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A Study of Microstructure and Porosity Formation in High-Pressure Die-Casting

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Abstract

The technology of high-pressure die-casting (HPDC) of aluminum alloys is one of the most used and most economical technology for mass production of castings. High-pressure die-casting technology is characterized by the production of complex, thin-walled and dimensionally accurate castings. An important role is placed on the effective reduction of costs in the production process, wherein the combination with the technology of high-pressure die-casting is the possibility of recycling using returnable material. The experimental part of the paper focuses on the analysis of a gradual increase of the returnable material amount in combination with a commercial purity alloy for the production of high-pressure die-castings. The returnable material consisted of the so-called foundry waste (defective castings, venting and gating systems, etc.). The first step of the experimental castings evaluation consisted of numerical simulations, performed to determine the points of the casting, where porosity occurs. In the next step, the evaluation of areal porosity and microstructural analysis was performed on experimental castings with different amounts of returnable material in the batch. The evaluation of the area porosity showed only a small effect of the increased amount of the returnable material in the batch, where the worst results were obtained by the casting of the alloy with 90% but also with 55% of the returnable material in the batch. The microstructure analysis showed that the increase in returnable material in the batch was visibly manifested only by a change in the morphology of the eutectic Si.

Keywords: Al-Si-Cu alloy, Returnable material, Numerical simulation, Porosity, Microstructure

1. Introduction

Aluminum castings cast produced by high-pressure die-casting technology account for 60% of the total consumption of aluminum castings in recent years. Currently, the largest customer of such castings is the automotive industry, where they play an important role as components that must meet high-quality standards [1,2].

In addition to their main use, the emphasis on castings and their production is to reduce the production costs of castings. For these reasons, it is almost necessary today to include returnable material, respectively the residue of unused metal (metal residues in the filling chamber or venting, inlet and gating systems) to the production process as part of the batch. The proportion of returnable material in the batch depends on the overall geometry of the casting or its use and operating conditions. An increased amount of returnable material in the batch can result in permanent deformations and a decrease in the overall quality of the casting. These are mainly parts of the venting system (chill vent and overflows) characterized by an increased content of air, oxide layers and inclusions, which are present in the aluminum melt during the subsequent remelting. The proportion of returnable material is most often from 20% of the content for castings with smaller dimensions and higher complexity up to 75% for large castings. [3-5].

The most commonly observed defect on HPDC castings is the porosity, which decreases the overall internal homogeneity of the casting. Porosity is most often formed by trapping air in the liquid metal during the filling process. It is also possible to observe pores in castings formed by the occurrence of the shrinkage phenomenon. Increased porosity can also be caused in the case of low mould temperature when excess water from the sprays is entrapped inside the casting, and its subsequent evaporation creates air bubbles. [6-8].

2. Experimental process

Experimental evaluation of porosity formation and microstructural change due to batch composition change was performed on a casting marked "Stator Buchse D 106". The Stator Buchse casting was cast in a double-cavity mould by HPDC technology (Fig. 1) from an aluminum sub-eutectic alloy AlSi9Cu3 (Fe). The casting is used as a part of electric motors for the air conditioning of buildings and halls.

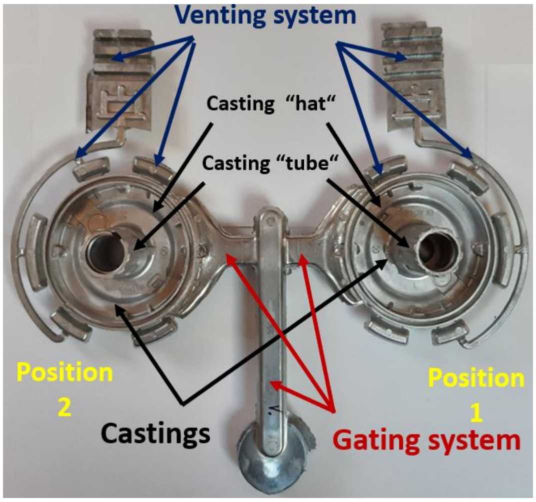

Fig. 1. The geometry of casting Buchse in double cavity mould

The experimental process was performed in cooperation with the Department of Technological Engineering at the University of Žilina and the company Rosenberg-Slovakia s.r.o., Medzev.

For experimental purposes, four experimental variants of AlSi9Cu3 (Fe) alloy with different contents of primary alloy and remelted returnable material in the batch were cast. The returnable material used consisted of non-conforming castings and in particular parts of gating and venting systems. The content of returnable material was determined to be 10, 55, 75 and 90% of the total weight of the batch. The castings were subsequently marked based on the alloy used as A10, A55, A75 and A90. The chemical composition of newly formed experimental AlSi9Cu3 (Fe) alloys is given in Tab. 1.

Batch preparation, melting and casting of experimental castings were performed in the premises of the Rosenberg-Slovakia foundry. A STRIKOWESTOFEN MHS 750/350 melting furnace with a holding space capacity of 750 kg was used for melting and A CLH 400 pressure press was used for casting. The melt was rotary degassed with nitrogen for 120 seconds at temperature 720 ° C before being poured into the dosing device. The degassing process took place automatically and after its completion, oxide layers were mechanically removed from the surface. The parameters of high-pressure casting are given in Tab. 2.

Table 1.
Chemical composition of the experimental AlSi9Cu3(Fe) alloys [wt.%]

	Si	Fe	Cu	Mn	Mg	Ti	Ni
A10	9.207	0.761	2.056	0.242	0.345	0.033	0.066
A55	9.672	0.717	2.111	0.189	0.193	0.042	0.084
A75	10.92	0.772	2.012	0.225	0.234	0.033	0.083
A90	10.42	0.815	2.006	0.221	0.149	0.035	0.081

Table 2.
HPDC process parameters

The temperature in the holding furnace		710 ± 10 °C
Casting (tapping) temperature		710 ± 10 °C
Temperature of mould	Stationary part	160 ± 5 °C
	Moveable part	180 ± 5 °C
Degassing temperature		720 ± 5 °C
Maximum pressure in the chamber		95 MPa
Filling chamber diameter		60 mm
Active chamber length		470 mm
The maximum speed of the pressing piston		3 m/s
Rotary degassed with nitrogen		120 s

3. Results

3.1. Porosity evaluation

The porosity of the castings was evaluated by means of control sections, on which the area porosity was evaluated. The location of the two control sections A-A and B-B is shown in Fig. 2a. and castings at position 1 were used for evaluation. The sections of each casting were wet grinded and in sections photographed by the Nikon AZ100 Multizoom device, and the images were subsequently formatted into a compact image (Fig. 2b, c). The evaluation of the area porosity took place on the entire area of the section (the evaluation area of the sections is indicated by a yellow frame in Fig. 2b, c).

The section images of each casting were inserted into the QuickPHOTO INDUSTRIAL 3.1 program, where the total section area was then marked together with all pores on the given section. The surface porosity methodology is shown in Fig. 3.

The measured values of the areal porosity of both sections are given in Tab. 3. The numerical values in section A-A indicate that the increase in returnable material in the batch did not have an as significant effect as expected. The highest value of areal porosity was measured for the alloy with the highest proportion of returnable material in the A90 batch (0.23 %). The values of areal porosity measured on sections B - B also varied in a narrow range of values. As expected, the highest areal porosity value was also measured on the A90 alloy casting (0.42 %). The narrow range of measured values and failure to exceed the area porosity above 0.5 % indicates the stability of the results and only a slight effect of the increasing proportion of return material in the batch.

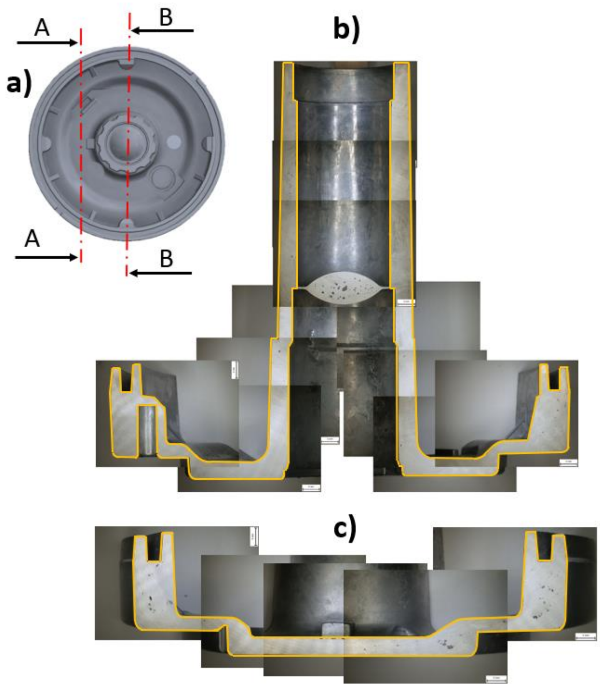

Fig. 2. Example of control sections by casting A55; a) Location of sections; b) Section B-B castings; c) Section A-A castings

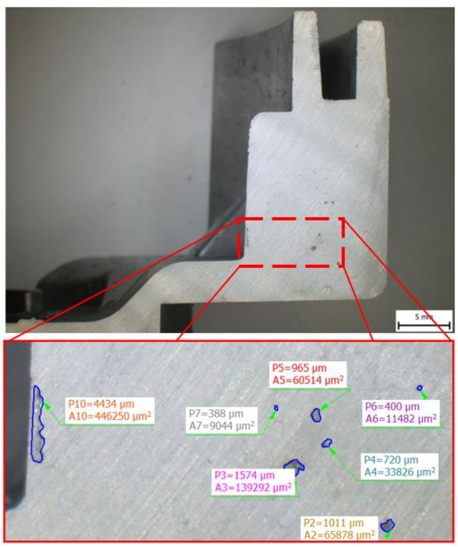

Fig. 3. Methodology of measuring areal porosity on control sections

Table 3.
Evaluation of areal porosity on the A-A and B-B sections

Alloy		A10	A55	A75	A90
Areal porosity [%]	**Sections A-A**	0.09	0.23	0.07	0.42
	Cut B-B	0.07	0.21	0.12	0.23

3.2. Structure evaluation

The wall of the hat part of casting was determined as the sampling site for structural analysis, and each sample was evaluated in the area of the surface and the central region.

The character of the microstructure of the castings of alloys A10 and A55 on optical microscope (OM) images are shown in Fig. 4. In the individual images, the difference of the microstructure from the wall to the centre of the casting is visible, which is caused by the different cooling rates in these places. Scanning electron microscope (SEM) images of eutectic Si after deep etchings show that fine, sharp-edged and fibrous morphology predominates in the surface area. The eutectic Si crystallized in the central region in a coarse plate-like morphology (Fig. 4a, b). The fine sharp-edged particles in the surface area and the plate morphology of the eutectic Si in the central area are also characteristic of the casting with a 55% content of return material A55 (Fig. 4c, d).

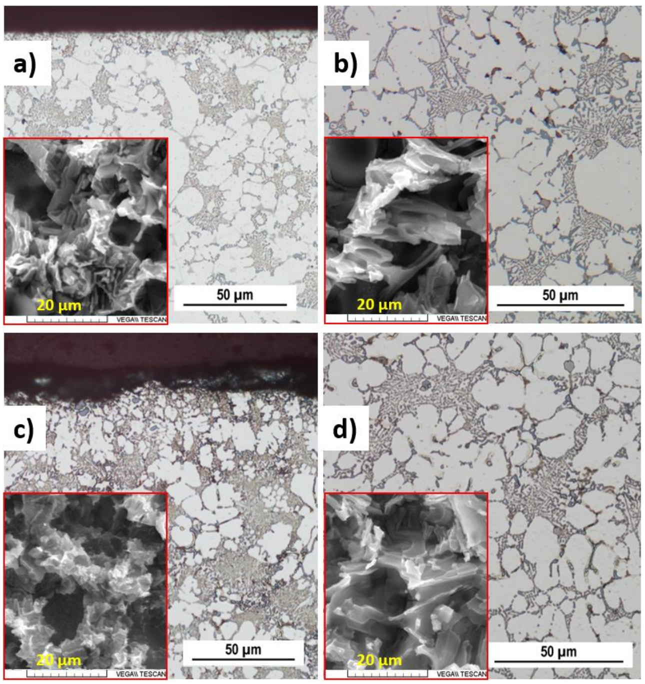

Fig. 4. Microstructure of casting A10 and A55 (OM – etc. Dix-Keller, SEM – etch. HCl); (a) surface area A10; (b) central region A10; c) surface area A55; (d) central region A55

With increasing amounts of returnable material in casting A75, there is a visible change in the shape of Si from the plate-like morphology at castings A10 and A55 to a coarse irregular morphology (Fig. 5a, b). The microstructure of the A90 casting is characterized by coarsely irregular eutectic Si particles with an undirected distribution in the central part (Fig. 5c, d). The eutectic Si crystallized in the surface area of the sample castings A75 and A90, similarly to the castings A10 and A55, with finer and in some places thicker sharp-edged particles.

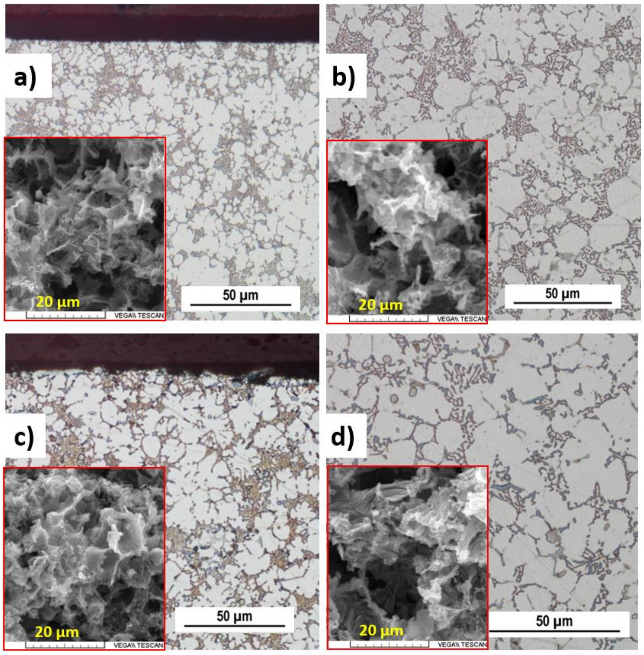

Fig. 5. Microstructure of casting A75 and A90 (OM – etc. Dix-Keller, SEM – etch. HCl); (a) surface area A75; (b) central region A75; c) surface area A90; (d) central region A90

5. Conclusions

The main goal of the presented article is to analyze and describe the effect of the gradual increase of multiple remelted returnable material in the batch during high-pressure casting.

The evaluation of the area porosity of the two control sections showed that the highest values were measured on castings from alloys A55 and A90. However, all measured values showed acceptable results, without exceeding the value of 0.5 % area porosity.

The structural analysis showed that due to the increase in returnable material, there was no fundamental change in the overall character of the microstructure of individual castings. The effect of the increase of the returnable material in the batch was visibly manifested by a change in the shape of the eutectic Si after exceeding 75% of the content when the coarsening of the originally thinner hexagonal plate structures of eutectic particles with an undirected distribution in the central region of the sample occurred. The increased cooling rate in the surface area of the sample was able to neutralize the negative effect of the increased content of return material in the batch (above 75%) and the morphology of eutectic Si was not significantly affected.

The use of returnable material as the most widely used form of recycling of aluminum alloys is a very complex and complicated issue, where also an important role is its proper way of sorting and oversight on the liquid metal.

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References

[1] Ragan, E. (2007). Die casting of metals. Prešov, Slovakia. (in Slovak).
[2] Eperješi, Ľ., Malik, J., Eperješi Š. & Fecko D. (2013) Influence of returning material on porosity of die castings. *Manufacturing Technology*. 13(1), 36-39. DOI: 10.21062/ujep/x.2013/a/1213-2489/MT/13/1/36.
[3] Gaustad, G., Olivetti, E. A. & Kirchain, R. (2012). Improving aluminum recycling: A survey of sorting and impurity removal technologies. *Resources Conservation and Recycling*. 58, 79-87.
[4] Matejka, M., Bolibruchová, D. & Kuriš, M. (2021). Crystallization of the structural components of multiple remelted AlSi9Cu3 alloy. *Archives of Foundry Engineering*. 21(2), 41-45. DOI: 10.24425/afe.2021.136096.
[5] Bruna, M., Remišová, A. & Sládek, A. (2019). Effect of filter thickness on reoxidation and mechanical properties of aluminium alloy AlSi7Mg0.3. *Archives of Metallurgy and Materials*. 3, 1100-1106. DOI: 10.24425/amm.2019.129500.
[6] Bryksi Stunova, B. & Bryksi, V. (2016). Analysis of defects in castings cast by rheocasting method SEED. *Archives of Foundry Engineering*. 16(3), 15-18. DOI: 10.1515/afe-2016-0041.
[7] Podprocká, R. & Bolibruchová, D. (2017). Iron intermetallic phases in the alloy based on Al-Si-Mg by applying manganese. *Archives of Foundry Engineering*. 17(3), 217-221. DOI: 10.24425/afe.2020.133321.
[8] Martinec, D., Pastircak, R. & Kantorikova, E. (2020). Using of technology semisolid squeeze casting by different initial states of material. *Archives of Foundry Engineering*. 20(1), 117-121. DOI: 10.24425/afe.2020.131292.