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The Influence of Different Wall Thicknesses of the Casting in the Direct Squeeze Casting

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Abstract

The paper deals with squeeze casting technology. For this research a direct squeeze casting method has been chosen. As an experimental material, the AlSi12 and AlSi7Mg0.3 alloys were used. The influence of process parameters variation (pouring temperature, mold temperature) on mechanical properties and structure will be observed. For the AlSi7Mg0.3 alloy, a pressure of 30 MPa was used and for the AlSi12 alloy 50 MPa. The thicknesses of the individual walls were selected based on the use of preferred numbers and series of preferred numbers (STN ISO 17) with the sequence of 3.15 mm, 4 mm, 5 mm, 6.3 mm and 8 mm. The width of each wall was 22 mm and length 100 mm. The mechanical properties (Rm, A5) for individual casting parameters and their individual areas of different thicknesses were evaluated.

For the AlSi7Mg0.3 alloy, the percentage increase of the tensile strength was up to 37% and the elongation by 400% (at the 8 mm thickness of the casting). For the AlSi12 alloy, the strength increased from 8 to 20% and the tensile strength increased from 5 to 85%. The minimum thickness of the wall to influence the casting properties by pressure was set to 5 mm (based on the used casting parameters). Due to the effect of the pressure during crystallization, a considerable refinement and uniformity of the casting structure occured, also a reduction in the size of the eutectic silicate-eliminated needles was observed.

Keywords: Squeeze casting, Wall thickness, Mechanical properties, Structure, Aluminium alloy

1. Introduction

The squeeze casting technology is a relatively unusual method. This is due, in particular, to little experience with practical use combined with the low lifetime of the mold, which is caused by high thermal and mechanical stresses combined with a long cycle time. With direct squeeze casting, the cycle time can be up to about 1 minute. Such stress greatly reduces the life of the mold [1, 2, 3]. The main characteristics of this method, which are distinguishing it from conventional high-pressure casting include, in particular, the slow filling of the melt into the mold cavity (approximately 0.5 $m.s^{-1}$) and considerably larger gates, than those used in the high-pressure casting. The slow filling of the mold cavity guarantees a laminar flow without turbulences. In addition, a longer filling time allows exclusion of gases from the mold cavity, which reduces the resulting porosity of the casting. Thanks to the large gates, the melt and later the casting itself are constantly under the influence of the applied pressure, while the gates solidified as last. This allows continuous melt substitution in interdendritic areas. The result of this is high integrity and minimum casting porosity. This also prevents the creation of various foundry defects. These castings shows high mechanical properties, which can be further increased by subsequent heat treatment. [2, 4, 5, 8, 10] The pressure at squeeze casting is from 30 to 150 MPa, depending on the type of alloy, the casting temperature, and more. The pressure itself prevents the formation of an air gap, which is normally formed at the gravity casting between the casting and the mold. This air gap substantially slows heat transfer and thus also the cooling rate of the casting. By eliminating the gap due to pressure, there are significant changes in the structure and also in the mechanical properties of the material. In the structure, the grains size of the primary structure is reduced and also change of the eutectic silicon morphology and intermetallic phases occurs, which act less harmful. The resulting structure is finer and more uniform throughout the volume. The concentration of silicon in the eutectic and the volume ratio of the primary α-phase is increased and the volume of the eutectic in the structure is reduced. The result is a change in mechanical properties, where the strength, elongation and fracture toughness increases. The gravity casting can achieve a better mechanical properties for the parts of casting, which solidified faster, in this case is about the thinnest parts of the casting. Pressure utilization at the squeeze casting technology greatly accelerates solidification and cooling in the thicker areas of the casting. This is associated with elimination of an air gap formed by gravity casting. The result is a change in structure and a significant increase in mechanical properties compared to gravity casting [1, 4, 6, 7, 9, 11].

2. Experimental material and process

As an experimental material was chosen the AlSi12 (EN AC 44100) and AlSi7Mg0.3 alloys (EN AC 42100), which chemical composition is shown in Tab. 1 and Tab. 2, respectively. Evaluated materials are eutectic and hypoeutectic alloys, respectively. The tensile strength after casting is similar for both alloys, approximately 170-180 MPa.

Table 1.
Chemical composition AlSi12 [Wt. %]

Si	Fe	Mg	Mn	Ti	Cu	Zn
11.96	0.27	0.053	0.038	0.0061	0.075	0.012

Table 2.
Chemical composition AlSi7Mg0.3 [Wt. %]

Si	Fe	Mg	Mn	Ti	Cu	Zn
7.60	0.074	0.348	0.002	0.0034	0.002	0.004

During the experiment, several technological parameters were varied like pouring temperature, mold temperature and pressure. The used technological parameters are shown in Tab. 3. Three melts were performed for all variants.

Table 3.
Technological parameters

Alloy - Casting	Mold temperature (°C)	Pouring temperature (°C)	Pressure (MPa)
AlSi7Mg0.3 - 7/1	250	730	0
AlSi7Mg0.3 - 7/2	250	730	30
AlSi7Mg0.3 - 7/3	200	735	30
AlSi7Mg0.3 - 7/4	150	740	30
AlSi12 - 12/1	250	700	0
AlSi12 - 12/2	250	690	50
AlSi12 - 12/3	230	700	50
AlSi12 - 12/4	200	715	50

The pressure applied for the AlSi7Mg0.3 alloy was 30 MPa and for the AlSi12 alloy 50 MPa. Various pressures have been chosen due to various morphologies of solidification of the alloys. For AlSi12 alloy, it is necessary to overcome the greater resistance caused by immediate solidification after filling the mold. The acting pressure was applied for 2 seconds after mold was filled, based on a numerical calculation.

The casting temperature was differed with respect to the alloy. The lowest casting temperature, when the melt completely filled the mold was at the alloy AlSi7Mg0.3 (730 °C). For the AlSi12 alloy, temperature was 690 °C.

The aim of the experiment was to verify the effect of casting wall thickness change on the mechanical properties and structure of the aluminium alloys under the influence of a low pressure during solidification. For this research a direct squeeze casting method has been chosen. The casting with different wall thicknesses is shown in the Fig. 1. The thicknesses of the individual walls were selected based on the use of preferred numbers and of series of preferred numbers (STN ISO 17) with the sequence of 3.15 mm, 4 mm, 5 mm, 6.3 mm and 8 mm. The width of each wall was 22 mm and length of 100 mm. Dimensions were chosen to evaluate the mechanical properties of individual casting walls (Rm, A5). The inlet system has been adapted to apply pressure. The piston diameter was 30.9 mm with a 750 mm^2 area.

After casting, the individual parts of the casting were machined into shape of 8x8, 6.3x10, 5x10, 4x14 and 3.15x14 mm to evaluate mechanical properties (Rm, A5). To evaluate the mechanical properties, a tensile test was performed. Tensile test was carried out on the WDW 20 machine with an extensometer on the Department of Technological Engineering. The test was run at ambient temperature and samples were tensile with a speed of 2 mm/min.

Using the ProCast simulation program, the verified time to the casting solidus temperature. In Fig. 2 and Fig. 3 shows the time to solidus for both alloys.

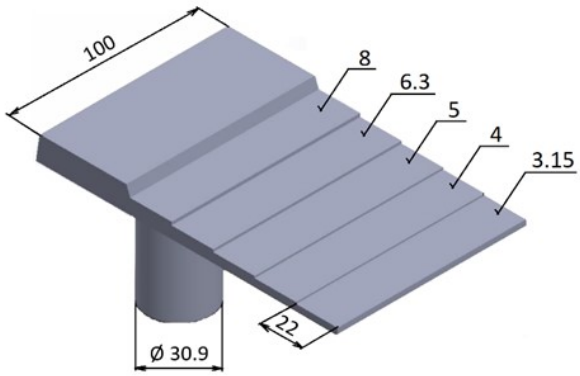


Fig. 1. Casting model

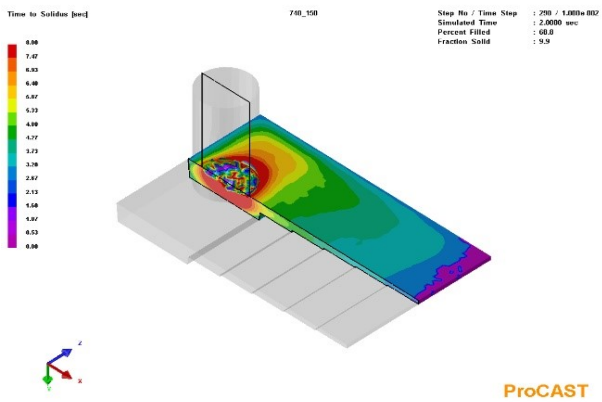


Fig. 2. Time to solidus - AlSi7Mg0.3 alloy

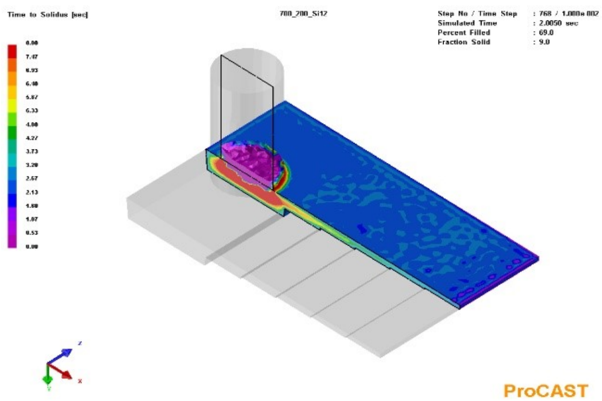


Fig. 3. Time to solidus – AlSi12 alloy

3. Results

The measured results of Rm, A5 for individual casting processes and their individual areas of different thicknesses are shown in Fig. 4 until Fig. 7.

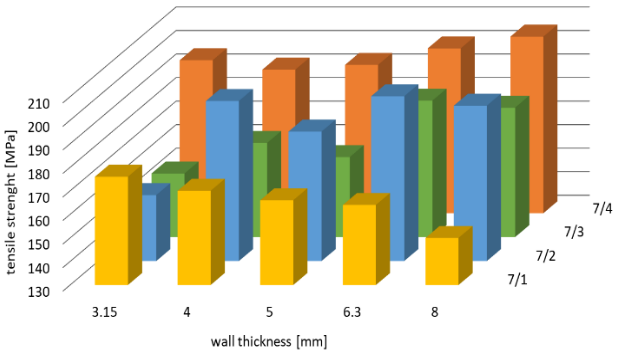


Fig. 4. The results of tensile strength for AlSi7Mg0.3 alloy

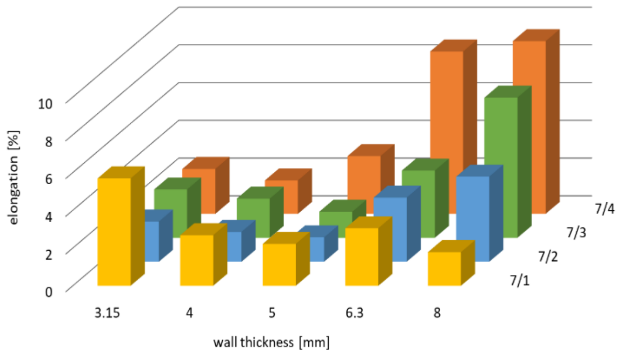


Fig. 5. The results of the elongation for AlSi7Mg0.3 alloy

In the case of gravity casting, the rapid cooling rate of the thinner parts resulted in the formation of a fine structure and thus the increase in mechanical properties. A maximum strength of 176 MPa and a ductility of 5.7%. In the thicker parts of the casting there was a slow solidification rate, reflecting lower mechanical properties with a strength of 150 MPa and a tensile strength of 1.8%.

In the case of the squeeze casting, the pressure in the thicker parts of the casting was active during the whole solidification and cooling process. The greater the casting thickness, the longer the applied pressure can affect the melt. This resulted in a significant increase in casting strength and tensile strength to a maximum measured strength of 205 MPa and a tensile strength of 9.2% in areas with a wall thickness of 8 mm. Compared to the gravity casting strength values at the same wall thickness, this represents increase in strength of 37% and elongation by 400%.

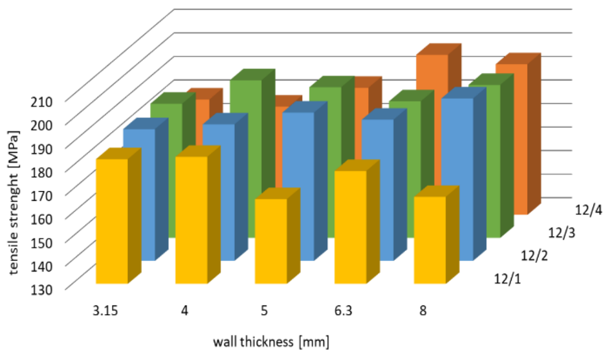


Fig. 6. The results of tensile strength for AlSi12 alloy

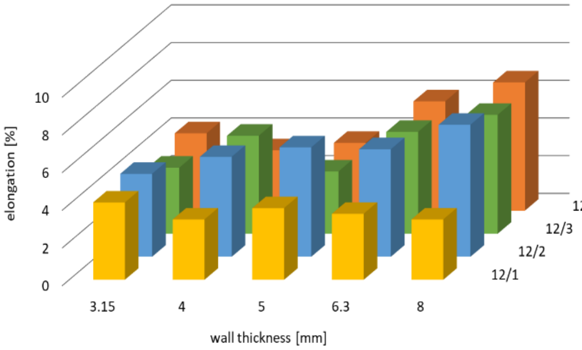


Fig. 7. The results of the elongation for AlSi12 alloy

For AlSi12 alloy, the higher cooling rate of thinner parts during gravity casting did not have such an high effect as in the previous case. Strength of thinner parts was 182 MPa, elongation 4.1%. The thicker parts of the cast have a strength of 171 MPa and a tensile strength 3.2%.

The pressure-affected castings did not have a significant change in mechanical properties even when changing the technological parameters. The strength ranged from 185 MPa to 203 MPa. The elongation was 4% for thicknesses up to 5 mm. At 6.3 mm, it was 6.1%, and at 8 mm it was 7.8% regardless the changes in the technological parameters.

After evaluating the strength characteristics, the samples were taken to evaluate the microstructure. A microstructure of gravity casted castings with a wall thickness of 5 mm is shown in Fig. 8 and Fig. 11.

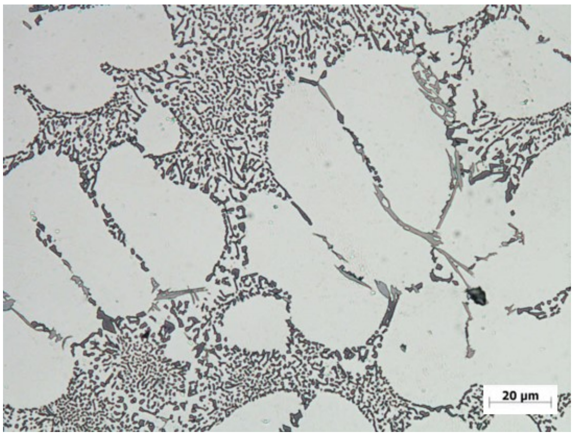


Fig. 8. Microstructure AlSi7Mg0.3 alloy, thickness 5 mm
Technological parameters: mold temperature 250 °C, pouring temperature 730 °C, pressure 0 MPa

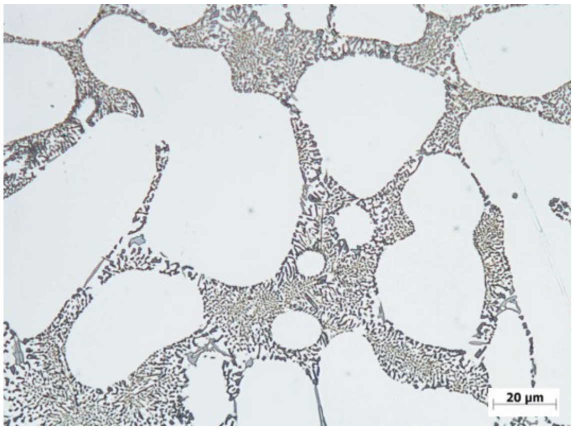
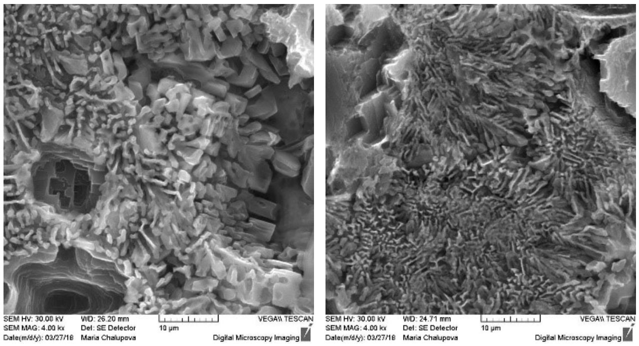


Fig. 9. Microstructure AlSi7Mg0.3 alloy, thickness 8 mm
Technological parameters: mold temperature 200 °C, pouring temperature 735 °C, pressure 30 MPa



a) b)

Fig. 10. Eutectic silicon, AlSi7Mg0.3 alloy
a) gravity casting, b) squeeze casting

The alloy AlSi7Mg0.3 consists of an alpha phase and a eutectic with the silicon, which is excluded in the form of the sticks. We can observe that the alloy is modified. In a castings affected by pressure, the eutectic silicon sticks are shortened, fig.9. The distribution of silicon in eutectic is more uniform. The morphology of eutectic silicon during gravity casting (a) during casting under pressure (b) is shown in Fig. 10. These changes were observed mainly in coarser sections (6.3 and 8 mm). Microstructure of thinner sections (up to 5 mm) corresponds to gravitationally cast samples.

After application of the pressure, the structure was significantly finer and uniform. There was an increase in the proportion of primary α-phase and a decrease of the eutectic in the structure. By casting under pressure, spheroidization of the primary α-phase grains also occurred. Due to pressure, the SDAS factor value was reduced by 24% on average.

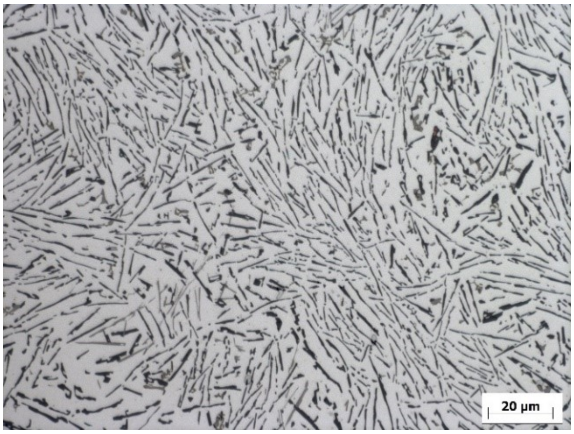


Fig. 11. Microstructure AlSi12 alloy, thickness 5 mm
Technological parameters: mold temperature 250 °C, pouring temperature 700 °C, pressure 0 MPa

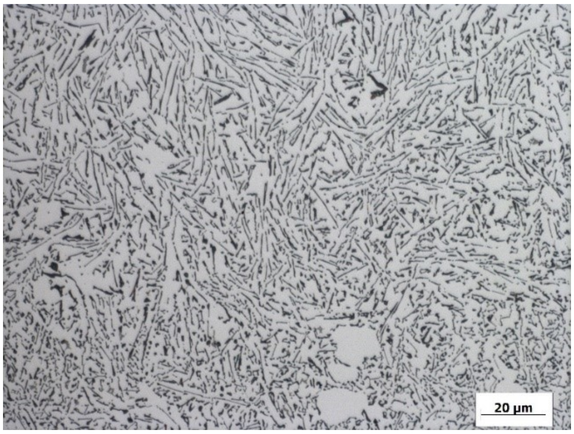
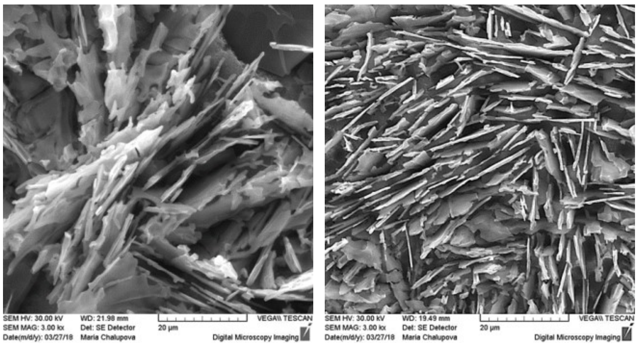


Fig. 12. Microstructure AlSi12 alloy, thickness 8 mm
Technological parameters: mold temperature 250 °C, pouring temperature 690 °C, pressure 50 MPa



a) b)

Fig. 13. Eutectic silicon, AlSi12 alloy
a) gravity casting, b) squeeze casting

The AlSi12 alloy is composed of an eutectic silicon, which is excluded in form of the lamels. In the pressure affected castings we can notice a significant shortening of lamellar eutectic silicon. These changes were observed only in the surface layers. The change of morphology of eutectic silicon does not occur. The morphology of eutectic silicon during gravity casting (a) during casting under pressure (b) is shown in Fig. 13.

4. Conclusions

By influencing of crystallisation by lower pressure, the mechanical properties and structural characteristics were favourably influenced. By observing the structure, it was found that the influence of AlSi12 alloy structure only occurred in the surface layers of the casting, which also confirmed a slight increase of the strength and plastic properties in the individual parts of the casting. Low pressure was not sufficient to affect thicker cross sections. For the AlSi7Mg0.3 alloy was due to the wide solidification interval affected both the structure and the mechanical properties was more pronounced. The influence was observed across the entire section of the individual cast parts. There was no change in the morphology of eutectic silicon. The change was only observed in the particle size of the eutectic silicon.

It can be concluded from the results that gravitationally cast samples obtained higher strength and plastic properties in thinnest parts of casting compared to the thicker parts. This is due to the shorter solidification time of the thinner parts of the casting. When using the pressure during crystallization, the trend of increase the strength and plastic properties is the opposite. The more pronounced effect of applied pressure was manifested in the thicker sections of the cast.

Acknowledgements

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