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INFLUENCE OF REFINING TREATMENTS ON THE PROPERTIES OF Al-Si ALLOYS

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The article focused on researching the influence of Ti, B, Sr and Na as a modifying treatment elements for Al-Si alloys. The influence of alloying additives such as Cu and Cr was studied. Tensile strength R_m, elongation A_5 and HB hardness was analysed, as well as the influence of the above-mentioned elements on the microstructure and solidification of alloys containing a varied content of Si, within the 7 ÷ 16 % range. The influence of heat treatment on the alloy properties was also researched.

Keywords: aluminium alloys, casting technologies, heat treatment, innovative materials, modification

INTRODUCTION

Aluminium alloys are commonly used in technique. Especially popular are Al-Si alloys. These alloys, as a material with favourable technological properties, dominate in the manufacturing of castings for the automotive, aviation, power engineering and other sectors of industry; e.g. for combustion engine pistons, cylinder blocks and heads, rocker covers, sumps, for wheels and rims as well as for large-size castings of construction elements for power engineering.

The casting alloys must have high strength properties together with good technological characteristics. Especially strict requirements are connected with the materials for construction castings and elements of machines and equipment that work under heavy load.

In the group of Al-Si matrix alloys, relatively good mechanical properties are shown by the standard AlSi7Mg, AlSi9Mn, AlSi9Cu and AlSi12CuNiMg alloys. Based on the chemical composition, structure and the properties of [1-5] alloys, it can be concluded that our search for highly resistant materials belonging to the Al-Si group should focus on multiple ingredient alloys. Literature analysis [6-15] suggests:

- researching Al-Si alloys containing increased amounts of Zn and other microadditives,
- researching the influence of varying content of Cu, Mg and Zr additions,
- the studies of the influence of modifying elements,
- the studies of the influence of rare earth elements,
- the studies of the influence of Cr, Ti, Mo and W,
- the studies of heat treatment optimisation.

Among many alloy contents an interesting characteristics was presented [5] for AlSi7 - 17 alloys, containing 7 %, 11 % and 17 % of Si, additions of Cu as well as micro-additions of Cr, Mo, W, V, and others. As a result of chemical content optimisation and heat treatment modification based on solution heat treatment in 560 °C and ageing in 180 °C, high strength properties are achieved (R_m 430 ÷ 500 MPa, A_5 2 ÷ 5 %) and high hardness (150 ÷ 190 HB).

Special properties are achieved owing to complex modification treatment [7-10], through nucleation with titanium and boron, and subsequently by overcooling the eutectics with Sr additions.

Effective heat treatment should be conducted in possibly the highest temperature, close to the solubility limit for non-equilibrium and equilibrium phases and for ageing in heightened temperatures. This ensures optimal mechanical properties of the casting.

According to [11-13] the most interesting castings alloys are:

- AlSi8Cu3Mg0,4Zn4 (after heat treatment R_m 338 MPa, $R_{0,2}$ 128 MPa, A_5 1,4 %),
- AlSi8Cu3Mg0,4Zn10 (after heat treatment R_m 342 MPa, $R_{0,2}$ 130 MPa, A_5 1,2 %),
- ZN-86/MH-MN-260-14 6 ÷ 8 % Si, 0,1 ÷ 0,3 % Mg, 7 ÷ 12 % Zn, up to 0,6 % of Cu, up to 0,5 % of Mn, up to 0,7 % of Fe, the rest of Al,
- highly resistant silumin 7 ÷ 8,5 % Si, 2,5 ÷ 3,5 % Cu, 0,2 ÷ 0,45 % Mg, 0,5 ÷ 1 % Zn, 0,05 % ÷ 0,25 % Be, 0,1 ÷ 0,25 % Ti, up to 0,4 % of Fe, up to 0,15 % of Zr, with the properties of R_m 400 MPa, A_5 about 4 %.

RESEARCH METHODOLOGY

The melts for the research were prepared in the Casting Laboratory of Moulding Materials, Mould Technol-

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Table 1 **The chemical composition of alloys**

Alloy symbol	Element / wt. %													
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	B	Zr	P	Sr	V	Al
AlSi7	7,27	0,68	0,028	0,231	0,286	0,027	0,052	0,039	0,015	0,0018	<0,0003	<0,0010	<0,0001	0,014	91,3
AlSi12	11,85	0,68	0,81	0,277	0,241	0,029	0,098	0,400	0,030	0,0022	0,0043	<0,0010	0,0003	0,0082	85,5
AlSi16Cu1	15,24	0,414	1,44	0,077	0,63	0,025	0,83	0,052	0,097	0,0012	0,03	<0,0010	<0,0001	0,022	81,1

ogy and Non-Ferrous Metals Department of the Faculty of Foundry Engineering, of the AGH University of Science and Technology.

The prepared stock materials were melted in chamotte graphite crucible in an induction thyristor furnace, and the heat treatment was conducted in a resistance furnace with air circulation. From successive melts, according to the norms, the samples were prepared for the chemical content research and metallographic analysis. The samples for strength tests were cast into sand and metal moulds and then machined to the dimensions of Ø8, Ø10 mm. The thermal analyses allowed registering the temperatures of phase transitions taking place during the solidification of the alloys examined.

The casting temperature for the alloys with 7 ÷ 11 % Si content was 720 °C, and for the alloys with about 16 % of Si was within the 760 ÷ 780 °C range; the temperature of the metal mould was 200 ÷ 220 °C. The dispersion hardening treatment was conducted in the temperature of 530 °C for the hypoeutectic alloys, and for the hypereutectic alloys in the 480 °C, 500 °C and 515 °C for four hours for the solution heat treatment, and 180 °C for eight hours for the ageing.

RESULTS ANALYSIS

For the assessment of the impact intensity of the modifying agents and alloying elements on the properties and microstructure of the alloys, the initial alloy contents with varying amount of Si were prepared (Table 1).

Within the scope of the research, the influence of Si, Cu and Cr content on the structure and properties of the Al-Si alloys was analysed, as well as the Ti, B Sr and Na modifying treatments influence on the structure and properties of the alloys.

The resulting changes in solidification character of the alloys, depending on the modification effects and Si and Cu content are presented in Figures 1a and 1b. The characteristic points of phase changes are presented in Table 2.

Copper was introduced in the form of AlCu50 master alloy and the following amounts of copper in alloy were received: 1,44 %; 2,33 %; 3,15 %; 3,83 %; 4,46 %; 5,1 %; 5,53 %. The received tensile strength samples were subjected to the dispersion hardening process.

Various solution treatment temperatures were applied, which were chosen based on the solidification characteristics of the alloy researched (Figure 1).

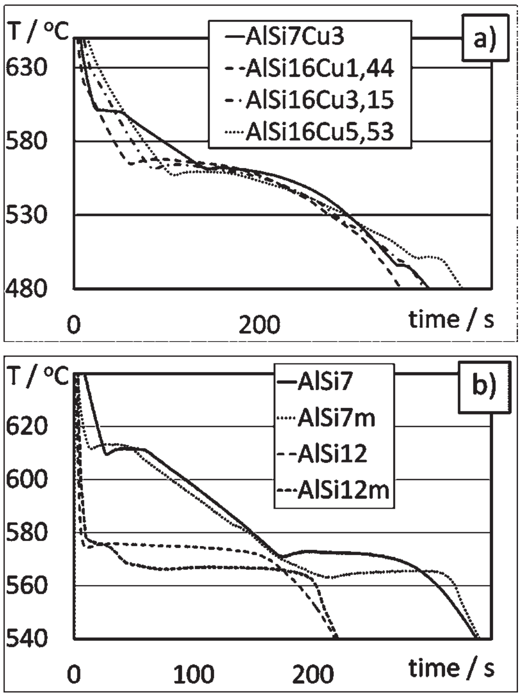

Figure 1 Exemplary pictures of solidification characteristics of the chosen Al-Si alloys; a) copper influence, b) modification influence

Table 2 **Characteristic crystallisation temperature ranges of the researched AlSi alloys**

Alloy symbol	Crystallisation temperature / °C				
	T1	T_E	T2	T3	T4
AlSi7	612	573	-	-	-
AlSi7m	613	565	-	-	-
AlSi12	-	575	-	-	-
AlSi12m	576	567	-	-	-
AlSi7Cu3	301	563	-	-	498
AlSi16Cu1.4	620	567	544	530	500
AlSi16Cu3.2	628	564	643	523	499
AlSi16Cu5.5	665	559	534	521	501

Table 3 **Properties of the alloy researched, with changing copper content in the chosen solution treatment temperatures**

Cu, / %	Heat treatment parameters								
	480 °C 3 h/ 180 °C 8 h			500 °C 3 h / 180 °C 8 h			515 °C 3 h/ 180 °C 8 h		
	R_m, / MPa	A_5, / %	HB	R_m, / MPa	A_5, / %	HB	R_m, / MPa	A_5, / %	HB
1,44	260,6	1,1	144	261,6	1,7	145	303,4	1	148
2,33	270,6	1,4	148	320,3	1,3	149	334,2	1,4	154
3,15	324,3	1,8	150	318,3	1,4	164	321,7	1,2	139
3,83	278,5	1,0	161	355,6	1,2	164	294,5	1,2	173
4,46	288,5	1,0	169	328,4	1,0	166	290,4	0,9	167
5,10	296,2	1,0	167	278,5	0,9	170	308,4	0,8	152
5,53	288,4	1,2	166	249,4	1,0	170	238,7	0,7	137

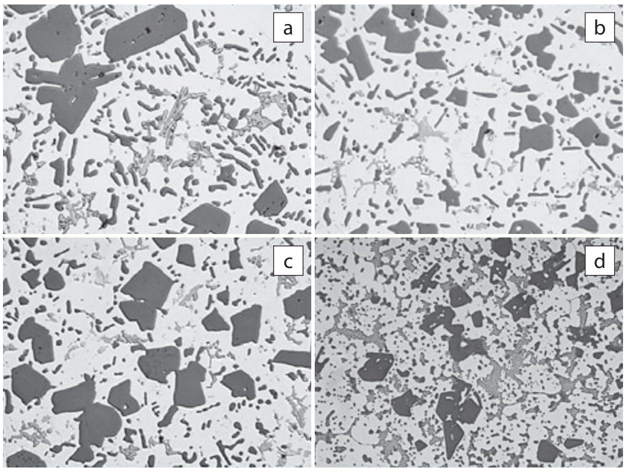

Figure 2 Alloy AlSi16 microstructure with different content of Cu and Cr: a) 1,44 % Cu, b) 3,15 % Cu, c) 5,53 %, d) 0,4 % Cr, magnification 500x

Table 4 **Heat treatment influence on the properties of hypereuctectic alloy of AlSi6Cu5 after Sr modification**

Alloy type / Kind of heat treatment	Researched alloy preliminarily modified (0,0056 % P + 0,1171 % Ti)			Researched alloy + 0,15 % Sr		
	Elongation A_5 / %	Tensile strength R_m / MPa	Hardness HB	Elongation A_5 / %	Tensile strength R_m / MPa	Hardness HB
solution heat treating 490 °C ageing 180 °C	3,33	410,70	122	3,00	416,00	122
solution heat treating 480 °C ageing 180 °C	3,75	378,85	154	2,83	359,61	155

The chosen temperatures allowed to determine at what solution treatment temperature there is a possibility of obtaining the best properties for a given alloy.

In Table 3 there are collated the results of the Cu influence on the strength properties of the hypereutectic AlSi16Cu alloy, after dispersive hardening treatment.

In Figure 2 there are exemplary microstructure pictures of the alloy researched, with varied copper content, after dispersive hardening treatment.

Exemplary test results of mechanical properties obtained for the AlSi16Cu5Cr alloy, after the Ti, B and Sr modification treatments, are presented in Table 4.

CONCLUSIONS

From researching of the structures and strength properties R_m, A_5, it can be concluded that the optimum solution heat treatment temperature for the AlSi16Cu alloys tested is 500 °C. Exceeding this temperature is not recommended, especially when the Cu content in the alloy is bigger that 3 %. In practice, the solution treatment temperature of 480 °C is enough to obtain high tensile strength R_m, and also maximum elongation A_5 for an alloy with 3,15 % Cu content.

The optimum addition of Cu in AlSi16 alloys which are dispersion hardened is about 3 %. Higher Cu content is conducive to lowering the strength parameters of the alloys.

To determine the solution heat treatment temperature for Al-Si alloy it is helpful to conduct thermal analysis, which gives information about the phase transformations in the solidifying alloy. The thermal effect taking place at the temperature close to 500 °C is connected with crystallisation of multiple component eutectics. This transformation is especially visible in the dT / dt relationship, with the Cu content above 2 %. The proper solution treatment ensures high R_m, A_5 and HB mechanical properties of the alloy.

Based on the research conducted, and especially the research concerning the alloying and heat treatment of the high silicon alloys it can be concluded that it is possible to obtain multiple component AlSiCu matrix alloys, with high tensile strength (over 400 MPa), with elongation above 3 %, and hardness of 150 HB. This is conditioned by precise gradual solution heat treatment and quick cooling, with ageing in two stages.

Primary Si precipitates occurring in excess, visible in the microstructure of the hypereutectic Al-Si alloys (Figure 2), cause hardness increase and plasticity loss. Modifying treatments do not significantly change plastic properties, and heat treatment only slightly influences the shape of the crystallised precipitates of Si. Better properties are shown by Al-Si alloys with lower Si content.

Solution heat treatment of the researched AlSiCu alloys in high temperatures causes shape changes and unfavourable intermetallic phases distribution at the crystallite boundaries, which lowers plastic properties.

Summing up, the knowledge of chemical content, the properly conducted analysis of the alloy solidification curve allows to choose the proper parameters of dispersive hardening, namely the solution treatment temperature, which will result in the most advantageous properties of the alloys cast of hypereutectic aluminium-silicone.

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