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Evaluation of the Effect of External Conditions During Crystallization and Solidification on the Final Structure of AlSi7Mg

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Abstract

The paper deals with the possibilities of influencing the final microstructure of aluminium alloy castings by changing the external conditions of crystallization and solidification. Aluminum alloys, especially Al-Si alloys, are nowadays one of the most used non-ferrous metal alloys, especially due to their mass application in the automotive field. It is in this industry that extreme emphasis is placed on the quality of cast parts with regard to safety. For this reason, a key production parameter is the mastery of the control of the resulting microstructure of the castings and the associated internal quality, which is subject to high demands defined by international standards. The aim of the experiment of this paper is to evaluate the effect of different preheating of the metal mould on the resulting structure and hardness of test castings made of AlSi7Mg0.3 material. The hardness measurement will be evaluated on a hardness tester. The parameter SDAS, Microporosity, Content of excluded eutectic will be evaluated. Dependencies will be found and plotted.

Keywords: Gravity casting, Silumin, Permanent mold, Eutectic, Microstructure

1. Introduction

In the case of aluminium-silicon alloys, these are "universal" materials applicable to different technologies and types of final castings. Due to the potential applications of Al-Si alloys where high mechanical and thermal loads are involved (e.g. pistons, cylinder heads, brake calipers and engine parts), an alloy with high corrosion resistance, good mechanical properties and dimensional stability at different operating temperatures is required [1-2]. Investigation of castings with thermal stresses for automotive driveline components has been carried out by authors [3-5], where they focus, for example, on the assessment of mechanical properties at high temperature and improvements are achieved by adding Mn or Ni.

These alloy property requirements are influenced, among other things, by the resulting microstructure.. There are a number of parameters that effect the resulting microstructure - purity of the melt in terms of inclusions and dissolved gases, chemical composition (use of alloying elements), heat treatment of already finished castings or solidification or cooling conditions of castings (especially cooling rate) [6]. By influencing the solidification process of the metal, microstructural changes in the material can also be achieved, e.g. high cooling rates enable the refinement of the eutectic silicon phase, which significantly influences the mechanical properties of the material, especially its brittleness [7-8].

The prerequisite would therefore be the choice of a mould with the highest possible cooling effect without preheating or the application of additional rapid cooling of the mould after casting. Under normal operating conditions, permanent metal moulds are most commonly used for casting Al-Si alloys. However, these metal moulds have to be preheated to a high working temperature to increase the runout, but in order to extend the lifetime of the moulds and to increase the requirement for production efficiency, i.e. the number of repetitions of the casting cycle per hour, the moulds cannot be shock cooled immediately after casting.

Therefore, it is necessary to consider the effect of preheating of metal moulds on crystallization and solidification and the resulting microstructure of cast parts. In describing the microstructure of silumin, microstructural parameters such as the spacing of secondary/dendritic arms (SDAS), the shape and size of eutectic silicon crystals (PSPA), the proportion and size of intermetallic phases, and porosity are evaluated. [1, 7, 9]. The evaluation of the SDAS parameter can be done, for example, manually. In order to identify and measure groups of secondary dendrite axes by image analysis, it is necessary to examine each photograph and label the dendrites to be measured. The dendrite axis distance value was automatically determined according to relation (1):

$$SDAS = L/n.M, \quad (1)$$

where L is the length of the line segment, M is the magnification used and n is the number of secondary dendrites crossed by the measurement line.

The effect of microstructure is also evident in the thermal expansion of castings, and therefore, instead of the conventional method of monitoring the solidification curves (TA) as the casting cools, thermal expansion on already solidified samples can be monitored and evaluated. The measurement of thermal dilation is also addressed by the authors in papers [9-10]. The authors emphasize the importance of dilatometric analysis, which is important for the evaluation of dimensional accuracy and stability at elevated temperatures. Silumines with the addition of Mg, Ni and Cu were also tested. An attempt was made to positively influence - reduce - linear dilatation.

2. Experiment description

The aim of the study is to compare the solidification conditions of AlSi7Mg alloy as a function of the preheating temperature of the crucible (25, 100, 200, 300 °C) S355J2 grade, where the metal mould was without the use of spraying or any other surface treatment. The research will be aimed at finding out how the defined preheating temperatures of the permanent mold will influence: the thermophysical properties of the alloy under study as well as its hardness (HB). Spectral analysis will be performed to verify the chemical composition of the metal. Finally, the correlation between the results of solidification of the test samples in permanent mold preheated to different temperatures, the thermophysical properties and the micro and macro structure of the studied alloy is established. AlSi7Mg0.3 alloy (EN 1706:2020) was used as the starting metal for the preparation of the samples. The melt was neither additionally alloyed nor was the metal refined by degassing.

The melting was carried out in an electric resistance furnace in silicon carbide (SiC) with a crucible volume of 2 l where the specified melting temperature was 740 °C. The casting temperature was 710 °C +-5 °C. The casting was done in a metal mould with a diameter of 90 mm and height of 70 mm, permanent mold wall thickness: 20 mm, casting size: height 50 mm, top diameter 50 mm, bottom diameter 45 mm, casting weight: 240 g (diameter) [11-12]. Two identical permanent molds were always used for casting the sample and thus 2 basic samples were always produced from one melt. Each base sample was then cut into samples for spectral analysis on a saw equipped with a cooling system (Fig. 1c). A Brinell hardness test was performed on the same sample and then 3 samples were cut from the same piece for metallography (Fig. 1d). Next, 3 samples were cut from which the solids were machined for the linear thermal expansion test (Fig.1 c,d). The specimen and section markings can be seen in Fig. 1 - a,b,c,d. Table 1 with sample markings and sample parameters is given below. Table 2 shows the verified chemical composition of the samples and the ranges according to the standard.

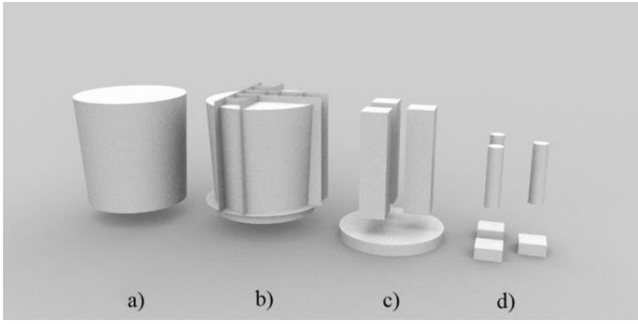

Fig. 1. a) Experimental casting, b) sample splitting, c) sample for spectral analysis and blank for dilatometry, d) samples for metallography, microhardness and rollers for dilatometric measurements

Table 1.
Marking of samples

Marking of samples	Temperature Casting °C	Mould temperature °C
25	710	25
100	714	100
200	710	200
300	710	300

Table 2.
Chemical composition of the investigated aluminium alloy in wt. %

	Si %	Fe %	Cu %	Mn %
Average values	7.01	0.16	0.004	0.008
Values according the standard	6.5-7.5	0.19	0.05	0.10
	Mg %	**Zn %**	**Ti %**	
Average values	0.42	-	0.11	
Values according the standard	0.25-0.45	0.07	0.25	

2.1. Categories evaluated

The assessment was carried out according to the relevant standards, where known, and the following assessment below was chosen. The authors' ratings were also considered in the selection process [13-17].

1. Brinell hardness according to EN ISO 6506-1
2. Microporosity - % of micropores in the structure
3. Microstructure - not defined by the standard - % proportion of eutectic excluded
4. Macrostructure
5. Evaluation of SDAS parameter
6. Dilation of samples
7. Chemical composition check

2.2. Measurement procedures

The microstructure of the AlSi7Mg0.3 alloy in the cast state consists of a network of primary dendrites of the solid solution α (Al) and a eutectic precipitated in the interdendritic spaces. The eutectic consists of a solid solution of α (Al) and eutectic silicon, which is precipitated with a very fine dispersion and fibrous morphology, as illustrated by the detail in Fig. 3, 4. The hardness measurement was performed on an EmcoTest DuraScan hardness tester [18].

The linear thermal expansion was measured on samples made from ingots cast into permanent mold which were preheated to defined temperatures (25, 100, 200, 300), samples (Ø 6 x 25 mm) were prepared with an accuracy of 0.01 mm, see Figure1d. Six samples were prepared from each defined temperature. Approximately 500 secondary dendrite axes were measured for each sample. The linear thermal expansion measurements were carried out on a Netzch device marked DIL 402/C. The apparatus was equipped with corundum components (cup, rod, washers). Before each measurement, the apparatus was corrected with a corundum correction sample. The temperature rise was set at 10 K/min. with a temperature rise of 25-530 °C. The individual alloy samples were loaded into the apparatus with a static inert atmosphere (argon 6.0).

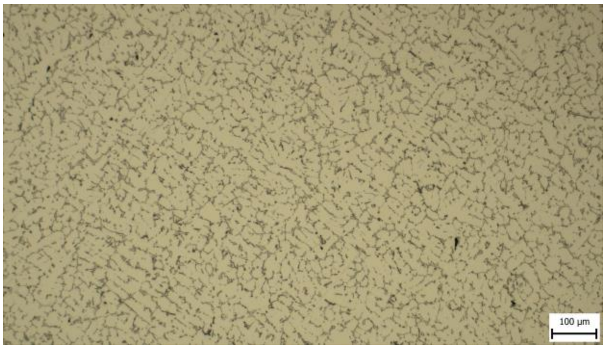

Fig. 2 Microstructure AlSi7Mg0.3 in cast state – 25

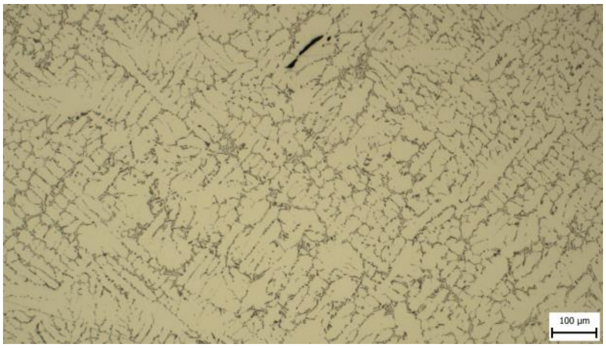

Fig. 3 Microstructure AlSi7Mg0.3 in cast state – 300

3. Achieved results

The results of the measurements were averaged and put into Table 3 for clarity. Table 4 shows the maximum elongation values of the sample at the target temperature of 530 °C. The averages are always from 6 to 10 measurements for each permanent mold heating temperature.

Table 3.
Values from individual measurements

Samples	Avg. Hardness HB	Standard deviation	Avg. Microporosity %	Standard deviation
25	56,41	1,23	0,037	0,064
100	55,68	1,88	0,028	0,031
200	54,75	0,65	0,136	0,119
300	53,85	2,02	0,196	0,096
	Eutectic %	**Standard deviation**	**SDAS µm**	**Standard deviation**
25	10,56	1,06	19,10	1,9
100	10,33	0,76	20,86	2,1
200	10,395	0,94	22,58	1,3
300	10,88	1,08	24,39	1,5

Table 4.
Dilation at temperature 530 °C

Samples	25	100	200	300
Average dL/Lo	1,42558	1,25037	1,60792	1,32745

3.1. Discussion of results

On macroanalysis, there was no dependence between the amount of pores and the different temperature of the coccyx. The evaluation of the images was not carried out according to known procedures, because the area examined did not show a sufficient number of visible pores. The samples were clean and the surface was smooth [19-20].
The individual samples showed a decrease in hardness with increasing heating temperature of the permanent mould. The However, there is a 4.5 % difference between sample 25 and 300.
Measured porosity was very low, but there was a jump of an order of magnitude for sample 200 and 300. There is a difference of 80 % increase in microporosity between sample 25 and 300.
The proportion of eutectic was determined for all samples and the difference between sample 25 and 300 is an increase of only 3 %.
For the SDAS parameter, the value for sample 100 increased gradually by 7% with increasing temperature. 8% for sample 200 and 7.5% for sample 300.
For the dilation, there was a gradual elongation of the test rollers as the sample was heated. Sample 200 showed the greatest elongation and sample 100 the least. The difference in dilation between these samples is 22 %.

3.2. The search for dependence

According to Figure 4, we can see that at lower porosity we have higher strengths and then when the porosity jumps, it negatively affects the strength, which then shows lower values. At the same time, when our strength decreases the SDAS parameter increases. According to Figure 5 and 6, we can see that the sample 25 with the lowest SDAS value also has the highest observed strength and the lowest porosity. The proportion of eutectic did not help us much in assessing the effect of permanent mold heating on the properties of the cast alloy. On a detailed evaluation of the results, we can state that the measured overall values were in a narrow interval of 10-11% where we cannot say with certainty that it is influenced by mold heating.

As the heating temperature of the permanent mould increases, the SDAS parameter increases continuously. Thus, the SDAS confirmed the direct relationship with the mold heating.

We did not find such conclusive values for the thermal dilation measurements (Fig. 7). We expected the highest dilation for sample 300 and the lowest for sample 25. However, this was not confirmed. Due to the extreme sensitivity of the measurements, the values are very accurate, but in our opinion additional measurements of thermal dilation should be made. There may have been a slight external influence and consequently a shift in the values when recording the measurements, or random internal inhomogeneity in the measured samples and the result may be affected.

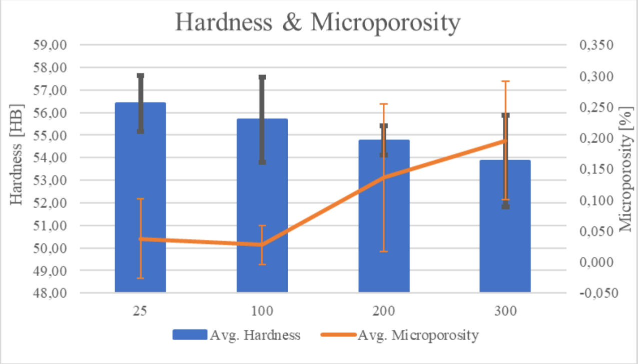

Fig. 4 Comparison of hardness and microporosity values

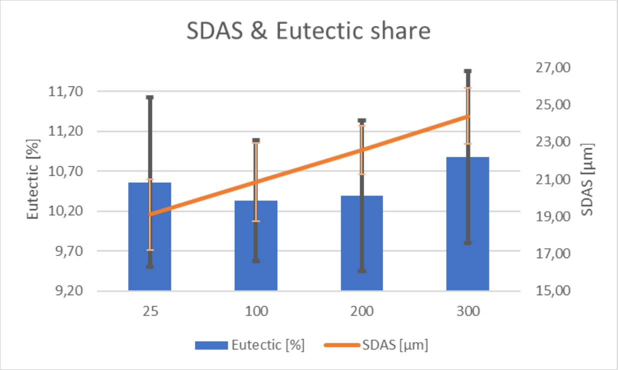

Fig. 5 Comparison of SDAS parameter values and eutectic quantity

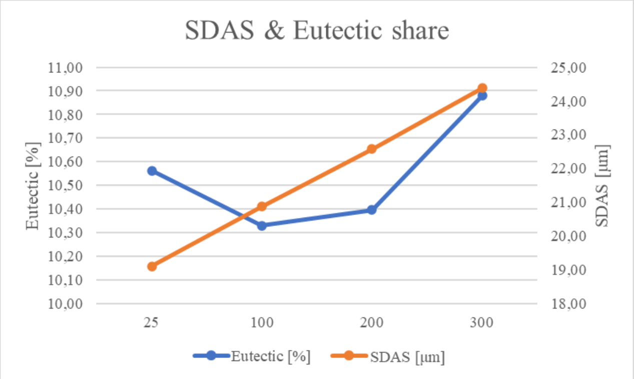

Fig. 6 Comparison of SDAS parameter values and the amount of eutectic in the graph

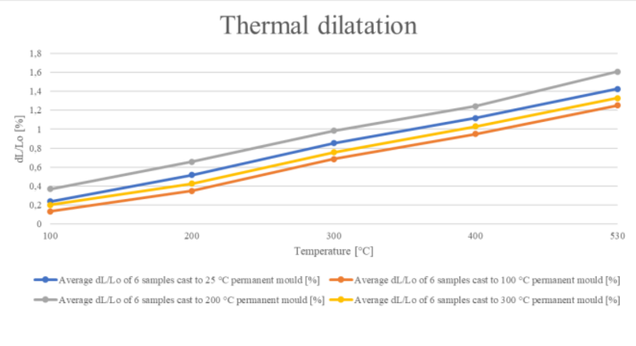

Fig. 7. Achieved values of thermal expansion in the graph

4. Conclusions

In this work, the effect of different heating temperature of the permanent mould before casting of AlSi7Mg0.3 alloy on its final properties was evaluated:

- The relationship between the measured properties of the alloy and the different heating of the mold was confirmed.
- A heating temperature of 25 °C was found to be the breaking temperature from which the hardness decreased and the SDAS parameter increased. Microporosity increased from a heating temperature of 100 °C.
- Dilatometric measurement of linear thermal expansion gave inconsistent results, where the value of dilation did not increase with increasing mould preheating temperature. Possible repetition of the measurements could refine the results. In future experiments, attention will be paid to testing even higher permanent mould preheating temperatures as well as the use of other aluminum alloys commonly used in foundry applications.
- Furthermore, we evaluated the current size of the base samples as borderline and recommend to increase the height of the base sample by 20 %. From 50 to 70 mm.
- To speed up the discovery of the SDAS parameter, we would recommend the acquisition of software for automatic evaluation.

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