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Calculation and Experimental Investigation of Structure and Phase Composition of 6XXX Alloys

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Alloys of 6XXX series based on the system Al-Mg-Si possess sufficiently high strength properties, have good corrosion resistance and contain small amounts of alloying elements. Currently, a promising direction is the development of 6XXX alloys for use in the aviation and automotive industry as a replacement of 2XXX alloys. To do this, increase the tensile strength of alloys of Al-Mg-Si at least up to 400 MPa while maintaining high ductility and corrosion resistance.
On the basis of calculation of multicomponent phase diagrams in the Thermocalc software concentration limits of alloying of Al-Mg-Si-Cu-Fe alloys are optimized to achieve the maximum alloying of the solid solution after homogenizing annealing. Also in this work the possibility of introducing additions of transition metals chromium and zirconium into aluminium solid solution is investigated. During homogenization these additions form disperse aluminides impeding recrystallization and increase the strength of deformed products. For the proposed alloys the effect of temperature and time of homogenizing annealing on the phase composition and structure of the ingots is investigated.

Keywords: *6XXX alloys, thermodynamic calculation, phase composition, microstructure.*

1. Introduction

Aluminium alloys of 6XXX series based on the system Al-Mg-Si are the most low-doped of heat-hardened aluminium alloys. The content of the main alloying elements is usually about 1-3%. These alloys possess high corrosion resistance, the good deformability and ability to deposite of various coatings [1]. Alloys of 6XXX series is currently great interest in the automotive industry [2, 3]. However, the strength properties of 6XXX alloys are yield to other aluminium alloys, such 2XXX series. Therefore, there is the important problem of increasing the strength properties of 6XXX alloys to a level of about 400 MPa.

The most doped alloys of 6XXX series (e.g., 6066) have tensile strength at the level of 380-400 MPa [4]. However, these alloys contain a large amount of copper (up to 1.5%) which reduces their corrosion properties. In addition, the compositions of commercial alloys of 6XXX series have not been optimized. Different content of alloying elements in alloys of the same brand may lead to different phase composition of alloys, and, consequently, will strongly affect the properties.

On the basis of calculation of multicomponent phase diagrams in the program Themocalc the concentration limits of alloying of Al-Mg-Si-Cu-Fe alloys to achieve the maximum alloying of the aluminium solid solution after homogenizing annealing are optimized. Also in the paper the possibility of introducing into solid solution the additions of transition metals chromium and zirconium is investigated.

2. Experimental

The calculation of multicomponent phase diagrams were carried in the program Thermocalc TCW4 using thermodynamic database TTAL5.

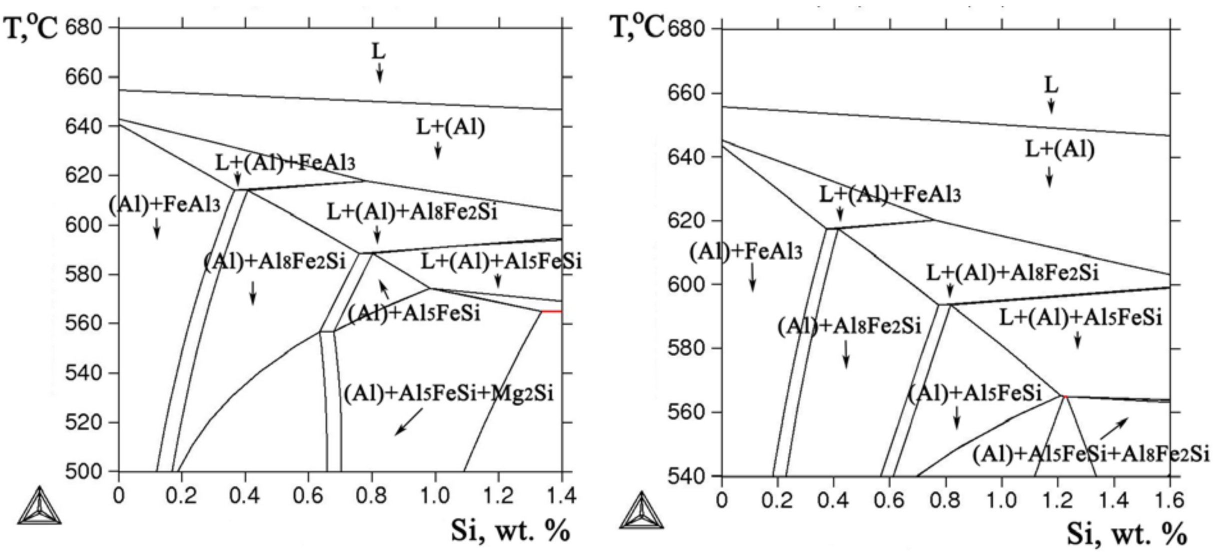
Charge materials to prepare the alloys were aluminium (99,99 %), silicon (99.90 %), magnesium (99.90 %), copper (99.90 %) and master alloys Al-3,5% Zr, Al-10% Fe, Al-10% Cr. Alloys were melting in electric resistance furnace NABERTHERM TOP45 in graphite-chamotte crucible. Casting temperature was 800 ^{0}C. The alloys were cast into the graphite mold size of 15 × 30 × 200 mm.

The ingots were subjected to homogenizing annealing in furnace SNOL -1,6.2,5.1/9-I5 with an accuracy to maintain the temperature of 5 ^{0}C. The aging of the samples was carried out in furnace SNOL 58/350 with an accuracy to maintain the temperature of 2 ^{0}C.

Metallographic investigation was carried out on the optical microscope «Axiovert 200 MMAT». Metallographic samples were prepared by standard mechanical method using Struers LaboPol-5.

3. Results and Discussion

Fig. 1 shows polythermal sections of Al-Mg-Si-Fe equilibrium diagram for the content of magnesium 0.8 and 1.0 %, depending on the content of silicon. From the above sections shows that the complete dissolution of crystallization phases (except iron-containing) during the homogenizing annealing occurs in the alloys Al-0.8% Mg-0.2% Fe in the silicon content of about 1%, and in the alloy Al-1% Mg-0.2% Fe - in silicon content – 0.8%.



a b

Fig. 1. Fragments of polythermal sections of equilibrium diagram Al-Mg-Si-Fe for alloys Al-1%Mg-0.2%Fe (a), Al-0.8%Mg-0.2%Fe (b) depending on the content of silicon

Improving the strength properties of 6XXX series alloys is possible by increasing the alloying of the aluminium solid solution. To increase the alloying of the solid solution and, consequently, increase the capacity of hardening during aging the addition of copper is injected in alloys.

Fig. 2 shows polythermal sections of Al-Mg-Si-Fe-Cu diagram for alloys Al-0.8%Mg-1% Si-0.2% Fe and Al-1% Mg-0.8% Si-0.2% Fe depending on the copper content.

From the above sections shows that the complete dissolution of phases of crystallization origin (except iron-containing) during homogenizing annealing occurs in the alloy Al-1% Mg-0.8% Si-0.2% Fe (alloy 1) with copper content up to 1%, while in the alloy Al -0.8% Mg-1% Si-0.2% Fe (alloy 2) - with the copper content up to 1.2%. However, the temperature range of homogenizing annealing at the maximum possible content of copper is very narrow (± 1 ^{0}C). Maintaining the temperature in the furnace with such precision in an industrial environment is impossible.

To expand the field of quenching temperatures should decrease the copper content in the alloy. Fig. 2 shows that with copper content of 0.7% in the alloy 1 the region of possible homogenizing annealing temperatures is 565 ± 5 ^{0}C. For alloy 2 with copper content about 0.8% homogenization and quenching may be carried out at temperatures of 557 ± 5 ^{0}C.

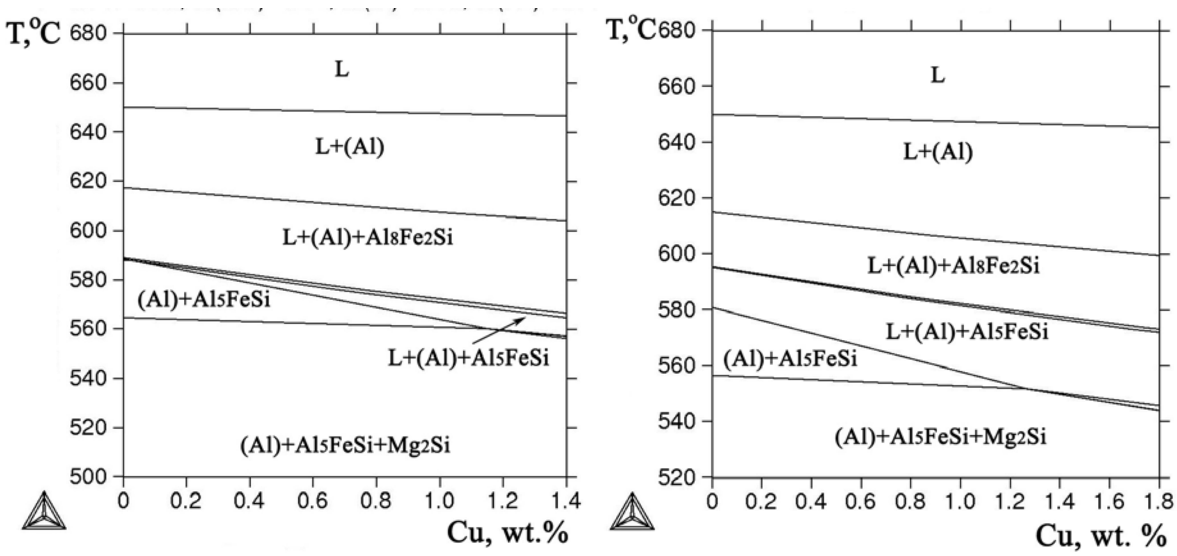


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Fig. 2. Fragments of polythermal sections of equilibrium diagram Al-Mg-Si-Fe-Cu for alloys Al-1%Mg-0.8%Si-0.2%Fe (a), Al-0.8%Mg-1%Si-0.2%Fe (b) depending on the content of copper

Thus, following alloy composition and temperatures of homogenizing annealing (heating for quenching) were selected:

Alloy 1: Al-1% Mg-0.8% Si-0.7% Cu-0.2% Fe; T = 565 ± 5 ^{0}C

Alloy 2: Al-0.8% Mg-1% Si-0.8% Cu-0.2% Fe; T = 557 ± 5 ^{0}C

Fig. 3 shows the microstructure of selected alloys in as-cast state. In the structure of both alloys we can see gray needles of phase β-Al_5FeSi, black streaks of phase Mg_2Si and fragments of skeletons of phase α-Al_8Fe_2Si insoluble during peritectic reactions.

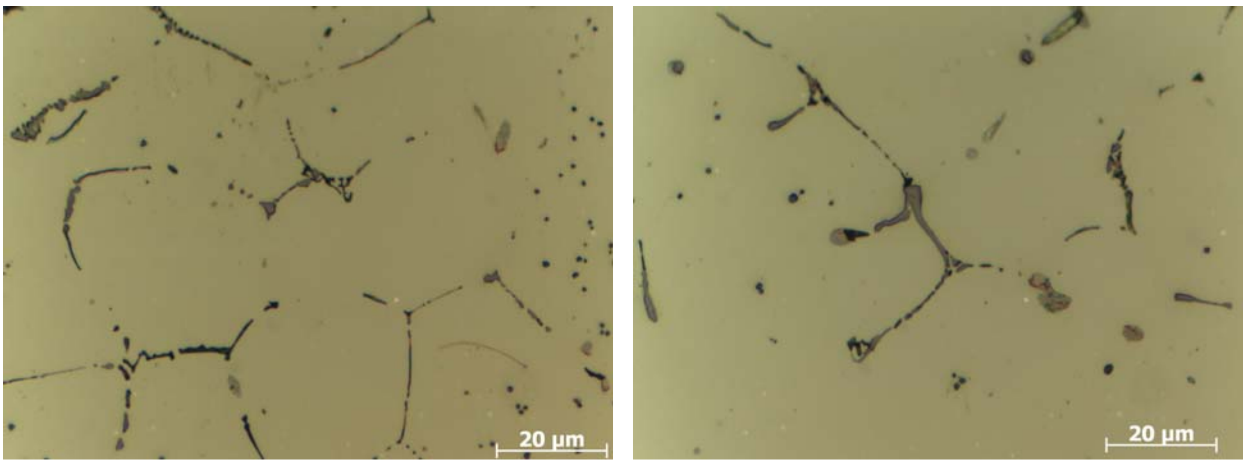

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Fig. 3. As-cast microstructure of alloys: alloy 1 (a), alloy 2 (b).

To determine the duration of the homogenizing annealing the samples were quenched after various holdings and aged at 180 ^{0}C, 5 h. Dissolution of phase Mg_2Si during the annealing leads to increase of alloying of the solid solution and increase age-hardening. Results of hardness measurement on the aged samples are shown in Fig. 4.

Fig. 4 shows that almost complete dissolution Mg_2Si phase in both alloys occurs only after 0.5 h holdings. To confirm this result the structure of the alloys after quenching with isothermal holding temperature was studied. Analysis of the microstructure showed that after 0.5 h holding in the structure contains a certain amount of phase Mg_2Si, in the structure after homogenizing annealing fo 1 h phase Mg_2Si completely absent, and the particles of iron-containing phases are heavily fragmented and spheroidized (Fig. 5).

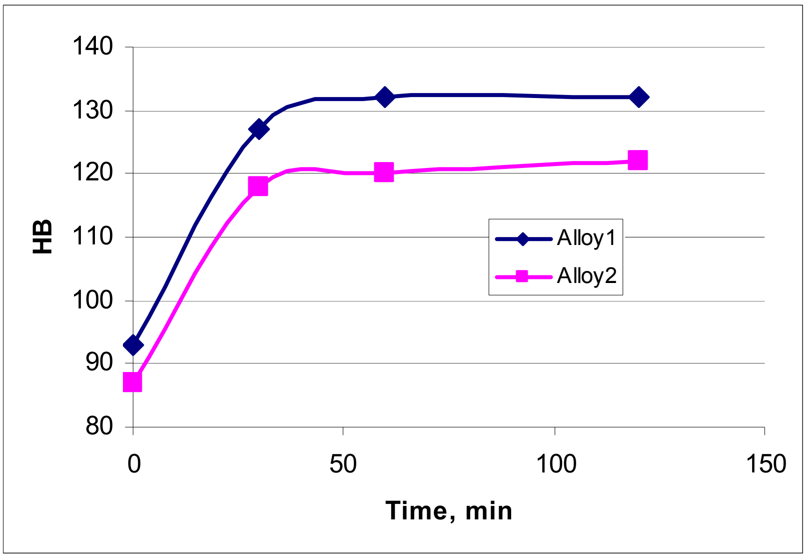

Fig. 4. Hardness of aged samples vs time of homogenizing annealing

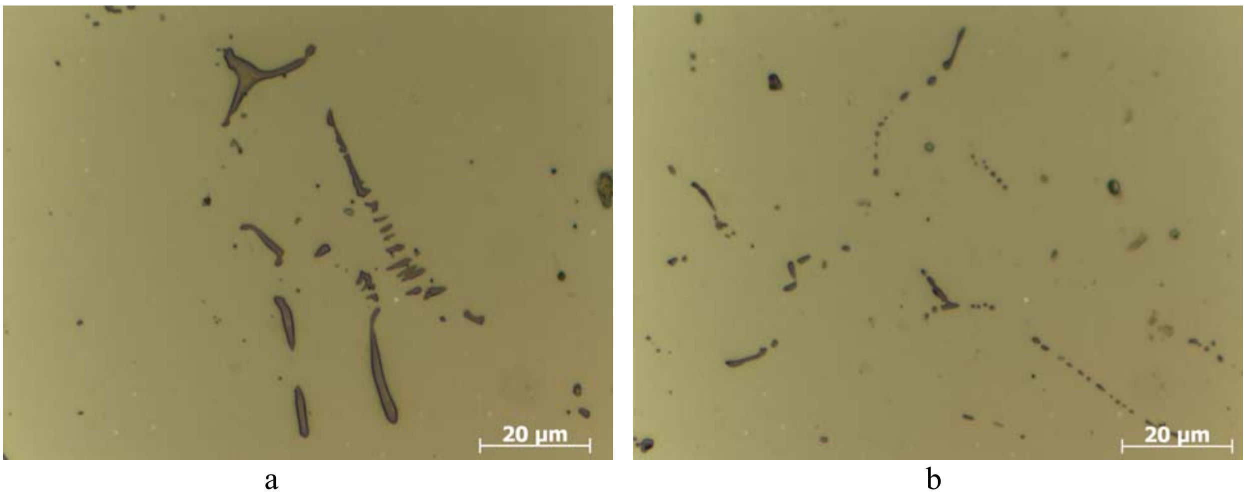

Fig. 5. Microstructures of alloys after homogenizing annealing for 1 h: alloy 1 (a), alloy 2 (b).

Also in the work the possibility of additional introduction of solid solution additions of transition metals chromium and zirconium was investigated. These additives form during homogenizing annealing a dispersed aluminides impeding recrystallization and increase the strength of deformed semi-products.

The primary task was to determine the limits of chromium and zirconium concentration in alloys. Transition metals have fully dissolved into solid solution after casting, otherwise they are allocated in the form of coarse primary aluminides which reduce the mechanical properties of alloys and do not prevent recrystallization.

Alloys containing Cr and Zr were cast at a temperature of 100 ^{0}C above the liquidus temperature. It was experimentally determined that with the content of zirconium up to 0.3% and content chromium up to 0.5% the allocation of primary aluminides does not occur (Fig. 6). Exceeding these limits of concentration leads to the formation of coarse primary crystals.

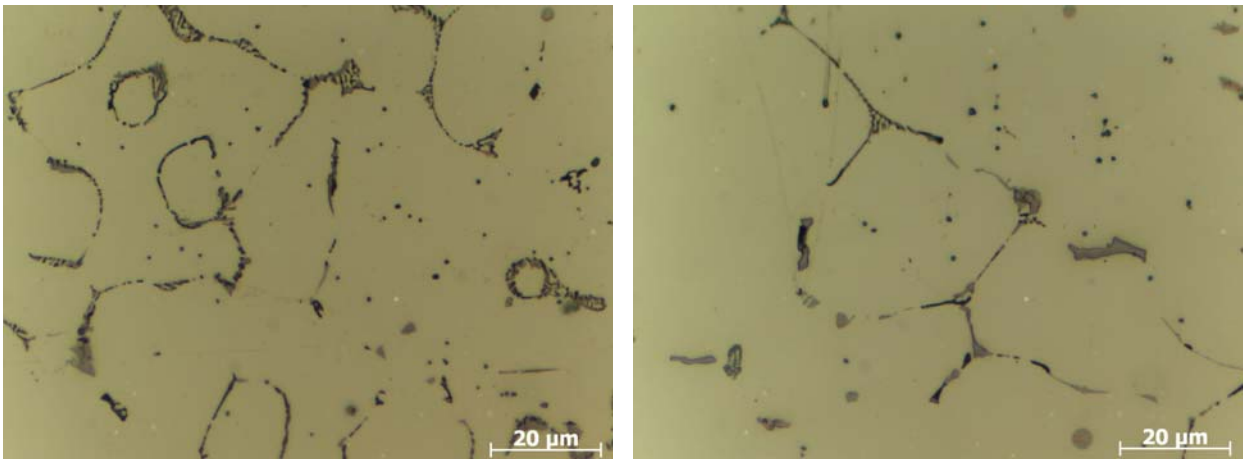

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Fig. 6. As-cast microstructure of alloys: alloy 1+ 0.3 % Zr (a), alloy 2 + 0.3 % Zr (b).

Thus, on the base of thermodynamic calculations and experimental data compositions of alloys of Al-Mg-Si-Fe-Cu for obtaining at homogenizing annealing the most alloyed aluminium solid solution were determined. The concentration limits of chromium and zirconium additions introduced in aluminium solid solution were defined.

Acknowledgement

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