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Effect of Technological Parameters on the AlSi12 Alloy Microstructure During Crystallization Under Pressure

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Abstract

The paper deals with the impact of technological parameters on the heat transfer coefficient and microstructure in AlSi12 alloy using squeeze casting technology. The casting with crystallization under pressure was used, specifically direct squeeze casting method. The goal was to affect crystallization by pressure with a value 100 and 150 MPa. The pressure applied to the melt causes a significant increase of the coefficient of heat transfer between the melt and the mold. There is an increase in heat flow by approximately 50% and the heat transfer coefficient of up to 100-fold, depending on the casting conditions. The change in cooling rate influences the morphology of the silicon particles and intermetallic phases. A change of excluded needles to a rod-shaped geometry with significantly shorter length occurs when used gravity casting method. By using the pressure of 150 MPa during the crystallization process, in the structure can be observed an irregular silica particles, but the size does not exceed 25 microns.

Keywords: Squeeze casting, Heat transfer, Pressure, Aluminium alloy

1. Introduction

The pressure applied to the melt causes a significant increase (up to ten times) of the coefficient of heat transfer from the melt to the mold. This positive effect is associated with the elimination of the air gap, which normally forms during solidification of the melt at the interface between the mold and the casting. The melt and later also solid cast constantly under pressure and in contact with a metal mold. The consequence of rapid cooling is to reduce the cooling time of the casting, and thus the finer structure of the alloy. The pressure also affects the structure of the castings, which causes a decrease in the grain size of the primary structure, changing the morphology of the eutectic and intermetallic particles, which have then less harmful effects. The consequence of affecting the structure is a change of the mechanical properties. The consequence of this change increases the strength, ductility and fracture toughness. The materials, which are cast under pressure have much better properties as the same materials casted by gravity technology in the permanent casting molds [1,2].

Advantages of the forms used in the squeeze casting technology are reusability, quality casting surface and tight dimensional tolerances [3,4]. Between the main disadvantages of this method are especially high investment costs, reduced molds lifetime due to high load pressure and little experience of the practical use of the method [5].

The process parameters, such as applied pressure, temperature and the initial temperature of the casting mold, can affect the pressure transfer, which subsequently affects the heat transfer at the metal – mold interface and also the quality of the final castings. Contact between the liquid metal and mold is not perfect due to the use of the coating on the surface of die and the formation of an air gap caused by the shrinkage. These thermal barriers can reduce heat transfer between the casting and the mold. They also reduce the cooling rate, which affects the quality and microstructure of the casting. The heat flux on the interface casting-mold can be calculated from the temperature gradient on the surface and the subsurface layer using the equation:

$$q(t) = -k\frac{dT}{dx} = -K\frac{T_1 - T_2}{\Delta x}\ [W.m^{-2}] \qquad (1)$$

where K is thermal conductivity of the casting or die materials. Index t is solidification time. Indexes *1* and *2* mean number of measuring points.

The average heat transfer coefficient *HTC* at the interphase may be expressed mathematically:

$$HTC = \frac{q}{(T_O - T_F)}\ [W.m^{-2}.K^{-1}] \qquad (2)$$

where T_O is the temperature of the casting and T_F is the temperature of the mold.

2. Experimental material and process

The eutectic alloy AlSi12 was chosen as experimental material. Chemical composition of AlSi12 alloy is shown in the Table 1.

Table 1.
Chemical composition AlSi12 [Wt. %]

Si	Fe	Cu	Mn	Mg	Ni
12.42	0.339	0.02	0.048	0.039	0.0092
Zn	Pb	Sn	Ti	Cr	V
0.012	0.004	0.01	0.102	0.0035	0.0061

For experimental casting, direct squeeze casting method was used. Precisely measured dose of the liquid metal was poured into the mold cavity. The mold was machined from low carbon steel. The surface of the mold cavity and the plunger has been treated with a protective paint type Terracotta. The liquid melt was pressed by using a plunger which section area was 1000 mm^2. The onset of action was approximately 10 seconds by filling mold. The sample was under pressure until the cooling of the melt to 400 °C. Position of the thermocouples is shown in Figure. 1. In the experiment 8 thermocouples type K were used, with a wire Do= 0.25 mm in order to respond rapidly. Temperature in the cast was measured 2, 4, 8 mm from the surface of metal mold and in the middle of experimental cast. Temperature of the mold was recorded by using 4 thermocouples: 2, 4, 8 and 16 mm below the surface. These casting parameters were chosen: die temperature 200 °C, pressure 100 and 150 MPa, casting temperature 715, 690 and 675°C. Comparative sample was casted without any pressure effect, casting temperature 715 and 675°C, mold temperature 200°C.

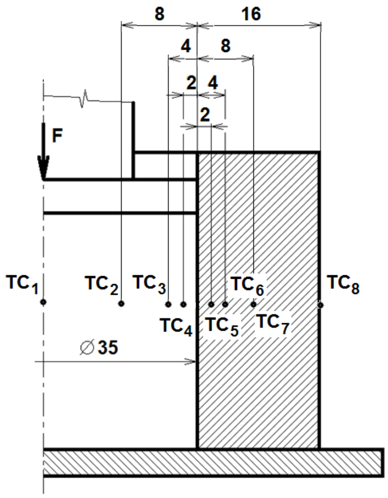

Fig. 1. Schematic drawing of measurement using thermocouples

Microstructures of castings were etched by 0.5% HF and observed on a light microscope Neophot 2. Observed was mainly the size of the alpha phase and morphology of excluded silicon. Microstructure was evaluated in the middle area, the surface layers responded to the character of structure casted by gravity casting method. The period of affecting the crystallization by the pressure was chosen between 10 and 60 seconds. The heat flux on the interface between cast and mold was determined from temperatures on the surface of a mold and temperatures 2 mm under the surface by the equation (1). The results of heat transfer coefficients were calculated by the equation (2). On the figure 2 is shown heat transfer coefficient curves and heat flux curve.

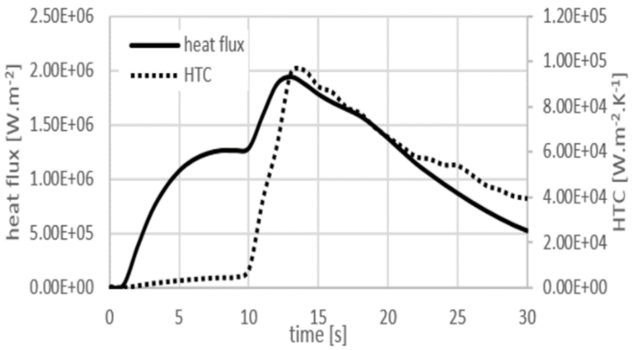

Fig. 2. Heat flux and HTC between the cast and the mold at the temperature of casting 690 °C, pressure 100 MPa

In Figure 2 can be observed that under the pressure effect the increase of heat flow occurs by approximately 50 % and the heat transfer coefficient of up to 100-fold, depending on the casting conditions. In Figure 3-10 is shown microstructure of casted experimental samples.

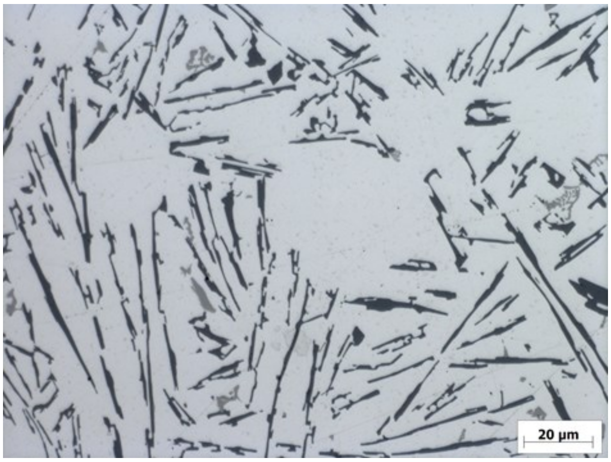

Fig. 3. Microstructure of samples, pressure 0.1MPa, temperature 715°C, etched with 0.5% HF

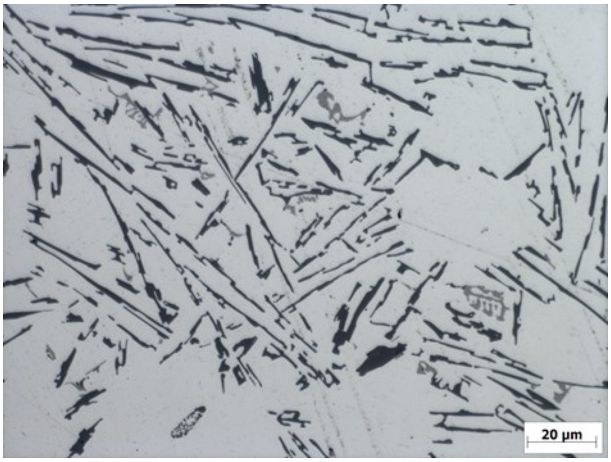

Fig. 4. Microstructure of samples, pressure 0.1MPa, temperature 675°C, etched with 0.5% HF

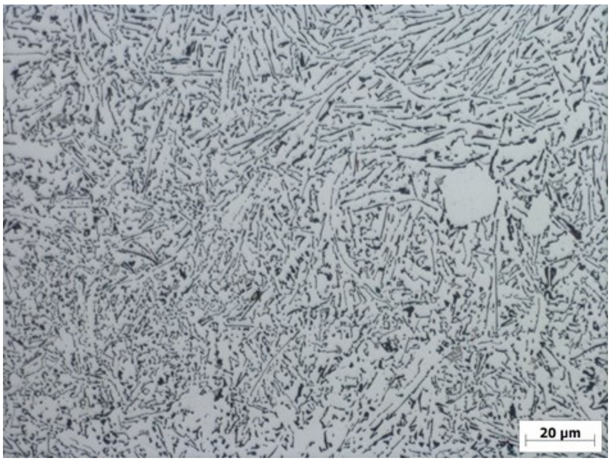

Fig. 5. Microstructure of samples, pressure 100 MPa, temperature 715°C, etched with 0.5% HF

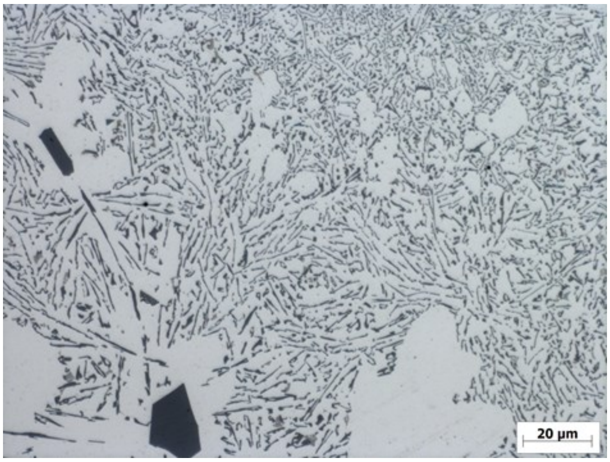

Fig. 6. Microstructure of samples, pressure 150 MPa, temperature 715°C, etched with 0.5% HF

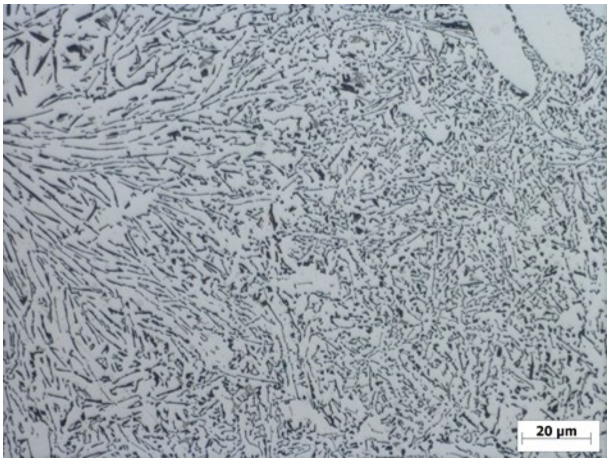

Fig. 7. Microstructure of samples, pressure 100 MPa, temperature 690°C, etched with 0.5% HF

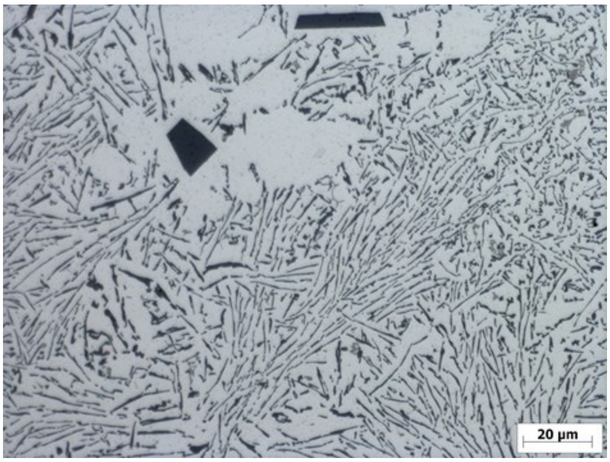

Fig. 8. Microstructure of samples, pressure 150 MPa, temperature 690°C, etched with 0.5% HF

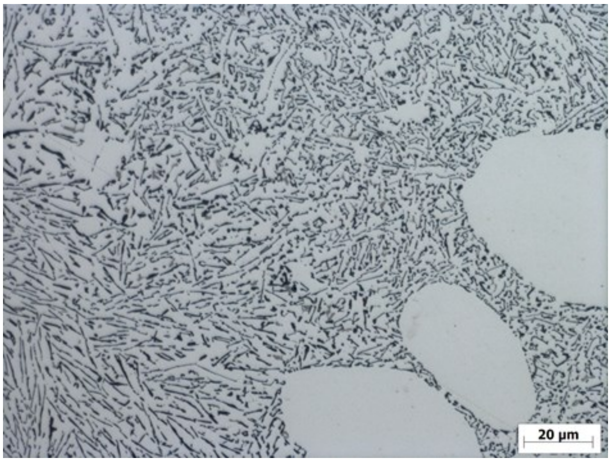

Fig. 9. Microstructure of samples, pressure 100 MPa, temperature 675°C, etched with 0.5% HF

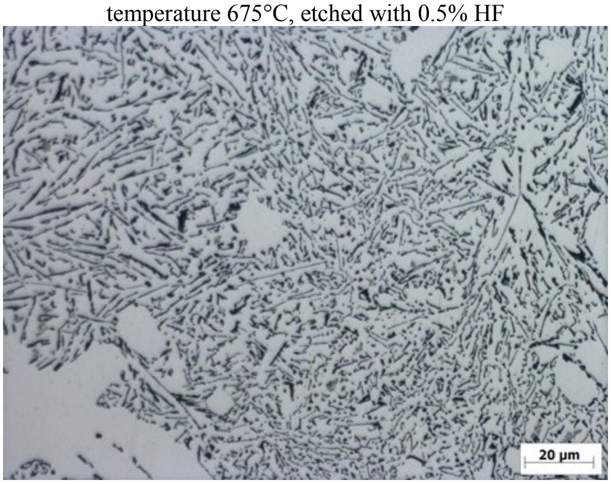

Fig. 10. Microstructure of samples, pressure 150 MPa, temperature 675°C, etched with 0.5% HF

3. Conclusions

From the collected data of heat flow coefficient and heat transfer coefficient were determined time characteristics of the process. In the gravity casting sample increases heat flow to 10 seconds after casting. At gravity casted sample the heat flux increases up to 10 seconds after pouring. As a consequence of shrinkage a gap in a cast was formed between the cast and the mold. Due to gap the heat flow from the cast was decreased.

The pressure effect during crystallization was chosen up to 10 seconds after filling the mold with the melt. At sample with pouring temperature 690 °C we started to affect solidification 10 seconds after filling of the mold. This fact was also reflected on the heat flux and heat transfer coefficient. At sample poured at temperature 690 °C, the heat flux gradually rise to a $1.23x10^6$ $W.m^{-2}$. By applying pressure 100 MPa, the value of heat flux rose to a maximum value $1.89x10^6$ $W.m^{-2}$. The value of heat transfer coefficient rose to $1.04x10^5$ $Wm^{-2}. K^{-1}$.

During gravity casting method can be seen in the microstructure the eutectic silicon particles in the form of sharp-edged needles longer than 50 microns. The application of pressure during the crystallization had an effect on the morphology of excluded eutectic silicon. A change to the needles from the rods occurs. Also, there was a drastic shortening of silicon rods. Casting at a temperature of 715 and 690 ° C and operating pressure of 150 MPa can be also observed in the pattern of irregular silica particles, but the size does not exceed 25 microns.

In the microstructure, it is not observable even a body of intermetallic phases. There has been a significant change in the size of these phases and their size does not exceed the size of 10 microns.

From the experiments, we can conclude that operating pressure of 100 MPa it is sufficient to influence the structural characteristics of the alloy AlSi12. From the above it can be expected to increase the mechanical properties, especially tensile strength and ductility. Confirmation of results will require evaluation of mechanical properties increase.

In the samples, casted by gravity casting method was observed significant porosity in the thermal axis of the casting. The samples casted with applied pressure during crystallization there was no porosity observed. The achieved results correspond with our previous results so far, and are comparable to measurement by Aweda (2012).

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