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Ceramic-Carbon Filters for Molten Metal Alloys Filtration

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Abstract

In 2014 we finished research works involved in the development of a technology for manufacturing innovative ceramic-carbon foam filters for molten metal alloys filtration, which were financed by the National Centre for Research and Development (NCBiR) from INNOTECH programme resources. A batch of the filters produced in this technology was tested in practice in domestic cast steel and cast iron foundries. The trials were successful and foundries declared their intention to purchase the newly-developed filters for the current production of casts. This provided an incentive for "Ferro-Term" Sp. z o.o. to start design works on the prototype line for a serial production of these filters. At the same time, in co-operation with a scientific consortium, including the co-authors of the technology, i.e. the Institute of Ceramics and Building Materials, Refractory Materials Division in Gliwice, Institute for the Chemical Processing of Coal in Zabrze and Foundry Research Institute in Cracow, the company made a successful attempt to raise some funds for the necessary adaptation of the developed technology from the semi-technical to industrial scale from Intelligent Development Operational Programme. In the article we have presented information on the effects of works performed within the framework of the project entitled "Modernization and adaptation of the existing technological line for purposes related to technology verification and start-up of the production of innovative ceramic-carbon filters for molten metal alloy filtration".

Keywords: Innovative foundry technologies and materials, Molten metals filtration, Foam filter, Technological line

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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, reducing the turbulence of the melt flow. Under laminar flow the risks of metal re-oxidation and cavity formation are diminished. 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].

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 usually applied. They are characterised by high thermal shock resistance, resistance to the corrosive effect of metal melts and mechanical strength at high temperatures. But sometimes, when these filters are used to get a big and heavy casts, requiring longer casting time, due to excessively fast cooling of the metal in the filter, solidification of the alloy in the filter canals is observed. This phenomenon can be prevented by increasing the alloy temperature (in the case of melting high-grade iron alloys with a high content of chrome and nickel, the temperature of mould filling is nearly 1700°C). However, this process is not economical and, additionally, it has an adverse effect on the thermomechanical properties of filters, causing their cracking or deformation.

To resolve this problem new type of filters was developed [3, 4]. These are carbon-bonded (Al_2O_3-C) filters. Recently they are gaining significant importance mainly motivated by their excellent thermal-shock and creep resistance. Additionally these filters, because of presence of carbon, compared to ZrO_2-based filters, characterise a lower density and, at the same time, lower thermal capacity, thus limiting the cooling of the alloy during filtration. Carbon-bonded filters produced by different firms like „Foseco" and „Lanik" exist on European market. It is known that in various centres research on this type of filters is still being carried out too [5-9]. Also in Poland such research has been undertaken.

In the years 2012-2014 „Ferro-Term" Sp. z o.o., the only Polish producer of ceramic filters for foundry industry, in co-operation with the Institute of Ceramics and Building Materials, Institute for the Chemical Processing of Coal and Foundry Research Institute, conducted investigations within the framework of the project financed by the National Centre for Research and Development from EU funds, and implemented under INNOTECH programme (the title of the project: "Innovative ceramic-carbon filters for molten metal alloys filtration"). They resulted in developing a technology for manufacturing a new generation of foam filters for molten metal alloys filtration, in particular high-grade alloy cast steels, based on own idea [10].

A characteristic feature of the newly developed filters is the presence of carbon, which, compared to ZrO_2-based filters, decreased the filter material density form approximately 3.5 g/cm^3 to ca 1.5 g/cm^3, and, at the same time, reduced its thermal capacity, thus limiting the cooling of the alloy during filtration.

The new type of filter was obtained by a well-known method [11], which involves coating the elastic polymer foam with appropriately prepared ceramic suspension in such a way that it covers only the elastic bridges surrounding the foam pores. So obtained foams are subjected to thermal treatment, during which the organic skeleton is fired and the coating ceramic material is sintered. Carbon is added to new filters in the form of caking coal - a novelty in the production of filters - with an addition of pitch characterized by a low emission of harmful polycyclic aromatic hydrocarbons. In the process of mix heating, the caking coke initially reaches a plastic state level, coats and sticks the ceramic components' grains, and, next, as the temperature increases, it gets sintered, forming a ceramic-carbon material [10].

The newly developed filters have been subjected to casting trials in both laboratory and industrial conditions. They were tested in mould gating systems that allow making 50-70-kg casts. The obtained results confirmed [12] the filters' high resistance to thermal shock and to the erosive effect of molten metal alloys as well as their mechanical strength at high temperatures and high effectiveness. The obtained results confirmed the rationality of starting a serial production of ceramic-carbon filters.

In the year 2016 „Ferro-Term" Sp. z o.o., in co-operation with a scientific consortium, including the co-authors of the technology, obtained a part of resources for modernizing its technological line and adapting the developed technology from the semi-technical scale to the industrial one from Intelligent Development Operational Programme.

The results presented and discussed in the article provided information on the effect of works performed within the framework of the project "Modernization and adaptation of the existing technological line for the purposes related to technology verification and start-up of the production of innovative ceramic-carbon filters for molten metal alloys filtration".

2. Methodology

In the first stage of the project the process of adding the caking coal to the slurry was optimized. Also the mass balance of the filter sintering process was prepared and its side products were characterized [13].

The conducted investigations provided data for designing a new industrial vacuum furnace for firing filters in an oxygen-free atmosphere and a device for disposing the volatile substances released in the process of firing, which are integral elements of the industrial line for the production of filters in the modified technology.

The first batches of filters produced on this line were subjected to tests in both laboratory and industrial conditions.

Trials in laboratory conditions were conducted at an experimental workstation in the Foundry Research Institute in Cracow. They involved passing a specified portion of molten metal through the tested filters from a height of approximately 50 cm. The dimensions of the filters subjected to tests were 75 x 75 x 22 mm. L450 and LCC cast steel was applied. In each of the trials, the molten metal mass was 60 kg, and its temperature reached 1650±10°C. To evaluate the effectiveness of filtration through the tested filters, samples of metal taken before and after the filter were subjected to tests, which included determination of the chemical composition using mass spectrometry. Additionally, 60 kg of LCC cast steel was passed through the filter in the gating system, so as to check whether the carbon material, which is one of the main components of the tested filters, does not penetrate into the filtered metal. After solidification of the metal, its samples were taken from the area over and under the filter and subjected to analysis in terms of carbon and sulphur contents, using a CS-600 analyser and oxygen and nitrogen contents, using a LECO analyser. The samples were also subjected to microstructural analysis.

Some of the trials in industrial conditions were carried out in a foundry belonging to „Ferro-Term" Sp. z o.o. They included the manufacture of 73 pcs of casts from carbon, low-alloy and high-alloy cast steels) having a mass of 16-145 kg, using round filters with a diameter ϕ = 50 ÷ 90 mm. In another foundry, which agreed to carry out tests, trials of manufacturing higher mass casts were conducted. The dimensions of the square filters applied were 100 x 100 x 22 mm. Six pieces of casts having a mass of 300, 1600 and 1700 kg (the number of filters per mould: 1 for 300-kg pieces and 4 for pieces having a mass of more than 1000 kg) were made from cast iron and cast steel. In the case of casts with a mass reaching 300 kg, the alloy was passed through one filter, and in the remaining cases – through a system composed of four filters. The mould filling temperature for cast iron was 1360°C, and for cast steel - 1500 ÷ 1600°C.

The list/characteristics of the trials has been presented in Table 1.

3. Results

During investigations conducted at the experimental workstation, the molten metal was not observed to cause any damage to the filters' structure. After filtration, the chemical composition of cast steels did not change (Table 2). The concentration of carbon in the process of LLC cast steel filtration did not increase in a significant way (Table 3), but the number of non-metallic inclusions was considerably reduced (Fig. 1).

All the trials involving application of ceramic-carbon filters in industrial conditions went smoothly. Small defects in the form of slag, which were repaired by the welding method, were identified on the upper surfaces of casts having a mass of more than 150 kg. It was also found that the process of filtration considerably reduced the number of repairs from: 3.15 min/kg to 0.9 min/kg.

Table 1.
List of materials cast

Grade	Standard	Number of casts, pcs	Cast mass, kg	Type of filters
GS38	DIN 1681	36	16 ÷ 145	ϕ = 50 mm x 22 mm ϕ = 70 mm x 22 mm ϕ = 80 mm x 22 mm ϕ = 90 mm x 22 mm
LII 450	PN-85/H-83152			
270-480	PN-ISO 3755			
340-550W	PN-ISO 3755			
GS52	DIN 1681			
G17Mn5	PN-EN 10213-3			
GS20Mn5	PN-EN 10213-2			
L30GS	PN-97/H-83156			
L35GSM	PN-88/H83156			
L30HM	PN-87/H-83156			
GS25CrMo4	DIN 17205			
GX5CrNi19-9	PN-EN 10213-4	7	20 ÷120	ϕ = 70 mm x 22 mm ϕ = 90 mm x 22 mm
GX5CrNiMo19-11-2	PN-EN 10213-4			
EN-GJS400-15	PN-EN 1563	1	300 ÷1700	100 mm x 100 mm x 25 mm
EN-GJS-350-22U-LT	PN-EN 1563	1		
340-550W	PN-ISO 3755	1		
G24Mn6	PN-EN 10293	1		
WCB	ATSM A216	1		
L120G13H	PN-88/H-83160	1		

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

Cast steel	Element, %	C	Si	Mn	P	S	Cr	Ni	Mo	Cu
L450	before filtration	0.190	0.450	0.550	0.021	0.029	0.330	0.080	0.020	0.100
	after filtration	0.220	0.460	0.530	0.020	0.035	0.330	0.080	0.020	0.100
LCC	before filtration	0.040	0.280	0.360	0.020	0.005	0.040	0.040	0.010	0.040
	after filtration	0.050	0.290	0.360	0.020	0.006	0.040	0.030	0.010	0.040

a)

b)

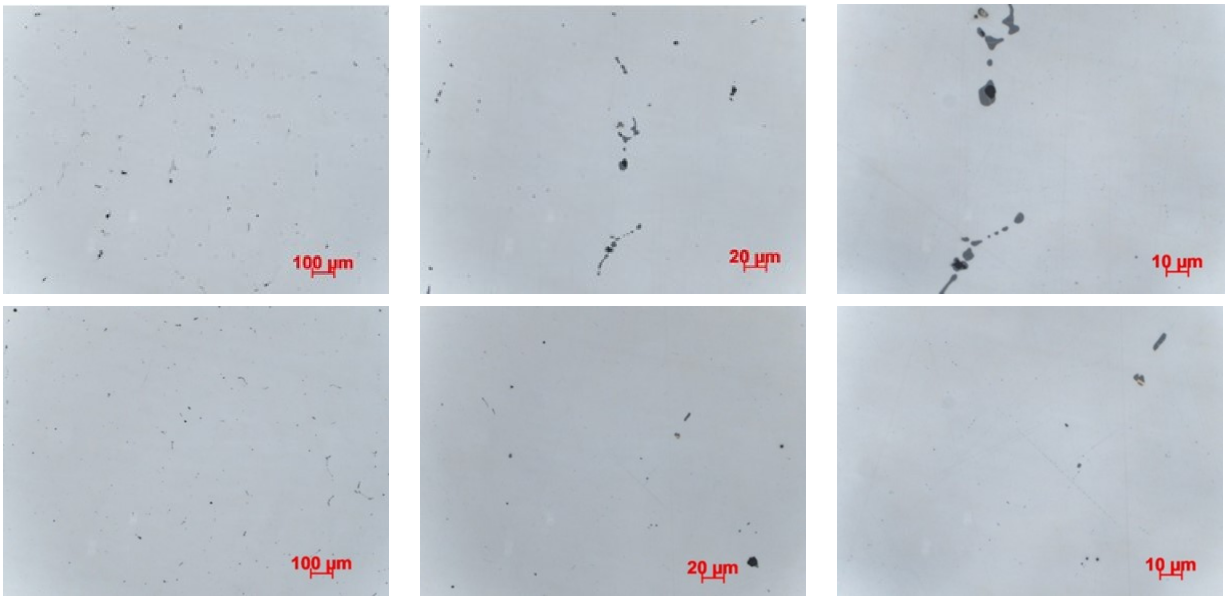

Fig. 1. Microstructure of LCC cast steel (unetched polished section): a) before filtration; b) after filtration

Table 3.
Carbon and sulphur concentration in the LCC cast steel before and after filtration

Element, % / Cast steel	Carbon	Sulphure
before filtration	0.044	0.008
after filtration	0.047	0.006

Table 4.
Oxygen and nitrogen concentration in the LCC cast steel before and after filtration

Element, % / Cast steel	Oxygen	Nitrogen
before filtration	0.084	0.099
after filtration	0.064	0.059

4. Summary

The technological line owned by „Ferro-Term" Sp. z o.o. was modernized so as to implement the production of the newly developed filters. Its major part is the specially designed furnace for firing filters in an oxygen-free atmosphere.

The first batches of ceramic-carbon filters produced on this line were subjected to tests. The obtained results were consistent with the results of laboratory tests carried out under the project "Innovative ceramic-carbon filters for metal alloys filtration", i.e. they confirmed that the newly developed filters:

- have low heat capacity, which eliminates the effect of metal initial solidification;
- due to their low wettability coefficient, they permeate through molten metal more quickly, and, at the same time, are characterized by high efficiency of non-metallic contaminants filtration;
- have a low specific weight, which allows reducing the filter mass in transport packaging;
- although the patent-protected ceramic-carbon slurry used to manufacture the filters contains carbon, it does not penetrate into molten metals;
- they are characterized by high versatility of application, i.e. they can be used to filter ferro-alloy metals (GJL, GJS, GS) and non-ferrous metals (Cu and Al).

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