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Cast Steel Filtration Trials Using Ceramic-Carbon Filters

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Abstract

Trials of cast steel filtration using two types of newly-developed foam filters in which carbon was the phase binding ceramic particles have been conducted. In one of the filters the source of carbon was flake graphite and coal-tar pitch, while in the other one graphite was replaced by a cheaper carbon precursor. The newly-developed filters are fired at 1000°C, i.e. at a much lower temperature than the currently applied ZrO_2-based filters. During filtration trials the filters were subjected to the attack of a flowing metal stream having a temperature of 1650°C for 30 seconds.
Characteristic of the filters' properties before and after the filtration trial were done. It was found, that the surface reaction of the filter walls with molten metal, which resulted in local changes of the microstructure and phase composition, did not affect on expected filter lifetime and filtration did not cause secondary contamination of cast steel.

Keywords: Molten metals' filtration, Foam filter, Microstructure

1. Introduction

The growing requirements regarding the metallurgical purity of cast steel, especially the one intended for use in constructional elements and parts of machines exposed to dynamic loads, forced the producers to modify the casting technology. One of the methods of cleaning and, in consequence, improving the quality of cast steel, is filtrating it through ceramic foam filters. This process enables removing impurities from liquid metal in the form of non-metallic inclusions and, additionally, ensures a stable, laminar flow of the metal stream through the filter. This reduces the risk of its secondary aeration, which results in the worsening of its properties [1, 2].

In the process of cast steel filtration the filters are exposed to the attack of high temperature (1600÷1650°C) and a large mass of the filtrated metal. Therefore, the efficiency of filtration and its failure-free course depend not only on the filter's ability to arrest non-metallic particles, but also on temperature shock resistance, corrosion due to cast steel effect as well as erosion caused by metal flowing through the inside of the filter.

Ceramic foam filters are produced from a number of ceramic materials, the composition of which depends on the type of metal subjected to filtration. For cast steel ZrO_2-based filters are currently applied. In the case of big and heavy casts, requiring a longer casting time, due to excessively fast cooling of the melt in the filter channels, it is frequently partially or completely blocked. This results in a decreased efficiency of filtration and, in extreme cases, may lead to the casting process stoppage. Avoiding this type of problems with the currently applied filters requires the temperature to be considerably increased before casting, which involves an additional energy expenditure. For this reason investigations were launched in order to develop a new type of filters, which , similarly to the currently used ZrO_2-based filters, should be characterised by high thermal shock resistance, resistance to the corrosive effect of metal melts, mechanical strength at high temperatures and effectiveness of the filtration process. The new filters should also have the following features: a lower mass resulting from the application of a lower density material, which should have a positive impact on the filters' thermal properties, high thermal conductivity and a possibility of firing the material at a lower temperature (ZrO_2-based filters need to be fired at a temperature of ca 1750^{o}C). This will allow the filters production costs to be considerably reduced (lower consumption of fuel gas and furnace heating elements).

To achieve the designed properties of the new filters, carbon, which is a phase binding ceramic particles, was introduced in their composition. This choice is justified by the beneficial properties of this element. Compared to other materials, carbon is characterised by high refractoriness (in an oxygen-free atmosphere) and thermal conductivity, which results in high thermal shock resistance [3].

The applied method for obtaining the filters involved impregnation of polymer foam with an appropriately prepared ceramic suspension in such a way that it covered only the flexible bridges surrounding the pores in the foam. So prepared foams are subjected to thermal treatment, during which the organic skeleton is fired and the coating ceramic material is sintered [4].

In the first stage of investigations, the results of which were published ~~in 2013~~ [5], raw materials for the new kind of filters were selected as well as the composition of suspensions for coating the foam organic matrix and thermal treatment conditions were determined. In this article the results of cast steel filtration trials using the newly-developed filters have been presented.

2. Methodology

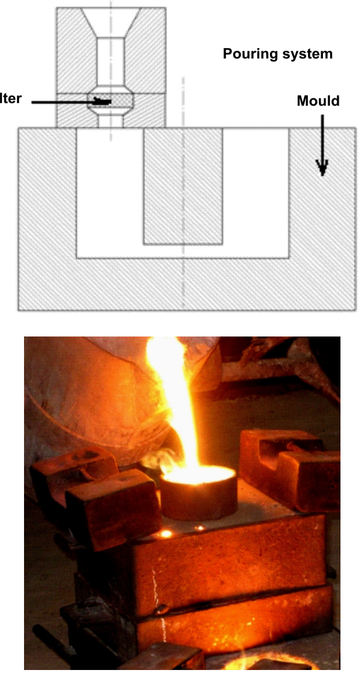
Trials were conducted for filters made from a suspension containing alumina, flake graphite and coal-tar pitch. Silica sol water suspension with an addition of sodium lignosulfonate, playing the role of a liquefier, was used as a binder. The suspension was applied on the polymer carrier characterised by 10 ppi porosity in a form of 75x (×)75(x)20mm shapes. After drying, the foams were fired at 1000^{o}C, in a nitrogen atmosphere. Trials were also carried out for filters in which graphite was replaced by another, cheaper carbon precursor. In the further part of the description both types of ceramic-carbon filters were marked with symbols A and Z respectively.

The conducted trials involved passing the cast steel having a temperature of 1600^{o}C through the filters. The cast steel was poured into moulds through a filter located at a height of ca 50cm from the mould (Fig. 1). The amount of the filtrated metal each time reached 50 kg, and the time of its flowing through the filter was approximately 30 s. The full description of this trial is presented in article [6].

Before the trial, the filters' basic properties were determined: apparent density, open porosity, compressive strength and chemical composition by X-ray fluorescent spectroscopy (XRF) and qualitative phase composition by XRD. Also investigations into the microstructure of ceramic-carbon filters were carried out, using microsections embedded in epoxide resin, observed in reflected light in an optical microscope. The characteristics of the filters after the trial included determination of their qualitative phase composition and microstructural analysis. Microstructural analysis, chemical composition (by means of mass spectrometry) and measurement of oxygen and nitrogen concentration (using Leco analyzer) in samples of cast steel prior to and after filtration were also performed.

3. Results and discussion

There are no significant differences in the basic physical and chemical properties of the newly-developed ceramic-carbon filters (Tab. 1). Commercial ZrO_2-based filters do not differ from carbon-ceramic filters with regard to open porosity (33.5%) and compressive strength (1.4 MPa), whereas their apparent density (3.75 g/cm^3) is twice higher than that determined for filters A and Z.



a)

b)

Fig. 1. A workstation for examining the process of filtration: a) diagram; b) view of field trial

Differences between filters A and Z, resulting from the application of different carbon raw materials for their obtaining, are revealed in their microstructure (Fig. 2). In both cases irregular concentrations of carbon substance, filling the inside of closed pores, were observed. In filters Z these concentrations were finer and more scattered. Locally, also pyrolytic graphite concentrations were observed inside the closed pores or on the walls of open pores. The microstructure of filter A also contained flakes of graphite. The filter matrix was microcrystalline and amorphous.

After conducting a filtration trial and cutting the inlet system it was found that the tested filters had not been damaged (Fig. 3). In the places where the internal walls contacted the solidified metal, the microstructure of filters (Fig. 4) contained a porous reaction zone, formed as a result of the melt reaction with the filter surface. The thickness of this zone was changeable, reaching 100÷400 μm for filter A and 50÷200 μm for filter Z. In this zone a glassy phase, corundum inclusions (α-Al_2O_3), metal concentration drops and $MgO \cdot Al_2O_3$ spinels were observed. The contact area between the reaction zone and material on the edges of filter Z contained numerous open pores.

Table 1.
Basic physical and chemical properties of filters before and after the cast steel filtration trial

Determination	Unit	Ceramic-carbon filters A	Ceramic-carbon filters Z
Apparent density	g/cm^3	1.47	1.51
Open porosity	%	32.1	31.2
Compressive strength	MPa	1.3	1.1
Basic components content:			
ignition loss	%	36.81	34.98
SiO_2	%	18.41	16.57
Al_2O_3	%	43.33	47.14
Fe_2O_3	%	0.20	0.21
CaO	%	0.11	0.04
MgO	%	0.13	0.15
Phase composition	before filtration trial	α-Al_2O_3 corundum graphite amorphous phase	
	after filtration trial	corundum MA spinel quartz graphite amorphous phase	corundum graphite quartz amorphous phase

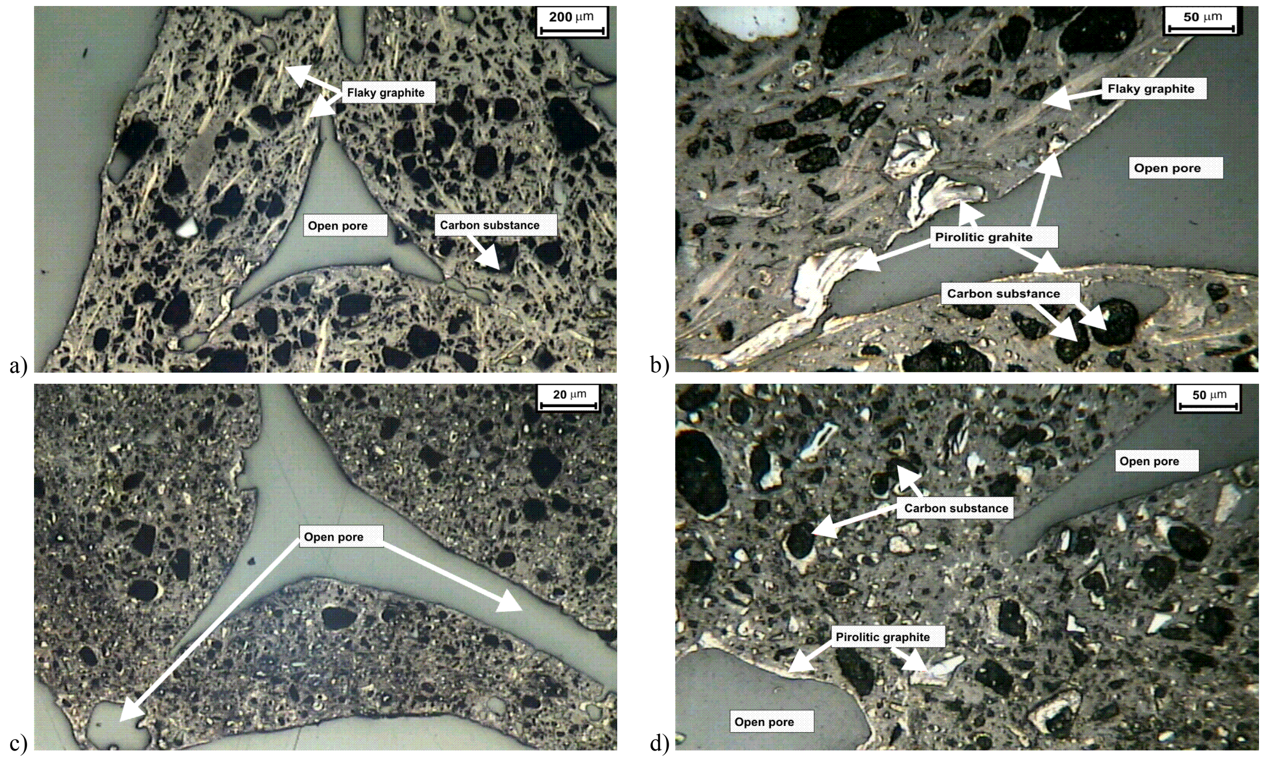


Fig. 2. Microstructure of the cross-section of a filter's wall before cast steel filtration trial: a) and b) in filter A, c) and d) in filter Z

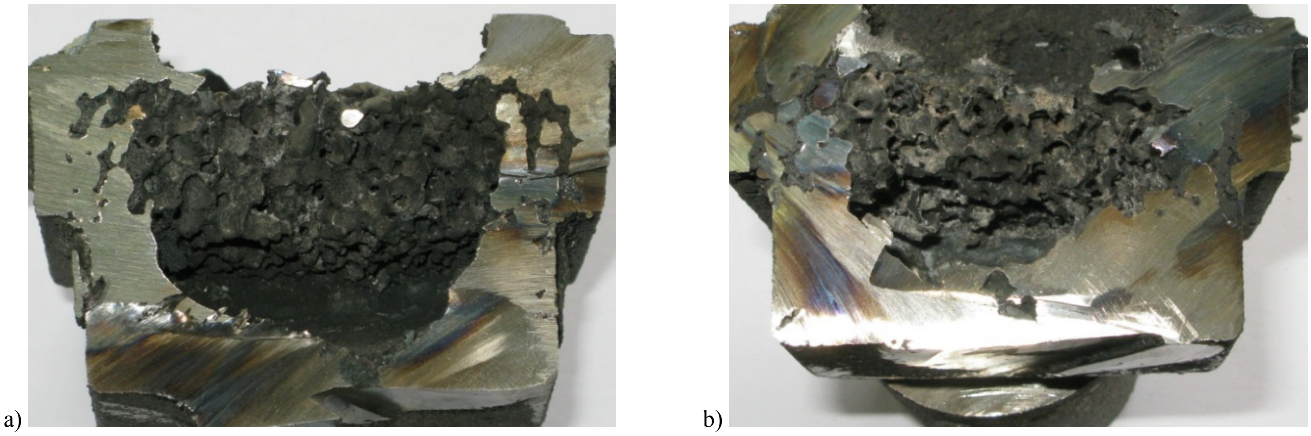


Fig. 3. Images of inlet system after filtration trial with: a) filter A; b) filter Z

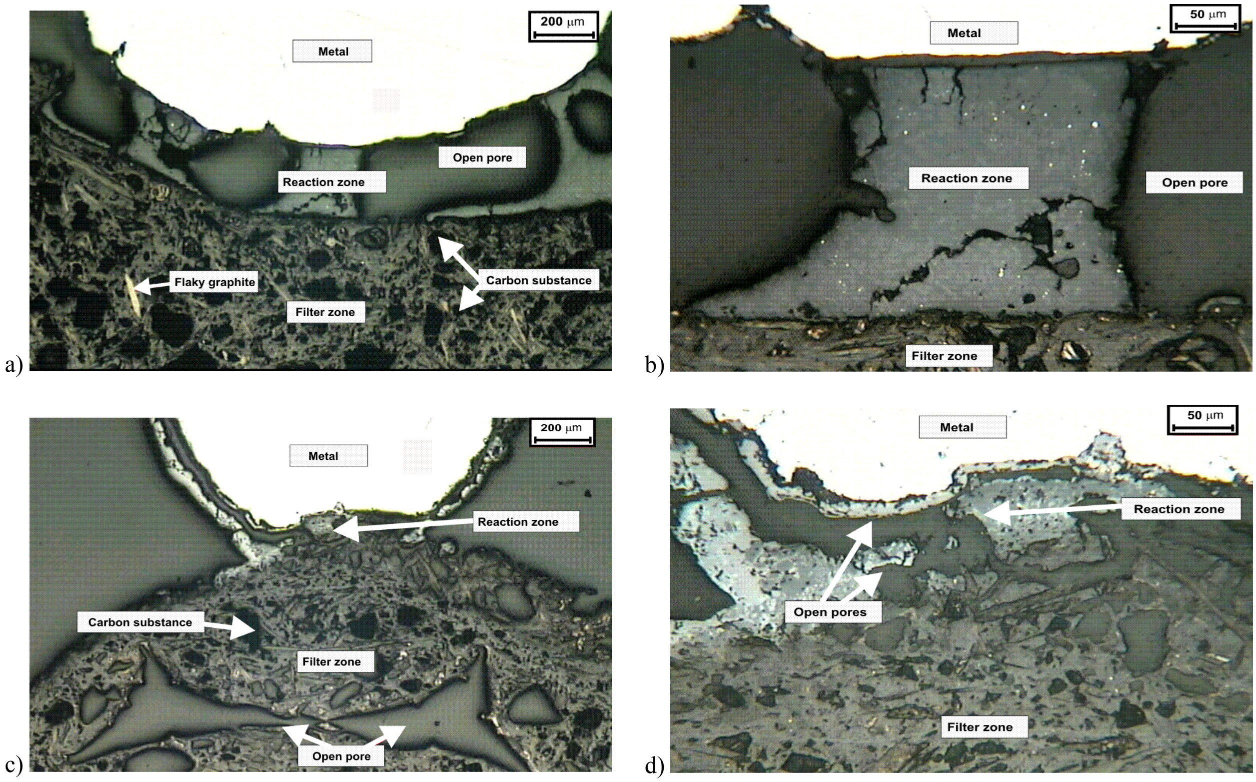


Fig. 4. Microstructure of the cross-section of a filter's wall after a cast steel filtration trial: a) and b) in filter A, c) and d) in filter Z

Table 2.
Chemical composition of cast steel before and after filtration

Element [%] / Cast steel	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V	W	Ti	Al	Sn
before filtration	0.12	0.42	0.56	0.011	0.003	0.14	0.11	0.02	0.14	0.004	0.01	0.001	0.055	0.004
after filtration through the filter A	0.17	0.40	0.57	0.014	0.007	0.14	0.11	0.02	0.15	0.003	0.01	0.001	0.052	0.006
after filtration through the filter Z	0.14	0.40	0.54	0.011	0.006	0.14	0.11	0.02	0.14	0.003	0.01	0.001	0.045	0.004

The area of contact between the molten cast steel and the wall of filter A were characterized by sharp boundaries. No changes were observed in areas located far from the surface in the microstructure of both filters compared to the microstructure of the sample before service.

The microstructural investigations indicate that during the process of filtration a surface reaction of the filter walls with molten metal takes place. This reaction results in the formation of a thin layer, differing in its microstructure and phase composition. Changes on the filter surface did not influence the course of the filtration process. The filters were not damaged and the chemical composition of the filtrated cast steel did not change (Table 2). Microstructural analysis (Fig. 5) and measured oxygen and nitrogen content in cast steel before and after filtration (Table 3) prove that the amount of nonmetalic inclusions in cast steel decreased as a result of filtration.

Table 3.
Oxygen and nitrogen concentration in the cast steel before and after filtration

Cast steel	Oxygen [%]	Nitrogen [%]
before filtration	0.0358	0.0159
after filtration through the filter A	0.0354	0.0150
after filtration through the filter Z	0.0103	0.0102

4. Summary

Trials of cast steel filtration using two types of newly-developed foam filters in which carbon is the phase binding ceramic particles have been conducted. In one of the filters the source of carbon was flake graphite and coal-tar pitch, while in the other one graphite was replaced by a cheaper carbon precursor. The newly-developed filters are fired at 1000°C, i.e. at a much lower temperature than the currently applied ZrO_2-based filters.

During filtration the filters were subjected to the attack of a flowing metal stream having a temperature of 1650°C for 30 seconds. On the basis of physical and chemical characteristics and an analysis of the filters' microstructure before and after the filtration trial the following were found:

1. Trials of filtration using the newly-developed filters were completed with a positive result. The filters were not damaged during the process, which proves their real resistance to high temperature and ferrostatic pressure of a liquid metal stream.
2. The surface reaction of the filter walls with molten metal, which results in local changes of the microstructure and phase composition, did not affect on expected filter lifetime an adverse effect on the filters' mechanical properties.
3. Filtration does not cause secondary contamination of cast steel.

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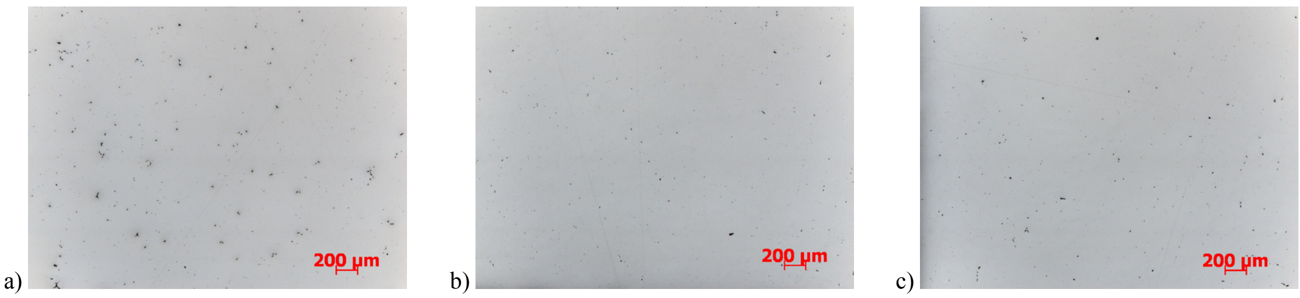

Fig. 5. Microstructure of cast steel (unetched polish section): a) before filtration; b) after filtration (filter A); c) after filtration (filter Z)

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