,02 | - |
| Mo | - | 0,08 |
| Cu | - | 0,30 |
| Ti | - | 0,03 |

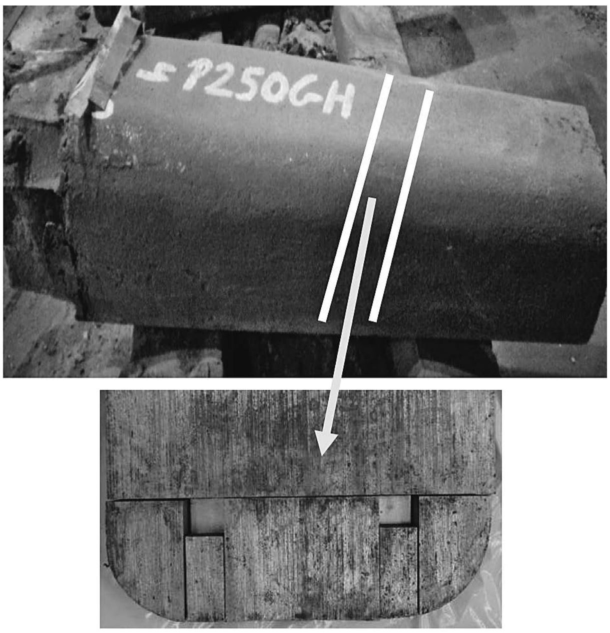


**Figure 1** Places and method of sampling filtered steel.

Samples of unfiltered steel for testing its contamination with non-metallic inclusions and changes in chemical composition were taken directly from the steel stream flowing from the ladle to the central funnel in the form of Lollipop samples. After solidification of the steel in the ingot mold and gating system, and then breaking the ingot, a sample was taken in the form of a slice (Figure 1) of filtered steel, from which the material was collected for analysis.

## RESULTS OF TESTS OF THE STEEL FILTRATION PROCESS

The Leco company's combustion method was used to analyze the content of total oxygen $[O]_{\Sigma}$. The chemical composition of the collected steel samples was tested by the use of spark analyzer. The microstructure images were recorded using the Olympus GX71 metallographic microscope (LM - light microscope) on samples taken from the Lollipop samples and an ingot in the form of polished specimens at a magnification of 500×. The determination of the content of non-metallic inclusions (surface fractions) and their number in filtered and unfiltered steel was performed with the Leica Q500 MC computer image analyzer by Leica. In the case of almost every element in the experimental melt, a change in its chemical composition was found. This applies to the least extent to manganese and carbon, and to a much greater extent to sulfur, silicon, aluminum and total oxygen. Minor losses of carbon and manganese may be caused by the secondary oxidation of steel with oxygen from the surrounding air. On the other hand, no increase in the element content after the filtration process was found in any of the heats.

The efficiency of the liquid steel filtration process was also assessed in relation to the total oxygen content in the unfiltered and filtered state. The methodology of the conducted research was consistent with that presented in the references [7, 9, 11]. After the analysis, a significant reduction in the total oxygen content $[O]_{\Sigma}$ in filtered steel in relation to unfiltered steel was found and it amounted to 25 %.

Non-metallic inclusions identified in unfiltered and filtered steel samples are characterized by various shapes and sizes. They occur in the form of single and various configurations of clusters of irregular shapes. In the vast majority of cases, the non-metallic inclusions in unfiltered steel were bigger than those in the filtered steel samples.

The analysis was carried out in relation to the change in the number and area fraction of the non-metallic phase. The degree of removal of non-metallic inclusions $\eta_{NMI}$ (measured by the change in their number and surface fraction) by filtration of liquid steel in individual ranges of inclusions size varies. The results of these analyzes are shown in Figures 2 and 3.

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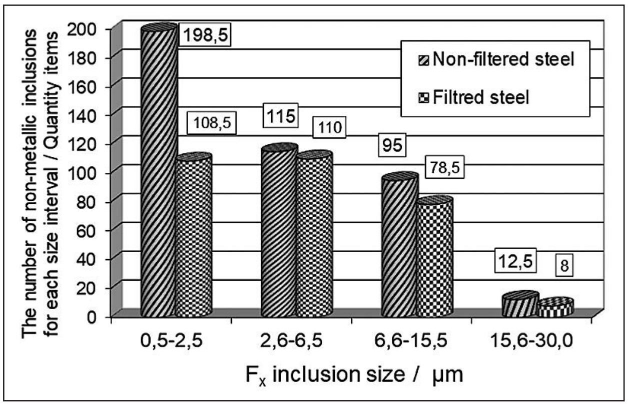


**Figure 2** The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion number variation $h_{NMI}$, with division into inclusion size intervals according to $F_x$ Feret diameters.

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In the analysis of steel purity, a microanalysis of the chemical composition of the analyzed non-metallic cavities present in the obsolete steel samples was also performed (Figure 4). The research was carried out on the HITACHI S-3500N scanning electron microscope. The chemical composition of the identified dispersion phase corresponds to the applied technology of deoxidation of steel with aluminum. This is confirmed by the X-ray spectrum with energy dispersion (EDS) of the identified non-metallic phase in Figure 5.

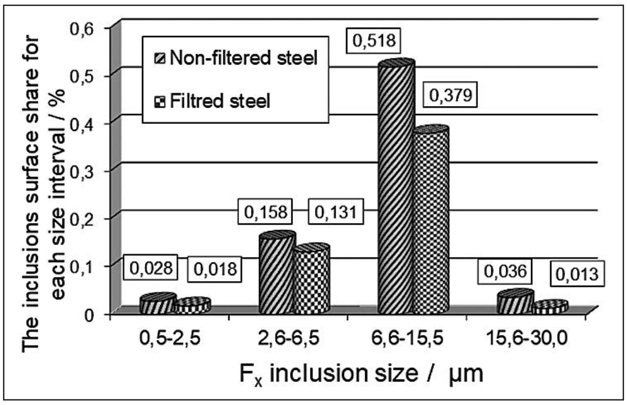


**Figure 3** The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share $h_{NMI}$, with division into inclusion size intervals according to $F_x$ Feret diameters.

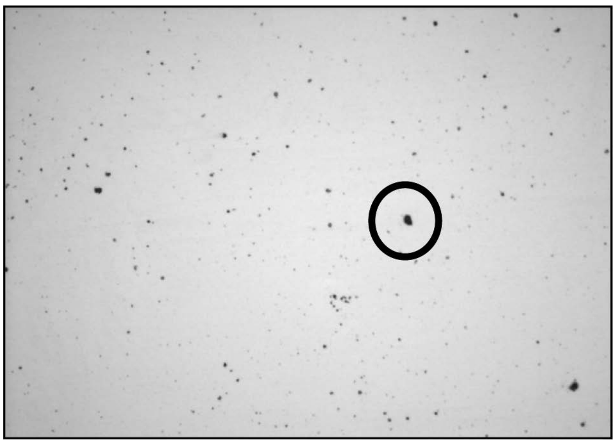

**Figure 4** The microstructure of the tested steel, magnification 500x

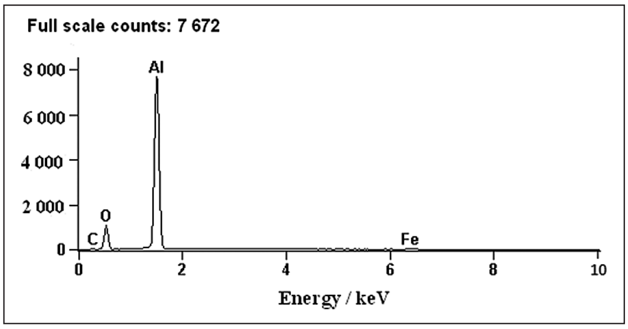


**Figure 5** X-ray photograph of non-metallic inclusions chemical composition identified on the surface of a ceramic filter and in steel volume from melt – P250GH steel.

## SUMMARY AND CONCLUSIONS

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. Based on the research and analysis of the impact of the steel filtration process during its casting carried out so far, the following conclusions can be presented:

- In unfiltered and filtered steel, the largest number of non-metallic inclusions are the small ones with a cross-sectional area of 0,04 $\mu m^2$. A small percentage in unfiltered steel are the largest inclusions with a cross-sectional area of about 34 $\mu m^2$. While in filtered steel they amount to approximately 31 $\mu m^2$,
- the average cross-sectional area of the tested non-metallic inclusions amounts to 0.69 $\mu m^2$ for unfiltered steel and 0,67 $\mu m^2$ for filtered steel, respectively,
- the total surface fraction of the non-metallic inclusions phase in the analyzed samples of unfiltered steel amounts to 0,740 %, and of filtered steel 0,547 %,
- The effectiveness of the filtration process, measured by the change in the surface fraction, amounted to 26,08 %, while the change in the number of non-metallic inclusions amounted to 23,50 %.

The presented research results are the next planned and successfully implemented stage of experiments on the issues of metallurgical cleanliness of steel. They al-low to conclude that filtration of liquid steel with ceramic filters may in the near future become an effective and cheap method of refining it from non-metallic inclusions - products of its deoxidation reaction.

## Acknowledgements

The research was carried out as part of the research work BK-230/RM2/2021 (11/020/BK_21/0080).

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**Note:** The responsible translator for English language is M. Mitas, Katowice, Poland.