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EFFECT OF FILTER THICKNESS ON REOXIDATION AND MECHANICAL PROPERTIES OF ALUMINIUM ALLOY AlSi7Mg0.3

The melt cleaning is an important aspect in the production of high-quality aluminum castings. Specifically inclusions within the melt and an excessively high hydrogen content lead to defects and undesired porosity in the castings. Although it is possible to reduce the amount of hydrogen and oxidic inclusions by purge gas treatment and the use of melting salts, it is impossible to remove oxides (bifilms) created during filling of gating system. Paper deals with the effects of melt quality and the placement of a filter in the filling system on Al-7%Si-Mg alloy mechanical properties. Three different filters were used: (a) rectangular ceramic pressed filter with 3 mm thickness (b) cubical pressed ceramic filter with thickness 10 mm (c) cubical pressed ceramic filter with thickness 22 mm. The results showed that the highest tensile strength values were obtained from the filter with thickness of 22 mm. Numerical simulation analysis of the filling process showed that velocity reduction by filter is the major phenomenon affecting the mechanical properties. Another evaluated aspect during experiments was capability of filters to retain old bifilms. For this purpose multiply remelted alloy was prepared and analyzed. Results showed that filter efficiency increases with decreasing melt quality as a result of possibility to retain "old" bifilms better than small and thin "new" bifilms.

Keywords: Bifilm, numerical simulation, reoxidation, mechanical properties, filtration

1. Introduction

Aluminum-silicon cast alloys offer a good combination of mechanical properties and castability, which account for their wide use in automotive and aerospace applications. Nevertheless, aluminum castings have been rarely used in safety-critical applications due to concerns about the variability in mechanical properties, especially in elongation and fatigue life. This high level of variability is the consequence of structural defects in castings, i.e. pores and oxide bifilms, which degrade mechanical properties. They cause premature fracture in tension and fatigue, resulting in low ductility, tensile strength and fatigue life. Therefore, the presence of major structural defects results in the high level of variability in mechanical properties as evidenced most notably by lower Weibull module. Hence, the minimization and even elimination of structural defects is vital for wider use of aluminum castings in structural applications in aerospace and automotive industries.

A general acceptance is gradually growing among researchers that oxide bifilms play a major role in the reduction of the quality and reliability of aluminum casting alloys. Campbell reported that oxide bifilms, which remain in the cast products, cause mechanical weakness and form leak paths through the walls of castings. Campbell also reported that oxide bifilms appear to be the source of most of the general casting defects and act as cracks to initiate failures. Furthermore, they exert major control of the cast microstructure, including (a) grain size, (b) DAS, and (c) the modification of the eutectic silicon in the aluminum alloys. Defects related to oxide bifilms have more importance when there is no presence of pores, because they present two-dimensional morphology and they have higher dependence on the loading direction while, on the other hand, pores present three-dimensional morphology – cavities. Earlier investigations for the effect of using ceramic filters on the tensile properties of A356 Al alloy, showed that only about 10% of the benefit of using a filter in the running system is derived from the prevention of solid inclusions from entering the mold cavity and the other 90% is actually from the improvement in the filling behavior of the casting. Also it has even been suggested that the entrained defects could account for as much as 80% of the total effective problems in castings [1,2].

2. Experimental work

2.1. Material

For purposes of experimental casts, Al-7%Si-Mg alloy was used. These alloys have very good casting and machining characteristics. Typically they are used in the heat-treated condition

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of T5 and T6 hardness properties. Corrosion resistance is good, mechanical properties are rated excellent particularly if given a solution and aging treatment (T5, T6). Typically this alloy is used in castings for aircraft parts, pump housings, impellers, high velocity blowers and structural castings where high strength is required. It can also be used as a substitute for aluminum alloy 6061.The fact that Al-7%Si-Mg have good castability makes it a logical choice for intricate and complex castings where light-weight, pressure tightness and excellent mechanical properties are needed. The chemical composition of the alloy is shown in Table 1 [3].

TABLE 1

Chemical composition of AlSi7Mg0.3 alloy

Element	Si	Fe	Mg	Ti	Cu	Mn	Al
[wt. %]	6.93	0.12	0.39	0.12	0.002	0.003	Bal.

2.2. Ceramic filters

Extruded ceramic filters with various thickness were used during experiments. Filters were made from material refractory mullite. Flat rectangular filter (3 mm) and two filters with a square cross-section (thickness 10 mm and 22 mm) are shown on Fig. 1.

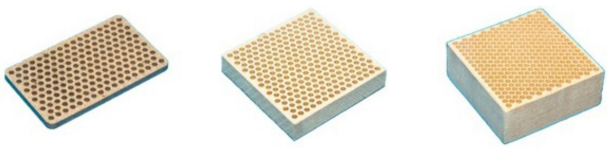

Fig. 1. Used ceramic filters

Main aim was to evaluate effect of filters on refining process for directly cast material (with only “new” and thin bifilms) and for material remelted 4 times (old, thicker bifilms). Filters were placed in a runner as shown on Fig. 2. The ceramic filter placement purpose was to remove previously formed inclusions and oxide bifilms, and also reduce the speed of flow of the molten alloy filling the mold in order to prevent any further oxide bifilm from being entrained. The pattern used for this experiment was the tensile test bar mold. Each mold contained three test bars, each with a diameter of 20 mm and length of 200 mm.

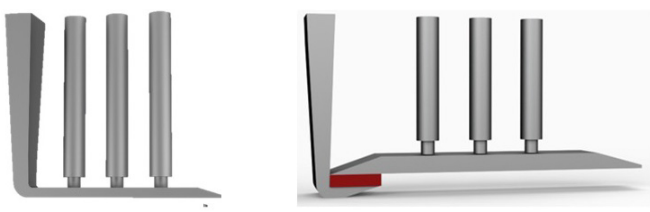

Fig. 2. Gating system layouts

Parameters of used filters are listed in Table 2.

TABLE 2

Parameters of used filters

Filter	Dimensions [mm]	Number of holes	Holes dimension [mm]	Area of holes [mm^2]
Rectangular thin (3 mm)	49×30×3	182	Ø 2 ± 0.15	571
Ceramic pressed (10 mm)	49×49×10	314	Ø 2,2 ± 0.15	1194
Ceramic pressed (22 mm)	49×49×22	247	Ø 2,2 ± 0.15	939

2.3. Methodology of experiments

The aluminum alloy used for each experimental combination was prepared in an electrical resistance melting furnace and the casting temperature was 720°C. For mold production, green sand was used. The experimental melts consisted of determining the hydrogen content at none, two and four times remelted aluminium alloy to quantitative determine oxides amount. Subsequently the experimental samples in the shape of rods were poured. First experimental samples were poured without filter in gating system, second, third and fourth set of samples were poured with use of above mentioned filters. Whole process has been done for alloy without remelting, but also for four times remelted alloy. Evaluation of mechanical properties were performed on prepared samples and numerical simulation results were used to support achieved results.

2.4. Batch preparation

The experiment itself preceded by the preparation of the batch, which consisted of dividing material into three parts. One part was used for direct casting, second part was before casting two times remelted and third part was four times remelted before casting. Remelting process consisted of melting the batch to temperature 720°C and poured into ingots, after solidification, the process was repeated.

3. Results

3.1. Hydrogen analysis

Reduced pressure test was used, which allows the quantitative assessment of the hydrogen content in the melt by the so-called “density index”. This type of test was used because of its widespread use in foundry industry, interpretative results and ease of use. It involves the solidification of two small samples of melt, one at atmospheric pressure, and the other under a partial vacuum. A comparison of the samples densities is then used to give a numerical indication of gas content. To perform the test, a Vacuum density tester from Melt Measuring Technology "3VT LC DT" type with a "GA 501" vacuum pump and a "mk 2200 LC" special scale was used, which has a built-in algorithm counter for density index. Results of RPT are listed in table 3 [3,4].

TABLE 3

RPT values

Number of remelts	Atmospheric density [g.cm^{-3}]	Density in partial vacuum [g.cm^{-3}]	Density index [%]
0	2.64	2.6	1.52
2	2.59	2.38	8.11
4	2.58	2.28	9.16

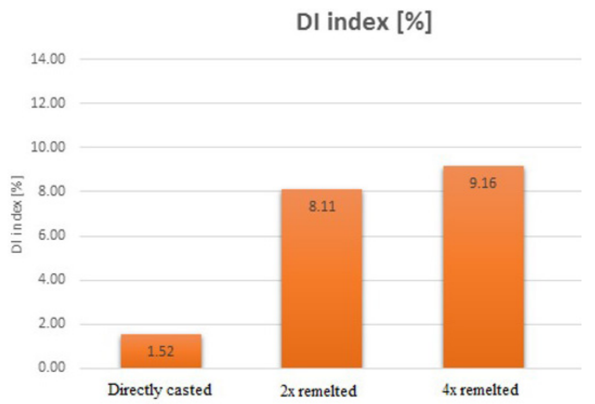

Fig. 3. Density index

In the clean melt, regardless of the hydrogen level, the density of the samples remained constant at close to the theoretical density of aluminium 2700 kg.m^{-3}, even though the samples were solidified under vacuum. However, once the bifilms were introduced (intentionally by remelting), a clear decrease in the density of the samples was observed. This reduction in the density of samples appeared to be the result of the inflation of the bifilms as can be seen on the sectioned surfaces of the samples in Fig. 4. These results corroborate that porosity is not nucleated in a melt of clean aluminium in the absence of entrained surface films. It can be stated that remelting has a very adverse effect on the melt alloys content. The largest difference in density index occurred between the directly casted sample (DI = 1.52%) and the two time remelted sample (DI = 8.11%). Between twice (DI = 8.11%) and four times (DI = 9.16%) remelted sample the difference is smaller, but amount of oxides (bifilms) increased as well (Fig. 3).

Fig. 4. Sample solidified in partial vacuum: Directly casted sample (left), 2× remelted (middle), 4× remelted (right)

3.2. Melt filtration

The test castings were cast into a green sand mold. The molten alloy was not additionally modified or refined. Before casting, the dross was removed from the surface of the melt, followed by casting itself into the mold. Three castings were cast for each filter and also for gating system without filter.

3.3. Tensile static test evaluation

The tests were carried out according to the methodological instructions „Methodical instructions for carrying out basic mechanical tests of metals, tensile test" and in accordance with STN EN ISO 6892-1. On the basis of this test, Rm (tensile strength) and A5 (elongation) were obtained. Tensile strength values of arithmetic mean from three samples are shown in Fig. 5 for directly casted samples and Fig. 6 shows results for four times remelted samples.

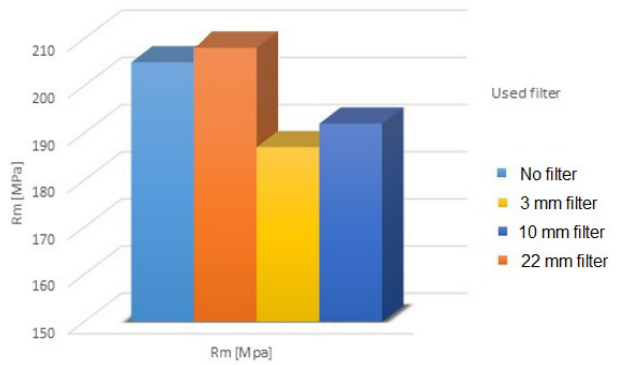

Fig. 5. Tensile strength evaluation for directly casted alloy

The primary (directly casted) alloy properties without filtration were almost the highest amongst the conditions tested in this work. Ultimate tensile strength (Rm 205 MPa) was only slightly lower then value reached by 22 mm filter (209 MPa) and the elongation was clearly highest (A_5 6.8%). By deliberately remelting alloy (4×) and pouring without filter, tensile strength decreased by 18% (Rm 169 MPa) and elongation decreased significantly by 90% (A_5 0.7%).

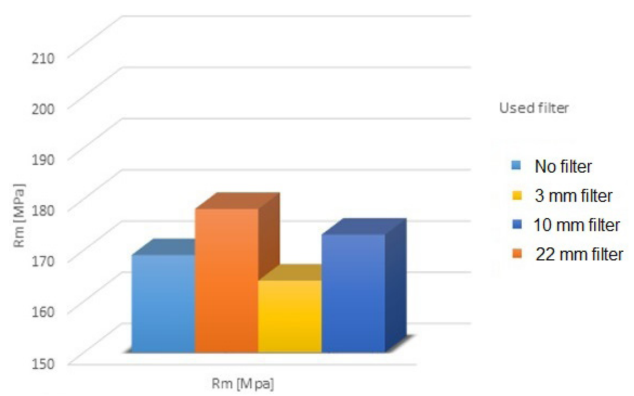

Fig. 6. Tensile strength evaluation for 4× remelted alloy

By using 10 mm filter and 3 mm filter during pouring the primary alloy, the mechanical properties decreased. This phenomenon is caused by fact, that filtration represent “obstacle” in gating system causing disturbances in melt flow. While pouring primary (relatively clean melt with only new bifilms) filter is unable to retain small, compact and thin bifilms and its effect is therefore minimal from the refining perspective. Only in case of 22 mm filter tensile strength increased (Rm 209 MPa). This is due to the fact, that only 22 mm thick filter can reduce a flow velocity near to a critical value 0.5 m/s (proven by numerical simulation – Fig. 12). The same goes for elongation whereas it is also dependent on bifilms amount, thickness and size. Specific values for elongation are [5]:

– No filter; A5 = 6.8%,
– 3 mm filter; A5 = 3%,
– 22 mm filter; A5 = 5.7%,
– 10 mm filter; A5 = 3.4%.

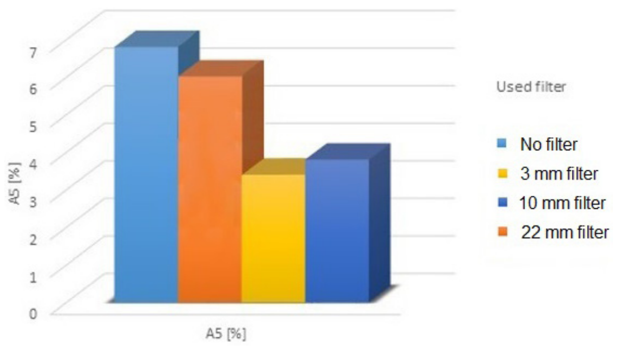

Fig. 7. Elongation evaluation for directly casted alloy

However, when pouring primary alloy (high quality melt), it does not necessarily mean that the elongation values will be high, as shown at Fig. 7. Campbell had shown the effect of reduction in area by the presence of a defect and how it would affect the elongation at fracture. In the same analogy, considering a bifilm with a size of 1 mm, its orientation with reference to the tensile axis has to play an important role for the determination of the elongation at facture. If it lies parallel with the tensile axis, the elongation at fracture might be high. On the contrary, the positioning of the same size bifilm perpendicular to the axis has to decrease the elongation at fracture at a relatively lower value. Dispinar had found similar results. It can be concluded that with the low quality melt, the higher the population of these defect, the most likely the material will fail easily [4,6].

By closer evaluation of elongation for four times remelted alloy we can conclude, that all three types of filters have positive effect (compared to primary alloy elongation values) due to the ability to refine old and large bifilms, which have major impact on elongation (Fig. 8). Specific values for elongation are:

– No filter; A5 = 0.7%,
– 3 mm filter; A5 = 2.1%,
– 22 mm filter; A5 = 1.8%,
– 10 mm filter; A5 = 1.6%.

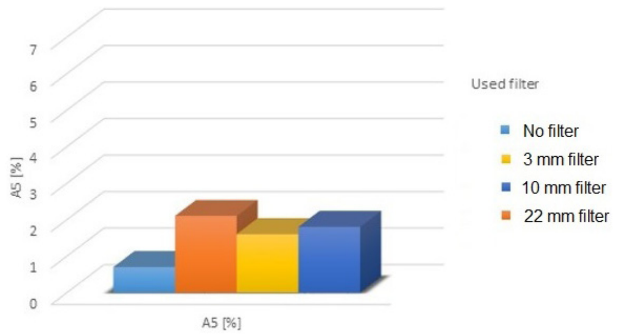

Fig. 8. Elongation evaluation for 4x remelted alloy

3.4. Evaluation of experiment by numerical simulation

ProCAST simulation software was used during flow analysis. The individual filter media was imported into the simulation software with the exact geometry created in third party CAD software. This fact has a considerable impact on the complexity of the whole simulation process, especially on the creation of fine mesh, which ultimately reflected on computational complexity. In the conventional method, the software does not take into account the geometry of the individual filter channels and calculate only with flow drop and pressure drop. The main advantage of the used simulation method is the possibility of more accurate observation of the melt flow in the area of the filter. With this method, we focused in particular on the nature of the melt flow (critical velocity) before and after the filter, in terms of reoxidation and turbulent energy. Main condition parameters for each simulation were based on real conditions during sample preparation: flow rate 1 kg/s; pouring temperature 720°C; air cooling parameter was plied at mold external area. Critical velocity for all engineering liquid metals is approximately 0.5 m/s, which, if exceeded, means that the melt has sufficient energy to splash, and so is in danger of enfolding its surface to create bifilms. Cross-section analysis for 3 mm filter shows three main problems shown at Fig. 9. Fluid velocity reduction is insufficient (critical velocity exceeded up to 1.5 m/s), extensive turbulences in close vicinity of filter and air pocket at the output section of the filter (melt exposed to air) [7, 8].

10 mm filter shows improvement from the flow velocity point of view. Maximum velocity reached at the output area of the filter is 1 m/s. By decreasing maximal velocity, also turbulent energy created by filter decreased as shown at Fig 10.

By evaluating flow velocity for 22 mm filter we can conclude, that this filter is capable to restrict melt flow to 0.5-0.6 m/s. Turbulence on both ends of filter are minimal and air pocket was completely eliminated, what have positive impact on gating system filling without bifilm creation (Fig. 11).

4. Conclusions

1. As the bifilm content increased, the decreases of mechanical properties occurred. In order to achieve high quality

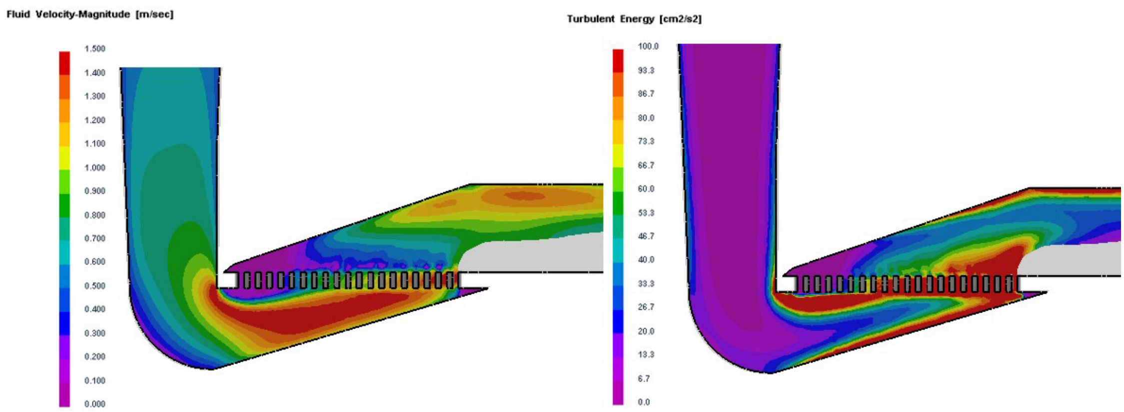

Fig. 9. Flow and turbulence analysis by ProCAST for 3 mm filter

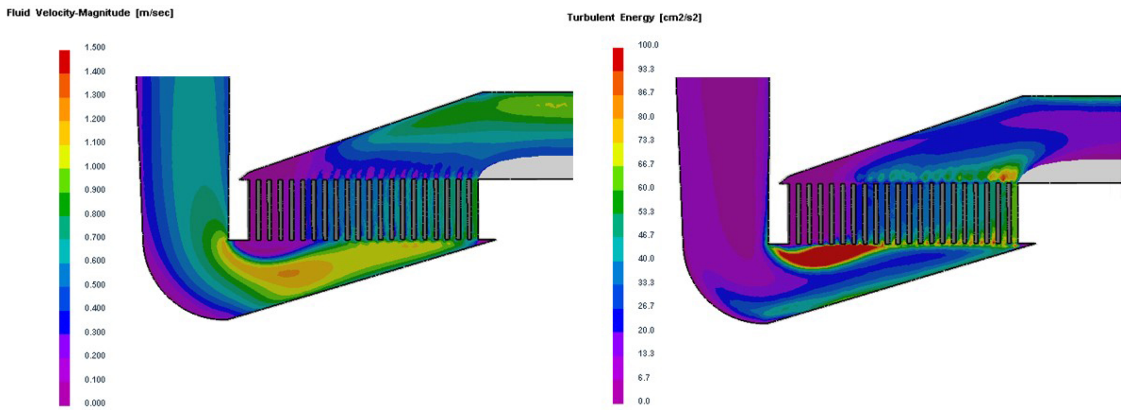

Fig. 10. Flow and turbulence analysis by ProCAST for 10 mm filter

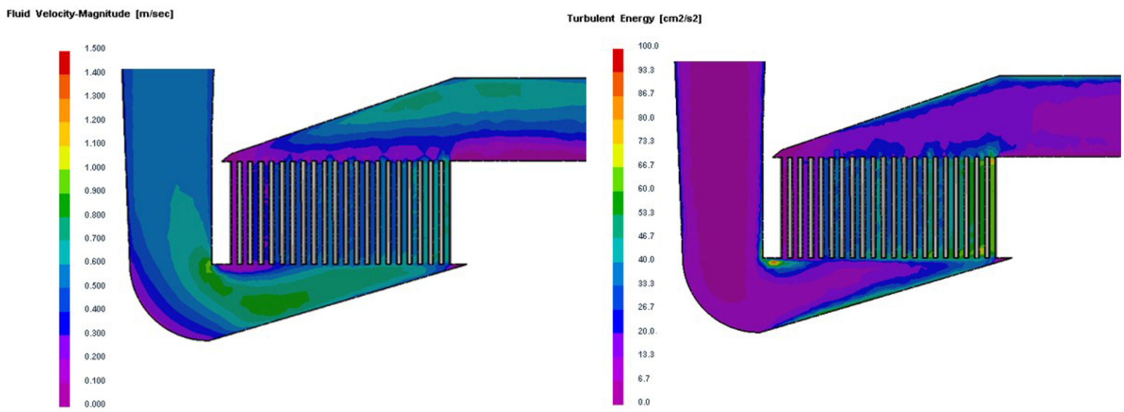

Fig. 11. Flow and turbulence analysis by ProCAST for 20 mm filter

castings, bifilm content of the melt has to be as low as possible.

2. As prof. Campbell suggested, the matrix must technically behave as a perfect plastic material; and only the presence of defects, the necking may be hindered to result in a premature fracture or brittle fracture. The presence of folded oxide skins (i.e. bifilms) already act as a stress riser and the earlier works have shown that these defects play a significant role on mechanical properties of the cast parts.
3. The more quiescently the casting is controlled, the higher the quality of the final products will be. Good control should include: (i) careful minimization of turbulence at tapping; (ii) minimized fall of the liquid; and (iii) filling conditions to reduce turbulence in the mold.
4. Filter position in the runner plays a significant role in the generation or elimination of bifilms.
5. From achieved results, only filter with thickness 22 mm proven to have significant positive effect on mechanical properties for primary alloy and also 4× remelted alloy. This is due to the fact that 22 mm filter is able to decrease the velocity to acceptable value and has a positive impact on flow pattern in gating system.

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