THE EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES OF SQUEEZE CASTINGS FROM AlSi7Mg ALLOYS

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Abstract

The characteristics of cast aluminum alloys are shown in the paper with particular emphasis put on AlSi7Mg alloy and method of silumin modification. Heat treatments have been described to enhance the mechanical properties of cast aluminum alloy. The work presents the melting process, modification and casting of the AlSi7Mg alloy by gravity method and squeeze casting. The paper describes the influence of solution heat treatment and ageing treatment to mechanical properties of AK7 silumin. Based on the research, it has been found that squeeze casting ensures the production of high-quality AlSi7Mg casting alloy. Modification with strontium improves the strength properties and significantly increases the elongation of gravity castings - the relative increase of A_5 in these castings has reached about 40 %. In all tested castings the treatments of solution heat and ageing have increased the strength of the material by 33-40 MPa. A combination of modification, heat treatment and squeeze casting allows to manufacture of AlSi7Mg alloy with high mechanical properties, R_m = 280 MPa, $R_{p0.2}$ = 190 MPa, A_5 = 16 %.

Keywords: Squeeze casting, aluminum alloys, mechanical properties

1. INTRODUCTION

Aluminum, due to its properties such as corrosion resistance, electrical and thermal conductivity and significant plasticity, is often used as one of the most important technical metals used in the form of pure metal as well as its alloys. Aluminum alloys are characterized by a high ratio of durability to specific gravity, higher than in the case of steel, and their resilience does not decrease as the temperature drops, resulting in higher resilience than steel at low temperatures. Aluminum alloys, however, are characterized by low fatigue resistance.

The AlSi7Mg alloy is one of the types of hypoeutectic silumin containing less than 10 wt.% Si. The presence of magnesium in this alloy allows perform heat treatment - precipitation hardening, which in turn increases the mechanical properties of this alloy. The mechanical properties of the alloy depend on the method of adding water and the heat treatment applied [1].

The heat treatment of aluminum alloys is primarily aimed at increasing their strength properties, and consists of their hardening dispersion, i.e., subsequent performance of the operation of supersaturation of a solid and aging solution. AlSi7Mg alloys undergo aging processes that are associated with the Al-Mg2Si pseudo-triple system [2]. With the growth of magnesium content, the tensile strength increases, increase of the yield point and the hardness, while elongation decreases. The state of alloy modification depends on temperature, soaking time, and accelerated aging parameters. The goal of supersaturation is to homogenize and enrich the solid solution with Mg and Si, and to reconstruct the skeleton that was formed by eutectic silicon in the cast structure [3].

The squeeze casting process offers many advantages over other casting methods under the influence of external pressure. This method gives the possibility to produce castings with a precise representation of the shape and surface, with yield of metal up to 95 %. The elements produced by this method are characterized by a highly-fragmented structure, devoid of porosity, which allows them to be heat treated and further processed [4-5].

2. AUTHOR'S IVESTIGATIONS

The aim of the study was the evaluation of the effect of heat treatment on the mechanical properties of AlSi7Mg alloys produced by the method of unmodified iron pressing and after modification with strontium mortar. For comparison purposes, castings were made by gravitation, also from unmodified alloys and after modification with Sr mortar.

2.1. Melting the charge and pressing the castings

The chemical composition of the research material used is shown in the **Table 1**.

Table 1 Chemical composition of the AlSi7Mg alloy according to the standard [1]

Type		**Chemical composition** (wt.%)						
Sign	Feature	Si	Cu	Mg	Mn	Ni	Fe	Zn
AlSi7Mg	AK7	6.0-8.0	0.2	0.25-0.4	0.1-0.5	-	0.5-0.8	0.2

The experimental smelting was carried out using a laboratory PIT50S/400 induction furnace. The furnace inductor was powered by a current of up to 2000 Hz. Castings were made on a PHM-250c hydraulic press equipped with a 250x100x50 mm metal recess. The nominal pressure of the press was 205 ton. The mold was made from two parts: a mold (connected to the press piston) and a die. At the bottom of the die, ejector plates were mounted to remove castings from the mold.

Before flooding, the mold was heated to about 200 °C and a protective graphite coating (solution of colloidal graphite in water) was applied to its surface. By using a crucible spoon, about 1350 grams of liquid metal was collected and poured into the lower half of the mold. The mold was closed and the melt was pressed under the pressure of 60 MPa. The press time was constant (50 seconds). After this time, the stamp was lifted and the casts were pushed using four ejectors located at the corners of the plates. The series of castings were made of unmodified and modified strontium mortar. AlSr10 mortar was used in the form of 10 mm diameter rods. The modification procedure was performed at a constant temperature about 720 °C. The liquid was then held at this temperature for 15 minutes and lowered to a pouring temperature of 680 °C. The amount of added modifier was 0.04 % Sr in relation to the weight of the charge.

In the die mounted on the press, the series of die castings were also made. Execution of the chill cast consisted of pouring the liquid metal into the lower half of the mold and then lowering the mold to the surface of contact with the liquid metal. At the moment of contact the stroke of the piston was stopped and the pressure of the press turned off. After the coagulation and cooling of the castings, with the help of ejectors, they were removed from the die.

2.2. Heat treatment procedure

AlSi7Mg alloy treatment was commenced with supersaturation, followed by artificial aging. Heat treatment of cast and gravity castings in the unmodified state and after modification was carried out in the following order: heating the casting to 520 °C; preheating at 520 °C for 12 hours; cooling in cold water; artificial aging at 160 °C for 8 hours; cooling at ambient temperature. The treatments were performed in an electric chamber oven controlled by an electronic temperature controller FCS 200 with an accuracy of ± 2 °C. Sample heating took place in air atmosphere.

2.3. Results of measurements of mechanical properties

As part of the conducted mechanical tests, the conventional yield strength ($R_{p0.2}$), the tensile strength (R_m) and the relative elongation (A_5) were measured. All mechanical indicators were specified in a stretch sample performed accordingly to the standard [6].

The mechanical properties of the castings prior to treatment and after thermal treatments were determined by performing eight measurements for each point of the experiment. During the tensile test, the value of the breaking force *P* and the elongation measurement Δl was recorded. As a result of compressing these two measurements taking into account the cross sections of the samples, strength charts were obtained - stress in the function of elongation. Based on the data from the stretch tests, characteristic values $R_{p0.2}$, R_m and A_5 were determined and statistically developed. Measurement results for AlSi7Mg alloy castings are shown in the **Table 2**.

Table 2 Results of tensile strength examination, contract yield strength and relative elongation of AlSi7Mg alloy before heat treatment and after supersaturation and aging

Alloy state	Before heat treatment				After supersaturation and aging			
	Sample number	R_m (MPa)	$R_{p0.2}$ (MPa)	A_5 (%)	Sample number	R_m (MPa)	$R_{p0.2}$ (MPa)	A_5 (%)
Castings made by gravity	1.1	177	91	4.25	5.1	224	143	8.41
	1.2	187	100	4.84	5.2	204	125	6.79
	1.3	192	103	5.73	5.3	215	138	7.83
	1.4	185	97	4.99	5.4	209	130	6.22
	1.5	171	87	3.87	5.5	208	127	6.87
	1.6	141	79	3.11	5.6	218	140	7.49
	1.7	173	90	4.23	5.7	158	103	5.12
	1.8	183	95	4.86	5.8	226	125	7.34
Pressed	2.1	218	114	11.66	6.1	265	172	15.37
	2.2	234	127	13.43	6.2	259	164	13.52
	2.3	230	117	12.65	6.3	267	176	14.96
	2.4	214	112	10.71	6.4	242	154	12.29
	2.5	227	115	11.58	6.5	264	171	14.34
	2.6	230	120	12.17	6.6	255	165	13.14
	2.7	217	113	10.67	6.7	262	169	14.23
	2.8	227	119	11.81	6.8	249	157	13.22
Castings modified and made by gravity	3.1	202	101	7.15	7.1	222	147	9.86
	3.2	187	91	5.86	7.2	229	149	10.22
	3.3	195	94	6.24	7.3	238	167	10.95
	3.4	147	63	5.71	7.4	243	169	11.14
	3.5	178	81	5.99	7.5	220	133	8.28
	3.6	205	102	7.45	7.6	230	147	9.53
	3.7	197	97	6.77	7.7	234	149	9.62
	3.8	190	86	6.43	7.8	234	151	9.74
Modificated and pressed	4.1	223	121	13.25	8.1	282	192	16.71
	4.2	254	145	15.19	8.2	274	185	16.86
	4.3	248	137	14.24	8.3	185	158	10.28
	4.4	241	136	13.87	8.4	295	197	17.27
	4.5	235	130	14.43	8.5	280	190	17.13
	4.6	249	128	14.54	8.6	275	185	16.26
	4.7	248	130	12.98	8.7	291	195	16.34
	4.8	234	119	13.52	8.8	282	194	15.89

The results shown in **Table 2** prove that several mechanical properties measurements are not within the maximum error limit - the results have a gross error. By analyzing **Table 2** regarding tensile strength R_m, conventional yield strength $R_{p0.2}$ and relative elongation A_5, it was noted that the results obtained in trials 1.6, 3.4, 5.7, 7.5 and 8.3 are not within the maximum measurement error and were rejected in the calculation of values of the arithmetic mean in **Table 3**. This table calculated the arithmetic mean of value for the samples tested.

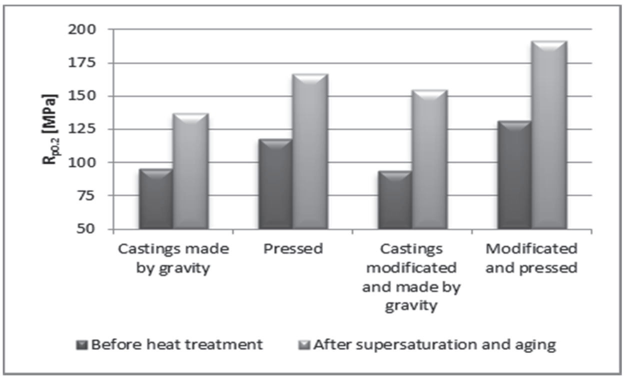
Table 3 Results of the arithmetic mean of the research results for tensile strength R_m, conventional yield strength $R_{p0.2}$ and the relative elongation A_5 of the alloy AlSi7Mg before heat treatment and after supersaturation and aging

Alloy state		Sample series number	R_m (MPa)	$R_{p0.2}$ (MPa)	A_5 (%)
Before heat treatment	Castings made by gravity	1	181	95	4.7
	Pressed	2	225	118	11.9
	Castings modificated and made by gravity	3	194	93	6.6
	Modificated and pressed	4	242	131	14.0
After supersaturation and aging	Castings made by gravity	5	215	136	7.3
	Pressed	6	258	166	13.9
	Castings modificated and made by gravity	7	231	154	10.2
	Modificated and pressed	8	283	191	16.4

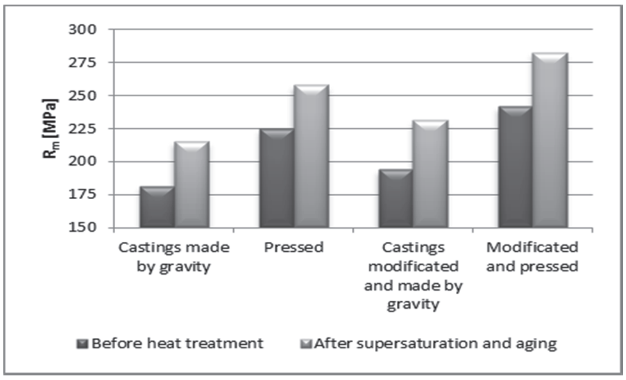
3. ANALYSIS OF RESULTS

Based on the performed studies, the influence of heat treatment on the mechanical properties of AlSi7Mg alloy castings was made in four variants: gravity-unmodified alloy, gravity-modified alloy strontium, pressed from unmodified alloy, pressed from alloy modified with strontium mortar.

By firstly comparing the mechanical properties of the castings before the heat treatment, it can be stated that they differ significantly depending on the method of manufacturing and modification. The technology of pressing ensures the production of the highest mechanical indexes. As a result of the external pressure on the solidifying cast, R_m increased by 35 MPa, $R_{p0.2}$ by 50 MPa and A_5 by 8 %. Particular emphasis should be placed on the final size determining the plasticity of the castings. The elongation of pressed castings is 3 times higher than that of gravity castings.



(a)



(b)

Figure 1 The comparative graphs of the conventional yield strength $R_{p0.2}$ (a) and of the tensile strength R_m (b) of AlSi7Mg alloy castings depending on the method of casting and modification before heat treatment and after supersaturation and aging

When analyzing changes in mechanical properties caused by the modification of the alloy with strontium mortar, it can be stated that it improves all tested mechanical parameters. The effect of the casting and modification method on the mechanical properties of AlSi7Mg alloys is illustrated in **Figures 1 and 2**.

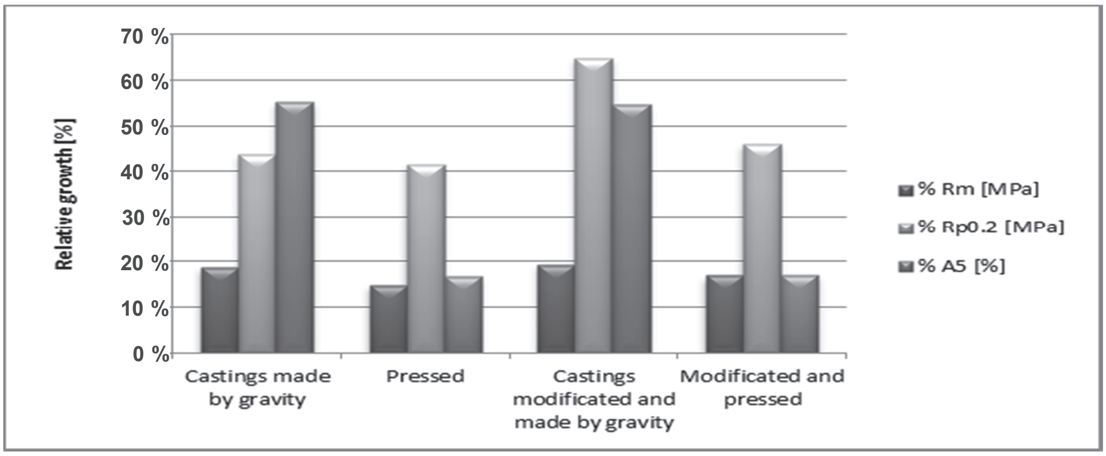


Figure 2 Comparative graph of the tensile strength R_m, conventional yield strength $R_{p0.2}$ and relative elongation A_5 of AlSi7Mg alloy castings, depending on the method of casting and modification before heat treatment and after supersaturation and aging

Table 4 Absolute growth (ΔR_m) and relative growth (% R_m) of the tensile strength, absolute increase ($\Delta R_{p0.2}$) and relative increase (% $R_{p0.2}$), absolute increase (ΔA_5) and relative increase (% A_5) of the yield strength of AlSi7Mg alloys obtained after saturation and aging

Alloy state	ΔR_m (MPa)	% R_m (MPa)	$\Delta R_{p0.2}$ (MPa)	% $R_{p0.2}$ (MPa)	ΔA_5 (%)	% A_5 (%)
Castings made by gravity	33.9	18.7	41.5	43.7	2.6	55.3
Pressed	33.3	14.8	48.8	41.5	2.0	16.8
Castings modified and made by gravity	37.4	19.3	60.6	64.9	3.6	54.5
Modificated and pressed	40.9	16.9	60.2	46.0	2.4	17.1

The performed heat treatment procedures: supersaturation and aging have allowed the hardening of castings AlSi7Mg alloy. As a result of heat treatment, the mechanical properties increased in all castings investigated. It should be noted that the alloy state and the casting method had a significant effect on the size of the changes in the individual mechanical indicators. These changes are listed in **Tables 4**. The evaluation of mechanical properties increase was performed in two categories: absolute increment ΔR_m, $\Delta R_{p0.2}$ and ΔA_5, and relative increase in properties before heat treatment, expressed in %.

The tests performed on heat-treated samples indicate that the highest relative increase in mechanical properties occurs in gravity-casting. The use of compression technology improves the mechanical parameters. It can be concluded that the tensile strength of R_m in unmodified alloy castings increases by approximately 33 MPa irrespective of the casting method, while in non-modified alloy castings it increases by 37 - 40 MPa. In the relative increase category, the effects of supersaturation and aging are more pronounced in gravity-cast samples. The relative increase in these castings is 20 %, and in pressed castings is 15 % for the unmodified alloy and 17 % for the alloy after the Sr modification.

The conventional yield strength $R_{p0.2}$ shows a characteristic similar to that of tensile strength, but shows a more pronounced effect of modification. Castings made of unmodified alloy show an absolute increase of 42 - 49

MPa, and in molds made from modified alloy it is at the level of 60 MPa. Relative growth of $R_{p0.2}$ is at the highest value in 65 % castings made via gravitation method. The remaining castings are approx. 40 %.

Modification and casting methods affect the changes in elongation A_5 the most. In pressed castings, the absolute growth is 2 and 2.6 % respectively for the unmodified alloy and the one after modification. On the other hand, gravitational castings are higher and are 2.6 and 3.6 %, respectively. This translates into significant relative gains obtained by heat treatment in die castings that reach a value of about 55 %, and in the case of pressed castings, due to the high initial values of A_5 they are only 17 %.

4. CONCLUSION

Based on the performed research regarding mechanical properties of the castings before heat treatment and after thermal treatments, it can be stated that:

- Liquid press technology ensures the creation of high quality AlSi7Mg alloy castings. It significantly affects the improvement of the cast elongation to the level of 14 %.
- Modification of the strontium mortar alloy increases the durability properties and significantly increases the length of the castings made by gravitation. Relative growth of A_5 in these castings reaches approx. 40 %.
- The performance of saturation and aging treatments has increased the strength of the plastics by 33-40 MPa in all tested castings.
- The effect of modifications on the course of precipitation hardening is mainly manifested in the increase in the yield strength and the additional plasticity (A_5) of castings.
- Combination of procedures of modification, heat treatment and pressing technology allows AlSi7Mg alloys with high mechanical properties to be produced: R_m = 280 MPa, $R_{p0.2}$ = 190 MPa, A_5 = 16 %.

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