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The influence of modification and squeeze casting on properties of AlSi11 alloy castings

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Abstract
The results of structural examinations and tests of mechanical properties of AlSi11 alloy, either gravity or squeeze cast, have been presented. The investigations have been carried out for both the non-modified silumin and the alloy modified with AlSr10 strontium master alloy. The measurements have been carried out for the cast plates of dimensions 200×100×25 mm. It has been found out that the modification combined with squeeze casting provides an advantageous set of strength and plastic properties ($R_m \approx 270$ MPa, $A_5 \approx 16\%$). The metallographic examination has revealed a significant refinement of both the primary α-phase dendrites and the silicon eutectics, however being dependent on the method of modification and casting. It has been found that the refinement of the primary crystals results from the influence of external pressure exerted on the solidifying casting, while the refinement observed for silicon eutectics is an effect of combined influence of modification and squeeze casting.

Keywords: Mechanical properties, Aluminium alloys; Squeeze casting technology; Modification.

1. Introduction

The squeeze casting technology belongs to the special casting methods and is intended for production of high-quality castings, especially made of aluminium alloys. Its advantages, i.e. high dimensional and shape accuracy, good tightness, fine structure, lack of surface defects, low roughness, the large capacity of the process, high output (up to 98% of molten metal), and small machining allowances, make it to be a technology of future. It meets current trends of metal industry, which tend to expand production processes providing for both high quality of products and low production cost, both material and energy savings, and proper manufacturing culture.

The squeeze casting technology combines three the most important and the most popular processes in the processing of aluminium alloy: die casting, pressure casting, and forging. Squeeze casting compares favourably with die casting and pressure casting with respect to the quality of products, and is superior to die casting and forging from the economic point of view. Squeeze casting is applied for production of combustion engine castings, car wheel discs, casings for compressors and electric engines, and hydraulic elements working under high pressure conditions [1–4].

High mechanical properties of squeezed castings, reaching values which frequently surpass the values obtained for plastic worked elements, results from the fine grain structure arising under the conditions of dynamic solidification under pressure [5-9]. The continuous pressure applied to the solidifying alloy increases the heat transfer coefficient and eliminates the shrinkage gap, diminishing by the same thermal resistance, what in turn increases the supercooling value and results in arising of a large number of crystallization nuclei [1, 6, 11, 12]. The degree of supercooling of the liquid alloy is related to the squeeze temperature. The best effect is achieved by applying pressure at a temperature close to the solidification range [6, 11–13]. Then the maximum supercooling of the alloy occurs and the nucleation rate exhibits the maximum increase. On the contrary, too high squeeze temperature can almost completely nullify the effect of increased pressure. High pressure also prevents arising of gas bubbles in the casting and eliminates shrinkage macro- and micro-porosity, what distinctly increases both the density and the plasticity of squeezed castings [11–14]. Pressure is a thermodynamic parameter which significantly affects phase transformations. For binary Al-Si alloys, an increase in pressure results in the simultaneous increase of the equilibrium solidification temperature of aluminium and the decrease of the equilibrium solidification temperature of silicon, according to the Clapeyron-Clausius relationship. There occurs a shift of the eutectic point towards higher silicon percentages. During the solidification of squeezed casting, both the rate of growth of the α solid solution dendrites and the volume percentage of this phase in the structure are increased. Simultaneously the silicon-rich regions arise in the liquid metal, so that primary crystals of silicon can originate [3].

Mechanical properties of squeeze cast silumin castings are hence dependent on a series of physical and chemical phenomena taking place during the solidification process, and they can be influenced mainly by the selection of Al-Si alloy type, its modification, and the technological parameters of squeezing. The purpose of the presented investigation has been an assessment of changes in the structure and in the mechanical properties of AlSi11 castings subjected to modification and squeezing.

2. The material and the methods of examination

The examinations have been carried out for the standardized AlSi11 alloy (PN-EN 1676). Squeeze casting has been manufactured by means of the PHM-250C hydraulic press equipped with a die of cavity dimensions 200×100×50 mm. The die has been heated up to 150°C prior to being poured, and its surface has been covered with a protective insulating and lubricating layer (a solution of colloidal graphite in water). The metal charge has been melted in the PIT 50S/400 induction crucible furnace, then overheated to the temperature of 700°C and drown from the crucible by means of a hand ladle. Each time about 1350 g of alloy has been taken and poured into the lower half of the die. Then the pressing die has been lowered, the die closed, and the squeeze pressure applied. The pressure has affected the solidifying and cooling casting for 50 s. After that time the die has been opened and the casting has been ejected by a set of four ejectors placed in corners of the plate. The castings have been produced either under the pressure of 60 MPa, or by gravity method (without applying pressure) at the mould temperature equal to about 150°C. The subsequent series of castings have been produced of the alloy modified with AlSr10 strontium master alloy. The modifying alloy (0.05% Sr) has been added after overheating the silumin up to 730°C. Then this temperature has been held for a period of 10 minutes in order to homogenize the chemical composition of the alloy. Specimens have been cast of such prepared metal under the same conditions as has been used for the non-modified alloy.

Examination of mechanical properties has been performed for the standardized tensile bars with length-to-diameter ratio of 5:1, according to the PN-91/H-04310 Standard, by means of the ZWICK-1488 servo-hydraulic testing machine. Microstructural observations have been carried out by means of the Nikon Epiphot light microscope for the specimens cut out of the middle parts of the plate castings.

3. The results and the analysis of examinations

The results of measurements concerning the strength properties (R_{02}, R_m) and elongation (A_5) have been presented in Figures 1 and 2. The performed examinations have unquestionably revealed the superiority of the squeeze casting over the gravity casting method. This is confirmed by the significantly higher R_m and R_{02} values. Modification of the examined alloys causes, in turn, additional increase of mechanical properties, and particularly of plasticity. Having analysed the particular mechanical parameters, one can say that:

- the yield point is at the level of 85-95 MPa for gravity cast items, while the applying of external pressure results in an increase of this parameter up to the value of about 100 MPa. The combined modifying and squeezing leads to the further growth of R_{02}, which is enlarged by about 40% with respect to the gravity castings (Fig. 1).
- the tensile strength of AlSi11 alloy castings depends mainly on the casting technology. The squeeze cast items exhibit the tensile strength greater by about 60 MPa than the gravity castings. The squeeze method integrated with modification allows for obtaining the highest strength of the alloy, exceeding 260 MPa (Fig. 1).
- the largest changes in plasticity of the AlSi11 alloy take place as a result of modification. Elongation of the gravity cast specimens made of the modified alloy is twice, and of the modified and squeezed castings is thrice the elongation of the non-modified gravity castings (Fig. 2).

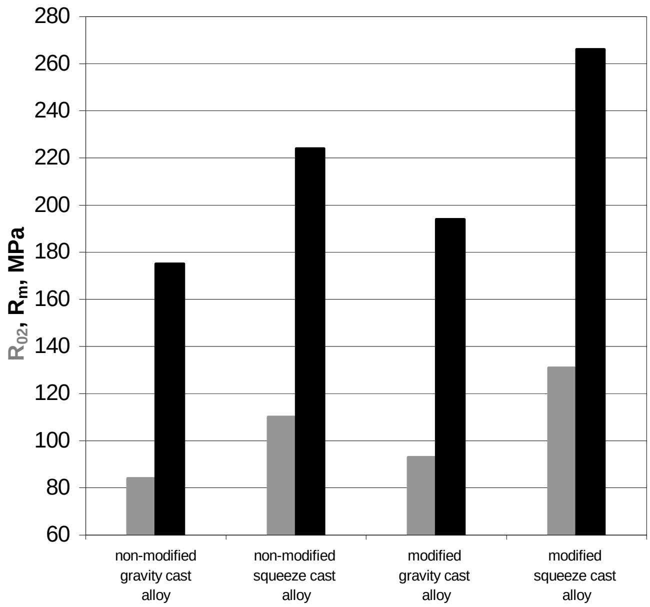


Fig. 1. The influence of casting conditions on the strength properties of AlSi11 alloy

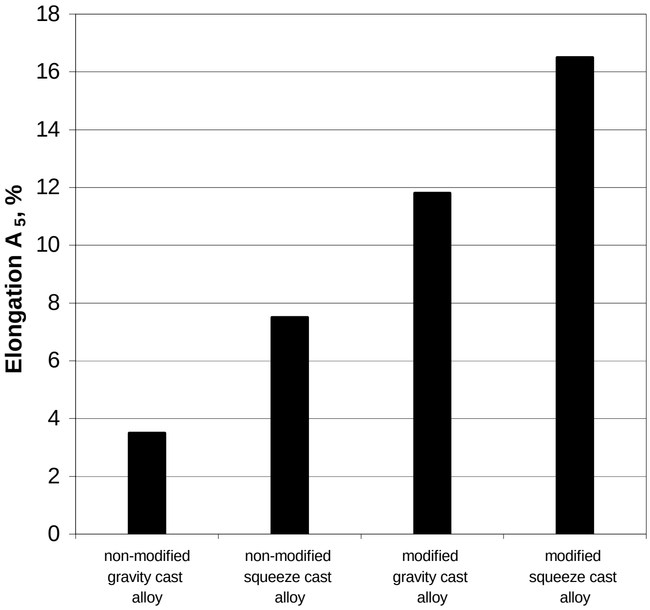
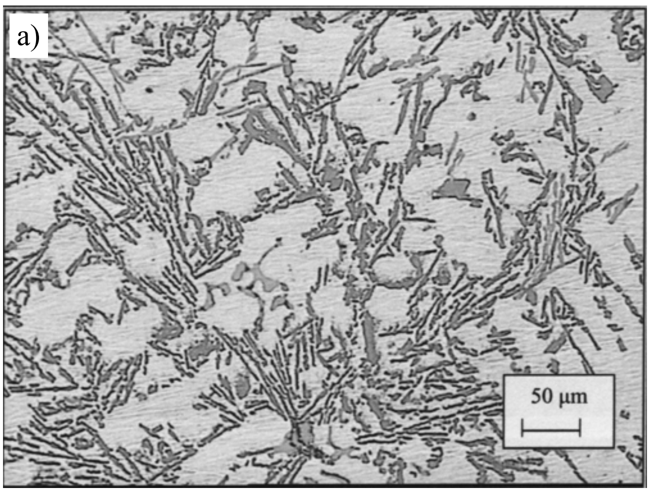


Fig. 2. The influence of casting conditions on the elongation A_5 of the AlSi11 alloy

The characteristic feature of a casting solidifying under pressure is the refinement of its structure, which results in the strengthening of the alloy. The structure of AlSi11 alloy consists of two phases. First of them is the plastic matrix of α(Al) solid solution, and the second one is constituted by hard and brittle silicon crystals. The structure of the non-modified gravity castings is characterised by relatively large dendrites of α phase on a background of the lamellar silicon eutectics (Fig. 3a). After the strontium master alloy had been added to the processed metal, the eutectics has been effectively modified to the fibrous one (Fig. 3b). Further structural changes are related to the pressure which influence the solidifying casting.



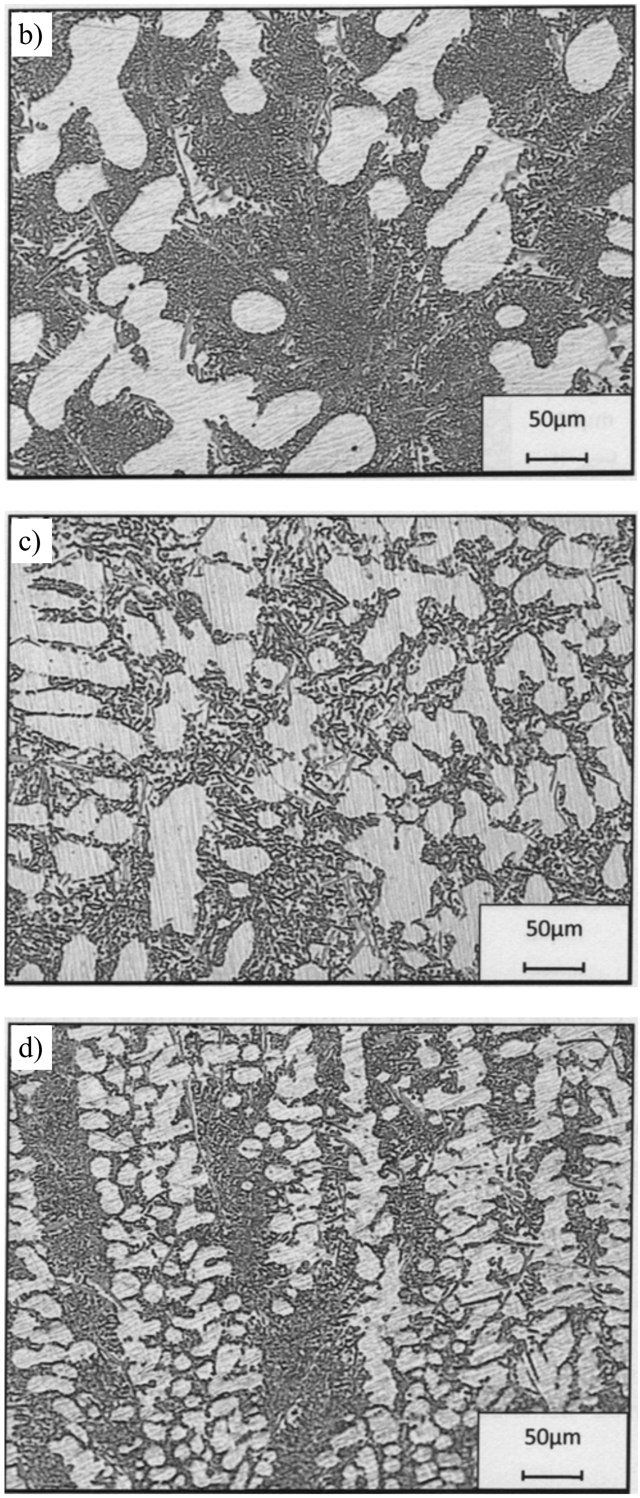


Fig. 3. Microstructure of AlSi11 alloy: a) non-modified, gravity cast alloy, b) non-modified squeeze cast alloy, c) modified gravity cast alloy, d) modified, squeeze cast alloy

Squeeze casting of the non-modified AlSi11 alloy has resulted in size reduction of α-phase crystals and in the refinement of the silicon eutectics, though the distances between silicon lamellae are much greater than for the modified alloy (Fig. 3c). Such changes in the alloy structure are related to the increased rate of heat extraction by the metal mould. Due to the applying of external force, the shrinkage gap occurring during the solidification process between a casting and the mould arises much later than it does for the case of the gravity die casting solidification. This means significantly less width of the gap and more intensive heat extraction by the die. Research works presented in references [Ref. 3, 15] show that squeeze casting shortens the solidification period of a casting by 1,5 up to 5 times. The combined influence of modification and external pressure has permitted for obtaining the most refined structure. Modification has assured for achieving the eutectics with very small interfacial distance, while the influence of pressure has caused the refinement of the α-phase dendrites (Fig. 3d). This refinement of structure has been accompanied by the enhancement of the mechanical properties, and first of all of plasticity.

4. Conclusions

1. Squeezing of castings generates first of all an increase in the strength properties, while modification influences principally the plasticity of the AlSi11 alloy. The combined application of both these treatment types allows for manufacturing of castings which exhibit high mechanical properties: $R_m \approx 270$ MPa, $A_5 \approx 16\%$.
2. The dynamic crystallization of the alloy under pressure results in the refinement of both the primary α-phase dendrites and the silicon eutectics, although the distances between silicon lamellae are much greater than for the modified alloy.
3. Integration of squeeze casting method and the modifying treatment permits for obtaining the most advantageous structure of AlSi11 alloy, consisting of fine crystals of the α-phase and the fibrous silicon eutectics.

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