ARCHIVES
of
FOUNDRY ENGINEERING
10.24425/afe.2022.140241
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
ISSN (2299-2944)
Volume 2022
Issue 3/2022
95 – 98
12/3

Effect of Filter Type on Mechanical Properties During Aluminium Alloy Casting

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Received 31.05.2022; accepted in revised form 16.08.2022; available online 30.09.2022

Abstract

The naturally pressurized gating system was used for reoxidation suppression during aluminium alloy casting. A naturally pressurized gating system appears to be a suitable solution to reduce reoxidation processes, which was proven by our previous works. The disadvantage of this system is that without inserting deceleration elements, the melt velocity is supercritical. Therefore, the aim of paper is to find a proper way to reduce the melt velocity, which is the main parameter affecting the scale of reoxidation processes. For the purpose of the melt velocity reduction, labyrinth filters, foam filters and flat filters effect on the melt velocity and the number of oxides were investigated by numerical simulation software in the first stage of the experiment. After simulations observation, the effect of filters on the mechanical properties was investigated by experimental casts. The simulations and experimental casts proved that filters had a positive effect on the melt velocity reduction and it was associated with increased mechanical properties of castings. The best results were achieved by the foam filter.

Keywords: Aluminium alloys, Filtration, Mechanical properties, Reoxidation, Melt velocity

1. Introduction

Reoxidation has a negative impact on the general quality of Al alloy castings. This phenomenon occurs mainly during the filling process of the gating system and mold cavity and also during melt transfers and melt treatments prior to pouring [1]. Reoxidation processes cause the double oxide films formation. The problem is their entrainment into the volume of the liquid metal by surface turbulence and their subsequent solidification in the casting. Entrained double oxide films are considered to be initiators of porosity and thus they can significantly influence the mechanical properties of castings [2,3,4]. Reoxidation processes are mainly affected by the gating system design and by melt velocity. For aluminium alloys, it is necessary that the melt velocity be lower than 0.5 m/s^{-1}, because higher melt velocity causes turbulence of the liquid metal which leads to entraining of surface oxide layers into the volume of the melt [5].

Improvement of the flow properties and the melt velocity reduction can be ensured by the filter in the gating system. Flow quality also depends on the type of used filter and its placement in the system. Filter media can also increase the mechanical properties of casting due to the inclusions removing process [6,7].

Aim of the work is to suppress reoxidation processes to a minimum by using a naturally pressurized gating system. High melt velocity in this type of gating system was expected and the main goal was to reduce it. For this purpose were used common foundry filters and their influence on the casting quality were analysed.

2. Experimental methods

Labyrinth filter, flat filter and foam filter effect on the melt velocity and the number of oxides in the gating system/final castings were investigated by simulations software ProCAST. In the second stage of experimental works, the influence of individual filters on mechanical properties was evaluated by experimental casts. For experimental purpose was used naturally pressurized gating system with slight modification, which positive effect on the reoxidation reduction during gating system filling was observed in previous work [8]. The cross-sectional ratio calculation for each part of the gating system is described in detail in the work [9]. As a reference gating system was used designed without a filter (Fig. 1a). For filter effect evaluation were constructed designs with labyrinth filter (Fig. 1b), flat filter (Fig. 1c) and foam filter with 20 ppi (Fig. 1d). Filters were placed in the gate area with horizontal positioning.

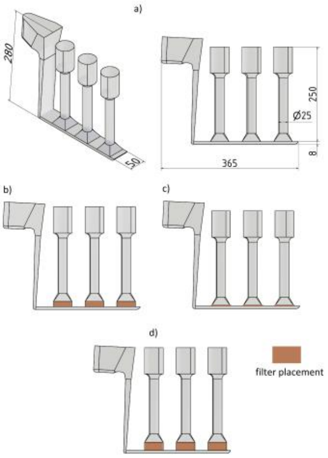

Fig. 1. Construction of gating system a) without filter, b) with labyrinth filter, c) with flat filter, d) with foam filter

Filters' placement effect on the melt velocity, melt flow character and number of oxides was evaluated by using the simulation software ProCAST**.** A two-phase filling module was used in contrast to previous works. Two-phase filling better and realistically describes the behaviour of the flowing metal, which is in contact with elements that are no longer considered „empty" in the cavity, as in the case of standard filling. It reacts with them according to parameters such as air back pressure, mold permeability resistance, places where air can leave, air temperature inside the cavity, etc. Relationship between mechanical properties of castings and filter types was analysed in the second phase of the experimental work. Identical conditions were applied to simulations and also to experimental casts, so both results can be compared. For purpose of experiments, aluminium alloy A356 with the chemical composition shown in Table 1 was used.

Table 1.
Experimental material

Element	Al	Si	Mg	Fe	Mn	Ti	Sr
[wt. %]	bal.	7.09	0.34	0.09	0.03	0.11	0.03

Mold was filled by gravity casting method from a 150 mm pouring height. The green sand mold was used for mold making process. The melt temperature was 720 ± 5 °C and the mold was filled at room temperature. The tensile strength, yield strength, elongation and rate of porosity were evaluated after experimental casts.

3. Results and discussion

3.1. Simulation analysis of melt flow and number of oxides

The scale representing the melt velocity and number of oxides is shown in Figure 2 for better visibility of values.

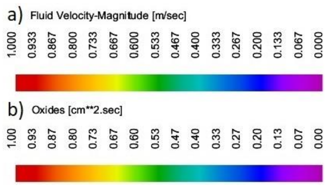

Fig. 2. Scale of a) melt velocity, b) number of oxides

In the naturally pressurized gating system, the cross section of the whole system is almost identical, therefore there is no possibility to reduce the melt velocity during the filling of the gating system without the addition of inserted „obstacle". As expected, it resulted in the supercritical melt velocity at the gate area (Fig. 3). The melt energy at the runner's end was relocated to the mold cavity. The reoxidation processes and thus the number of oxides increased due to the high melt velocity. Unreduced melt velocity resulted to extensive splashes which caused double oxide layers entraining into the melt volume. In this phase of filling according to Figure 3, the melt surface was folded at the entrance to the casting. During this process, a large amount of air was trapped in the melt volume. This process ensured that a large number of oxides were trapped in the final casting (Fig. 4). All benefits of naturally pressurized gating system were negated at this point, because mold cavity was not filled calmly.

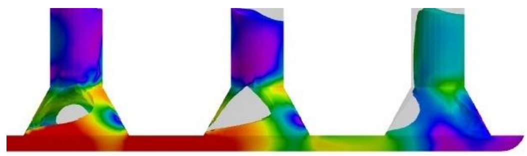

Fig. 3. Melt velocity in the construction without filter

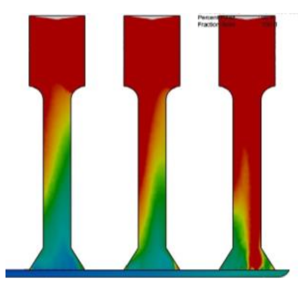

Fig. 4. Number of oxides in the construction without filter

A labyrinth filter is not commonly used for the aluminium alloy casting process, but due to its complex geometry, it was interesting to analyse the filter effect on melt flow in general. According to the simulation (Fig. 5), the labyrinth filter ensured a calmer filling of the mold cavity. However, it can be seen that the melt at the top of the filter is divided into separate melt streams which are almost immediately covered by the oxide layer. Subsequently, the turbulent character of the filling caused double oxide layer entrainment into the melt volume. Despite of splashes height reduction, the large number of oxides was trapped in the casting, which is clearly undesirable as shown in Fig. 6.

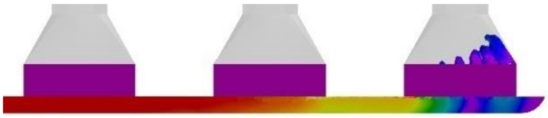

Fig. 5. Melt velocity in the construction with labyrinth filter

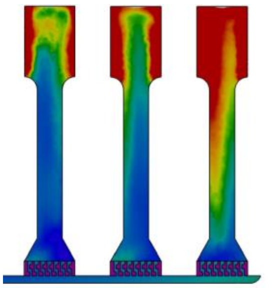

Fig. 6. Number of oxides in the construction with labyrinth filter

Construction with a flat filter (Fig. 7) and foam filter (Fig. 9) ensured that the mold cavity was filled calmly, splashes rate was decreased compared to the reference gating system. These types of filters reduced the melt velocity, which resulted in a more controlled filling of the mold cavity and splashes height was minimized.

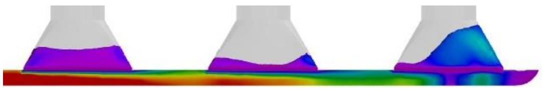

Fig. 7. Melt velocity in the construction with flat filter

Double oxide layer formation was suppressed and it ensured significantly better results in term of oxides amount trapped in the casting (Fig. 8, Fig. 10).

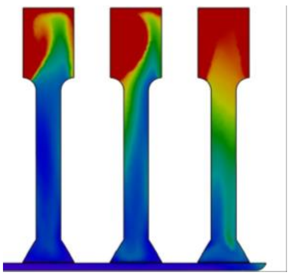

Fig. 8. Number of oxides in the construction with flat filter

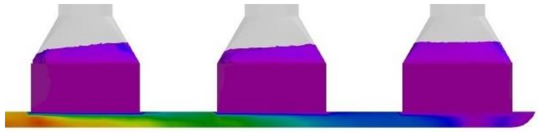

Fig. 9. Melt velocity in the construction with foam filter

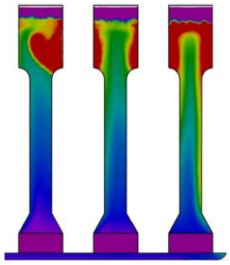

Fig. 10. Number of oxides in the construction with foam filter

The velocity evaluation is shown in the graph represented in Fig. 11. The velocity was evaluated as the average value of the melt velocity for all nodes at the entrance gate area cross-section measured for all three castings. As expected, the reference design reached supercritical melt velocity values. Melt velocity was reduced using filter media. Construction with labyrinth filter reduced melt velocity by 50%, flat filter by 60% and foam filter reduced melt velocity by 75%.

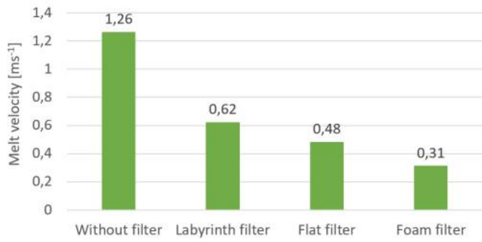

Fig. 11. Evaluation of melt velocity

3.2. Evaluation of porosity and mechanical properties

Experimental samples were cast in order to evaluate the influence of filter types on the porosity quantity and mechanical properties. The quantification of pores was evaluated by QuickPHOTO INDUSTRIAL software which allows to mark all pores in analysed area and summarize the area they represent in the sample. Figure 12 shows the average values of porosity for each type of filter.

Without melt velocity reduction, the mold cavity suffers from splashes causing extensive reoxidation. Therefore, construction without filter media achieved the highest values of porosity. The rate of porosity decreased by using filter media. The lowest effect had a labyrinth filter due to the character of melt flow at the filter outlet. The analysis of porosity revealed, that the foam filter greatly reduced the rate of pores, which was considered because of the mold cavity avoided a large amount of double oxide layer formation. The porosity rate in this construction was reduced by 42 %.

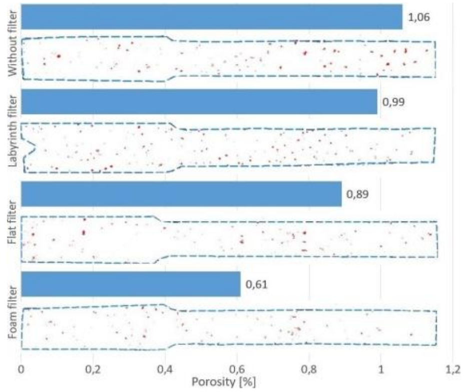

Fig. 12. Evaluation of porosity

As expected, the design without the filter achieved the lowest tensile strength, yield strength and elongation values. Using the filter is connected to the mechanical properties increase. These mechanical properties increased according to the porosity rate decreased. Fig. 13 shows the average mechanical properties values. The best results of mechanical properties were achieved with a foam filter. It ensured tensile strength and yield strength enhancement about by 15 % and elongation by 50 %.

After simulation observation, it can be noticed that mechanical properties are affected by melt velocity at the entrance of the mold cavity. It is correlated with the number of oxides captured in the casting. Increasing of the number of oxides caused porosity rate growth which negatively affects the mechanical properties and quality of the final casting.

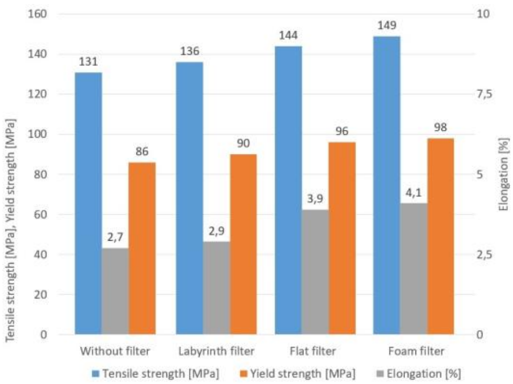

Fig. 13. Evaluation of mechanical properties

4. Conclusions

The naturally pressurized gating system was designed in order to achieve reoxidation suppression. Due to critical melt velocity, use of naturally pressurized system is not common in practice. Experimental work has proven, that melt velocity can be reduced by filter media. After simulation observation and experimental casts, it can be stated, that labyrinth filter is not suitable for increasing casting quality. Although it caused about 50 % melt velocity reduction, the mechanical properties are almost the same as without filter. It is due to wrong melt flow behaviour at the filter outlet. It resulted to a large amount of entrained oxide layers in the melt volume.

After simulation evaluation, it can be stated, that the melt velocity and splashes height in the casting cavity were significantly reduced by flat and foam filter. Experimental casts proved positive effect of flat and foam filter presence on castings mechanical properties. Construction with foam filter media showed the biggest improvement in terms of mechanical properties. Results of porosity analysis also proved relationship between number of oxides analysed by numerical simulation and pore rate evaluated on casted samples.

Acknowledgements

This paper was written with financial support from the UNIZA Grant System project 01/2021 (13858).

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