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The Influence of the Method of Mould Filling on the Quality of Castings Made of EN AC-44000 or EN AC-46200 Alloy

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Abstract

The performed examinations concerning the process of filling the plaster ceramic moulds with aluminium alloys allowed to assess the influence of various methods of introducing the metal into the mould cavity on the macro- and microstructure of the obtained experimental castings. The comparison was performed for castings with graded wall thickness made either of EN AC-44000 alloy or of EN AC-46000 alloy, produced either by gravity casting, or by gravity casting with negative pressure generated around the mould (according to the Vacumetal technology), or by counter-gravity casting. It was found that the silicon crystals grow in size with an increase in wall thickness due to the slower cooling and solidification of castings.

Keywords: Innovative foundry materials and technologies, Plaster mould, Counter-gravity casting, Vacuum casting

1. Introduction

The selection of casting technology, the way of introducing the molten metal into the mould cavity, and the position of a casting within the mould are decisive for the quality of produced items. The most frequently applied technology of casting aluminium alloys is the pressure die casting. The technology, despite its multiple advantages, is burdened, however, with the tendency to create internal porosity of castings due to the great metal injection speed. One of the ways used to reduce or eliminate the internal porosity of castings is extending the pressure die casting machines with vacuum systems supporting the die cavity filling [1-5].

The assistance of vacuum (i.e. the negative relative pressure) is generally applied during the mould filling process for two purposes, namely:

– the refining of liquid metal from gaseous inclusions, applied during or between the melting and the pouring operations by degassing the melt in the vacuum chamber in order to improve properties of the resulted castings;
– the filling or the supporting of filling the mould cavity due to the generated negative pressure.

Vacuum can be applied either as a supportive factor only – in the so-called vacuum-assisted systems, or can be the main driving force for the filling operation, the latter process being called the vacuum casting. Vacuum-assisted and vacuum casting processes include gravity, centrifugal or pressure filling of the mould cavity, inside which the pressure is lowered [3-6]. Various types of moulds can be used, e.g. plaster, metal, ceramic (for investment casting), or sand moulds [7].

As far as the aluminium-silicon alloys are concerned, the change in casting parameters (pressure, temperature) implies the change in the solubility of silicon in aluminium dependent on the number of components, phases and factors determining the phase equilibrium in the system. The relationship between the temperature and the pressure at the solid-liquid phase transition point is determined by the Clausius-Clapeyron equation [8]:

$$\left(\frac{dT}{dP}\right)_{T_A^{\alpha}}^{\alpha\to L} = \left(\frac{\Delta V}{\Delta S}\right)_{T_A^{\alpha}}^{\alpha\to L} \tag{1}$$

where: T – absolute temperature; P – pressure; ΔS – the entropy change during the α→L (solid-to-liquid) transition; ΔV – the volume change during the α→L transition.

The volume change ΔV takes the positive value for the α→L transition for most of metals, so that – according to the Le Chatelier-Braun principle – an increase in pressure rises the melting point. But such elements as gallium, germanium, silicon, or bismuth reduce their volume during this transition, so that the increased pressure lowers their melting point. The change in pressure results also in the increased thermal conductivity and latent heat of crystallization values. The value of ΔV would tend to zero for great pressure values, so that the deviation from the linear temperature-versus-pressure relationship would occur, and within the range of great pressures the same overcooling value ΔT could be achieved for different pressure values ΔP_1 and ΔP_2, ΔP_2 being greater than ΔP_1 while assuming that $P_2 > P_1$.

The pressure influences also the basic parameters of crystallization: the number of nuclei generated per unit time per unit volume and the linear rate of the nucleus growth. The relationship between the critical radius of the nucleus and the pressure and other parameters is given by the equation [9]:

$$R^N = \frac{2\sigma dT}{\Delta T \Delta V dP} \tag{2}$$

where: σ – the interfacial tension, ΔT – overcooling, ΔV – change in volume in the course of the phase transition, ΔP – change in pressure in the course of the phase transition.

The characteristic feature of castings solidifying under the external pressure is their fine-grain microstructure. The grain refining is a result of overcooling generated due to the applied pressure, as well as of the increased heat transfer in the casting-mould system.

2. Methods of investigation

The theoretical considerations indicate that the change in pressure is a factor which influence the solidification process, and by the same the properties of cast metals and alloys.

Therefore the present work attempted to determine the influence of the mould cavity filling conditions on the quality of experimental castings with graded thickness of the wall.

The investigated materials were the EN AC-44000 and the EN AC-46200 alloys. Three various methods of the mould filling were applied according to the scheme shown in Fig. 1, i.e. gravity filling (Fig. 1a), gravity filling with application of negative pressure around the mould (Fig. 1b), counter-gravity filling by negative pressure applied around the mould (Fig. 1c).

The second filling option was realised by means of the Mario di Maio vacuum casting machine [7], the third one was carried out at the laboratory stand designed and assembled for that purpose.

The pattern with graded wall thickness (2 mm, 4 mm, and 6 mm), made of low-melting mixture, was used to produce moulds of Al_2O_3 aggregate and plaster binder, according to the investment casting technology [5]. The selection of refractory aggregate was based on its value of thermal conductivity equal to about 20÷25 W/mK, which is close to the value of thermal conductivity of the pressure die.

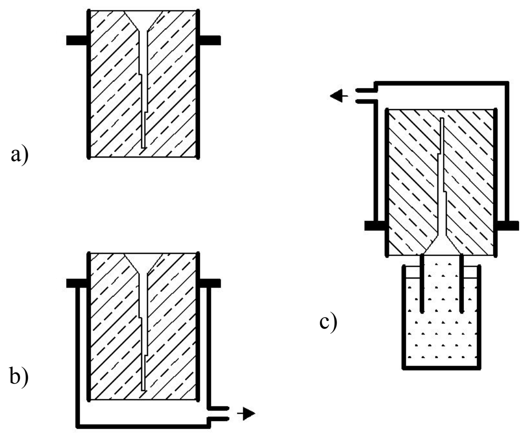


Fig. 1. The scheme of mould filling methods: a) gravity filling, b) gravity filling supported by the negative pressure, c) counter-gravity sucking under the negative pressure action

The temperature of the test moulds used during the experiment was equal to 150°C, and the temperature of the molten alloy was 660°C. Both the pressure around the mould for Vacumetal technology and the sucking pressure for the counter-gravity filling were 550 mm Hg, i.e. about 0.0665 MPa. The obtained test castings with graded wall thickness were assessed with respect to their macro- and microstructure.

3. Results of examinations

The obtained castings were examined with respect to their macrostructure. Observations revealed the presence of shrinkage porosity situated in places schematically indicated in Figs. 2 and 3.

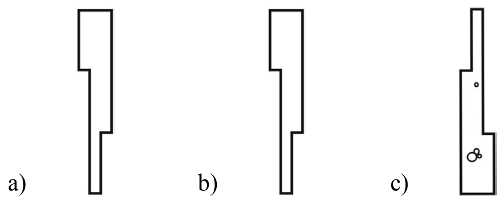


Fig. 2. Occurrence of porosity in castings made of EN AC-46200 alloy: a) gravity filling, b) gravity filling supported by the negative pressure, c) counter-gravity sucking under the negative pressure action

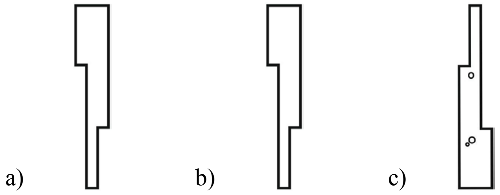


Fig. 3. Occurrence of porosity in castings made of EN AC-44000 alloy: a) gravity filling, b) gravity filling supported by the negative pressure, c) counter-gravity sucking under the negative pressure action

The ground and polished metallographic specimens were etched with Mi2Al etching solution according to the PN-75/H-04512 Standard "Non-ferrous metals - Reagents for revealing microstructure". The microstructures were observed at magnification 200× by means of the Nikon Epiphot microscope equipped with digital camera and recorded by means of the MultiScan program.

Table 1 gathers the results of examinations concerning the influence of the mould filling method on the microstructure of the obtained experimental castings with graded wall thickness (2 mm, 4 mm, and 6 mm) cast of the EN AC-46200 alloy, while the results for EN AC-44000 alloy are presented in Table 2.

Table 1.
The influence of the mould filling method on the microstructure of the obtained castings made of EN AC-46200 alloy

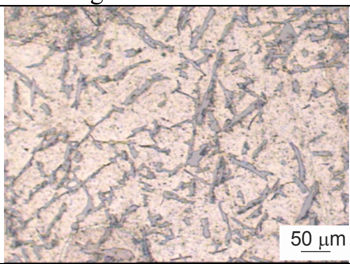
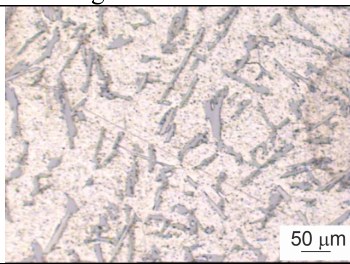
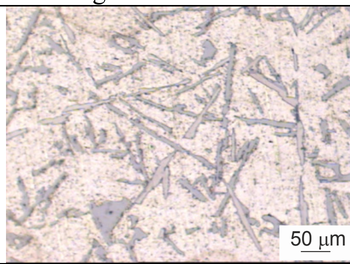
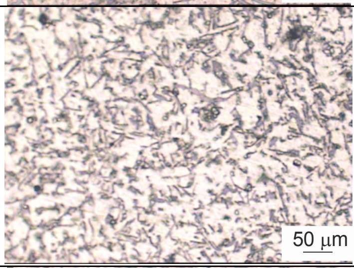
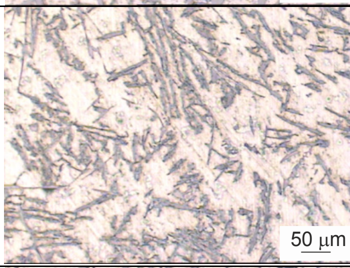
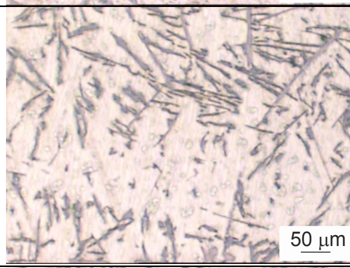
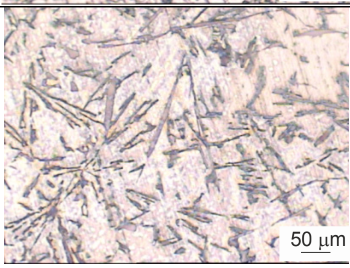
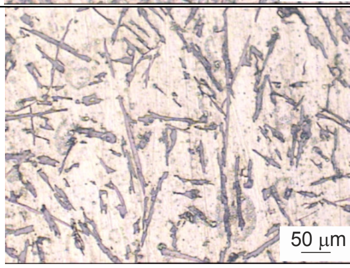
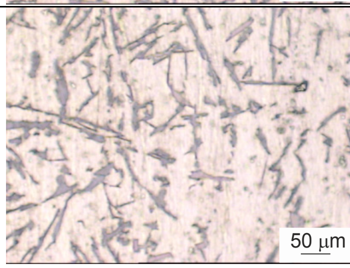
Technology	Casting wall thickness 2 mm	Casting wall thickness 4 mm	Casting wall thickness 6 mm
gravity filling			
gravity filling supported by the negative pressure			
counter-gravity sucking under the negative pressure action			

Table 2.
The influence of the mould filling method on the microstructure of the obtained castings made of EN AC-44000 alloy

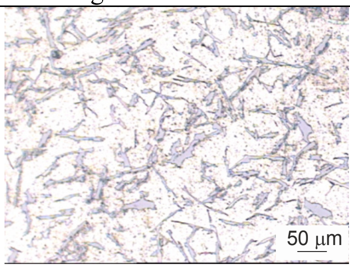
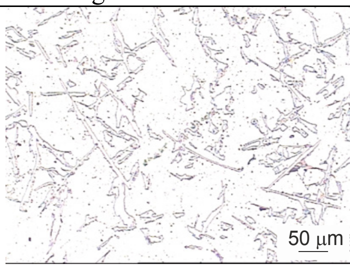
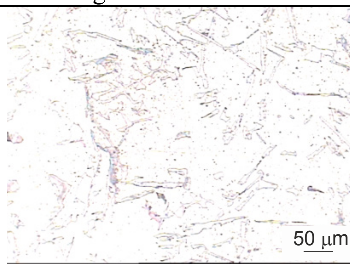
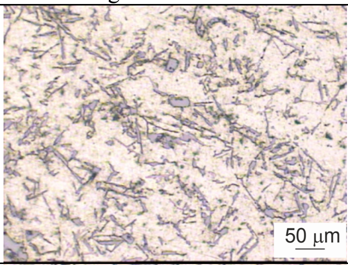
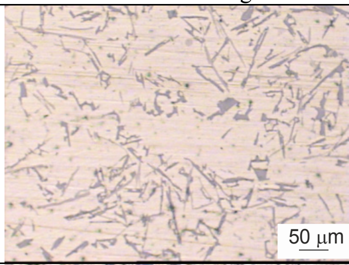
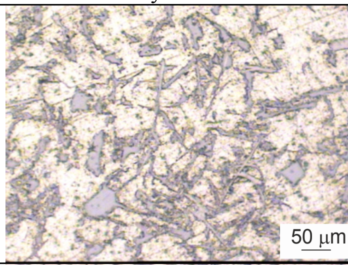
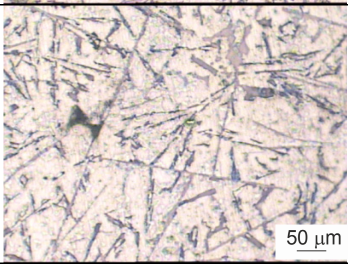
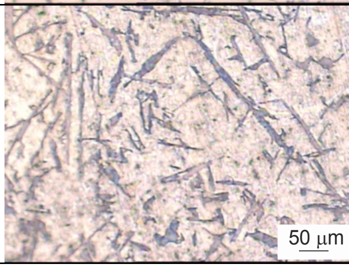
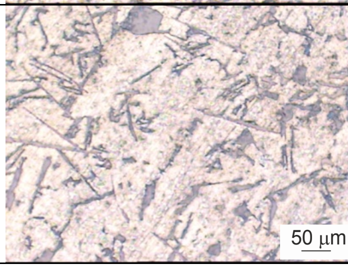
Technology	Casting wall thickness 2 mm	Casting wall thickness 4 mm	Casting wall thickness 6 mm
gravity filling			

Table 2 (continued)
The influence of the mould filling method on the microstructure of the obtained castings made of EN AC-44000 alloy

gravity filling supported by the negative pressure			
counter-gravity sucking under the negative pressure action			

4. Conclusion

The shrinkage porosity in castings produced of the EN AC-46200 or EN AC-44000 alloy was observed in the counter-gravity cast ones, in regions close to the places where the wall thickness abruptly changes. It can be attributed to the generation of a thermal centre under the thinner, faster solidifying wall, and the lack of suitable feeding.

The results of examinations concerning the influence of the method of mould filling on the microstructure of the obtained experimental castings with graded wall thickness (2 mm, 4 mm, and 6 mm), made of either EN AC-46200 or EN AC-44000 alloy, presented in Table 2, show microstructures characteristic for the applied alloys. As the wall thickness rises, the size of silicon crystals increases because of the lower cooling rate of the thicker casting wall. The microstructures of castings produced according to the Vacumetal technology are characterised by finer grain size than the other castings. It can be most probably attributed to the lower temperature of the mould, being decreased by the air flush in the mould cavity while the vacuum system tightness is controlled. In general, the influence of the negative pressure on the microstructure of castings made of the examined alloys was not observed.

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