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# Utilization of Heat Treatment Aimed to Spheroidization of Eutectic Silicon for Silumin Castings Produced by Squeeze Casting

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## Abstract

This paper describes the possibility of using very short periods of solution annealing in the heat treatment of unmodified hypoeutectic silumin alloy AlSi7Mg0,3 casted by method of casting with crystallization under pressure with forced convection (direct squeeze casting process). Castings prepared at different casting parameters were subjected to special heat treatment called SST (Silicon Spheroidization Treatment), which were originally used only for the modified silumin alloys to spheroidization of eutectic silicon. Temperature holding time in solution annealing of T6 heat treatment is limited in the SST process to only a few minutes. It was studied the effect of casting parameters and periods of solution annealing on ultimate strength, yield strength, and especially ductility that in the unmodified silumin alloy castings is relatively low.

**Keywords:** Heat treatment, Silicon spheroidization treatment, Casting with crystallization under pressure (Direct squeeze casting), Hypoeutectic aluminium alloy

## 1. Introduction

The critical structural components must meet the required strength in addition to the minimum elongation of 15 % which is in practice generally known. In today's automotive industry most used aluminium alloys such as AlSi7Mg0,3 (A356) or AlSi7Mg0,6 (A357) have major problems to achieve of this value. To increase of ductility is currently the most commonly used refinement of eutectic silicon by adding the appropriate modifier to the melt before casting, but even that does not always get sufficient results.

Cost-effective increasing of ductility of silumins with refined eutectic silicon by appropriate heat treatment were presented by the authors [1, 2]. By studying the conventional heat treatment processes of silumins concluded that to achieve the desired elongation over 15 % is necessary to focus mainly on spheroidization of eutectic silicon in the first phase of solution annealing and eliminate its coarsening. Spheroidization of very fine fibrous silicon occurs already at the first minutes of solution annealing. The new heat treatment is called the SST (Silicon Spheroidization Treatment). SST is an effective heat treating process, which is virtually identical to conventional procedures T6 or T4 (solution annealing and artificial or natural aging), with

the difference that the solution annealing times are extremely short. Therefore, if solvent annealing took 3 minutes for example, authors tagged the heat treatment as T6x3 respectively T4x3. SST heat treating process was verified on specific parts, and even with non-constant wall thickness.

Partial modification of eutectic silicon can also be achieved by pressure application on solidifying alloy. Such conditions of solidification provides process of casting with crystallization under pressure (Direct Squeeze Casting - DSC) [3, 4]. Conventional DSC or modified DSC with forced convection of the melt [5] aimed at creating of non-dendritic (spherical) primary solid solution  $\alpha$ -Al can also achieved various degrees of eutectic silicon modification, which can be classified with scale presented by G. Chai and L. Bäckerud [6]. In the present work were investigated options affecting ductility of DSC castings produced from chemically unmodified alloy AlSi7Mg0,3 (A356) by using principles of non-conventional heat treatment process SST.

## 2. Preparation of experimental material

The shape and dimensions of the castings are shown in Fig. 1. In the castings took place forced convection of the melt induced by volume changes during solidification or by violation of the mass balance through the diversion of melt fraction. Both procedures were described in detail in [5]. Casting No.1 was casted by DSC method in which the forced convection of the melt was caused only by the volume changes of solidifying alloy. Casting No.2 was casted by modified method of DSC in which the forced convection of the melt was intensified through the diversion of 10 % of main melt volume into the grooves. Cast No.3 is only comparative and it was gravity casted via using of the chill mould.

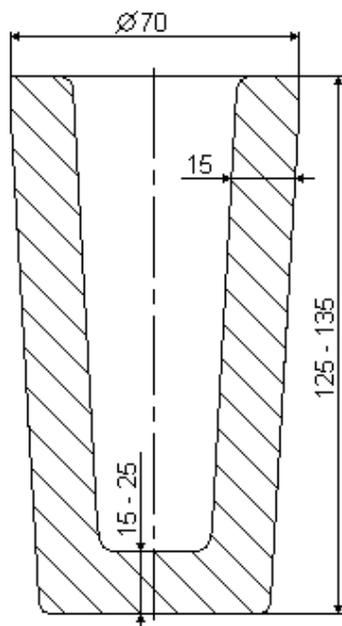


Fig. 1. Shape and dimensions of the castings

For the production of DSC castings was used a hydraulic press PYE 250 SS M with an approach speed of  $200 \text{ mm}\cdot\text{s}^{-1}$  activated to full die closure and attained the preset value of pressing force. Switching to work speed of  $20 \text{ mm}\cdot\text{s}^{-1}$ , which corresponds to the set pressing force of 400 kN was activated automatically after reaching this value and not by standard mechanical press stop used for switchover of the piston movement before pressing stage. Die temperature has always been stable for at least 90 minutes before casting at temperature of  $80 \text{ }^\circ\text{C}$ . Punch (upper part of die) was heated only by radiation in a closed die and its temperature was not controlled.

Medium chemical composition of basic elements in the alloy EN AC-AlSi7Mg which was used is: 92,713 % Al; 6,701 % Si; 0,362 % Mg; 0,112 % Fe; 0,030 % Ti; and 0,015 % Mn. Other elements in the alloy were contained only in trace amounts. The alloy has been treated with covering salt SYLUKRIT and degassed before casting with cleaning salt ECOSAL-AL 114 at temperature of  $720 \text{ }^\circ\text{C}$ . The temperature was controlled during the metallurgical operations and before casting by calibrated thermometer OMEGA HH306 OMEGATTE<sup>®</sup>. Casting temperature was at DSC  $615 \text{ }^\circ\text{C}$  and at chill casting  $625 \text{ }^\circ\text{C}$ . During the cooling of the melt in graphite crucibles to casting temperature was mechanically removed surface oxide layer. When the melt temperature was  $620 \text{ }^\circ\text{C}$  operator of the press opened the die and when the temperature dropped to  $617 \text{ }^\circ\text{C}$  it was began the pouring phase. Within 5 seconds the die was closed and the pressing force reached a preset maximum of 400 kN, which corresponds to the compacting pressure in the cavity of about 100 MPa. After 30 seconds the die was opened and casting thrown out. Endurance of 30 second at the selected value of compacting pressure of 100 MPa was measured with a handheld digital stopwatch, so pressing time varied in the range of several seconds.

Measured and evaluated variables were: melt temperature  $T$ , die temperature  $T_D$ , punch position  $h$  (pursuing and describing the volume changes during solidification of the casting) and pressure in the die cavity  $p$ , which is converted from the pressure measured in the hydraulic system  $p_h$ . Temperatures were scanned with an accuracy of  $0,1 \text{ }^\circ\text{C}$ , pressure with accuracy of  $0,1 \text{ MPa}$  and punch position (punch motion) with accuracy of  $0,01 \text{ mm}$ . Scanning frequency of all variables was  $0,01 \text{ s}$ .

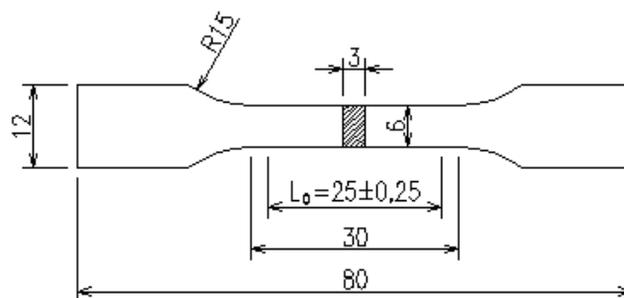


Fig. 2. Machined test pieces for tensile testing (EN 10002-1:2001)

Heat treatment was performed in a calibrated and thermocouples controlled laboratory muffle furnace VEB Elektro

LM 212.11 (with power 2,3 kW) on tensile test pieces (Fig. 2) prepared by machining according to EN 10002-1:2001. The temperature in the furnace was stabilized before heat treatment for 6 hours at 540 °C. Solution annealing times were determined according to the theory of SST at 3, 5 and 10 minutes (T6x3, T6x5, T6x10) [1, 2]. The standard T6 heat treatment in this part of the experiment because of the limited number of test pieces was not performed. Time to reach temperatures over 500 °C at the core of the test pieces was determined by calculation for 2 minutes, so the resulting dwell times in the furnace were 5, 7 and 12 minutes. After removal pieces from the furnace was cooled (quenched) in water at 20 °C. Artificial aging was carried out in the same furnace stabilized also 6 hours before the heat treatment at 160 °C. Artificial aging time was 4 hours. Cooling of pieces was carried out in the open air at ambient temperature.

Tensile test was performed at room temperature on universal tensile testing machine LabTest 5.250 SP1 with a speed of movement of the cross 2,5 mm.min<sup>-1</sup>. The tensile strength UTS, proof (yield) strength YT and percentage elongation after fracture *A* was evaluated.

### 3. Results and Discussion

Table 1 shows the average values of three measurements of tensile tests. For comparison the table also presents typical mechanical properties of DSC castings made from alloy A356 (AlSi7Mg0,3) after a standard T6 heat treatment reported in the NADCA standards [7]. The basic as cast condition is marked with an established symbol F (as fabricated), post-heat treatment conditions are marked by the solution annealing times, excluding the preheating time as T6x3, T6x5 and T6x10.

From the values of mechanical properties of selected DSC castings (Table 1) it can be seen that in the as cast condition (F) is a very high tensile strength (about 315 MPa), even higher than the typical tensile strength of DSC castings after T6 heat treatment

[7]. But it should be noted that the castings had time for aging of several weeks after they were casted (before the tensile testing). Elongation of DSC castings in as cast condition, which is significantly influenced by the morphology of eutectic silicon was standard (about 11 to 12 %). Eutectic silicon in the castings was fine lamellar with an average thickness about 1 micron, and the sharp edges. High tensile strength of DSC castings in as cast condition may be due to more oversaturated solid solution by silicon, which was achieved by altered diffusion of elements in liquid state and high cooling rate, fineness and homogeneity of the final structures and, finally, by the excellent soundness of the castings.

After T6x3 heat treatment tensile strength has risen about 50 to 60 MPa, to the value of about 370 MPa, while the elongation increased rapidly from 11 to 18 % for casting No.1 and from 12 to 16 % for casting No.2. This fact is caused by gradual rounding the edges of eutectic silicon.

In other modes of heat treatment the tensile strength has changed only slightly, but other changes of elongation were observed. Casting No.1 had the best elongation at 21 % after T6x10 heat treatment and casting No.2 at 20 % after T6x5 heat treatment. From the SEM observations it can be concluded that the eutectic silicon with longer heat treatment times is more soluble and the ends more rounded. It was observed, that the lamellas of eutectic silicon, which are already dissolved inasmuch that at the ends were created the globules, which are connected with the original lamellas only with thin connecting bridges. After dissolution of the connecting bridges would create a separate eutectic silicon particles with spherical shape.

At the casting No.2, which achieved the highest mechanical properties after T6x5 heat treatment was an increase of tensile strength about 23 % (from 314 to 386 MPa) proof strength about 14 % (from 152 to 174 MPa) and elongation about 67 % (from 12 to 20 %). Therefore T6x5 heat treatment was rated as the best mode for processing of the DSC castings.

Table 1.

Mechanical properties of DSC castings (No.1 and No.2) and comparative chill casting (No.3) before and after heat treatment observed by tensile testing according to EN 10002-1:2001 compared with typical mechanical properties of squeeze casted A356 (AlSi7Mg0,3) alloy castings after T6 heat treatment reported in the NADCA standards [7]

Mechanical properties	Casting condition	Casting No.1	Casting No.2	Casting No.3	Squeeze Casting A356
UTS [MPa]	F	315	314	234	-
	T6x3	374	367	298	-
	T6x5	379	386	297	-
	T6x10	371	381	324	-
	T6	-	-	-	300
YS [MPa]	F	133	152	135	-
	T6x3	154	168	144	-
	T6x5	156	174	157	-
	T6x10	152	178	164	-
	T6	-	-	-	225
A [%]	F	11	12	4,5	-
	T6x3	18	16	6	-
	T6x5	18	20	6	-
	T6x10	21	15	8	-
	T6	-	-	-	12

After the T6x5 heat treatment at the casting No.1 was an increase of tensile strength about 19 % (from 315 to 379 MPa) proof strength about 17 % (from 133 to 156 MPa) and elongation about 64 % (from 11 to 18 %). It should be noted that after T6x10 heat treatment at the casting No.1 was an increase of elongation as much as 91 % (from 11 to 21 %).

At the comparative chill casting No.3, which reached the highest mechanical properties significantly after T6x10 heat treatment was an increase of tensile strength about 38 % (from 234 to 324 MPa), proof strength about 21 % (from 135 to 164 MPa) and elongation about 78 % (from 4.5 to 8 %).

All measured values of proof (yield) strength are relatively low compared with the literature where the yield strength is approximately at 225 MPa [7]. The highest proof strength of 178 MPa was achieved at the casting No.2 after T6x10 heat treatment. At the mode of T6x5 heat treatment, which was rated the best it was 174 MPa. Casting No.1 reached the highest value of proof strength right after T6x5 heat treatment, and only 156 MPa. In practice for the evaluation of critical components is exerted the required minimum yield strength of these alloy at 180 MPa, so further study is necessary to focus on the causes affecting the achievement of this minimum limit.

## 4. Conclusions

The results of this study brings the knowledge that to increase the elongation of aluminium alloy castings over 15 % goes without major problems, and even in some cases is possible to achieve the values over 20 %. Anyway, by using suitable heat treatment the elongation standard for critical components (over 15 %) together with a sufficiently high tensile strength (over 300 MPa) can be achieved at AlSi7Mg0,3 alloy DSC castings without prior modification of the alloy and for a very short time of solution annealing.

As the best mode of heat treatment for chemically unmodified alloy EN AC-AlSi7Mg (A356) prepared under the above mentioned conditions of DSC was evaluated the T6x5 heat treatment, that means 5 minutes of solution annealing at 540 °C (plus few minutes preheating to the temperature over 500 °C), cooling in water at 20 °C and 4 hours of artificial aging at 160 °C. In this mode, the elongation values of DSC castings (No.1 and No.2) were obtained 18 and 20 %, and tensile strength 379 and 386 MPa. Proof (yield) strength were 156 and 174 MPa.

Effect of intensity of forced convection of the melt at tensile strength and ductility in the as cast condition and after T6x5 heat treatment is negligible. Tensile strength 315 respectively 314

MPa, was changed to 379 respectively 386 MPa, and elongation 11 respectively 12 % was changed to 18 respectively 20 %. However, the intensity of forced convection of the melt probably had effect at the yield strength value. The proof strength in the as cast condition was 133 respectively 152 MPa, and it was changed after T6x5 heat treatment to 156 respectively 174 MPa.

Low values of yield strength compared with those of NADCA standards [7] as well as the behaviour of the material in the elastic deformation zone will be the subject of further research.

## Acknowledgements

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