ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 14
Issue 2/2014

19 – 22

4/2

The Influence of the Mould Filling Conditions on the Quality of Castings Made of EN AC-44000 Alloy

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Received 14.03.2014; accepted in revised form 30.03.2014

Abstract

The work deals with the influence of change in the filling conditions of the ceramic moulds with plaster binder on the presence of gaseous porosity and the microstructure of the achieved test castings with graded wall thickness. Castings made of EN AC-44000 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 were compared. The results of examinations concerning the density of the produced castings indicate that no significant change in porosity was found. The increased size of silicon crystals was found for the increased wall thicknesses 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 is decisive for the quality of produced castings. The most frequently used technology of casting applied for aluminium alloys is the pressure die casting. However, the technology is burdened 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 [1,2].

In general, the assistance of vacuum (i.e. negative relative pressure) is applied in casting technologies for two purposes, namely:

– the vacuum refining of liquid metal or alloy, applied during or between the melting and pouring operations by degassing the melt in the vacuum chamber, aimed to the improvement of properties of the resulted castings;
– filling or supporting the filling of 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 negative pressure is generated [3,4]. Various types of moulds can be used, e.g. plaster, metal, ceramic (for investment casting), or sand moulds [5].

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 [6]:

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

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 [7]:

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

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.

The increased density of castings is another result of applied pressure. This increase is caused by elimination of gaseous and shrinkage porosity.

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 material was the EN AC-44000 alloy. 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 according to the Vacumetal technology (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, the third one was carried out at the laboratory stand designed and assembled for that purpose.

The patterns with graded wall thickness (2 mm, 4 mm, and 6 mm, see Fig. 2), made of low-melting mixture, were used to produce moulds composed of Al_2O_3 refractory aggregate mixed with plaster binder, according to the investment casting technology. The refractory aggregate exhibited the value of thermal conductivity equal to about 20÷25 W/mK, which is close to the value of thermal conductivity of the pressure die.

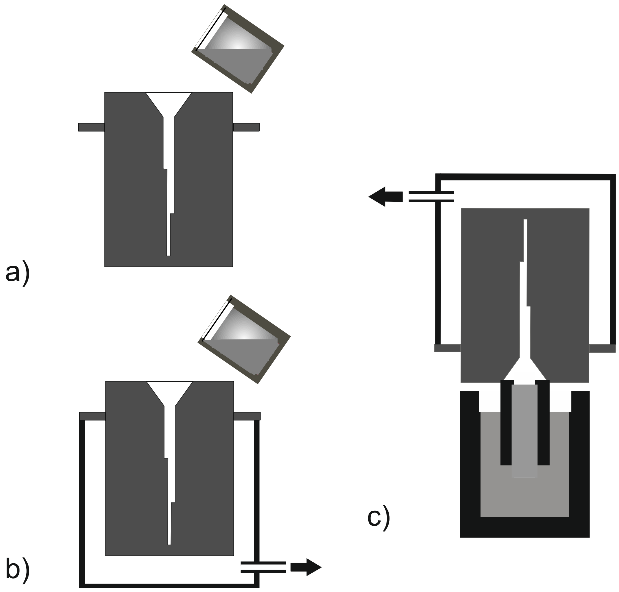


Fig. 1. The scheme of mould filling operation: a) gravity filling, b) gravity filling supported by the negative pressure, c) counter-gravity sucking under the negative pressure action

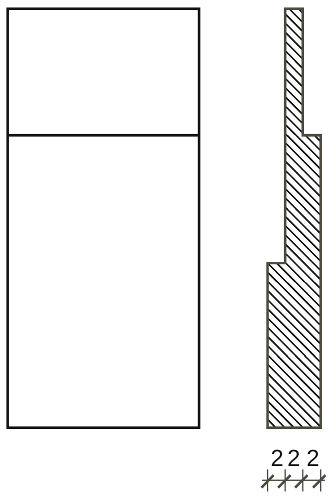


Fig. 2. The view and the cross-section of the test pattern

The temperature of the test moulds used during the experiment was equal to 150°C, and the pouring 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 allowed for the assessment of microstructure and porosity.

The assessment of porosity was carried out according to the BN-75/4051-10 Standard. The examinations were performed by the method of hydrostatic weighing for five test castings.

3. Results of examinations

The obtained measurement results concerning the average density and the average porosity of castings along with the porosity standard deviation are presented in Table 1.

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 magnifications of 100× and 200× by means of the Nikon Epiphot microscope equipped with digital camera and recorded by means of the MultiScan program.

Table 1.
The average density and the average porosity of castings

Type of the mould cavity filling	Density g/cm^3	Porosity %	Porosity standard deviation S(P) %
Gravity filling	2.573	2.90	0.41
Vacumetal-type filling	2.596	2.33	0.36
Counter-gravity filling	2.593	2.44	0.40

Table 2 gathers the results of examinations concerning the influence of the mould filling conditions on the microstructure of the obtained experimental castings with graded wall thickness (2 mm, 4 mm, and 6 mm) cast of the EN AC-44000 alloy.

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

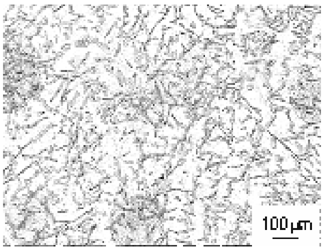
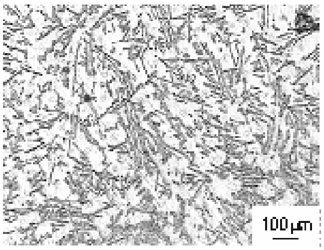
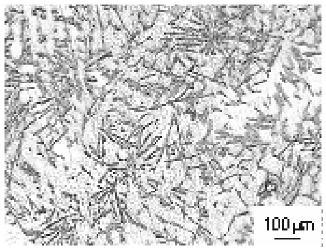
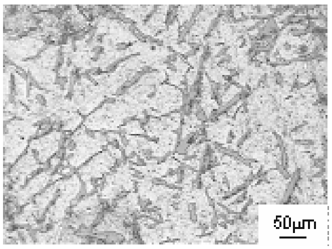
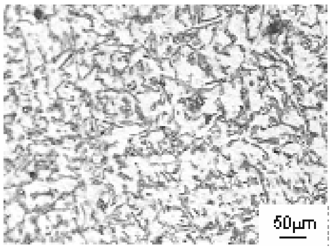
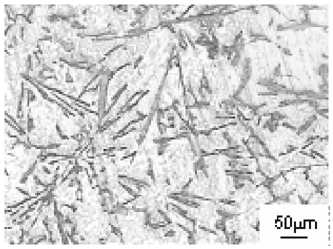
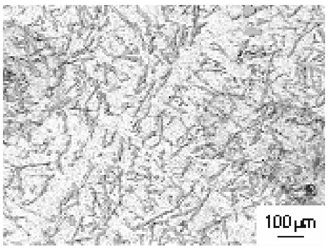
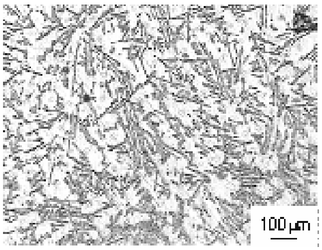
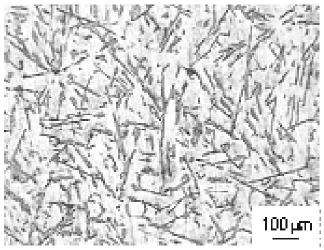
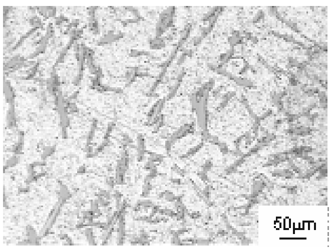
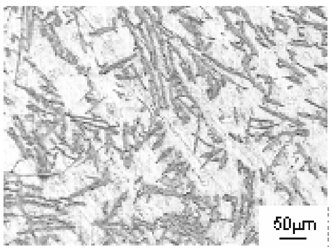
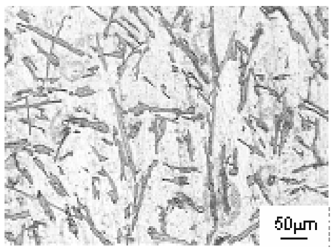
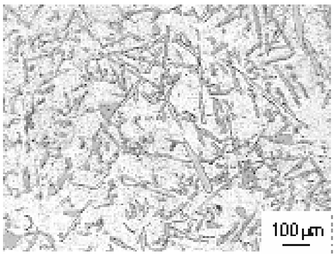
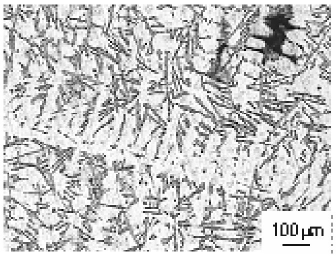
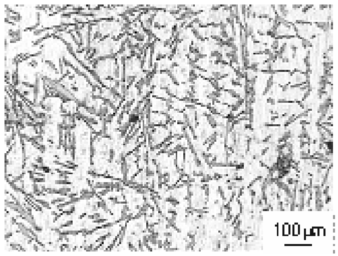
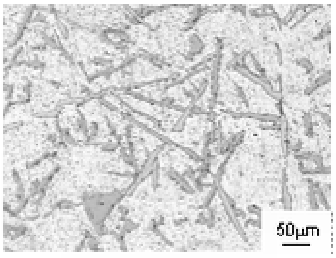
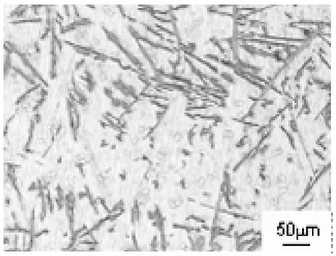
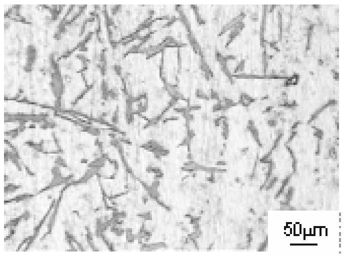
Casting wall thickness	Type of the mould cavity filling		
	Gravity filling	Vacumetal-type filling	Counter-gravity filling
2 mm			
			
4 mm			
			

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

Casting wall thickness	Type of the mould cavity filling		
	Gravity filling	Vacumetal-type filling	Counter-gravity filling
6 mm			
			

4. Conclusion

The results of examinations concerning the influence of the mould filling conditions on the microstructure of the obtained EN AC-44000 alloy experimental castings with graded wall thickness of 2 mm, 4 mm, and 6 mm show microstructures characteristic for the applied alloy. As the wall thickness rises, the size of silicon crystals is increased due to the lower cooling rate of the increased volume of the casting wall. The microstructures of castings produced according to the Vacumetal technology are characterised by finer grain size than the other casting technologies. This can be attributed however 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 EN AC 44000 alloy was not observed.

The results of examinations concerning the density of the produced castings performed by the method of hydrostatic weighing (Table 1) indicate that no significant change in porosity was found.

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