



Improving the quality of Al-Si castings by using ceramic filters

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Article history

Received 08.01.2020
Accepted 23.02.2020
Available online 31.03.2020

Keywords

aluminium alloy
ceramic filters
hardness
porosity

Abstract

The use of cast aluminium has still increased, so have the mechanical property requirements. By casting and also in other metallurgical processes, the inclusions enter to the molten aluminium alloy and it exhibits poor ductility or toughness. It can cause a variety of problems in the manufacture of aluminium alloy castings. Therefore, the purification of the molten aluminium alloy is one of the most important processes for improving the quality of Al-products. Filters have been used for many years in order to improve the quality of castings. The inclusions in molten secondary AlSi7Mg0.3 cast were removed using depth filtration by ceramic foam filters of 20 ppi porosity. Were used 4 types of ceramic filters in 2 thicknesses (15 and 22 mm); Brinell hardness and porosity were measured. Quality of microstructure (occurrence of oxidic particles and larger non-metallic inclusions) was observed. Experimental results show that the insertion of ceramic filters into the inlet system has contributed primarily to a decrease in porosity. On the microstructure, the inclusion of filters was not significantly reflected.

DOI: 10.30657/pea.2020.26.05

JEL: L69, M11

1. Introduction

The use of aluminium in the automotive industry has grown dramatically in recent years. Current applications of Al-alloys in transport industry are used to fabricate components such as engine blocks, cylinder heads, electronic system box, suspension control arms, front strut supports, wheels, pistons, turbo and so on (Boileau, 2001).

The quality of cast products directly depends on the quality of molten metal from which the products are cast. Comprehensive understanding of the melt quality is of vital importance for the control and prediction of actual casting characteristics. Any defect added or created during the melting stage will be carried to the final microstructure, and certainly, affect the quality of cast products. Therefore, it is apparent that the control of the quality of the cast products begins with the control of the quality of the melt (Djurdjevic, 2010).

Recycling of aluminium is important due to environmental and economic reasons. Recycling of aluminium is still increased and requires only 5% of the energy for primary aluminium. Recycling 1 kg of aluminium can save up to 8 kg of bauxite, 14 kWh of electricity and 4 kg of chemical products. Nowadays, some Al-foundries collect process Al-scrap (Sabatino, 2005; Kuchariková, 2006).

An increased amount of effort and attention are devoted to the improvement of the molten metal quality, because the molten Al-alloy has a great influence on the final microstructure and, so the mechanical properties (Boileau, 2001). One of the main concerns, when recycling Al-scrap, is to avoiding inclusions which affect the properties of alloy (Sabatino, 2005).

Molten Al is so active that it can easily chemically react with O₂ and H₂O to form Al₂O₃ inclusions and H during melting practice. However, some other inclusions (TiB₂, Al₄C₃, MgAl₂O₄, etc.) form by the electrolytic process. Under turbulent flow conditions, the inclusions are distributed unevenly in the molten aluminium. They may associate with cracks or be the locations of crack initiation in solidified casting. Al-products containing these inclusions will probably exhibit poor ductility or toughness. Therefore, purification of the molten aluminium is one of the most important processes for improving the quality of Al-products (Boileau, 2001; Zhou, 2003; Fuoco).

Filtration is used prior to casting (Boileau, 2001). Filtration reduces the impurities which could lead to the casting defects (inclusions); eliminates of bubbles in metal; regulates and homogenizes the metal flow, reduces the oxidation and improves casting quality.

A separate process occurs during filtration, where the melt passes through a capillary porous environment, while solid particles are captured and liquid particles are passing freely through the melt (Tillová, 2015). Filters are applied to the inlet system and they positively affect the quality of liquid metal that flows through. It is desirable and ideal if the material of a filter does not cause the melt to solidify in the cavities of a filter. The flow of melt through the filter takes place in three phases (Fig. 1). In the first phase, metal flows at a constant rate. In the second phase the filter is being gradually clogged due to trapped inclusions and the last phase the filter is clogged completely, so melt does not flow further (Tillová, 2015; Zhou, 2003).

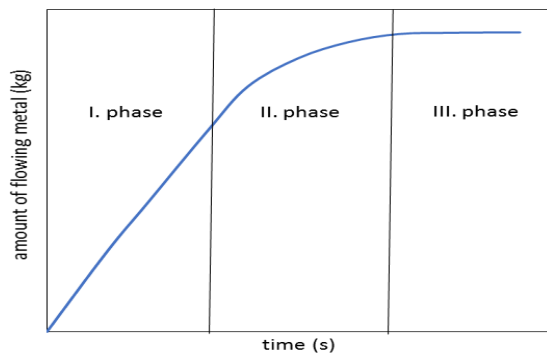


Fig. 1. Time course of filtration

Depending on how inclusions are separated, three kinds of filtration processes can be applied (Fig. 2). The coarse filtration captures particles of larger dimensions, such as the size of the filter holes. The final filtration works the way that the inclusions get trapped on the inflow side of the filter what also causes slowing down of the melt flow. In the depth filtration, smaller inclusions than holes of filter are captured due to adhesion inclusion on the filter walls and, also, in associating inclusion with each other (Adler, 2005).

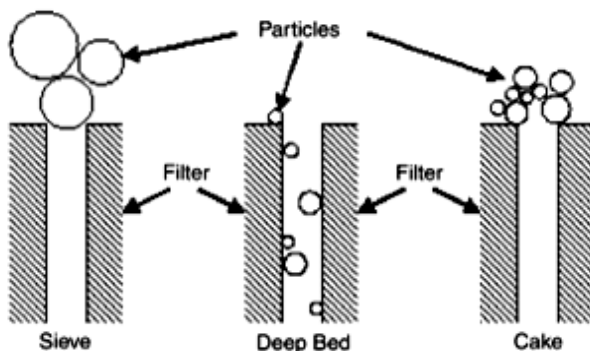
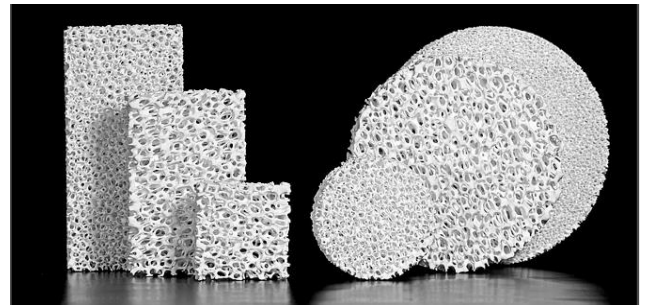


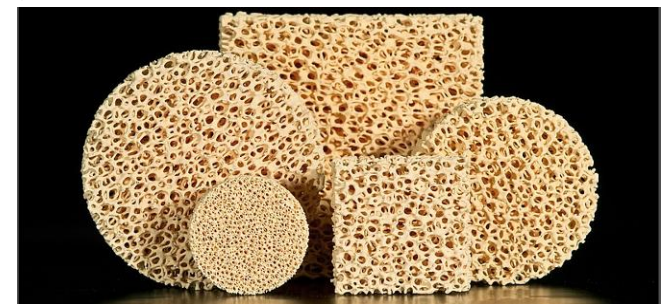
Fig. 2. Models of filtration (Adler, 2005)

The ceramic filters to be effective have to be resistant to the initial impact of the liquid metal, of the thermal shock, to have optimal heat capacity and mechanical resistant, to be chemically immutable, and to have sufficient filtration effectivity. Foam ceramic filters consist of a set of chambers that have

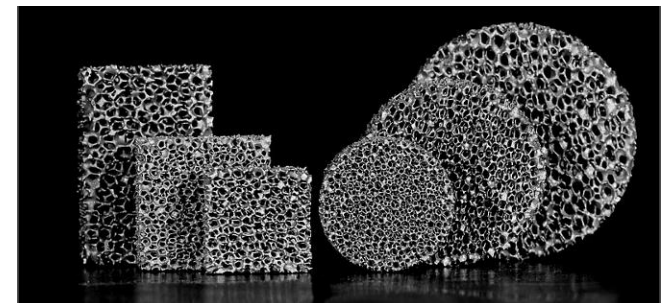
a lot of transitions, sections, and directions. The ceramic filters (Fig. 3) are made of polyurethane foam which has the required porosity. The porosity is given according to the number of pores per floor inch ppi. The most commonly used types of filters are the ones with a porosity size of 10 ppi, 15 ppi, 20 ppi. The higher the number is, the higher the density of the filter (Adler, 2005; Moraes, 2006).



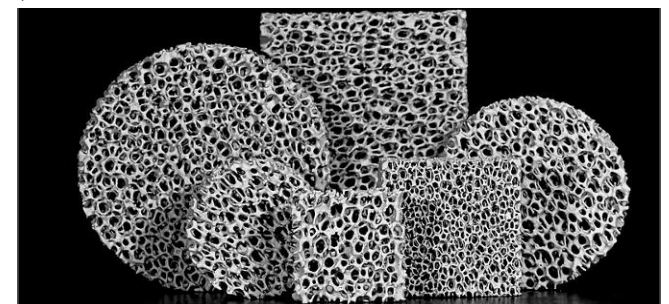
a) VUKOPOR A



b) VUKOPOR HT



c) VUKOPOR LD



d) VUKOPOR S

Fig. 3. Types of VUKOPOR filters used in Al-alloy casting (Láník, 2006)

The present study is a part of larger research project, which was conducted to investigate and to provide better understanding properties of secondary Al-cast alloys. This work focuses

on the filtration effect on mechanical properties of secondary (recycled) Al-Si cast alloy.

2. Experimental material

The main aluminium casts alloys are AlSi(Cu,Mg) alloys. These materials contain silicon due to its capability to increase fluidity and elevated temperature resistance to cracking. Copper and magnesium increase strength and toughness in AlSi alloys, as well as provide hardening phases that precipitate during the aging treatment (Kuchariková, 2006; Tillová, 2011; Uhrčík, 2018). As the experimental material was used AlSi7Mg0.3 cast alloy (Table 1). AlSi7Mg0.3 is hypoeutectic Al-Si cast alloy and is suitable for thin-walled casting and they use in the transport and vehicle industry. Basic microstructure consist of eutectic (α -phase and eutectic Si particles), Fe-rich phases in form skeleton/Chinese script (probably $Al_{15}(FeMn)_3Si_2$) or needles (probably Al_5FeSi) and Mg_2Si phases (Fig. 4) (Bolibruchová 2019; Kuchariková, 2018, Tillová 2015). The alloy was melted in a high frequency electric furnace at melting temperature at 760 °C. The melt was modified by AlSr5 (20ppm) and grain refined by AlTi5B1 (55 ppm).

Table 1. The chemical composition of experimental alloy.

Si	Mg	Fe	Mn	Ti	Cu	Sr	Al
7.01	0.308	0.42	0.018	0.122	0.001	0.021	rest

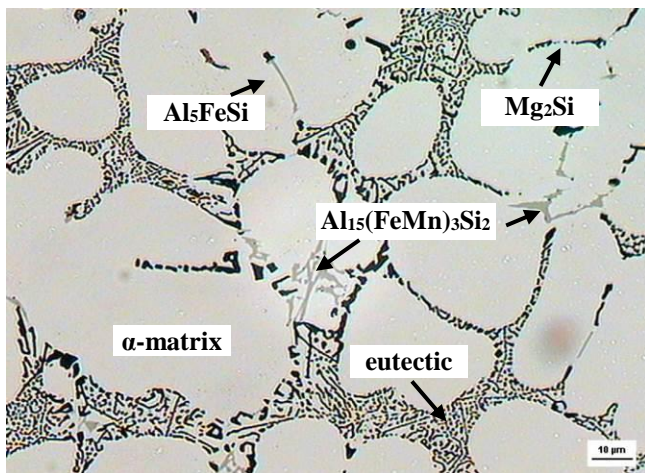


Fig. 4. The microstructure of experimental material AlSi7Mg0.3, etch. 0.5% HF

Eight series of AlSi7Mg0.3 melts were cast in to metallic mould with the using of ceramic foam filter (VUKOPOR A, VUKOPOR HT, VUKOPOR LD and VUKOPOR S in 2 thicknesses - Fig. 3; Table 2). The filters were located in a casts hollow in front of entrance of melt to the mould (Fig. 5). Experimental bars (18 x 155 mm) were made on which the Brinell hardness (load 250 kp, dwell ball with diameter 5 mm and time 15 s) was measured. The resulting values represent the average value of the six measurements.

Porosity was evaluated by quantitative metallography (software NIS Elements) as the area share of pores on one section by 25x magnification.

Metallographic samples were prepared from selected bars (after testing) and the microstructures were examined by optical (Neophot 32) microscopy. Specimens were sectioned and prepared by standards metallographic procedures including etching by 0.5% HF. EDX analyses of oxide films or clusters was study by scanning electron microscope VEGA LMU II.

Table 2. The basic characteristics of the ceramic filters.

Type of ceramic filter	Size	Chemical Composition	Porosity	Max. heat temperature
VUKOPOR A	68/44 x 22	Al ₂ O ₃ SiO ₂	20 ppi	1350°C
	60.5/44 x 15			
VUKOPOR HT	68/44 x 22	phosphorus bond	20 ppi	1700°C
	60.5/44 x 15			
VUKOPOR LD	68/44 x 22	Al ₂ O ₃ SiO ₂ graphite	20 ppi	850°C
	60.5/44 x 15			
VUKOPOR S	68/44 x 22	SiC Al ₂ O ₃ SiO ₂	20 ppi	1450°C
	60.5/44 x 15			

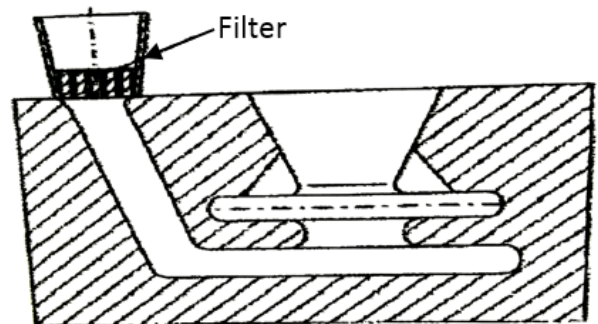


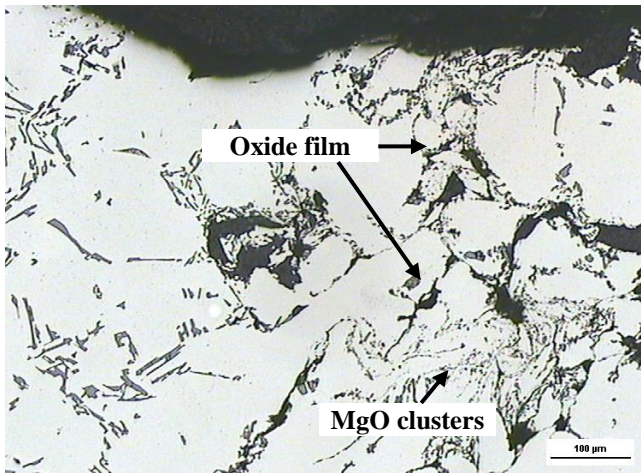
Fig. 5. Location of ceramic filter

3. Results and discussion

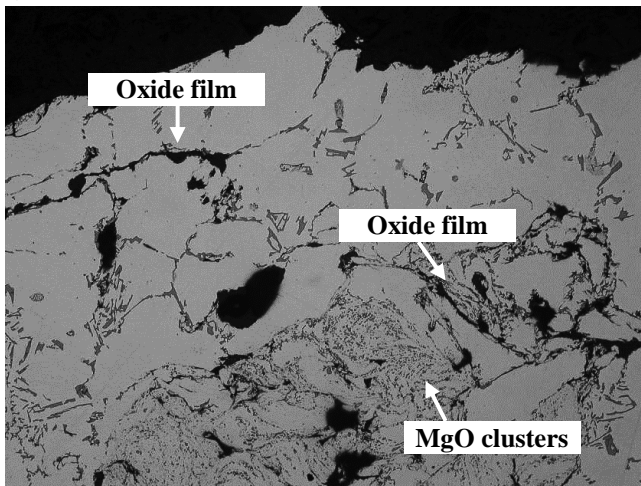
The effect of filtration is well demonstrated by oxide films density. Oxide films are an import source of casting defects. A thin oxide film forms on the surface as soon as liquid aluminium comes in contact with air. If the liquid is quiescent, this oxide film stays on the surface and does not affect metal quality. However, if there is any turbulence or splashing, the oxide film is mixed (or folded) into the melt; and the quality of the casting suffers (Fuoco).

In Fig. 6 is documented microstructure from AlSi7Mg0.3 alloy retained in the filters. One can observed oxide films, that were by filters receive. EDX analysis of the oxides revealed two types: the thin, dark - colored Al₂O₃ films and the MgO

clusters. These oxide films and clusters were study independently of type and filters thickness. Nonetheless, more oxide films were measured in VUKOPOR S.



a) VUKOPOR LD



b) VUKOPOR S

Fig. 6. Microstructure observed in filters, etc. 0.5% HF

Brinell hardness confirmed increasing hardness in samples where filters have the highest thickness (Fig. 7). The HBW 5/250/15 of alloy with filters thickness 22 mm - filter A was 57 HBW, for filter HT 56 HBW, for filter LD 55 HBW and filter S 59 HBW. Filters with thickness 15 mm resulted in alloy having following hardness: filter A 54 HBW, filter HT 53 HBW, filter LD 51 HBW and filter S 53 HBW. In terms of filter thickness, the smallest difference in hardness was achieved for HT filter (about 5.2%) and for filter A (about 5.4%). These low value differences can be considered a common measurement error, which is 5%.

Porosity is another major defect in the castings. The most frequently found porosity in cast aluminium alloys are gas porosity and shrinkage porosity. The formation of porosity, therefore, directly relates to the hydrogen content in the melt and shrinkage during solidification. The area of porosity in Al-Si-Mg alloy castings increased with an increase in oxide film content in the melt.

Many authors (Fuoco; Boileau, 2001; Damoah, 2010) suggest that oxide films can act as heterogeneous nucleation sites for porosity during solidification due to the presence of porosity associated with oxide films. The ceramic foam filter is thought to remove previously formed inclusions, and also reduce the speed of flow of the molten alloy filling the mould in order to prevent any further oxide film from being entrained. Removing the filters meant that oxide films already present were not removed and more oxide films were introduced by surface turbulence in the empty filter print.

The result of quantitative porosity measurement is documented in Fig. 8. Average porosity in filters with thickness 22 mm was for filter A - 3.5%, for filter HT - 0.8%, for filter LD - 2.9% and filter S - 0.6%. Porosity in alloys casted with filters with 15 mm thickness was measured for filter A - 2.8%, for filter HT - 1.1%, for filter LD - 2% and for filter S - 0.5% (Fig. 8). The highest porosity was recorded for filters A and LD, independently from filter thickness; the lowest porosity was observed for filter S.

The results show that thickness of filter does not affect porosity. Major influence has probably material (chemical composition) of filter. The best result was observed for filter VUKOPOR S - made from SiC, Al₂O₃ and SiO₂.

Macrostructure of AlSi7Mg0.3 alloy for filters with thickness 15 and 22 mm documented Fig. 9 and Fig. 10. Macrographs correlated with porosity quantitative measurements.

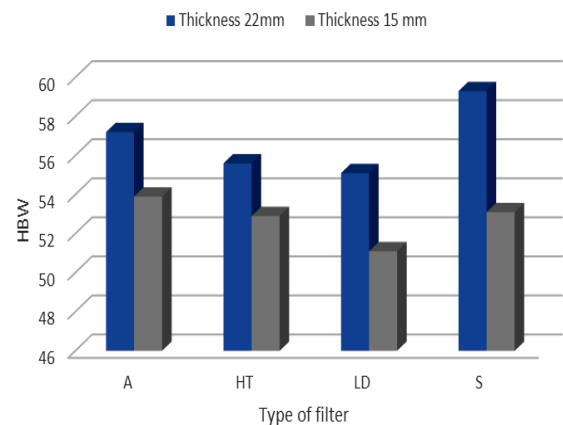


Fig. 7. Effect of filtration on Brinell hardness

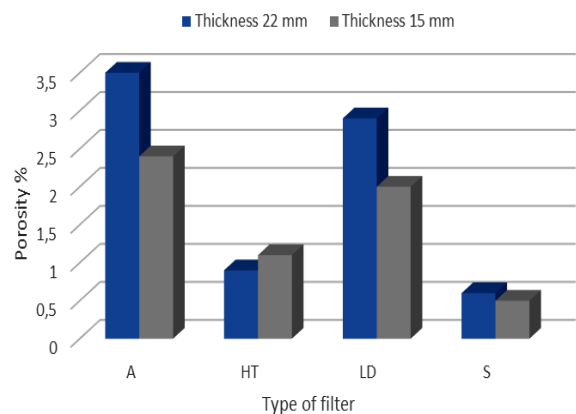
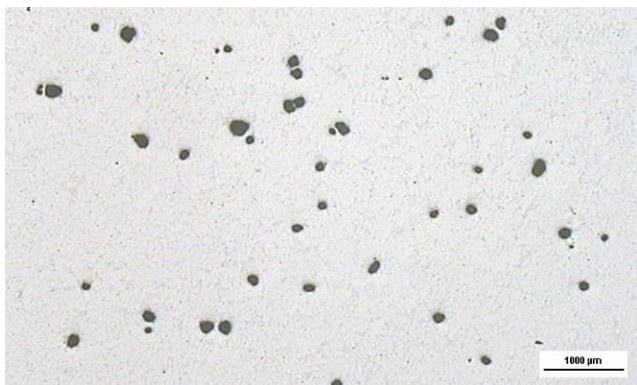


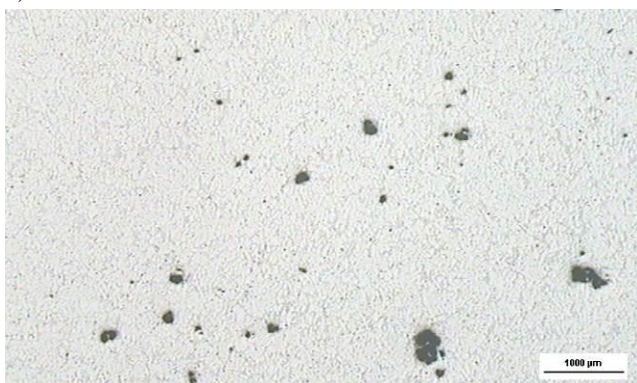
Fig. 8. Effect of filtration on porosity



a) VUKOPOR A



b) VUKOPOR HT



c) VUKOPOR LD

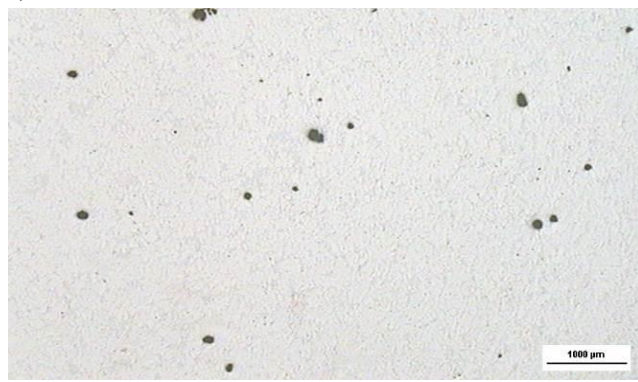


d) VUKOPOR S

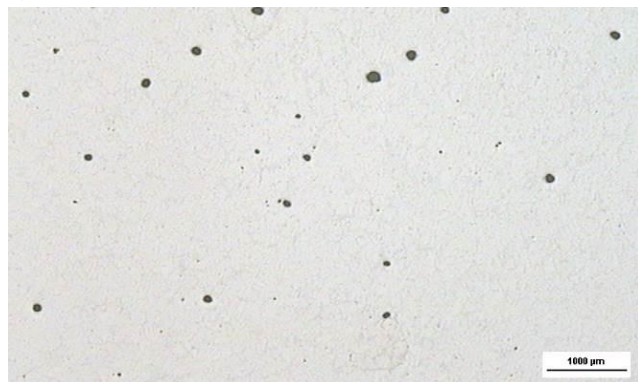
Fig. 9. Porosity of AlSi7Mg0.3 alloy for filters with thickness 15 mm, macrostructure, unetched



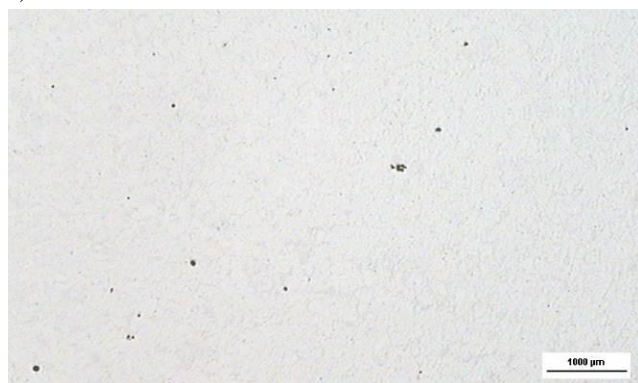
a) VUKOPOR A



b) VUKOPOR HT



c) VUKOPOR LD



d) VUKOPOR S

Fig. 10. Porosity of AlSi7Mg0.3 alloy for filters with thickness 22 mm, macrostructure, unetched

4. Summary and conclusion

The result of this study shows that:

- the use of all tested ceramic foam filters VAKUPOR would greatly help to remove the oxide films (Al_2O_3) and oxide clusters (MgO);
- these ceramic filters reduce probably the velocity of the $AlSi7Mg0.3$ melt too, which in turn reduces the surface turbulence. Reduced surface turbulence after the filter means less risk for creation and entrainment of oxide films or air in the liquid metal, which has an overall beneficial effect on porosity;
- the area of porosity in $AlSiMg0.3$ cast alloy decreases with presence of filters by casting; this effect is dominant in VUKOPOR S (for both filters thickness);
- quantitative evaluation of porosity showed that thickness of filter does no strong effect on porosity. Major influence has probably material (chemical composition) of filter. The best result was observed for filter VUKOPOR S - made from SiC , Al_2O_3 and SiO_2 .

Acknowledgements

This work was supported under the projects VEGA 01/0398/19, KEGA 049ŽU-4/2017 and project of Operational Programme Research and Innovation: Research and development activities of the University of Zilina in the Industry of 21st century in the field of materials and nanotechnologies, No. 313011T426. The project is co-funding by European Regional Development Fund.

Reference

- Adler, J., 2005. *Ceramic Diesel Particulate Filters*. Int. J. Appl. Ceram. Technol., 2, 429-439.
- Boileau, J. M., 2001. *An Examination of Inclusions in a Quiescent Metal Furnace*. An Examination Of Impurities In A Quiescent Metal Furnace. 1-19.
- Bolibruchova, D., Podprocká, R., 2019. *The Effect of Different Mn/Fe Ratio on Microstructure Alloy Based on Al-Si-Mg*. Archives of foundry of engineering, 19, 15-20.
- Damoah, L. N. W., Zhang, L., 2010. *Removal of Inclusions from Aluminum Through Filtration*. Metallurgical and Materials Transactions B, 41B, 886-907.
- Djurdjevic, M. B. et al., 2010. *Melt quality control at aluminum casting plants*. MJoM, 16(1), 63-76.
- Fuoco, R., Correa, E. R., *The Effect of Gating System Design on the Quality of Aluminum Gravity Castings*, IPT - Technological Research Institute São Paulo, Brazil.
- Kuchariková, L., Liptáková, T., Tillová, E., Kajánek, D., Schmidová, E., 2018. *Role of Chemical Composition in Corrosion of Aluminum Alloys*, Metals, 8, 581.
- Kuchariková, L., Tillová, E., Bokůvka, O., 2006. *Recycling and properties of recycled aluminium alloy used in the transportation industry*, Transport problems, 11(2), 117-122.
- Moraes, H. L., et al., 2006. *Removal of Iron from molten recycled Aluminium through Intermediate Phase Filtration*. Materials Transactions, 47(7), 1731-1736.
- Láník, I. et al., 2006. *Lanik Foam Ceramics*. Czech Foundry Society, Boskovice.
- Sabatino, M.D., Arberg, L., Rovnik, S., Prestmo, A., 2005. *The influence of oxide inclusions on the fluidity of Al-7 wt.%Si alloy*. Materials Science and Engineering A, 413-414, 272-276.
- Tillová, E., et al., 2011. *Quality control of microstructure in recycled Al-Si cast alloys*. Manufacturing Technology, 70-76.
- Tillová, E., Chalupová, M., 2015. *Changes of Mechanical Properties of AlSi7Mg0.3 Cast Alloy through Filtration*. Key Engineering Materials, 635, 1-4.
- Uhříček, M., Palček, P., Chalupová, M., Frkáň, M., 2018. *The influence of the structure on the fatigue properties of aluminium alloys for the casting*. MATEC Web of Conference, 157.
- Zhou, M., et al., 2003. *Deep filtration of Molten Aluminium using Ceramic Foam Filters and Ceramic Particles with Active Coatings*. Metallurgical and Materials Transactions A, 34A, 1183-1191.

通过使用陶瓷过滤器提高铝硅铸件的质量

關鍵詞

铝合金
陶瓷过滤器
硬度
孔隙率

摘要

铸铝的使用仍在增加，因此对机械性能也有要求。通过铸造以及在其他冶金工艺中，夹杂物进入熔融铝合金中，并且表现出差的延展性或韧性。在铝合金铸件的制造中会引起各种问题。因此，熔融铝合金的提纯是提高铝产品质量的最重要的方法之一。过滤器已经使用了很多年，以提高铸件的质量。使用深度为20 ppi的陶瓷泡沫过滤器进行深度过滤，去除熔融的二次 $AlSi7Mg0.3$ 铸件中的夹杂物。使用了2种厚度（15和22毫米）的4种类型的陶瓷过滤器；测量布氏硬度和孔隙率。观察到微观结构的质量（出现氧化性颗粒和较大的非金属夹杂物）。实验结果表明，将陶瓷过滤器插入入口系统主要是导致孔隙率降低。在微观结构上，没有明显反映出过滤器的包含
