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Research Article

INFLUENCE OF THE HOMOGENIZATION TEMPERATURE ON THE MICROSTRUCTURE AND PROPERTIES OF ALSI10CUNIMGMN ALLOY

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ABSTRACT

The article examines the impact of changes in homogenization temperature in the hardening process on the microstructure of aluminum alloys. The research samples were cast from AlSi10CuNiMn alloy produced by gravity casting technology in metal mold. Subsequently, the castings were subjected to a heat treatment. In an experiment with changing temperature and staying time in the process of homogenization. The microstructure of the alloy was investigated by methods of light and electron microscopy. Examination of the microstructure has focused on changing the morphology of separated particles of eutectic silicon and intermetallic phases. The analysis of intermetallic phases was supplemented by an analysis of the chemical composition – EDS analysis. Effect of heat treatment on the properties investigated alloy was further complemented by Vickers microhardness. Investigated alloy is the result of longtime research conducted at the Faculty of Production Technology and Management.

Keywords: aluminum alloy, heat treatment, microstructure, intermetallic phase, microhardness.

INTRODUCTION

Al-Si alloys are most commonly used type of casting aluminum alloys. Their application are mainly in the automotive industry with casting technologies created by gravitational and pressure casting. The combination of good mechanical and technological characteristics (in particular foundry) together with low density is the basic prerequisite for their considerable extension. Mechanical properties of castings of these alloys can be further increased through a heat treatment process - hardening. The curing process stack the three basic steps:

1. Homogenization (Dissolution heater) – heating the solubility curve of the casting, which leads to dissolution of intermetallic phases and gaining a homogeneous solid solution αAl.
2. Quick cooling – seeks to prevent the exclusion of intermetallic phases and gaining a supersaturated solid solution.
3. Precipitation hardening (aging) – decaying supersaturated solid solution and a precipitate (reinforcing structure). May take place when cold (natural aging) or at elevated temperature (artificial aging).

The basic prerequisite for the possibility of curing castings of aluminum alloys is the presence of chemical elements ensuring hardenability (especially Cu and Mg). The feature which allows the use of content you have these elements for hardening is the change in solubility of Al in solid solution, which dramatically changes with temperature [1, 3, 10, 11].

EXPERIMENTAL SAMPLE PREPARATION

Input material

For the preparation of castings pure aluminum was used with addition of pure copper and man-

Table 1. Chemical composition of the castings

Ch. Element	Si	Fe	Cu	Mn	Mg	Ni	Ti	Sr	Al
Content [wt. %]	9,832	0,337	1,140	0,354	0,491	0,971	0,052	<0,0010	base

ganese and master alloy AlNi the desired content of alloying elements in the alloy (chemical composition of the castings) is reported in Table 1.

Sample preparation – melting and casting

Melting the charge held in a graphite crucible placed in an electric resistance furnace at a temperature of 760°C. The increase in temperature and melting of the charge in the crucible took approximately 2 hours. After melting the batch was purified melt through a refining salt and placement of the charge back to the furnace. Subsequent molding was performed at 720°C and a metal mold (preheated to 200°C) with four cylindrical cavities. The resulting cast was shaped like a cylinder with a diameter of 19 mm and a length of 210 mm and a weight of about 180 grams.

Sample preparation – heat treatment

One of the castings was left without a heat treatment, and another six castings were subjected to a heat treatment process of the prescribed parameters (parameters of individual variants of heat treatment are listed in Tab. 2). The parameter which was varied was the homogenazation temperature (in variants 520, 510 and 490°C) and staying time on this temperature (in variants 1 and 2 hours).

Process of homogenazition was carried out in an electric resistance furnace, wherein the ramp to an annealing temperature was set to 45 minutes, further followed staying and quenching in water at 50°C (cooling tank of 15 liters), followed by artificial aging process in a laboratory hot-air drier at 170°C for 4 hours. The last step was the removal of samples from the dryer and free cooling in air.

EVALUATION OF THE EXPERIMENTAL SAMPLES

Light microscopy

The microstructure analysis was used confocal microscope OLYMPUS LEXT OLS 3100 were analyzed as samples of alloys without heat treatment, and the samples after heat treatment (in all the above variants). The microstructure of the alloy is composed of dendritic cells α solid solution and eutectic (mixture of solid solution α and particles of eutectic silicon). Furthermore, in the microstructure observed different types of intermetallic phases (the result of a high content of alloying ele-

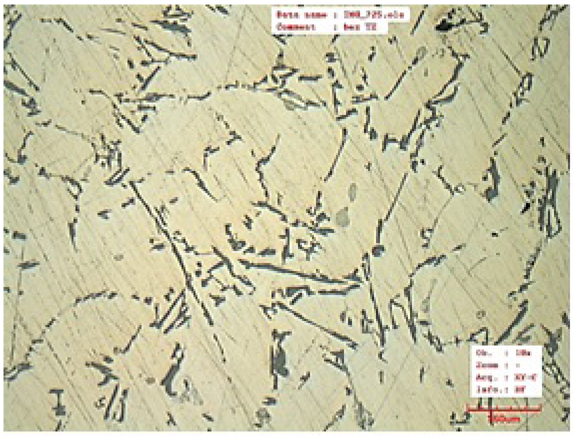

Fig. 1. Alloy without heat treatment

Table 2. Variants of heat treatment

<table>
<tr><th rowspan="2">Variants</th><th colspan="2">Homogoneziation</th><th rowspan="2">Quick cooling – water temperature [°C]</th><th colspan="2">Precipitation hardening</th></tr>
<tr><th>Homogenzation temperature [°C]</th><th>Staying [hrs]</th><th>Aging temperature [°C]</th><th>Aging time [hrs]</th></tr>
<tr><td>Variant 1</td><td>520</td><td>1</td><td rowspan="6">50</td><td rowspan="6">170</td><td rowspan="6">4</td></tr>
<tr><td>Variant 2</td><td>520</td><td>2</td></tr>
<tr><td>Variant 3</td><td>510</td><td>1</td></tr>
<tr><td>Variant 4</td><td>510</td><td>2</td></tr>
<tr><td>Variant 5</td><td>490</td><td>1</td></tr>
<tr><td>Variant 6</td><td>490</td><td>2</td></tr>
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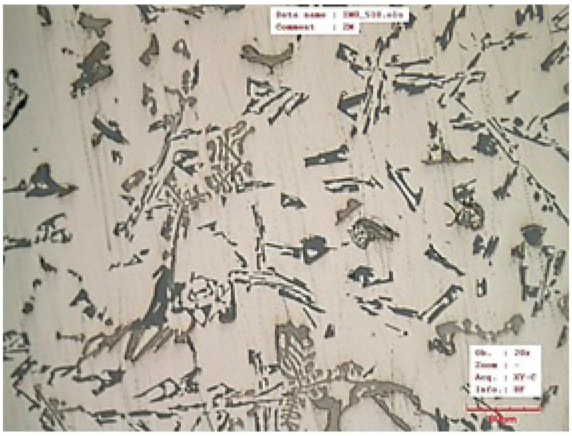

Fig. 2. Alloy without heat treatment

Fig. 3. After heat treatment – variant 1

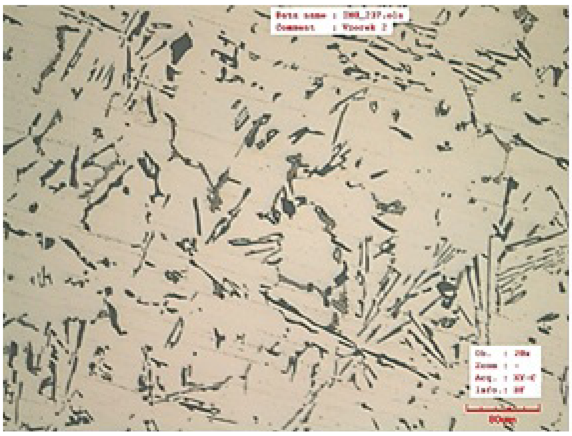

Fig. 4. After heat treatment – variant 2

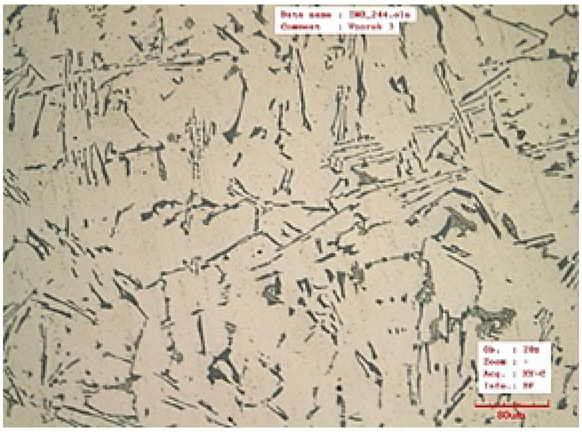

Fig. 5. After heat treatment – variant 3

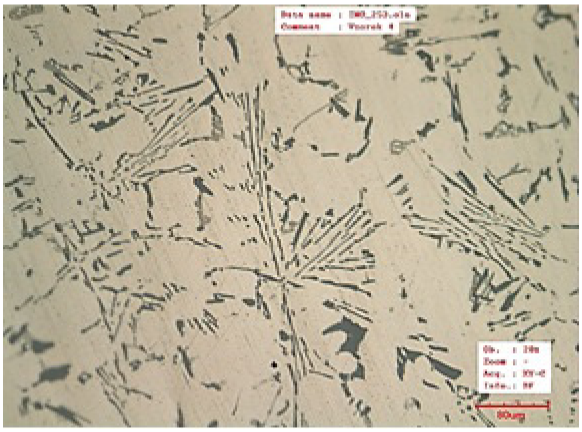

Fig. 6. After heat treatment – variant 4

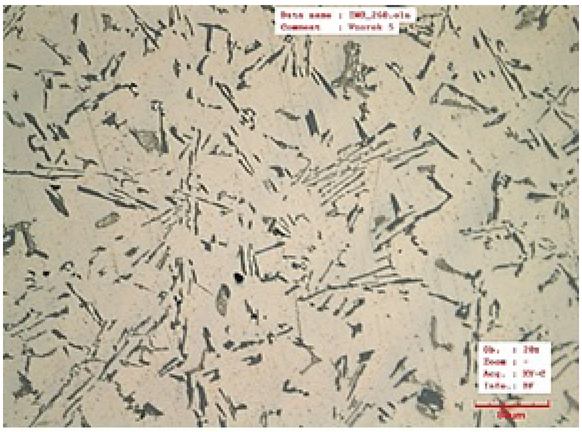

Fig. 7. After heat treatment – variant 5

ments). Microstructure of the sample without heat treatment is shown in Figures 1 and 2. The microstructure of the alloy after heat treatment of the individual variants is shown in Figures 3 to 8.

Microstructure of the material without heat treatment showed the presence of substantial amounts of various kinds of intermetallic phases. Silicon eutectic microstructure was expelled in the form of coarse needles (spatially shaped hexagonal plates). The effect of heat treatment has been a significant change in particle morphology of eutectic silicon. After all the variations of heat treatment

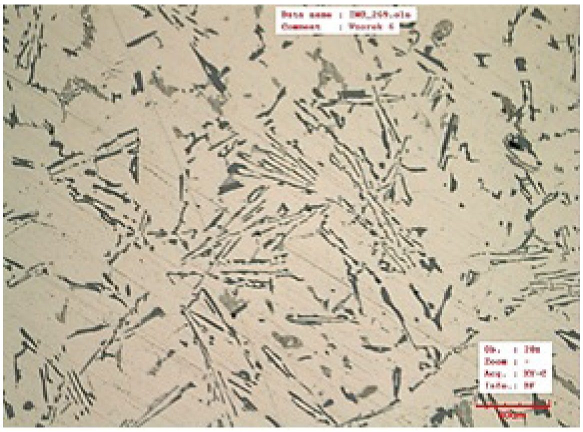

Fig. 8. After heat treatment – variant

led to the collapse of coarse particles of silicon and its elimination in the form of fibers and fine spherical particles. The effect of heat treatment has also been a significant change in the dimensions of intermetallic phases and their frequency.

SEM and EDS analysis

The microstructure was by SEM analyzed with a scanning electron microscope VEGA 3 Tescan complemented by EDS analyzer Bruker X-flash**.**

Figure 9 shows one of the recognized intermetallic phases (without heat treatment), with a designated area for EDS analysis. The record of analysis is shown in Figure 10. Quantification results of EDS analysis are given in Table 3.

Figure 11 shows the same type of intermetallic phases after heat treatment (including the area marked out for the EDS analysis). EDS analysis record is designated as Figure 12 and quantification results are reported in Table 4. In both cases it is a polycomponent intermetallic phase Al-Ni-Fe-Cu-Si-Mn-Mg.

In the described intermetallic phase all the alloying elements in the alloy are contained. Furthermore, intermetallic phases rich in iron (which is alloyed impurity) are recognized.

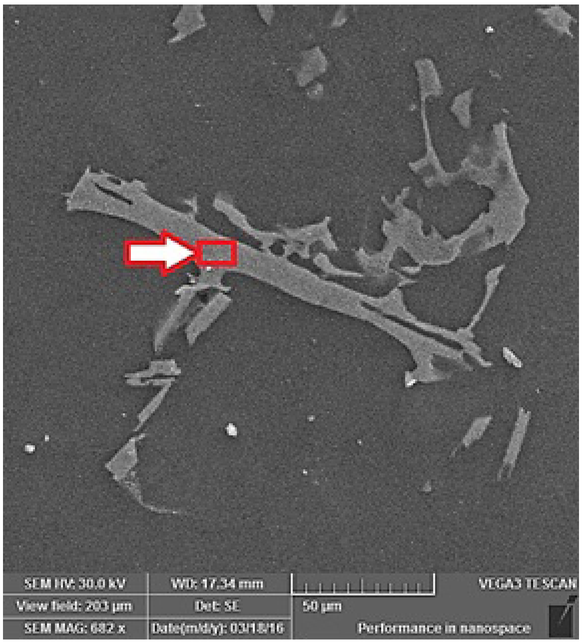

Fig. 9. Intermetalic phase (without heat treatment)

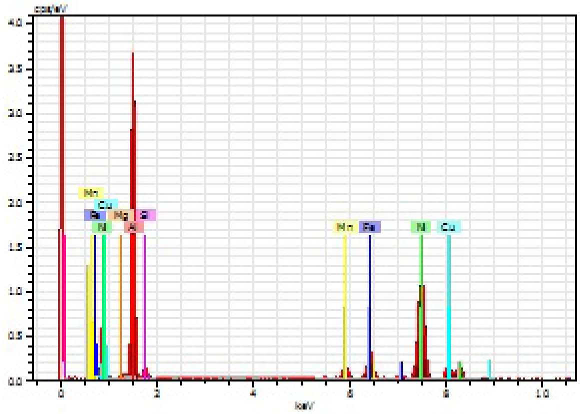

Fig. 10. EDS analysis record

The heat treatment process was manifested by reducing the content of alloying elements in polycomponent intermetallic phase. Homogenization ensure diffusion of elements into a solid

Table 3. Quantification results of EDS analysis (from Figure 9)

Ch. Element	Content [wt. %]	Content [at. %]
Aluminium	50,08	67,23
Nickel	33,61	20,74
Iron	5,71	3,70
Copper	5,48	3,12
Silicon	2,58	3,33
Manganese	2,32	1,53
Magnesium	0,23	0,34
Total	100,00	100,00

Table 4. Quantification results of EDS analysis (from Figure 11)

Ch. Element	Content [wt. %]	Content [at. %]
Aluminium	64,85	78,47
Nickel	22,54	12,54
Iron	4,26	2,49
Copper	3,81	1,96
Silicon	1,68	1,95
Manganese	1,66	0,99
Magnesium	1,19	1,60
Total	100,00	100,00

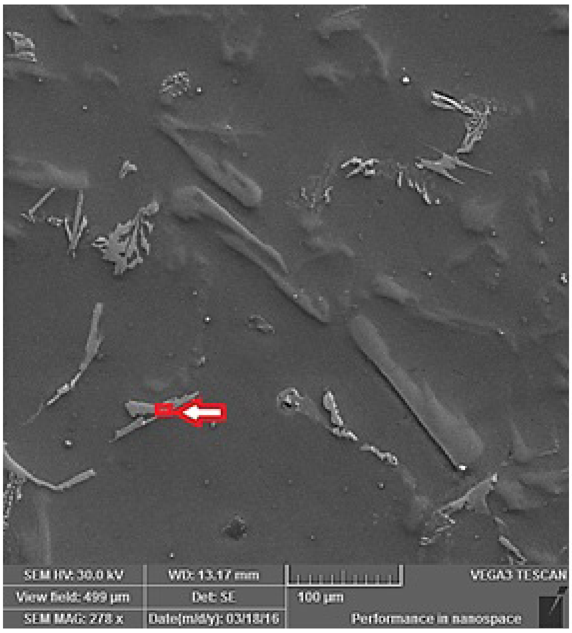

Fig. 11. Intermetalic phase (after heat treatment)

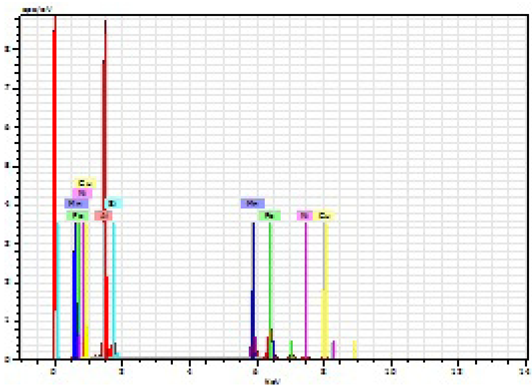

Fig. 12. EDS analysis record

solution. Subsequent rapid cooling prevents their recurrence opting into the intermetallic phase and ensuring the formation of a supersaturated solid solution. Formation of supersaturated solid solution became the basis for the subsequent artificial aging, which, thanks to its disintegration, was the precipitation hardening.

Figure 13 shows another recognized intermetallic phases (with marked areas EDS analysis). The records of this analysis are shown in Figure 14 and quantification results are given in Table 5. These units are excluded in microstructure did not change its shape or chemical composition due to thermal processing.

The addition of manganese reflected positively described creation of intermetallic phases α-AlFeMnSi, with almost identical contents of manganese and iron in the alloy (ratio of the content of these elements is about 1: 1). There is a decoupling of iron in the intermetallic phase. In the absence of manganese in the alloy, the relatively high iron content způobil creation of intermetallic phases Al_5FeSi. This intermetallic phase in the

Table 5. Quantification results of EDS analysis (from Fig. 13)

Ch. Element	Content [wt. %]	Content [at. %]
Aluminium	59,53	71,54
Manganese	17,68	10,44
Iron	13,56	7,88
Silicon	8,40	9,70
Nickel	0,82	0,45
Total	100,00	100,00

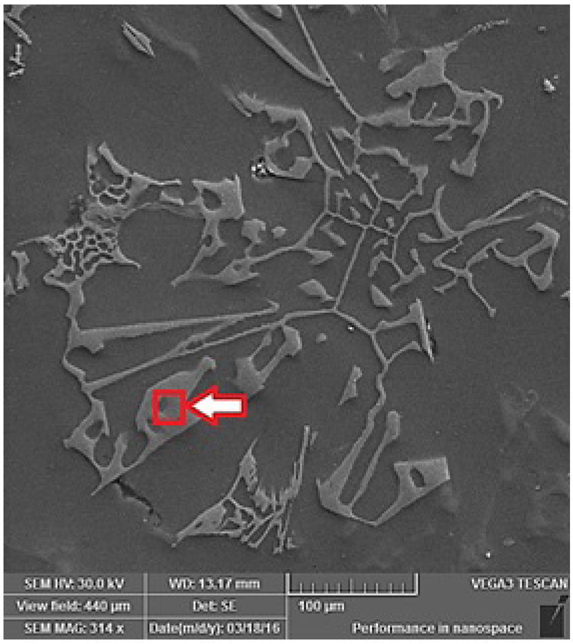

Fig. 13. Intermetalic phase α-AlFeMnSi

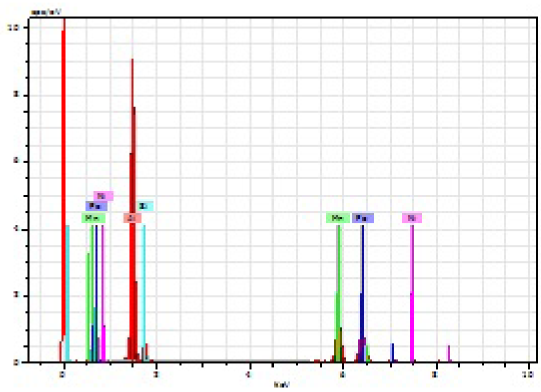

Fig. 14. EDS analysis record

microstructure is eliminated as coarse needles consequently significantly reduces the mechanical properties of aluminum alloys.

Vickers microhardness

Vickers microhardness was performed by using Microhardness SHIMADZU HMV-2. The measurements focused on finding and comparing microhardness dendritic cells of solid solution α. e load that was used for the measurement was 100 g and the loading time of 10 s. The measured hardness of the solid solution α are reported in Tab. 6.

The heat treatment increased the microhardness of the solid solution by an average of 26%. This fact is the result of precipitation-hardening alloys caused by the disintegration of a supersaturated solid solution. The main element involved in this process, the copper, which has a significant change in the solubility depending on the temperature in the system Al-Cu. Differential microhardness of solid solution between the versions of the heat treatment is minimal. Reduce the temperature and the time of homogenization is not manifest on microhardness.

CONCLUSIONS

All variants of heat treatment caused significant changes in the microstructure. The effect of heat treatment has been a significant change in particle morphology of eutectic silicon. Silicon, which was excluded in the microstructure as coarse needles, owing to the heat treatment transformed into a form of fine and elongate fibers and spherical particles. Because of this significant change in the microstructure is significant prerequisite for increasing the plasticity of the investigated alloy.

The addition of manganese to the alloy had a positive effect on the disengagement of iron in the intermetallic phase α-AlFeMnSi. The addition of this element being offset by negative influence of iron on mechanical properties of the alloy, which is due to the needles of intermetallic phases Al_5FeSi in the microstructure (for alloy without Mn).

Due to the heat treatment to dissolve intermetallic phases, when the diffusion of copper from the intermetallic phases into solid solution α. This resulted resizing excluded intermetallic phases containing copper (to reduce the influence of heat treatment). Furthermore, the copper diffusion reflected by reducing its content in the intermetallic phases after heat treatment.

Another manifestation of precipitation hardening process was to increase micro solid solution α. Compared with the non-heat treated state to result in increase on average by 26%.

For each variant of heat treatment resulting microhardness differed only minimally. Based on this fact, it can be stated that the homogenization temperature of heating is due to the saving of energy can be reduced to a temperature of 490 °C without significant changes in microstructure and microhardness of the examined alloys.

Table 6. Quantification results of EDS analysis

No. of messur.	Without HT [$HV_{0.1}$]	Variant 1 [$HV_{0.1}$]	Variant 2 [$HV_{0.1}$]	Variant 3 [$HV_{0.1}$]	Variant 4 [$HV_{0.1}$]	Variant 5 [$HV_{0.1}$]	Variant 6 [$HV_{0.1}$]
1	45.40	59.80	54.40	55.70	51.10	51.90	60.40
2	46.10	56.00	54.40	58.00	54.90	52.60	54.90
3	44.20	59.50	60.70	58.00	54.70	54.40	53.60
4	44.10	54.90	62.00	58.30	53.40	58.60	55.50
5	43.80	56.60	55.20	54.10	57.40	56.00	59.50
6	44.50	53.90	59.80	57.80	57.70	56.30	60.40
7	46.70	58.60	57.70	56.30	56.50	57.20	62.00
8	45.10	59.20	59.10	58.00	55.00	56.10	59.80
9	46.50	58.70	60.30	55.90	56.60	52.40	61.60
10	45.40	59.30	61.10	56.10	55.90	58.00	60.70
Average value	45.18	57.65	58.47	56.82	55.32	55.35	58.84

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