THE MECHANICAL PROPERTIES OPTIMIZING OF Al - Si ALLOYS PRECIPITATION HARDENING AND THE EFFECT ON THE CHARACTER OF THE CHIP

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Abstract
The aim of this work was the optimizing of mechanical properties of AlSi12CuMgNi alloy by heat treatment, as the artificial ageing with different temperatures of purpose to acquire the best mechanical properties (breaking limit and creep limit in comparison with required dilatability min. 7 – 8 %). Further aims were to search exchanges in material substructure for several heat conditions, to compare this with reached mechanical values and with influence into form and character of receiving chip on the machining under the same conditions. From heat treatment view and strength properties influence for this alloy is some important intermetallic phase Al_2Cu_3Ni marked as the T phase, what makes precipitates stable in higher temperatures to the 300 ^oC, too. Cu and Mg presence also makes intermetallic phase $CuMgAl_2$, what participates on the strength properties increase after heat treatment. There were made chip generation experiment for every temperature regime of test. The chip generation is the best for temperature regime 140 and 180 ^oC / 10 hours.

Keywords: aluminum alloys, precipitation hardening, mechanical properties, heat treatment, intermetallic phases

1 Introduction

Al-Si Alloys are pertinent to eldest and now these are the most extended aluminium foundry alloys. Their application is in the first place in means of transport area in particular in automobile industry. Recently initially foundry alloy is now used as a forming alloy, too (for example rods for subsequent fabrication). AlSi12CuMgNi alloy is in the foundry alloys group on the Al-Si base with composition in eutectic point area (11.3% Si) – eutectic silumin [1, 2].

From the chemical composition view it is complicated polycomponent system with five fundamental components (Al, Si, Cu, Mg, Ni) and other admixtures (mainly Fe, Mn, Ti and Zn can have a influence into different intermetallic composition generation). According to theoretic knowledge in literature [3] there (AlSi12CuMgNi alloy (AA 4032)) are these intermetallic compositions Al_5SiFe, Al_8Si6Mg_3Fe, $W(Al_4CuMg_5Si4)$, $T_{Ni}(Al_6Cu_3Ni)$, $e(NiAl_3)$, $d(Al_3Ni_2)$ a $CuAl_2$ in balanced state in α phase matrix. In the d phase (Al_3Ni_2) Cu dissolves. Because in this technical alloy Fe occurs as a contaminant, too, there originates the intermetallic phase Al_7Cu_2Fe. This is able to resolve Ni to the 6.8% at 530 ^oC temperature.

Every intermetallic phases with contents Ni assure α phase rigidity to the 300 °C and we are meaning phases $T_{Ni}(Al_6Cu_3Ni)$, ε ($NiAl_3$) and δ (Al_3Ni_2)**.** From a view of heat treatment and influence into strength properties is some important intermetallic phase Al_6Cu_3Ni designated as a T phase, which as only one generates stable precipitate in higher temperatures, too. Cu and Mg content in this alloy also generates intermetallic phase $CuMgAl_2$, which participates on the strength properties elevating, too, but it don't generates stable precipitate in higher temperatures [4].

2 Material and experimental methods

For experiments of temperature regime optimization for AlSi12CuMgNi alloy was used material with the next chemical composition: Si – 11.92%, Cu – 0.991%, Mg-1.055%, Ni – 0.736%, Fe – 0.21%, Mn – 0,039%, Zn – 0.01%, Ti – 0.014%, Pb – 0.0129%, Cr – 0.003%, Bi – 0.007%, remain Al. For tests was used the experimental rods with diameter 23 mm, which was made by extrusion pressing of AlSi12CuMgNi alloy. For every rod was used dissolving heat by temperature 520 °C while 20 minutes. After solution annealing was made artificial ageing for temperature 140 °C, 160 °C a 180 °C for the 10 hours in laboratory heater BINDER. Were used mechanical strength tests, substructure analyses and chip tests.

3 Results and discussion

3.1 Heat Treatment and a Mechanical Test Results

Each temperature regime was made for three experimental rods. Test bars for static tensile test and the test itself were prepared and carried out according to DIN EN 10002-1, so that the axis of the rod axis was identical to the active force and loading rate of 2 mm / min. Static tensile test was performed on a universal testing device INSPECT 100 and the results are in **Table 1**.

Table 1 Mechanical test results

Artificial ageing temperature [°C] / hours number	Rm [MPa]	Rp0,2 [MPa]	A [%]
140 / 10	352	230	13.1
	350	228	13.3
	350	228	13.4
160 / 10	387	320	8.7
	391	325	9.0
	385	321	8.8
180 /10	384	342	5.1
	381	338	5.2
	381	339	5.1

3.2 Substructure Analyses Results

The individual samples were made thin films gradual electrolytic thinning to a thickness of up to 200 nm, which were then observed and evaluated by conventional transmission electron microscopy methode with accelerating voltage of 100 to 400 kV transmission electron microscope. Wrought condition matrix of AlSi12CuMgNi alloy displays polygonal dislocation substructure and sub-boundary have the in-plane dislocation network character. Dislocations concentration inside subgrains is relatively low modified by particles presence and detectable great angled sub-boundaries are orderly and the **Fig. 1** documents, that in the material recuperation and recrystallization processes passed through completely.

It is possible to differentiate present particles to the three groups:

a) equiaxial directed bacillary dark particles with length from 100 to 200 nm (Fig. 1), it is possible, that these are intermetallic phases of the types Al_6Cu_3Ni, Al_7Cu_2Fe, $Cu_2Mn_3Al_{20}$, $FeAl_3$ and phases with Ni content [5, 6],
b) fine bright particles wit length from 50 to 100 nm (Fig.1), these are θ´ respective θ´´ and β´ phases homogeneously nucleus in α matrix [7],
c) fine globular shape particles deposit on the dislocations (helicoidal and dislocation networks), it is possible, that it is heterogenic discharge θ´´ and β´ phases (**Fig.2**).

Chemical composition of present structural components for AlSi12CuMgNi alloy as is described in literature [2, 3] is not correspond with actually identified intermetallic phases, which was identified by colour metallography and EDX analyses at real produced alloy. Attention was dedicated to this problem in some publications [8, 9, 10]. Based on percentage content of every single element in a EDX analyses and after their calculation for a stochiometric ratio was (in [11, 12]) stated that in real produced alloy $AlSi_{12}CuMgNi$ had been found following intermetallic compound phase: Al_7Si_7Mn, $Al_{12}MnSiMg$, $Al_{10}SiNiMn$, Al_5Si_2Mn, $Al_{11}Si_8Mn$, Ni_2FeCr, Ni_4Cr and oxide Cr_2O_3 contaminated by Ni.

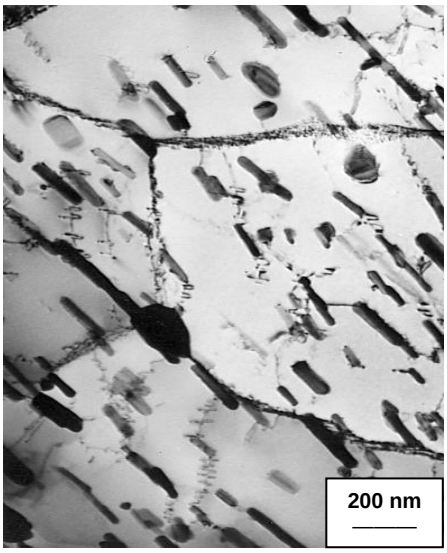

Fig.1 Subgrains borders and bacillary particles

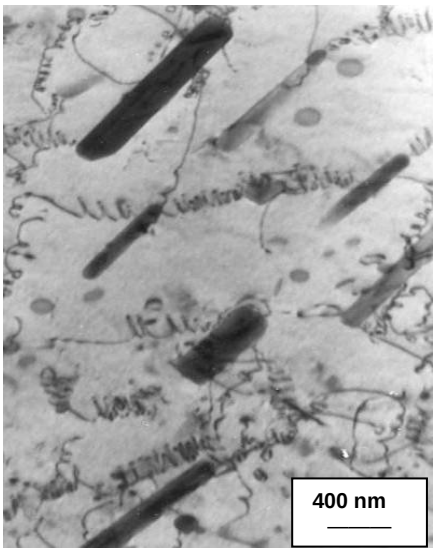

Fig.2 Presence of gentle globulitic particles cluster

Several samples structure was analysed by thin foil method on the transmission electron microscope (TEM) over accelerating voltage 100 kV. Thin foils were in the last preparation phase electrolyticaly thinned. Substructure parameters are presented in **Table 2** and photodocumentation is on the **Fig. 3 - 6**.

Table 2 Substructure parameters

Stage	Dislocation density [cm^{-2}]	Big bacillary particles [nm]	Delicate bacillary particles [nm]
Cast material	$10^6 – 10^7$	100 – 200	50 – 100
H.T. – 140 °C	$10^6 – 10^7$	80 – 160	40 – 80
H.T – 160 °C	$10^6 – 10^7$	70 – 140	40 – 70
H.T. – 180 °C	$10^6 – 10^7$	60 – 120	30 - 70

On the Fig. 3 we can see dislocation substructure with bacillary particles occurance of different dimensions, where the dislocation network occur in particles cluster area.
On the Fig. 4 is to view, that for sample 160/10 it is dislocation substructure, which is identical with sample 140/10 on the Fig.3, but there are evident less bacillary particles and better part of less particles. On subgrain's border are remarkable smaller size of rod-shaped parts and accumulation of dislocation networks.
The sample 180/10, as it is sees on the Fig.5 (magnification 84 000 x) and 6 (magnification 125 000 x), has a maximum part of gentile bacillary particles from every analyzed affections. As a consequence there it is generated maximum stress intensity in lattice and there strength properties elevate by this [13, 14].

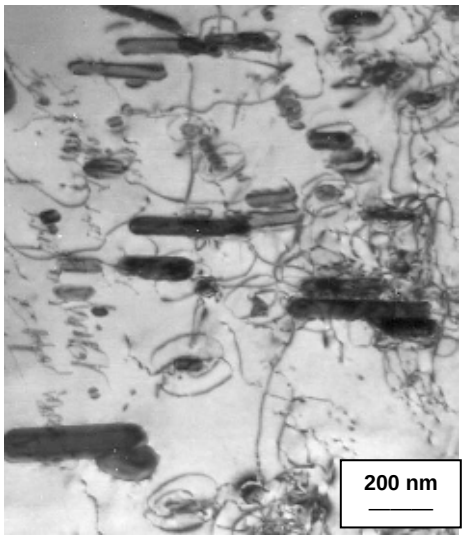

Fig.3 Sample 140/10, x75 000

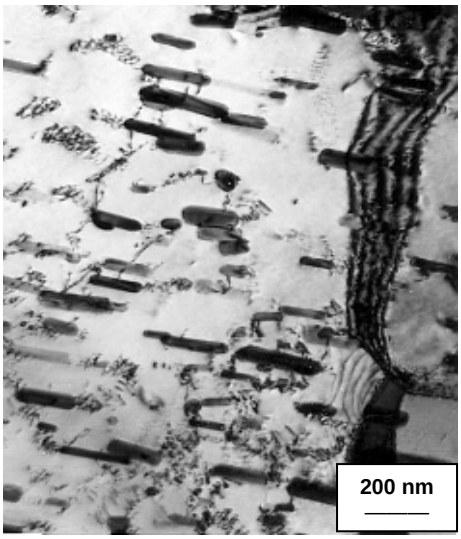

Fig.4 Sample 160/10, x75 000

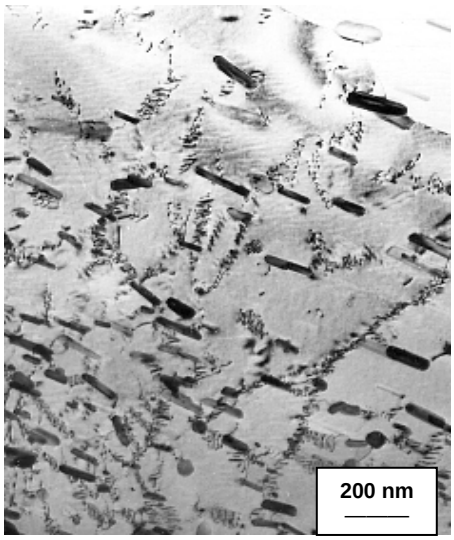

Fig.5 Sample 160/10, x75 000

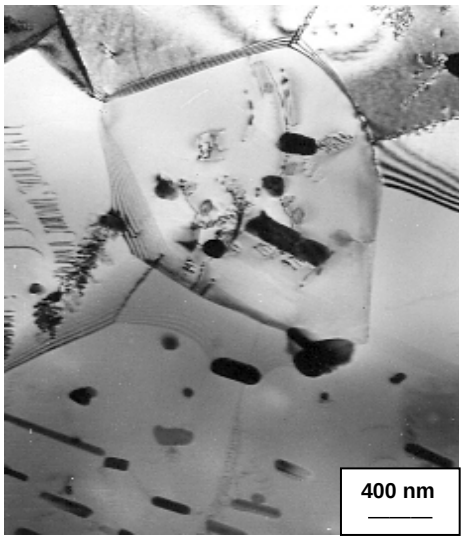

Fig.6 Sample 180/10, x135 000

3.3 Chip test

For every experimental rods, which were processed by the heat treatment (dissolvent heat at temperature 520 ^{o}C while 20 minutes, consequent artificial ageing by temperature 140 ^{o}C, 160 ^{o}C and 180 ^{o}C, every while 10 hours), were made shape chip test for cutting parameters: revolutions 1300 rev/min, feed 4 mm/s. The nature and shape of the chips were evaluated according to internal methodology of company ALCAN.

Shape chip ranking is one from important parameters in material machinability taxing, where is used visual classification and the chips are divided to the five groups marked A to F on the shape [15].

By machining of rod after artificial ageing for 140 ^{o}C (**Fig. 7**) was required the chip A type (it means small chip of needly till helical shape), for 160°C (**Fig.8**) was required the chip B type (it means small chip in the form of short or long spiral) and for 180 ^{o}C (**Fig. 9**) was required the chip A type [16].

Fig.7 Chip of Sample 140/10

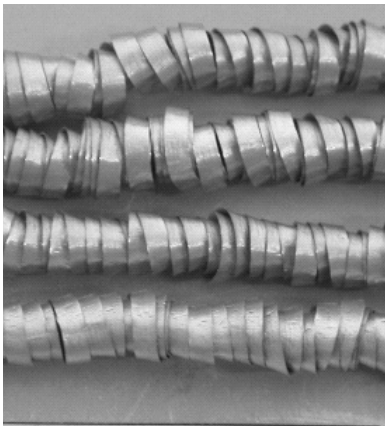

Fig.8 Chip of sample 160/10

Fig.9 Chip of Sample 180/10

4 Conclusion

- From a maximal ductility reach view optimal regime is 140 °C / 10 hours, where the ductility values are round 13% and to the temperature 180 ^{o} departure ductility sharp decreasing is apparent to the values 5% for temperature regime 180 ^{o}C/10 hours.

- Ultimate strength and extension values advancing agree plastic values decreasing represented by ductility (A). In term heat treatment total optimization with a view to access the ultimate strength and required ductility min. 7% is optimal the heat regime 160 ^{o}C/10 hours.
- The chip generation in machining (gentile needles) is some better for temperature regime 140 and 180 ^{o}C/10 hours (group A) than temperature regime 160 ^{o}C/10 hours (group B).
- From mechanical values optimization view respectively for requirement of ultimate strength and elongation maximal values acquirement is optimal regime 180 ^{o}C/10 hours. There are reaching values of strength limit round 350 MPa and elongation limit round 340 MPa. Lowest values of this are for temperature regime 140 ^{o}C.
- From several particles kind largeness in the precipitates form (large and small bacillary particles) is visible, that extra-fine particles are for temperature regime 180 ^{o}C/10 hours. From a view of heat treatment and influence into strength properties is some important intermetallic phase Al_6Cu_3Ni designated as a T phase, which generates stable precipitate in higher temperatures.
- Analyze of substructure confirm, that processes of recovery and recrystallisation has run through completely. Low density of dislocations inside sub grains confirms it. Observable big angle borders of sub grains are regular.

Acknowledgements

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