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WEAR OF REFRACTORY MATERIALS FOR CERAMIC FILTERS OF DIFFERENT POROSITY IN CONTACT WITH HOT METAL

OBRABA OGNJEVZDRŽNEGA MATERIALA KERAMIČNIH FILTROV Z RAZLIČNO POROZNOSTJO V STIKU Z VROČO KOVINO

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This paper deals with an investigation of the development of refractory materials for the fabrication of ceramic filters for the filtration of steel. Ceramic filters are used for increasing the cleanliness of steel and they must meet several strict requirements, such as the ability to remove impurities, a resistance to sudden changes in temperature, a resistance to corrosion and erosion by metal. The use of filters must not lead to an excessive reduction of the steel's temperature, as this may lead to solidification of steel and thus to filter clogging. That is why a special refractory material has been developed with reduced thermal capacity caused by increased porosity. Tests were made in a laboratory of the Department of Metallurgy at VŠB-TUO in order to simulate the industrial conditions of the filtration of steel with a focus on the evaluation of the erosion and corrosion effects and also on a determination of the resistance and service life of ceramic filters.

Keywords: steel, ceramic filter, refractory material, corrosion and erosion, porosity

V članku je opisano raziskovanje v zvezi z razvojem ognjevzdržnih materialov za keramične filtre za filtriranje železa. Te filtre se uporablja za izboljšanje čistosti jekla, zato morajo izpolnjevati več strogih zahtev, kot npr.: odstranitev nečistoč, odpornost proti sunkovitim spremembam temperature in odpornost proti koroziji in eroziji zaradi kovine. Uporaba filtra ne sme preveč znižati temperature jekla in povzročiti njegovega strjevanja ter zato tudi mašenja filtra. Zato je bilo razvit poseben ognjevzdržen material, ki ima zmanjšano termično kapaciteto zaradi povečane poroznosti. Preizkusi so bili opravljeni v laboratoriju Oddelka za metalurgijo VŠB-TUO, da bi simulirali industrijske razmere filtriranja jekla s poudarkom na oceni korozijskih in erozijskih učinkov in za določitev odpornosti in dobe uporabe keramičnih filtrov.

Ključne besede: jeklo, keramika, ognjevzdržni material, korozija, erozija, poroznost

1 INTRODUCTION

The technology of filtration, i.e., the use of ceramic filters in a gating system, is one of the possibilities for enhancing the cleanliness of steel and the quality of as-cast ingots. This makes it possible to achieve an increase of the steel's purity, a reduction of the occurrence of non-metallic inclusions, a reduction of the costs of repairs of defects, etc.

Ceramic filters are exposed to extreme working conditions, such as sudden changes of temperature, the resistance to corrosion and erosion caused by hot metal or molten slags, etc. Ceramic filters are currently commonly used for increasing the cleanliness of steel in steel shops, where filtration is used for the removal of non-metallic inclusions, particularly those of an exogenous character and of the rest of slide valve nozzle fill, e.g., during uphill casting, but also in the tundish during the continuous casting of steel. Nowadays, a whole series of structurally different types of ceramic filters for the filtration of metals are manufactured. The most commonly used types are strainer and foam filters [1]. The paper concentrates on the influence of the porosity of refractory materials on their density and thus on the reduction of their thermal capacity.

2 USE OF CERAMIC FILTERS DURING THE CASTING OF STEEL INGOTS

The technology of the filtration of steel was tested in industrial conditions in a steel shop at the company ŽĎAS, a. s., during the uphill casting of ingots through a gating system in order to eliminate the occurrence of inclusions and to ensure an improved purity of the steel. The system for the casting of ingots consisted of a gate stick, a stool and an ingot mould with a shrink head (**Figure 1**). The application of the filtration system for the casting of ingots consisted of the use of a series of filters situated in a ceramic cartridge arranged in succession. The cartridge is placed in the gating system in the broadened channel of the stool (**Figure 2**).

The steel shop of ŽĎAS, a. s., participated in the design and realisation of the technical solution, including

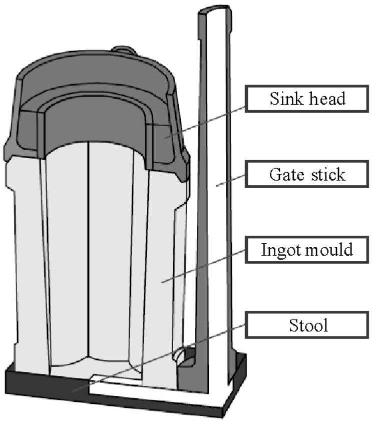

Figure 1: Cross-section of system for casting of ingots
Slika 1: Prerez sistema za litje ingotov

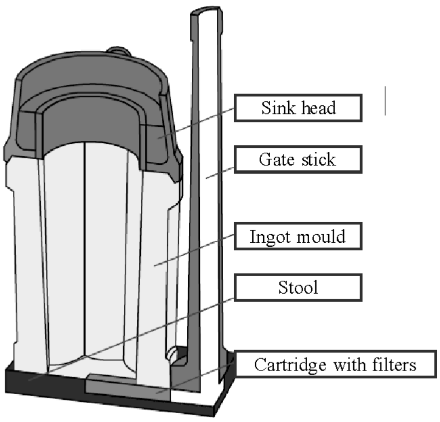

Figure 2: Cross-section of casting system with the application of a filtration cartridge
Slika 2: Prerez sistema za litje ingotov s filtrirnim tulcem

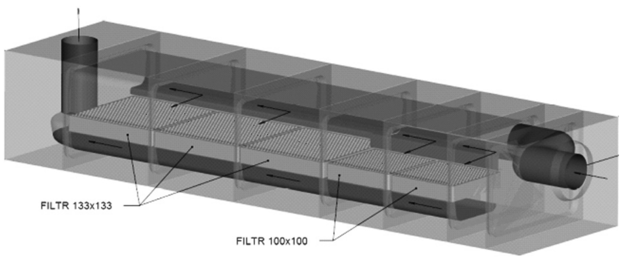

Figure 3: Filtration cartridge
Slika 3: Filtrirni tulec

the manufacture of cartridges and filters. Ceramic foam filters of 150 mm × 150 mm × 30 mm made of material based on ZrO_2, SiO_2 + SiC, as well as of material based on carbon, Al_2O_3 and SiO_2 were then tested in this steel shop. Due to problems during pouring (mechanical damage and freezing of the metal) in the next stage the filtration cartridges were modified and ceramic strainer filters based on mullite with dimensions of 100 mm × 100 mm × 20 mm and 133 mm × 133 mm × 20 mm were used. The filtration cartridge was made of fireclay material with the share of the mass fraction of Al_2O_3 > 61 % (**Figure 3**).

It was ascertained during industrial applications that this arrangement is satisfactory; however, in this case too during the flow of steel through the filter channels, the steel was cooled and problems with its freezing occurred as well. Subsequently, in order to minimise this problem, the company KERAMTECH, s. r. o., developed and tested a refractory material, in which its porosity was purposefully increased (up to 10 % of material), which led to a reduction of its mass and cooling effect.

3 DEVELOPMENT AND TESTING OF REFRACTORY MATERIALS FOR NEW CERAMIC FILTERS

The refractory material was developed by the company KERAMTECH, s. r. o., and a refractory material consisting of a mullite-corundum mass with higher contents of Al_2O_3 was chosen for the modification. **Table 1** gives the chemical composition of this material. The porosity of this material was increased by the addition of organic mass in portions of (3, 5, 7.5 and 10) % in order to reduce the material's thermal capacity.

Table 1: Chemical composition of modified refractory material
Tabela 1: Kemična sestava modificiranega ognjevzdržnega materiala v masnih deležih, *w*/%

Chemical composition in mass fractions (*w*/%)							
SiO_2	Al_2O_3	Fe_2O_3	TiO_2	K_2O	CaO	MgO	Na_2O
21.0	75.0	0.8	0.6	0.8	less than 0.5		

The specific thermal capacity of ordinary material is 1800 kJ K^{-1} kg^{-1}. The addition of 1 % of organic mass to the basic material reduces, by increased porosity, the mass of the final product by 2 %, and thus also its thermal capacity.

The modified refractory materials with increased porosity were tested with experimental heats in a laboratory of VŠB – Technical University of Ostrava to verify the erosion and corrosion effects and to determine the resistance and service life of the new ceramic filters. These experimental heats were supposed to simulate the conditions during the industrial filtration of hot metal. Two types of steel were used for all the experimental heats, i.e., ordinary carbon steel and high-manganese steel. **Table 2** gives the chemical compositions of both these steels, including the liquidus temperature.

Table 2: Chemical compositions of the used steels with liquidus temperatures
Tabela 2: Kemična sestava uporabljenih jekel in likvidusna temperatura

Type of steel	Chemical composition (*w*/%)					T_l/°C
	C	Si	Mn	P	S	
Carbon steel	0.44	0.23	0.67	0.019	0.016	1495
Manganese steel	1.1-1.5	max. 0.70	12.0-14.0	max. 0.10	max. 0.050	1375

Samples with dimensions 10 mm × 10 mm × 100 mm were made from the modified refractory material. For the simulation of the usual industrial conditions, prior to their insertion into the hot metal the samples were pre-heated to a temperature of 350 °C for 10 min. This tempering of the samples simulates the heating of the casting system in industrial conditions. Before their insertion into the reheating furnace and the start of the experiment, the samples were weighed in order to determine the mass loss. A comparison of the results showed that the re-heating of the samples did not cause any loss of mass. Afterwards, experimental heats were carried out. The induction furnace served as a melting unit. For the evaluation of corrosion and erosion phenomena, the experiments were made afterwards with use of both carbon and manganese steel at temperatures of 1560 °C, 1600 °C and 1680 °C for 20 min, while the porosity of the tested refractory materials was increased by the addition of various organic masses 10 wt.%.

4 EVALUATION OF REFRACTORY MATERIALS

The evaluation of the exposed samples was made in several steps. It started with a visual evaluation (photographs of the whole samples taken after the experiment) followed by an evaluation of cross-sections with a focus on the structure and the surface (edge) of the samples.

4.1 Visual evaluation of erosion and corrosion

With the experiments the refractory materials were tested from the point of view of the influence on carbon and manganese steels at the extreme temperature of 1680 °C for 20 min with contents of organic mass in the refractory material in volumes of (3, 5, 7.5 and 10) %. **Figure 4** shows the results of the first series of experiments.

It is evident from this figure that the addition of organic mass in the quantity up to approx. 3 % had no significant influence on the wear of the refractory materials. However, larger additions of organic mass up to 10 % brought about a distinct wear and deformation of refractory material in both the carbon and manganese steels. It is also evident that in the case of use of manganese steel, the corrosion effects of refractory materials were substantially higher than for the heats of the carbon steel.

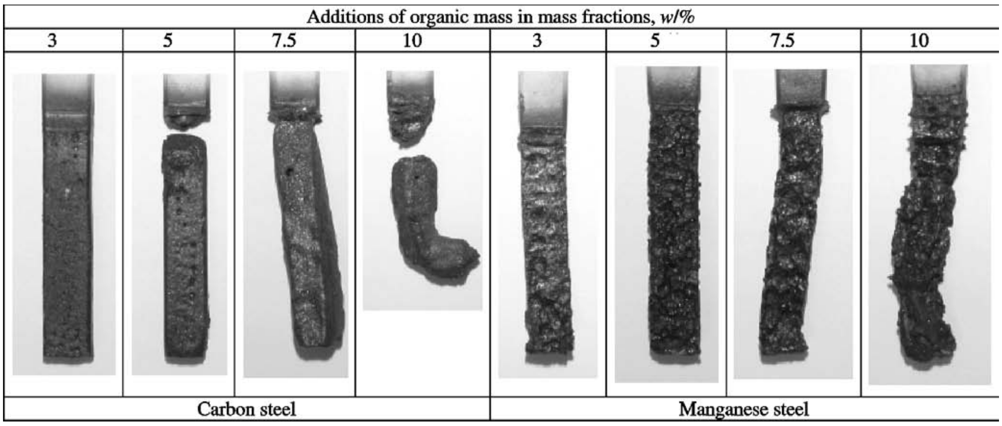

Figure 4: Pictures of refractory material after exposition in carbon and manganese steel at a temperature of 1680 °C for a period of 20 min
Slika 4: Posnetki ognjevzdržnega materiala po 20-minutni izpostavi ogljikovemu in manganovemu jeklu pri temperaturi 1680 °C

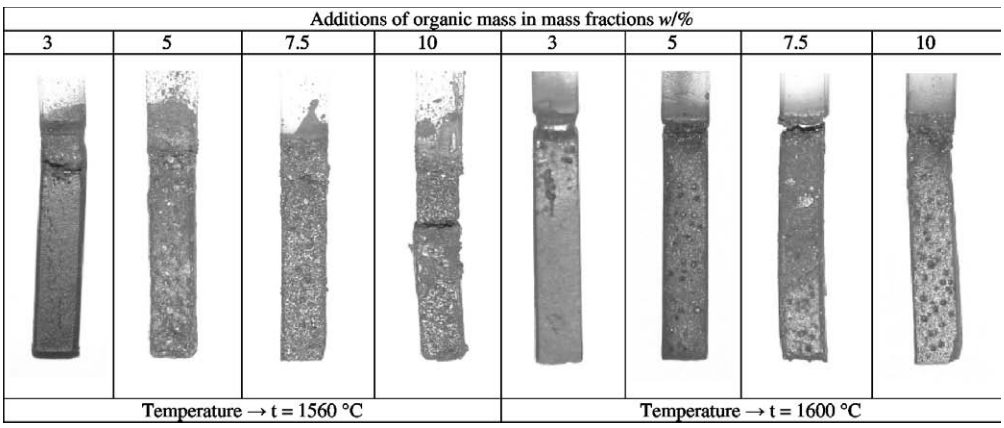

Figure 5: Pictures of refractory material after exposition in carbon steel at temperatures of 1560 °C and 1600 °C for a period of 20 min
Slika 5: Posnetki ognjevzdržnega materiala po 20-minutni izpostavi ogljikovemu jeklu pri temperaturah 1560 °C in 1600 °C

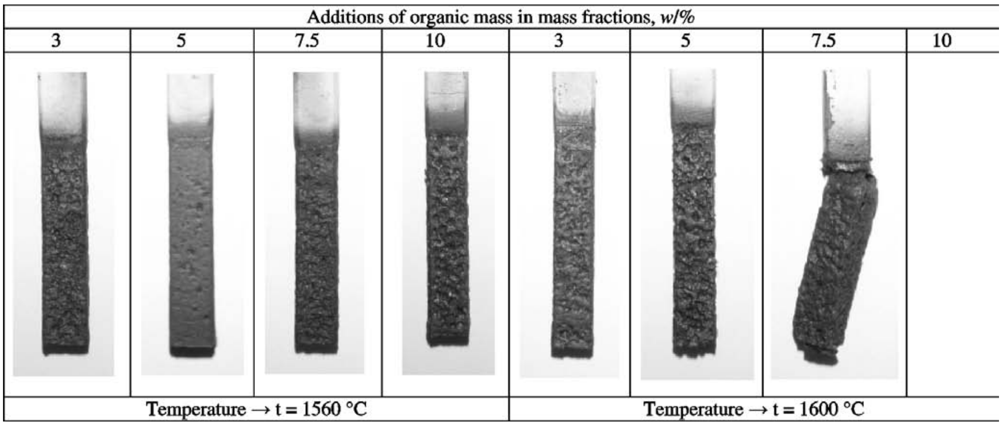

Figure 6: Pictures of refractory material after exposition in manganese steel at temperatures of 1560 °C and 1600 °C for a period of 20 min
Slika 6: Posnetki ognjevzdržnega materiala po 20-minutni izpostavi manganovemu jeklu pri temperaturah 1560 °C in 1600 °C

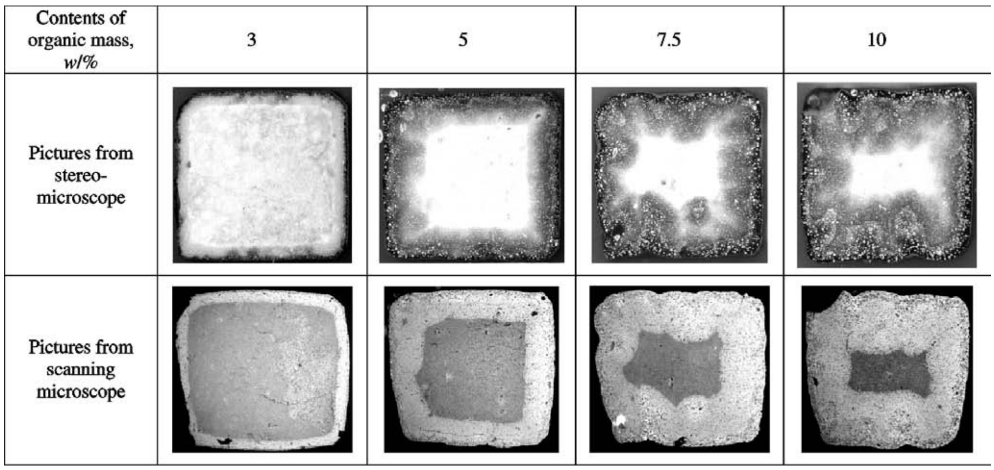

Figure 7: Comparison of pictures of cross-sections stressed at the temperature of 1600 °C in carbon steel taken with stereo-microscope and scanning electron microscope
Slika 7: Primerjava posnetkov prereza, obremenjenega pri temperaturi 1600 °C v ogljikovem jeklu, pripravljenih s stereomikroskopom in z vrstičnim elektronskim mikroskopom

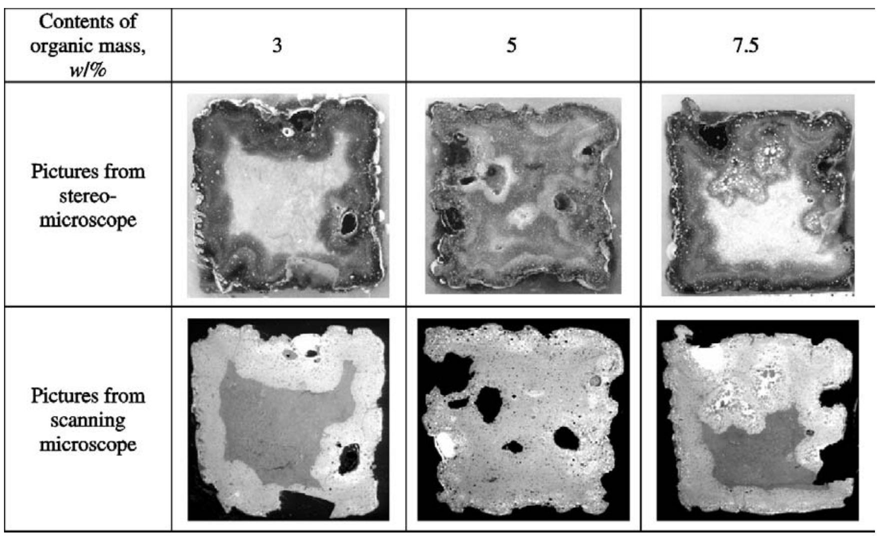

Figure 8: Comparison of pictures of cross-sections stressed at the temperature of 1600 °C in manganese steel taken with stereo-microscope and scanning electron microscope
Slika 8: Primerjava posnetkov prereza, obremenjenega pri temperaturi 1600 °C v manganovem jeklu, pripravljenih s stereomikroskopom in z vrstičnim elektronskim mikroskopom

On the basis of previous results the experiments were carried out under modified conditions, again with refractory materials with contents of organic mass of (3, 5, 7.5 and 10) % with use of carbon and manganese steel with an interaction time of 20 min, but at temperatures of 1560 °C and 1600 °C. The objective of these tests was to simulate the temperatures in practical conditions of the uphill casting of steels into ingot moulds, as well as to test the influence of various additions of organic mass on the wear at these reduced temperatures. The results of the experiments are shown in **Figures 5 and 6**.

An analysis of these figures revealed that a temperature of 1560 °C seems to be too low for carbon steels. The liquidus temperature calculated on the basis of the chemical composition of the steel is 1495 °C (see **Table 2**). In this case freezing of the steel on the walls of the ceramic samples occurred during testing. In the case of an industrial application this would require an increase in the pouring temperature from the usual 1560 °C (pouring temperature used at ŽĎAS, a. s.) to approximately 1570–1575 °C (i.e., by about 10–15 °C).

However, with the same steel and temperature of 1600 °C, the refractory materials showed, with contents of 5 % of organic mass, only minimum wear, and slightly higher wear for a content of 7.5 %. Nevertheless, higher contents of organic mass up to 10 % already had a negative impact at this temperature. During the use of manganese steel at the temperature of 1560 °C and at calculated liquidus temperature of 1375 °C (see **Table 2**) the degree of wear was higher for contents of organic mass higher than 7.5 %. For this reason, experiments at a temperature of 1600 °C were made without the sample containing 10 % of organic mass. At the temperature of 1600 °C a minimum loss was determined in the same (manganese) steel for the contents of 3 % of organic mass in the refractory material [2].

4.2 Evaluation of cross-sections

Apart from a visual evaluation of the samples after the experiments, their cross-sections were evaluated as well. The evaluation itself was made on the basis of a visual comparison of images taken using an Olympus stereo-microscope and Tescan Vega scanning microscope operating in the "fish eye" mode. The photos taken with the stereo-microscope make it possible to determine the depth of penetration, the material structure and also the losses of material. The pictures taken with the scanning microscope enable a determination of the cracks, fissures, structure failures, and in some cases, also the depth of the penetration. For an illustration, only the samples with use of carbon and manganese steels for 20 min at the temperature of 1600 °C were used, with the contents of organic mass in the refractory materials of (3, 5, 7.5 and 10) %.

The photographs of the cross-sections taken with the stereomicroscope and the scanning microscope of the carbon steel at the temperature of 1600 °C are shown in **Figure 7**. The images show that the character and morphology of the surfaces of the refractory materials are similar. Refractory materials with contents of organic mass up to 5 % showed minimum wear, and a slightly higher wear was observed for the contents from 7.5 %. **Figure 8** shows pictures of the cross-sections taken with the stereo-microscope and the scanning microscope of the manganese steel at the temperature of 1600 °C. The pictures show that for this steel the addition of organic mass >5 % at the temperature of 1600 °C had a negative impact, and it influenced not only the surface layers of the refractory material, but also its central parts. Larger additions had a very negative impact on the material's structure.

5 CONCLUSIONS

With the development of new ceramic filters intended for the filtration of steel in the gating system during the casting of ingots, experiments were carried out in laboratory conditions with a focus on the verification of the influence of porosity in refractory materials on the erosion and corrosion caused by the steel. Afterwards, various pictures were visually evaluated. This evaluation made it possible to assess the influence of the additions of the organic mass on the degree of wear of the refractory material under various operating conditions. The following conclusions may be drawn on the basis of the results of the laboratory experiments:

– it is obvious from the results obtained in both series that the manganese steel had a much greater corrosive impact on the tested refractory materials than the carbon steel,
– for the tested samples in the first part during the contact with carbon and manganese steel at the temperature of 1680 °C for 20 min, the addition of organic mass up to approx. 3 % had no significant influence on the wear of the refractory materials. However, larger additions of organic mass up to 10 % caused a distinct wear and deformation of the refractory material,
– the samples of refractory materials in the second part were in contact with the carbon and manganese steel for 20 min, but at temperatures of 1560 °C and 1600 °C. The temperature of the experiments at 1560 °C was too low for the carbon steel, since freezing of the steel on the walls of the samples occurred during testing. In the case of the same steel and a temperature of 1600 °C the samples showed up to the contents of 5 % of organic mass only a minimal amount of wear. However, larger contents of organic mass of 10 % had a negative influence at the temperature of 1600 °C,
– for the manganese steel and a temperature of 1560 °C an increased degree of wear was found for contents of organic mass exceeding 7.5 %. For this reason, the experiments at the temperature of 1600

°C were realised without the sample containing 10 % of organic mass. The samples showed for the same steel a minimum loss of refractory material at the temperature of 1600 °C and contents of 3 % of organic mass,
- it was determined from the pictures of the cross-sections for the carbon steel and the temperature of 1600 °C, that up to the contents of 5 % of organic mass the refractory materials showed only minimal wear, while at the contents of 7.5 % and more of organic mass they showed slightly increased wear. However, the manganese steel had a negative impact during the addition of organic mass >5 %, and this phenomenon influenced not only the surface layers, but also the central areas of the refractory material,
- on the basis of the obtained results the company KERAMTECH, s. r. o., produces ceramic filters with the addition of 5 % of organic mass under the designation RK-5/5.

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6 REFERENCES

[1] Stránský, K., Bažan, J., Horáková, D. *Filtrace taveni železa v průmyslové praxi [Filtration of molten steel in practice]*. Editor. Ostrava, VŠB-TU Ostrava, 2008, 113 pp. ISBN 978-80-248-1844-3

[2] Bažan, J., Socha, L., Martínek, L., Fila, P., Balcar, M., Lev, P. Effect of Refractory Materials Porosity on Erosion and Corrosion of Ceramic Filters by Molten Steel Treatment. *Hutnické listy*, 63 (**2010**) 2, 20–2