Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume III, 48-52

Investigation of the influence of artificial aging parameters on the micro and macro hardness of AlSi12Cu5MgCr and AlSi12Cu5Mn alloys

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Abstract. **Non-standard aluminium-silicon alloys of the eutectic type are complexly modified. The alloys were subjected to T6 heat treatment at different artificial aging parameters. The influence of the working parameters of the dispersion hardening process on the microhardness of the α-solid solution and the macrohardness of the alloys was investigated. The influence of alloying elements on the phase composition of the alloys is discussed.**

Keywords: eutectic aluminium-silicon alloys, heat treatment, microhardness, macrohardness

I. INTRODUCTION

Eutectic aluminium-silicon alloys are characterized by good casting properties - high ductility, low tendency to crack formation, low percentage of linear shrinkage, high hermeticity. Their mechanical properties are significantly improved after modification. The most effective eutectic modifier in the structure of aluminium-silicon alloys is sodium, which is a classic example of a Type I modifier. Sodium salts (NaF, NaCl, Na_3AlF_6) are also successfully used, and strontium (Sr) and antimony (Sb) also have a satisfactory modifying effect. The modifying action of the remaining elements of the 1A group of the periodic system of elements is weakly expressed. In [1], the comparative data on the modifying ability of the elements of the I-IV group are presented.

As the main combination of alloying elements of aluminium-silicon alloys, copper and magnesium are used because they form strengthening phases. When alloying with copper and magnesium, the following phases are separated: α, Si, $CuAl_2$, S(Al_2CuMg_4), Mg_2Al_3, T(Al_2CuMg) W($Al_XMg_5Cu4Si_4$ or $Al_5Cu_2Mg_8Si_6$) and Mg_2Si. The percentage ratio of Si and Mg has a significant influence on the formation of the phases in the Al – Si – Cu – Mg alloy. When the value of this ratio is less than 1.73, the strengthening phase Mg_2Si is not formed, but in this case the presence of the $CuAl_2$ phase, the W-phase and Si is observed in the alloy [1].

Heat treatment is one of the main technological operations ensuring the necessary properties of the treated alloy. To obtain aluminium alloys with increased mechanical and improved operational properties, quenching with subsequent artificial aging (T6) is used [2]-[19].

During aging of the hardened alloys, the saturated solid solution breaks down, accompanied by a change in the physical and mechanical properties. In most cast aluminium alloys, this breakdown is characterized by the formation of Guinier–Preston cluster zones [20] – [21]. These zones are formed as a result of the development of diffusion processes, which are accelerated as a result of the majority of vacancies formed as a result of the previous hardening.

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol3.8103

II. Materials and methods

The object of the present study are non-standardized aluminium-silicon alloys with a eutectic composition (Table 1 and Table 2).

Table 1 Chemical composition of AlSi12Cu5MgCr (%)

Si	Cu	Mg	Cr	Fe	Al
11,66	4,65	1,25	0,59	0,31	rest

Table 1 Chemical composition of AlSi12Cu5Mn (%)

Si	Cu	Mg	Mn	Fe	Al
11,41	4,42	0,1	0,386	0,28	rest

The modifying treatment of the two investigated alloys was carried out by a method different from that generally accepted for eutectic aluminium-silicon alloys, i.e. without the use of the Na modifier.

The AlSi12Cu5MgCr alloy is complex modified using 0.02% Ti, 0.004% B, 0.04% P and 0.007% Be. The use of titanium and boron is to modify the α-phase in the composition of the eutectic. The finer it is, the finer its branches are and the distance between them is minimal. This inhibits the growth of eutectic silicon crystals and they are significantly reduced in size. The combination of Ti and Be is used to refine the structure and the uniform distribution of the separating phases in the Mg-doped silumins. The addition of these two elements in very small concentrations improves the mechanical properties of the alloys, which is most likely due to the fact that these two chemical elements increase the concentration of vacancies during quenching, i.e. they accelerate the diffusion processes of Mg and Si during aging, which in turn facilitates nucleation of the β' metastable phase. In addition, beryllium does not form refractory compounds with silicon. The product of modification of silumins with beryllium is the refractory BeO, which is highly soluble in the melt and therefore its thermodynamic activity in it is maximum. Beryllium dissolves well in liquid aluminum, and it is the only element that has the ability to protect the liquid alloy from interaction with oxygen. The use of beryllium as a modifier is appropriate because it has the second largest coefficient of modification of silicon in the structure of this type of alloys at a relatively low concentration (K=73% with a content of Be-0.005%) [1]. Also used is the modifier phosphorus, which is commonly used to modify the primary silicon crystals in the structure of hypereutectic silumins. Considering that modifiers usually have a double action [22], it is most likely that phosphorus is also adsorbed on the boundaries of α-crystals, thus preventing them from growing, i.e. has an impact on structure and as a first-order modifier.

To modify the AlSi12Cu5Mn alloy, titanium and boron were again used, but in significantly larger quantities compared to the AlSi12Cu5MgCr alloy. The introduced amount of titanium in the melt of the studied alloy is 0.2%, and the amount of boron used is 0.04%. At the specified concentration of the element Ti, its maximum modifying effect on silicon was registered, and the condition that the maximum amount of boron in the composition of the alloy was 0.04% was observed. With a higher content of boron in the alloys, the formed borides have a tendency to agglomerate and precipitate when the melt is standing, as a result of which the properties of the alloys deteriorate. The combination of modifiers is supplemented with Sr in an amount of 0.05%, because it successfully replaces the most commonly used modifier for this type of alloys - sodium.

The introduction of the modifiers into the melts of the investigated alloys is through the use of the ligatures AlTi5B1, CuP10, AlSr10 and beryllium bronze CuCo1Ni1Be.

After conducting the metallurgical processing of the melts of the studied alloys, experimental castings were cast from them under the same conditions.

The two studied compositions were subjected to T6 heat treatment. The heating to homogenize the structure is up to a temperature of 510-515ºC, holding at this temperature for 6h30min. and subsequent hardening in water with a temperature of 20ºC. Artificial aging was carried out at temperatures of 170ºC and 190ºC, and the retention times at these temperatures were 10h, 12h and 14h.

The microhardness of the α-solid solution and the macrohardness of the alloys were measured both before heat treatment and after conducting T6 under the indicated experimental conditions.

III. Results and discussion

To strengthen and increase the mechanical properties of aluminium alloys, the T6 heat treatment is most often used, which includes quenching with subsequent artificial aging. The mechanism of alloy strengthening is due to the formation and separation of dispersion-like phases on the basis of the alloying elements. To study the influence of the parameters of the artificial aging (temperature and holding time) after quenching of the studied alloys, the microhardness of the α-hard solution and the macrohardness of the alloys were measured. The results are shown in Table 3 and Table 4.

Table 3 Microhardness and Macrohardness of AlSi12Cu5MgCr Alloy

T6	Artificial aging	Microhardness $\mu HV_{50/10}$	Macrohardness $HV_{10/10}$
-	-	87	107
T6	170ºC/10h	129	144
T6	170ºC/12h	119	159
T6	170ºC/14h	123	165
T6	190ºC/10h	104	132
T6	190ºC/12h	105	120
T6	190ºC/14h	113	134

TABLE 4 MICROHARDNESS AND MACROHARDNESS OF ALSI12CU5MN ALLOY

T6	Artificial aging	Microhardness $\mu HV_{50/10}$	Macrohardness $HV_{10/10}$
-	-	75	101
T6	170ºC/10h	120	127
T6	170ºC/12h	129	138
T6	170ºC/14h	117	135
T6	190ºC/10h	120	144
T6	190ºC/12h	113	128
T6	190ºC/14h	110	118

As a result of the heat treatment, the two studied alloys have significantly higher values of micro and macro hardness compared to the values measured before the alloys were subjected to heat treatment.

In the case of the AlSi12Cu5MgCr alloy, the highest value of macro hardness ($165HV_{10/10}$) was measured on the test bodies subjected to artificial aging at a temperature of 170ºC and a holding time of 14h at this temperature. The microhardness of the α-solid solution at the specified artificial aging parameters is $123\mu HV_{50/10}$, a value comparable to the highest measured of the α-phase for this alloy at artificial aging at 170ºC for 10h. The measured values of the micro- and macro-hardness of AlSi12Cu5MgCr alloy after artificial aging at a working temperature of 190ºC and different retention periods at it are lower compared to the values measured at an aging temperature of 170ºC. The selected working temperatures of artificial aging (170ºC and 190ºC) of the AlSi12Cu5MgCr alloy are in the aging temperature interval (150ºC and 200ºC) in which dispersed particles of the intermediate phase θ', which does not differ in chemical composition, are formed in the places of GP 2 zones of the stable θ-phase ($CuAl_2$), possesses a tetragonal lattice and is coherently associated with the solid soln. The operating temperature of 190ºC is at the limit of the temperature interval at which the metastable phase θ' coagulates and the stable θ-phase is formed, as well as the coherence between the lattice of the α-phase and the θ-phase is broken. This leads to a reduction in the distortion of the crystal lattice of the α-solid solution and causes the alloy to weaken. Carrying out the process of artificial aging of AlSi12Cu5MgCr alloy at temperatures close to the limit (θ'→ θ) is undesirable due to the fact that there is a decrease in the microhardness of the α-phase, as well as a decrease in the macrohardness of the alloy.

During artificial aging carried out at a temperature of 170ºC, the highest micro- and macro-hardness values of AlSi12Cu5Mn alloy were measured at a process duration of 12h. With increasing holding time at an operating temperature of 170ºC, a weakening of the alloy is observed. The highest value of macrohardness ($144HV_{10/10}$) of the studied AlSi12Cu5Mn alloy was measured during the artificial aging process at an operating temperature of 190ºC and a retention time of 10h. With increasing holding time at a temperature of 190ºC, a decrease in the values of micro and macro hardness of the AlSi12Cu5Mn alloy was recorded. As with the AlSi12Cu5MgCr alloy, conducting the artificial aging process at temperatures close to the limit (θ'→ θ) is undesirable.

When the artificial aging process is carried out at an operating temperature of 170ºC, the AlSi12Cu5MgCr alloy has higher macrohardness values compared to the AlSi12Cu5Mn alloy. The most likely reason for this is the combination of alloying elements used and rather the fact that the AlSi12Cu5MgCr alloy is alloyed with Mg (1.25%), an element characterized by high diffusion mobility and involved in the composition of various strengthening phases. The difference in the measured values of the microhardness of the α-phase in the structure of the two investigated alloys is insignificant. In the composition of the alloy AlSi12Cu5Mn, Mn was introduced in the amount of 0.386%, and its characteristic is the reduced diffusion mobility. This is a prerequisite for the lower values of macrohardness of the alloy during artificial aging carried out at a temperature of 170ºC, but also an increase in both macro and microhardness when the process is carried out at higher temperatures (190ºC).

The combinations of modifiers used have a positive effect on the structure of the investigated alloys. The Si crystals in the composition of the eutectic of the AlSi12Cu5Mn alloy before exposure and heat treatment have a rounded shape and the majority of them have a conditional average diameter of 3 μm, some with rims up to 7-10 μm are also observed (Fig. 1). The eutectic silicon crystals in the AlSi12Cu5MgCr alloy structure before heat treatment are needle-shaped and the average linear dimensions are 25 μm (Fig. 2).

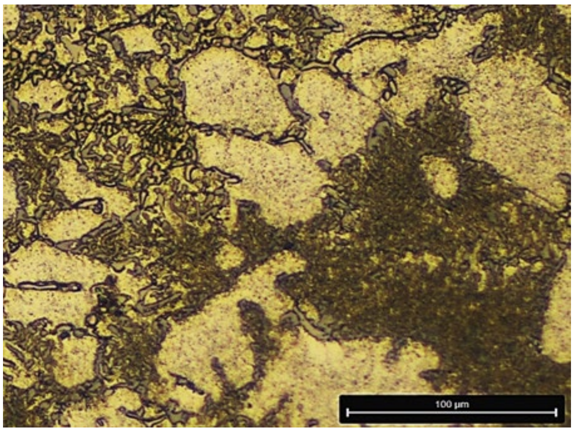

Fig. 1. Microstructure of AlSi12Cu5Mn alloy without heat treatment

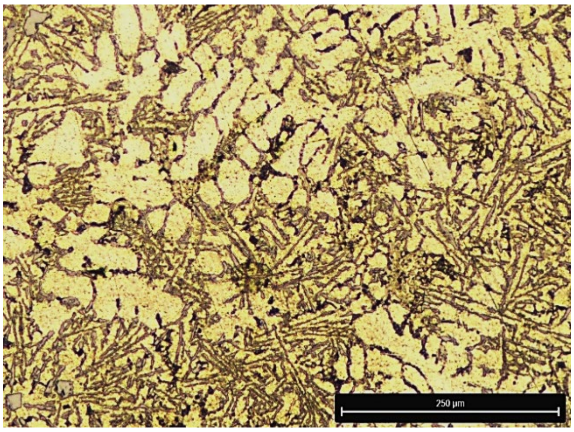

Fig. 2. Microstructure of AlSi12Cu5MgCr alloy without heat treatment

As a result of the used combinations of alloying elements and modifiers, as well as the used artificial aging regimes, structures were obtained (Fig. 3, Fig. 4), which ensure a macrohardness of the investigated alloys comparable to that recommended for this type of silumin [23]. The measured values of the microhardness of the α-solid solution are high, which is a prerequisite for increased strength and operational properties of the developed alloys.

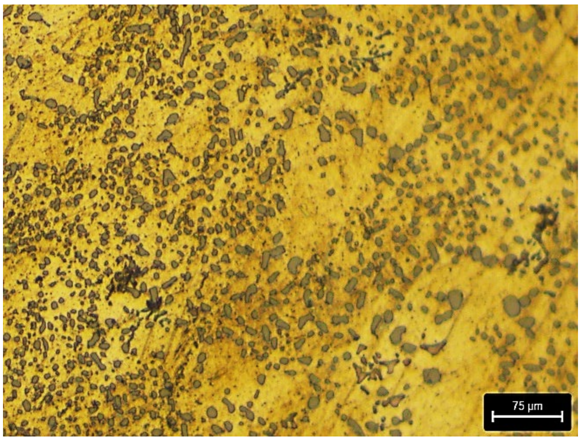

Fig. 3. Microstructure of AlSi12Cu5Mn alloy T6 artificial aging 190ºC/10h

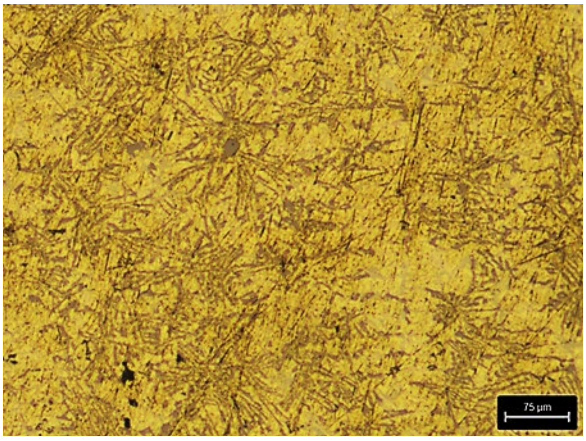

Fig. 4. Microstructure of AlSi12Cu5MgCr alloy T6 artificial aging 170ºC/14h

IV. Conclusions

Eutectic aluminium-silicon alloys have been developed which are alloyed with a non-standardized combination of chemical elements. A complex modifying treatment was carried out, in which the most commonly used modifier (Na) for this type of alloys was not used. As a consequence of the obtained structures after T6 heat treatment, the studied AlSi12Cu5MgCr and AlSi12Cu5Mn alloys have a macrohardness comparable to the macrohardness of the standardized eutectic silumins. A high microhardness of the α-phase in the structure of both compositions was also recorded.

The influence of the temperature and time parameters of the artificial aging process on the micro- and macro-hardness of the AlSi12Cu5MgCr and AlSi12Cu5Mn alloys was investigated. It was established that their maximum strengthening depends on the diffusion mobility of the alloying elements used.

Acknowledgments: This study was supported by the Bulgarian National Science Fund **№ КП-06-ПМ67/12**, project title: "Investigation of the tribological properties of new nickel-free piston aluminum-silicon alloys"

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