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# Evaluating the effectiveness of heat-resistant cast steel filtration from the results of structure examinations

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## Abstract

Filtration guarantees castings characterised by high quality and free from any non-metallic inclusions, which are formed at the stage of melting and pouring of liquid metal.
This article discusses the problem of the effectiveness of filtration process taking as an example heat-resistant cast steel poured into ceramic moulds. In investigations, foamed zircon filters made by FerroTerm Sp. z o.o. Łódź, Poland, were used.
The effectiveness of filtration was described and examined using the results of metallographic examinations, including macro- and micro-structure examinations of metal and of cast metal/ceramic filter interface, and measurements of the content of non-metallic inclusions.
The methods of investigations were presented, the obtained results were described, and relevant conclusions were drawn, all of them unmistakably indicating a very beneficial effect that filtration has on molten metal quality.

**Keywords:** Innovative casting materials and technologies, cast steel, filtration of molten metal, ceramic filters, structural examinations, non-metallic inclusions.

## 1. Introduction

Filtration of molten metal through foamed ceramic filters is nowadays a standard industrial procedure in casting manufacture. The costs of this operation are in excess compensated by the reduced level of rejects and definitely improved casting quality. The applied filters are characterised by a specific constitution (structure, shape, porosity, dimensions) and chemical composition. This unique constitution (structure) of the filter is due to its surface development. In its design, the filter is composed of a system of continuous and sinuous pores, the presence of which renders a ceramic product characterised by low density, high permeability, and porosity [1,2].

As regards the size of filter pores and of non-metallic inclusions, the following types of filtration are distinguished:

- external (surface-type) filtration, in which all particles of a diameter larger than the holes of a filter are retained on the filter face, forming a „filtration cake”; this mechanism operates in filters of all types;
- internal (deep type) filtration, which consists in absorption of non-metallic particles by the walls of internal channels and penetration into filter pores and capillaries.

Internal filtration is typical of foamed filters and makes them more effective than filters of other types.

The genuine process of internal filtration is composed of two stages, i.e. transport of particles towards filter walls and their adhesion to these walls [4,5].

The transport of inclusions in molten metal depends, first of all, on the metal stream flow rate, on the size and density of particles, and finally, on the diameter of pores and their shape intricacy. When the density of the particles of impurities is lower than the density of molten metal, they are carried by the forces of hydrostatic lift.

Particles adhesion to a filter can be explained by the wettability process which takes place between the liquid metal and filter wall, and between the liquid metal and the particle of impurity.

The effectiveness of filtration process is demonstrated, first of all, by the properties of cast metal and, in practice, its evaluation consists in description of the metal structure and of the structure of cast metal/ceramic filter interface, in determination of the mechanical properties and changes in the chemical composition of metal [3].

The authors of the present study investigated the effectiveness of filtration process examining the changes which take place in the structure of a chosen metallic material (in this case - heat-resistant cast steel).

## 2. Methods of investigation

A method to evaluate the effectiveness of filtration process are structure examinations, including:

- measurement of the content of non-metallic inclusions in cast metal;
- examinations of macro- and microstructure of the cast metal;
- examinations of microstructure at the cast metal/ceramic filter interface [1,4];

Comparing the results of the above described measurements and observations made for a metallic material cast without and with filtration (under the same conditions), one can describe visually or numerically changes proceeding in the structure, and basing on thus obtained results determine the effectiveness of liquid metal filtration.

In the studies described in this article, the following method has been adopted: in ceramic moulds made by the investment process, metal specimens were cast according to two technological variants, i.e. with filter and without. The specimens were bars of a round cross-section and dimensions Φ 15 x 200 mm (six pieces were placed in each mould). The foamed ceramic filter was placed at the lower level of a gating system (Fig.1).

Fig. 1 Ceramic filter placed in mould –the appearance after metal flow.

Tests were made on heat-resistant cast steel, type GXSOCrNi264, of the following chemical composition C = 0,35÷0,50%; Si = 1,0÷2,5%; Mn = max 1,5%; P = max 0,035%; S = max 0,030%; Cr = 24÷28%; Ni = 3,5÷5,5%.
Specimens for tests were taken from a selected (and identical for all specimens) area of the cast bar.

The casting process parameters were as follows:

- ceramic mould temperature – 800÷850°C;
- liquid metal temperature – 1560±10°C;
- metal volume in mould – 16kg;
- filter – ϕ85x25mm;
- filter porosity – 15ppi;

Tests were made on foamed zircon filters made by FerroTerm Sp. z o.o. Łódź, Poland.

## 3. Examination of non-metallic inclusions

For the measurement of non-metallic inclusions a method consistent with ASTM E1245-03 was applied. Microscopic observations and measurements of non-metallic inclusions were made on a Metaplan 2 metallographic microscope and Quantimet 570color image analyser using unetched, polished metallographic specimens. To complete the results of the measurements, mean value and standard deviation were calculated for the perimeter area and inclusions number.

The results of the investigations in the form of numerical data are plotted in Table 1 and in Figures 2÷7, where the descriptive parameters of inclusions (surface, perimeter, number) are plotted in various relations; the photographs of microstructures are shown in Figures 8÷9.

Table 1.
Parameters describing the non-metallic inclusions

| Casting conditions | Results of measurements | | | | | |
|---|---|---|---|---|---|---|
| | Area [%] | | Perimeter [$mm/mm^2$] | | Number [$1/mm^2$] | |
| | mean | devia-tion | mean | devia-tion | mean | devia-tion |
| without filtration | 0,320 | 0,256 | 6,135 | 2,949 | 1047984 | 455258 |
| filter 15ppi | 0,22 | 0,206 | 4,097 | 2,039 | 673006 | 262424 |

The above presented results confirm the effectiveness of filtration, which in this case is described by the number and size of non-metallic inclusions present in the cast material.

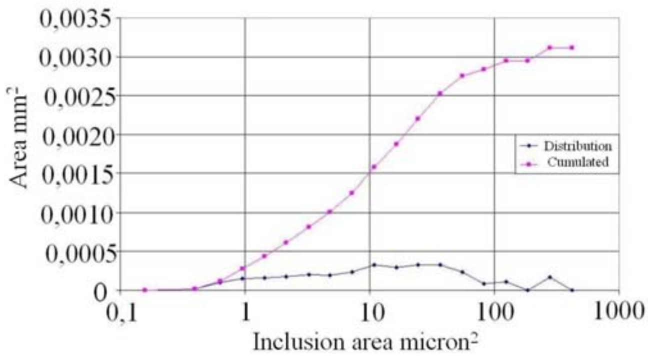


Fig.2. Parameters describing inclusions – area– non-filtered sample.

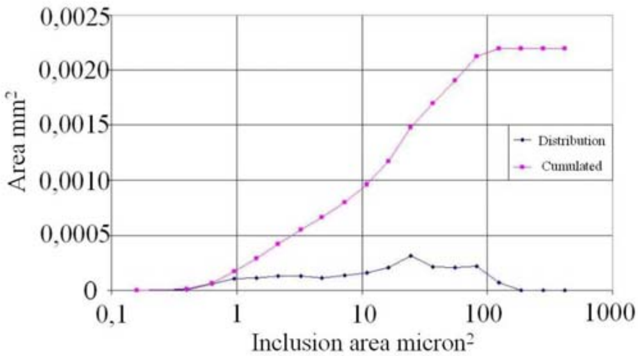


Fig.3. Parameters describing inclusions – area– filtered sample.

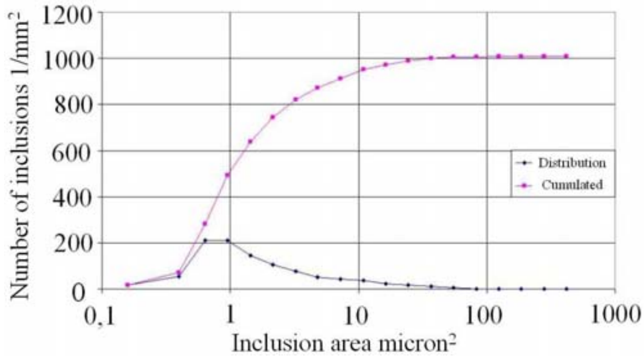


Fig.4. Parameters describing inclusions – number– non-filtered sample.

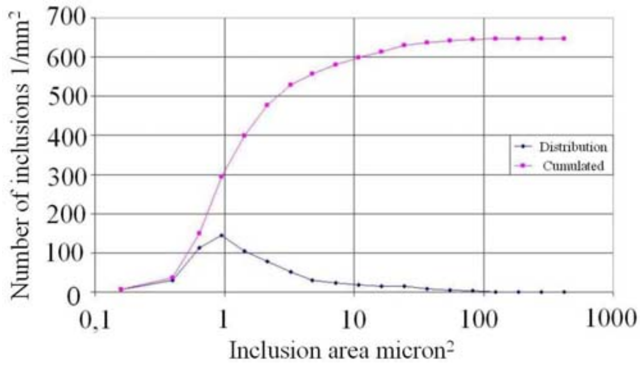


Fig.5. Parameters describing inclusions – number– filtered sample.

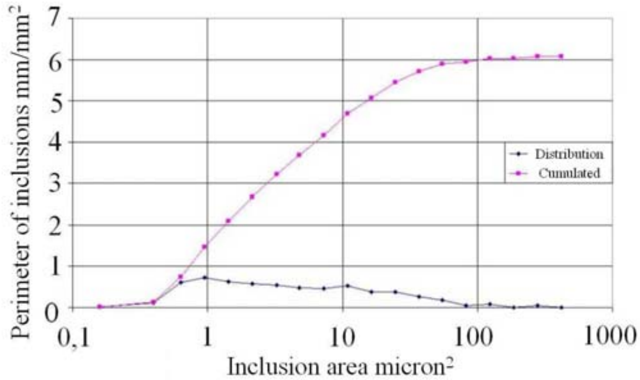


Fig.6. Parameters describing inclusions – perimeter– non-filtered sample.

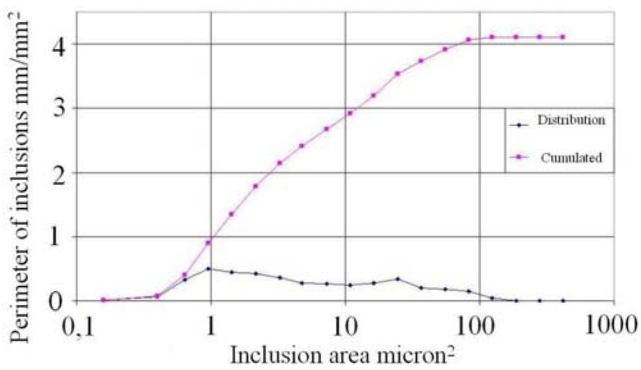


Fig.7. Parameters describing inclusions – perimeter– filtered sample.

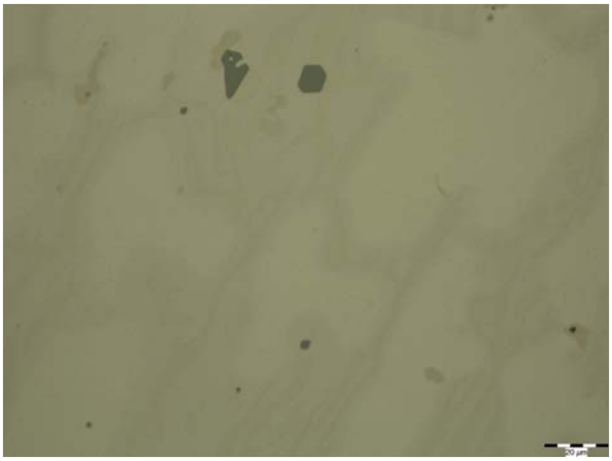

Fig.8. Microstructure of non-filtered sample. Unetched section; 500x.

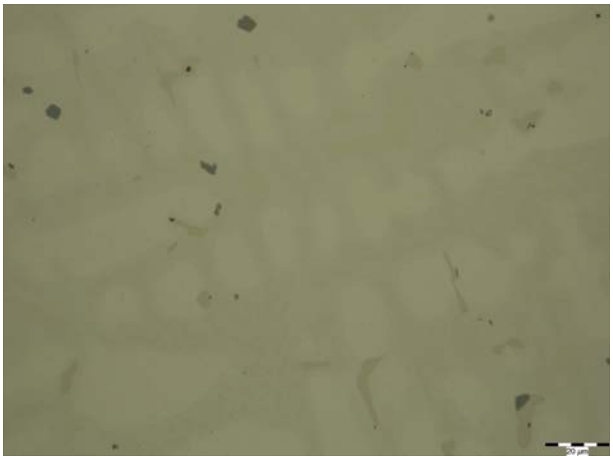

Fig.9. Microstructure of filtered sample. Unetched section; 500x.

American literature [4] states a parameter which describes the effectiveness of filtration. This is the, so called, filtering efficiency factor calculated according to the following equation:

$$E = \frac{A_u - A_f}{A_u} \cdot 100[\%] \qquad (1)$$

where:

E – filtering efficiency factor [%];

$A_u$ – oxides area on the surface of non-filtered sample [$cm^2/kg$];

$A_f$ – oxides area on the surface of filtered sample [$cm^2/kg$];

# 4. Structural examinations

Structural examinations (observations under the microscope and photographs) were carried out under a metallographic NEOPHOT 32 microscope, using polished metallographic specimens etched in LBI reagent. The LBI reagent colours austenite, leaving ferrite and carbides uncoloured.

Figures 10÷11 show microstructures obtained after the filtration process; in contrast, Figures 12÷13 show the same microstructures before filtration.

From the micrographs it clearly follows that filtration refines the structure of metallic material.

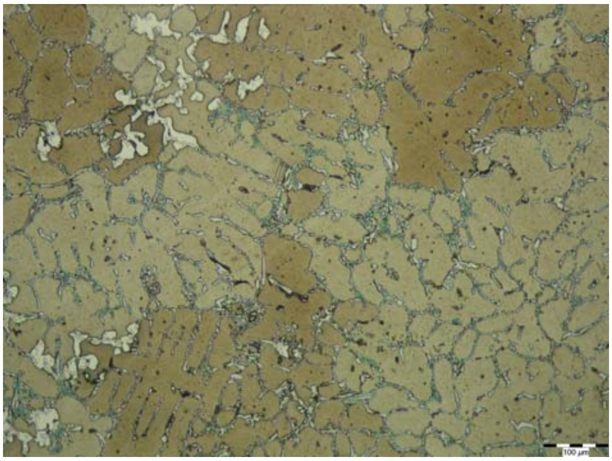

Fig.10. Microstructure of filtered sample - metallic matrix; polished section etched in LBI, .100x.

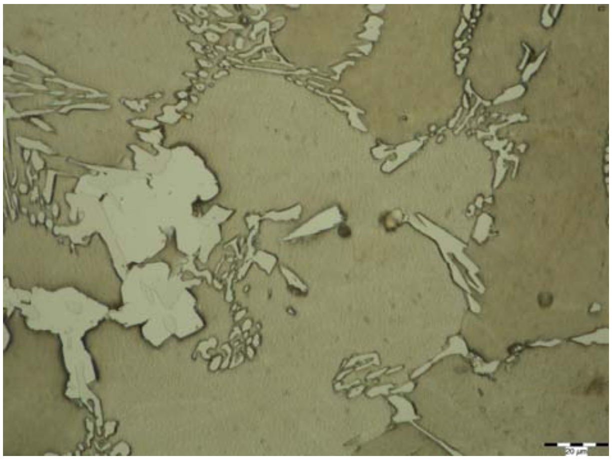

Fig.11. Microstructure of filtered sample - metallic matrix; polished section etched in LBI, .500x.

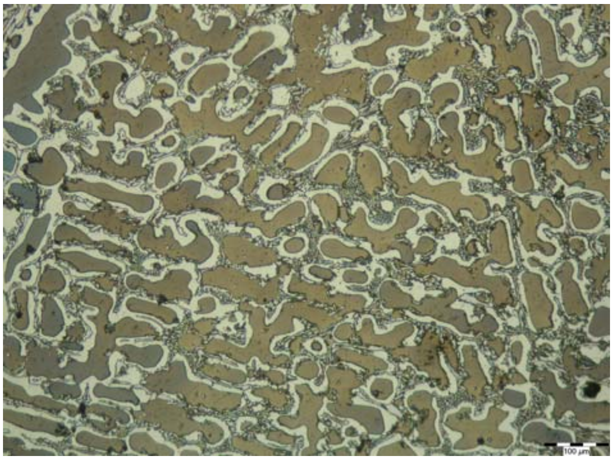

Fig.12. Microstructure of non-filtered sample - metallic matrix; polished section etched in LBI, 100x.

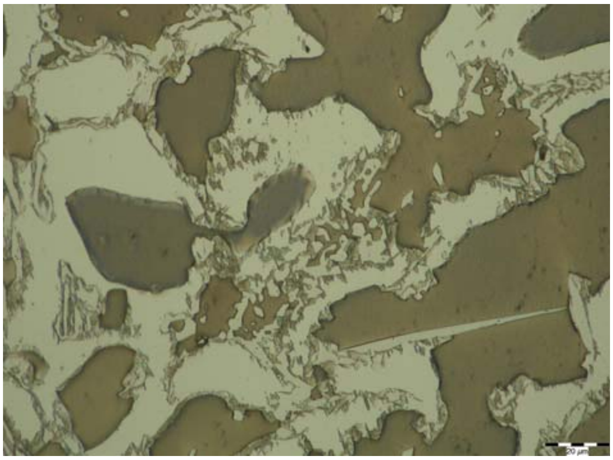

Fig.13. Microstructure of non-filtered sample - metallic matrix; polished section etched in LBI, 500x.

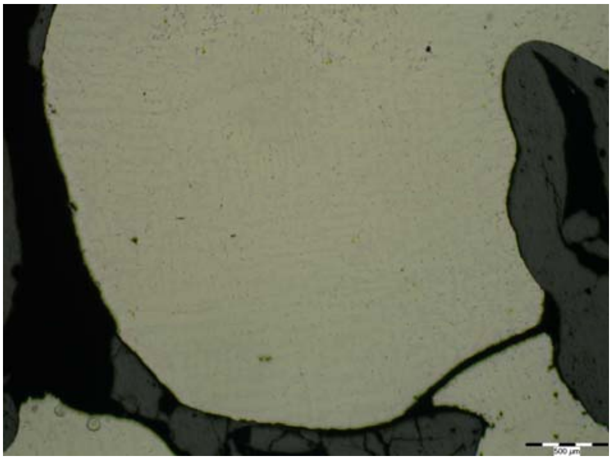

Fig.14. Cast metal/ceramic filter interface; unetched polished section, 25x.

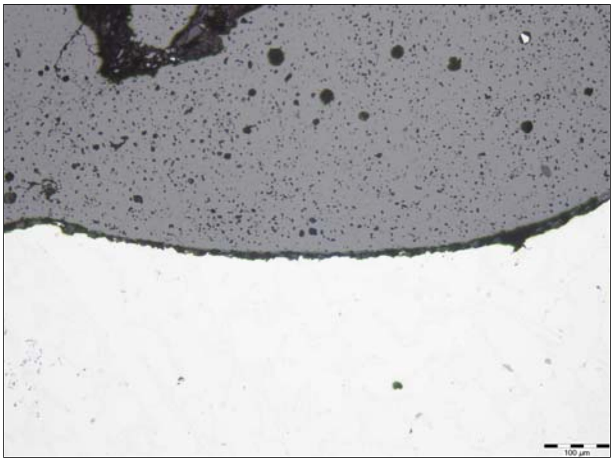

Fig.15. Cast metal/ceramic filter interface; unetched polished section; 100x.

Irrespective of the investigations carried out and described above, observations and metallographic examinations were also made at the cast metal/ceramic filter interface. The results are shown in Figures 14÷15.

The obtained results indicate the effect of adhesion, further confirmed by the presence of intermediate phases (non-metallic inclusions) at the cast metal/ceramic filter interface.

# 5. Conclusions

The described methods of investigation as well as the obtained results confirm the possibility of evaluation of the effectiveness of filtration process through structure examinations. The proposed method of the measurement of non-metallic inclusions, used for the first time in this field of investigations, describes in an adequate way the effectiveness of filtration (Figs. 2÷7).

Besides these investigations, the conducted examinations of microstructure have proved that during filtration:

- a refinement of the cast metal structure occurs;
- the effect of absorption of the non-metallic particles occurs at the cast metal/ ceramic filter interface, thus proving that the filtration process is of an internal character (penetration of inclusions into the filter walls);

The authors of the present study are carrying out further investigations to trace changes in the mechanical and chemical properties (the content of $O_2$) of cast metal subjected to filtration. Combining the complete results of all the investigations with their full assessment is expected to give a consistent determination of the effectiveness of filtration process.

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