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# The Effects of Pressure During the Crystallization on Properties of the AlSi12 Alloy

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## Abstract

The paper deals with the impact of technological parameters on the mechanical properties 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. From the experiments we can conclude that operating pressure of 100 MPa is sufficient to influence the structural characteristics of the alloy AlSi12. The change in cooling rate influences the morphology of the silicon particles and intermetallic phases. A change of excluded needles to a rod-shaped geometries with significantly shorter length occurs when used gravity casting method. At a pressure of 100 MPa was increased of tensile strength on average of 20%. At a pressure of 150 MPa was increased of tensile strength on average of 30%. During the experiment it was also observed, that increasing difference between the casting temperature and the mold temperature leads to increase of mechanical properties.

**Keywords**: Squeeze casting, Pressure, Aluminium alloy, Mechanical properties, Microstructure

## 1. Introduction

In the direct squeeze casting method, the melt is cast directly into the open bottom part of the preheated metal mold. After the pouring of the metal, there is a gradual closing of the mold through an upper part, which is also the piston. After the close of the mold, upper part begin act on the molten metal with high pressure across the entire cross section.

The biggest advantage of the direct method is that the pressure acts on the entire surface of the cast metal during solidification, what causes an increased density in the whole casting. With the direct squeeze casting method is achieved the fastest heat transfer, however this method does not modify the stage of filling the mold cavity with liquid metal. This leads to turbulent flow and capture the fragile surface of oxide films. Time delay, which occurs between the end of casting and the beginning of pressure effect by the piston leads to early solidification process of the melt.

**The process parameters**

*Casting temperature*

Casting temperature significantly affects the final quality of the casting and overall lifetime of the mold. Due to the relatively short path, which molten metal must overcome during the filling of the mold, it is possible to use lower casting temperatures compared to other technologies.

Too low casting temperature leads to incomplete filling of the mold especially in critical areas of the casting. Too high temperature during casting adversely affects the life of the mold and can cause problems with the piston. Casting temperature mainly depends on the solidification interval of the used alloy. With increasing interval of solidification, casting temperature is decreases. Alloys with a narrow interval of solidification tend to produce immediately after contact with the walls of mold a solidified shell of metal. This is a reason, why these alloys needs a higher preheating of melt. [1-6]

*Mold temperature*

The mold temperature should be kept within well-defined limits. The correct operating temperature is determined depending on the type of alloy and casting structures. With decreasing temperature instruments it is necessary to increase the operating pressure. Too low temperature of the mold or the injection device can cause early solidification of the melt and misruns. Too high temperature can cause creating of the surface defects, and also there may be created the solid connections between the casting and the mold. For aluminum alloys is recommended the maximum temperature up to 300 ° C. [1, 6]

*Size of applied pressure and the duration of action*

Most often is used for the majority of non-ferrous materials amount of the pressure in range from 30 to 150 MPa. This is the minimum pressure value required to suppress shrinkage and porosity, typical for this method. The size of applied pressure essentially depends on the properties of the material and the geometry of the casting. Eutectic alloys, pure metals and alloys with a narrow solidification interval require high pressures due to the very rapid formation of a solid metal layer around the cavity of the mold. But, for alloys with a wide solidification interval are required lower pressures. [1, 2]

Due to the pressure effect on the solidifying melt, this phenomenon occurs: (KST, 2010)

- increasing the temperature of phase transformations,
- reducing the critical size of the nucleation.
- increasing the cooling rate,
- change the solubility of the additive elements,
- affecting the morphology of eutectic and intermetallic phases.

The timing of the pressure application depends on the type of used alloy, the casting parameters and conditions of heat transfer into the mold. Between the pouring and beginning of pressure action is necessary to maintain a short delay. This delay helps to calm the melt and allow gas to escape. Action of the pressure is complete, when the entire casting is solidified. [3]

*Microstructure of the castings*

When the die is made from metal, the die/casting interface becomes the greatest resistance to heat transfer. Due to the contraction of most metals and expansion of the mold during solidification, detachment of the casting from the die wall takes place once the initial solid shell of the casting has sufficient strength to hold the remaining molten metal. Consequently, an air gap is formed between the mold and the casting, which considerably increases resistance to heat transfer. In squeeze casting, the applied pressure of about 70 MPa on the casting forces the initial solid shell to remain in contact with the die. The intimate metal-die contact is maintained by the plastic deformation of the casting throughout solidification. This leads to very fast heat transfer rates, high cooling rates and increased temperature gradients in the casting. The cooling rate in squeeze casting, therefore, can be much faster than during gravity castings, depending on applied pressure, die preheat temperature, casting thickness, die lubricant and other factors. [3-5]

Application of the pressure during solidification affects the microstructure of the casting, also after T4 and T6 heat treatment. The squeeze casting refines the primary alpha phase and the eutectic Si phase, and Si gets fibrous morphology; whereas, in a permanent mould, Si has a plate or needle shape. [3]

The reduction in the eutectics volume fraction in the Al-Si alloys compared to equilibrium state, while increasing the concentration of silicon in the eutectic and structure refinement is more significant with the higher the value of the pressure during solidification. By increasing pressure, in addition to refining of the structure also to spheroidisation of solid solution α dendrites occurs. This phenomenon is explained by the fact, that the formation and growth of α-phase under pressure occurs in the volume of the melt, wherein until the temperature of eutectic transformation no other solid phase exists. In result of evenly spread pressure in all directions, the growth of α-phase is performed without a preferred direction. Changes in the structure and physical-mechanical properties, which occur under the action of pressure are also in results of slowing the disintegration of supersaturated solid solutions, formation of deformations arising from the solid phase, increasing the density of the dislocations and increases the cooling rate. [2, 7]

The consequence of affecting the structure is change of mechanical properties, increasing strength, ductility and fracture toughness.

## 2. Experimental material and process

Eutectic alloys are for their excellent fluidity used to shape complicated castings, thin-walled castings, pistons for rotors and compressors and other components in the automotive and aerospace industries. These alloys are widely used in pressure and gravity die casting. The eutectic alloy AlSi12 was chosen as experimental material. The chemical composition of used alloy AlSi12 shown in Tab. 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 amount 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 piston has been treated with a protective paint based on graphite. The liquid melt was pressed by using a piston which section area was 780 mm2. The pressure action was approximately 10 seconds by filling mold. These casting parameters were chosen: die temperature 150 and 200 °C, pressure 100 and 150 MPa, casting temperature 710 and 690°C. Comparative sample was casted without any pressure effect, casting temperature 715, mold temperature 200°C.

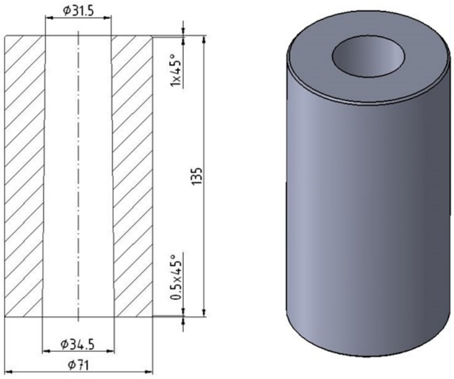


Fig. 1 Schematic drawing of measurement

# 3. Experimental material and process

Microstructures of castings were etched by 0.5% HF and observed on a light microscope Zeiss Axio Observer Z1m. 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. Based on the solidification curves observation of the samples casted by gravity casting method, the period of affecting the crystallization by the pressure, was chosen between 10 and 60 seconds.

Crystallization under pressure have significant effect on critical size of crystallization particles, mainly hypothermia of the melt due to the high accumulation capacity of the mold and athermic hypothermia of the melt caused by increased pressure, which affected melt during the crystallization.

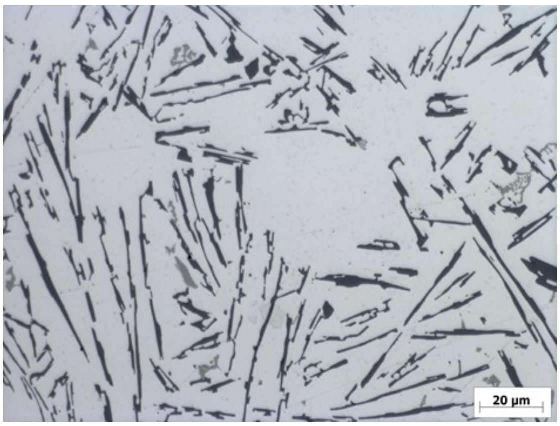


Fig. 2. Microstructure of samples, pressure 0.1 MPa, temperature 715 °C, etched with 0.5% HF

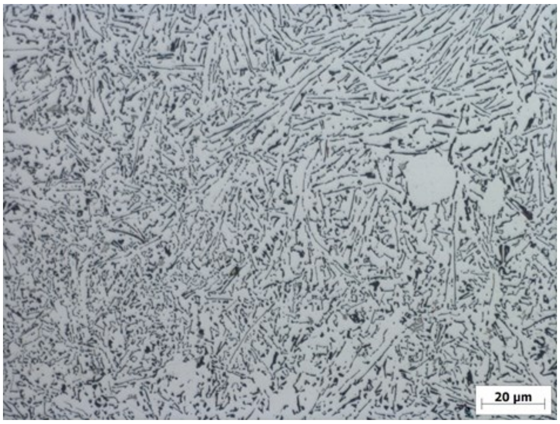


Fig.3. Microstructure of samples, pressure 100 MPa, temperature 710 °C, etched with 0.5% HF


Fig. 4. Microstructure of samples, pressure 150 MPa, temperature 710 °C, etched with 0.5% HF

Experimental samples for evaluating mechanical properties were removed from the center of the casting. Figures 5 and 6 shows the values of tensile strength and elongation in dependence on the applied pressure.

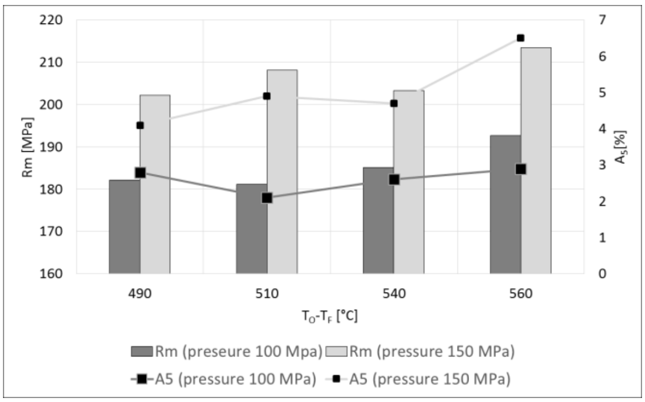


Fig. 5. Tensile strength and elongation, applied pressure of 100 and 150 MPa

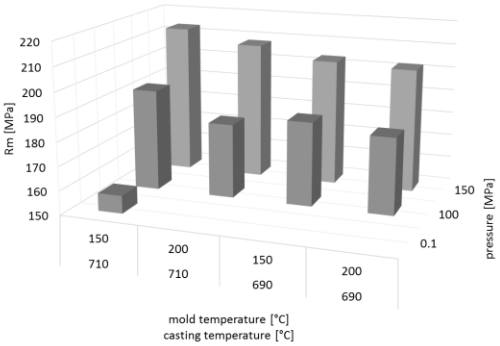


Fig. 6. Tensile strength applied pressure of 0.1, 100 and 150 MPa

The difference of temperatures in the graph represents the casting conditions, where the casting temperature ($T_O$) and the mold temperature ($T_F$) variated. At a value of 490 °C was the casting temperature 690 °C and the mold temperature 200 °C. At a value of 510 °C was the mold temperature 200 °C and the casting temperature 710 °C. At a temperatures of 540 °C and 560 °C was the mold temperature 200 °C and the casting temperature 690 °C respectively 710 °C.

## 3. Conclusions

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. In the cross-section area can also be observed intermetallic phases excluded in the form of Chinese script that is smaller than 20 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 significant shortening of silicon rods occurred. By casting at a temperature of 715 and 690 °C and operating pressure of 150 MPa can be also observed the pattern of irregular Si particles, but the size does not exceed 25 microns.

In the microstructure it is not observable even a bodies 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 is sufficient to influence the structural characteristics of the alloy AlSi12.

In the samples casted by gravity casting method was observed significant porosity in the thermal axis of the casting. This phenomenon had an impact on the tensile strength and elongation of gravity casted samples. At a pressure influenced samples was not observed significant porosity. At a pressure of 100 MPa and a mold temperature of 200 °C there was an increased strength to 181.16 MPa (at casting temperature of 710 °C). At a mold temperature of 150 °C the tensile strength reached value of 192.67 MPa (at casting temperature of 710 °C). At a mold temperature of 690 °C, the strength reached value of 185.16 MPa. Increase the tensile strength was on average of 20%. With pressure of 150 MPa during the crystallization and with the mold temperature of 200 °C, the tensile strength of the sample at a casting temperature of 710 °C reached value of 208.1 MPa and the sample casting at a casting temperature of 690 °C reached value of 202.17 MPa. At the mold temperature of 150 °C and the casting temperature od 690 °C, the tensile strength reached vales of 203.34 MPa. The highest tensile strength was achieved at a mold temperature of 150 °C and casting temperature of 710 °C with a value of 213.41 MPa. At a pressure of 150 MPa was increased of tensile strength on average of 30%. The elongation was an increased from the original of 1% to about 3% at a pressure of 100 MPa and even to 5% at the applied pressure of 150 MPa.

During the experiment it was also observed, that increasing difference between the casting temperature and the mold temperature leads to increase of mechanical properties. This effect was not observed in our previous experiments with alloys, which had a wider interval of solidification. Exogenous solidification of eutectic alloys is more widely affected by the rate of heat transfer, which is determined by the temperature gradient.

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