ON THE INFLUENCE OF SCANDIUM ON THE FLUIDITY OF THE AlMg6Li2 MELTS

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Abstract
We conducted the study of viscosity liquid alloys AlMg6Li2(Sc) under the heating and subsequent cooling of samples. Results of these measurements allowed defining critical temperatures. The processing melt by heating above the critical temperature cause irreversible destruction of micro-inhomogeneities of hereditary nature. The irreversible destruction of micro-inhomogeneities improves the casting properties of the melts AlMg6Li2(Sc).

1 Introduction

The alloys based on Al-Mg-Li system are being actively developed over the last years. Aluminum alloys containing lithium have a number of advantages in comparison with aluminum alloys based on other systems: their specific mass is averagely 10% lesser and the modulus of elasticity is 12% higher. Moreover, aluminum-lithium alloys can possess high mechanical characteristics (tensile strength reaches 600-650 MPa) with the good factors of crack resistance and corrosion resistance [1-3]. Despite all these advantages, AlMg6Li2 alloys are not widely used, mainly because of the low technological plasticity [4]. Reduced plasticity of annealed alloys with lithium is associated with high alloying and high volume ratio of phases compared to traditional alloys and also, to a lesser extent, with the incompleteness of recrystallization, reason for this is the large number of interfering particles $Al_3(Zr,Sc,Li)\beta'$-phase[4-5]. Magnesium content has a strong influence on technological plasticity of annealed alloys of system Al-Li-Cu-Mg-Zr [5]. The studies have shown that annealing process at 400-530°Cfollowed by slow cooling results only in formation of phaseT_2 (Al_6CuLi_3) [5]. The measurements of the lattice period allowed determining that nearly all of magnesium in alloy remains in solid solution after annealing, a small portion of it is included in T_2-phase and precipitates under annealing. Reducing of plasticity of annealed alloys mainly correlates with the high content of magnesium in solid solution and also with increasing of T_2-phase quantity. Structural studies have demonstrated [2, 5] that the main reason for low plasticity of annealed alloys of this system is a big volume fraction of δ'-phase (Al_3Li) particles not crossed by dislocations or β'- phase composite particles with δ'- phase shells. These particles larger than

15 nm are formed under ageing at the temperature of annealing and slow cooling of alloys. They strengthen the matrix, preventing stress relaxation during cold deformation. The second factor that significantly reducing plasticity is a high magnesium concentration in solid solution, same for alloys of Al-Li-Cu-Mg-Zr system [6]. Annealing at 400-500°C with subsequent slow cooling to 180°C or holding in the temperature range of 250-350°C results in formation of δ'- and also δ-phase (AlLi) – a key phase for alloys containing ≤ 3% mass. Mg, and S1-phase (Al$_2$MgLi), which exists in all alloys containing ≥ 1% Mg and is a main phase for alloys containing ≥ 3% Mg. The presence of the δ-phase in annealed alloys with low magnesium content adversely affects plasticity, so the shift δ' → δ does not improve plasticity. The shift δ' → S$_1$ in alloys with higher content of magnesium increases plasticity under annealing in temperature range of 250-300°C, but a large quantity of magnesium remains in solid solution and the plasticity is low. The study shows that plasticity of annealed alloys of Al-Li-Cu-Zr-(Sc) system dramatically decreases after appearance of large allocations of T$_1$-phase (Al$_2$CuLi) [7]. The authors [8] reported discovery of the particles of iron-containing α$_{cube}$(Al$_{12}$Fe$_3$Si) phase and the composite particles of δ/β'phase with L1$_2$ structure with δ′-phase shell and β′-phase core containing zirconium, scandium and lithium in original hot-rolled state.

Scandium and zirconium in the Al-Mg-Li alloys are introduced to improve strength R$_m$ and conditional σ$_{0,2}$ metal yield strength by maintaining in quenched alloys unrecrystallized structure and β'-phase Al$_3$(Zr,Sc). This dispersoids Al$_3$(Zr,Sc) stand out during the decay of a supersaturated of zirconium and scandium solid solution [9].

The best combination of strength and ductility (R$_m$ = 330-360 MPa, δ = 6-12%) have alloys with 5,5-6,5% Mg and 1,5-2,0% Li. This means that limiting the concentration of magnesium (up 6.5%) does not lead to the formation of a large number of fragile β'-phase, and the main strengthening phase with the phase becomes S$_1$ (Al$_2$MgLi), uniformly distributed along the grain section and causes a significant reinforcing effect [10].

An important task in the production of ingots AlMg6Li2 is to further increase the quality of finished products through definition of the heating temperature of the melt prior to casting. Widely known idea about that, which is higher than the liquids temperature in the melt of microinhomogeneity hereditary nature, can exist for a long time. The overheating before the temperature determined for each composition alloy or other energetic effects on melt (e.g., ultrasound) required for of their destruction. The heating of the liquid metal to T* significantly change the crystallization will conditions, microstructure and mechanical properties of solid metal [11-15]. Earlier experiments found that the destruction of microscopic in homogeneities in the of aluminum melts is usually accompanied by abnormalities of the temperature dependence of the properties of the liquid metal, in particular viscosity. Found a divarication of the temperature dependence of the melt viscosity, the corresponding modes of heating and subsequent cooling of the sample. The T* temperature at which the irreversible destruction of microscopic in homogeneities and the melt transition in the homogeneous state happening, determined by at the branching point the temperature dependences of viscosity obtained during heating and subsequent cooling of the sample [12-15]. The temperature T* is called the homogenization temperature.

We performed measurements of temperature dependencies of viscosity of AlMg6Li2Sc (0-0.4) to determine the temperature T*, to which the liquid alloy 01421 (5.29% Mg; 2.20% Li; 0.06% Mn; 0.14% Si; 0.11% Fe; 0.15% Zr; 0.21% Sc; the rest is aluminum) is heated before casting and crystallization in order to destroy micro-inhomogeneities of hereditary nature. The study also allows recommending the optimum content of scandium in AlMg6Li2 alloy for decreasing of T*.

The method is based on alloying of a melt with substances that reduce interfacial tension at the border of dispersed particles [16]. This way allows to lower the temperature T* corresponding to irreversible transition of a melt into homogeneous state. The data on the temperature dependence of viscosity are also relevant for foundry production of these alloys.

Earlier, the viscosity of AlMg6Li4Sc liquid alloys no was measured. However, the viscosity of liquid Al-Li and Al-Mg alloys was measured and they are well-known. The liquid Al-Li alloys have been studied by KONONENKO et al [17]. The viscosity of liquid alloys concentration Al-Li was measured in the range for 1.1, 3.3, 5.4, 7.2, 9.6, 13.2, 15.9 % of lithium. The temperature dependence of the viscosity of melts obtained under heating and cooling are the same and correspond to the Arrhenius law. The dependencies of viscosity the liquid Al-Li alloys from the quantity lithium are presented in work [18], where viscosity increases with increasing Li content. The work [18] presents measured viscosity in the range for 10, 20, and 25 at. % of lithium content in Al-Li alloys. An associative tendency in the liquid state can be observed. CFM thermodynamic modeling showed that Al_2Li_3 clusters can exist in liquid alloys Al-Li[18].

The viscosities of liquid alloys $Al_{(1-x)}Mg_{x(0\leq x\leq 0.10)}$ have been measured in the temperature range of 973K-1173 K using torsion oscillation cup method [19]. The temperature dependence of viscosity for liquid alloys $Al_{(1-x)}Mg_{x(0\leq x\leq 0.10)}$ obeys Arrhenius equation. The viscosity increases with increasing magnesium concentration in the investigated system. The viscosities of liquid alloys Al-Mg with different compositions increase with decreasing temperature. The viscosity change is in a good accordance with the structure of melt. It is a quasi-eutectic structure made up of clusters Al_2Mg_3 and pure Al near the liquid for Al-rich Al-Mg melts. However, when heated to 200-300 K above liquid, magnesium atoms start to intensively dissolve in aluminum. To sum it up, the viscosity of liquid alloys is a structure sensitive property [19].

2   Materials and methods

The ingots of aluminum alloy AlMg6Li2Sc(0-0.4) were used as the study object. Samples were gathered from the central zone of specially prepared industrial ingots in conditions of J.S.C «KUMZ». The microstructure was studied traditional methods of quantitative metallographic using JSM-5900 Scanning Electron Microscope (SEM) with EDS for microanalysis. For preparing of samples was used "Logitech PM5".Phase analysis performed using a diffractometer X-ray "Bruker D8 Advance". The studies of the phase composition and crystalline structure of specimens were carried out by means of the EBSD methods using the Auriga Cross Beam scanning electron microscopy station.

The viscosity of melts AlMg6Li2Sc(0-0.4) was measured using method of damping torsion oscillations of the crucible under heating up to 900°C and subsequent cooling of the sample. We failed to perform measurements at higher temperatures due to the high volatility of the melt. Experiments were conducted in inert atmosphere of the pre-purified helium at excessive pressure 2.5 Pa. BeO crucibles were used. The viscometer working chamber was preliminary vacuum zed up to 0.001 Pa. The measurement of kinematic viscosity was conducted with increments of 50°C at isothermal exposure in reference points were at least 15 minutes. Measurement error for values of kinematic viscosity did not exceed 3%. The measurement of kinematic viscosity was performed on the device described in [20-21].

3   Results and discussion

The microstructure of alloy 01421 (5.29%Mg; 2.20%Li; 0.06%Mn; 0.14%Si; 0.11%Fe; 0.15%Zr; 0.21%Sc; the rest is aluminum) shown in **Fig. 1**. EDS-analysis suggested the presence Al_6Cu_2Fe

phase and Al_6Fe_2Cu phaseinclusions [22-23]. Explanation of diffraction patterns obtained with Bruker D8 Advance, found reflections from phases: α-Al, Al_2CuLi, Al_2Cu, Al_3Li and $Al_6(Fe,Mn)$ in the region of large angles. As a result of EBSD-analysis failed to identify the phases: α-Al, Al_2CuLi, Al_2Cu, Al_3Li.
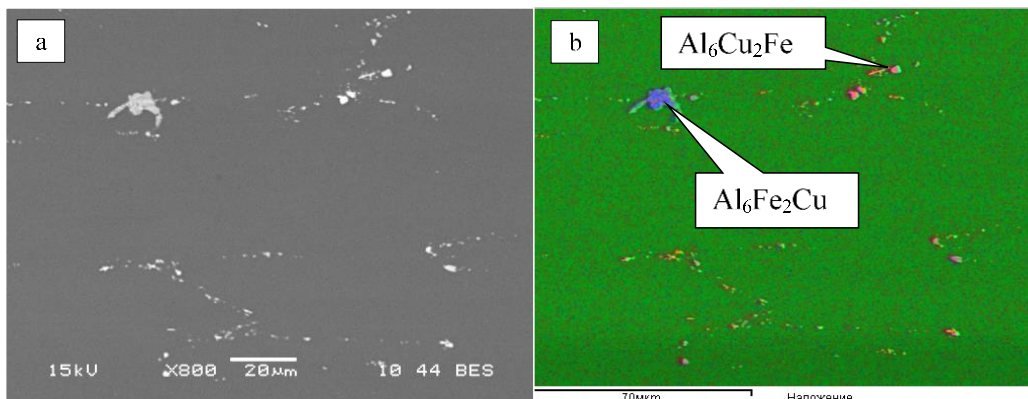

Fig. 1 The microstructure of alloy AlMg6Li2Sc0.2. a - SEM micrograph of the microstructure, b - of the element distribution map: Al(green), Cu(red), Fe(blue)

The results of study of viscosity of melts are presented in **Figs. 2-7**. The branching of temperature dependencies of kinematic viscosity for the heating and cooling modes was found for the melts AlMg6Li2 and AlMg6Li2Sc0.1. Temperature dependencies of kinematic viscosity differ in the temperature range from liquivdus to 750 and 780°C, respectively. According to [12], this suggests that the homogenization temperature for AlMg6Li2 melt T* = 750°C and for AlMg6Li2Sc0.1 melt T* = 780°C. In the heating mode (**Figs. 1-2**) in areas with temperatures 850°C several abnormalities of v(t) dependency were identified − intermittent changes in values of kinematic viscosity for melts Al-6%Mg-2%Li and 01421 (5.29% Mg; 2.20% Li; 0.06% Mn 0.14% Si; 0.11% Fe; 0.15% Zr; 0.21% Sc; the rest is aluminum). One should note that the introduction of scandium into AlMg6Li2 melt in quantity of 0.2wt. % allows to decrease T* up to the liquidus temperature that meets composition of 01421 alloy. The study also allows to recommend the optimum content of scandium in AlMg6Li2 (Sc) alloy for decreasing T*.
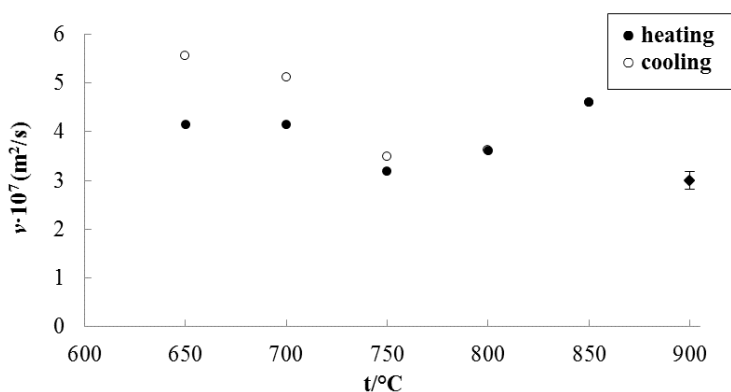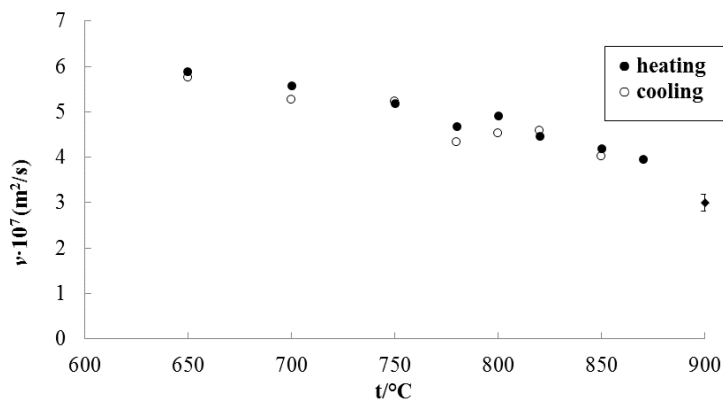

Fig. 2 The temperature dependence of kinematic viscosity of liquid alloy AlMg6Li2
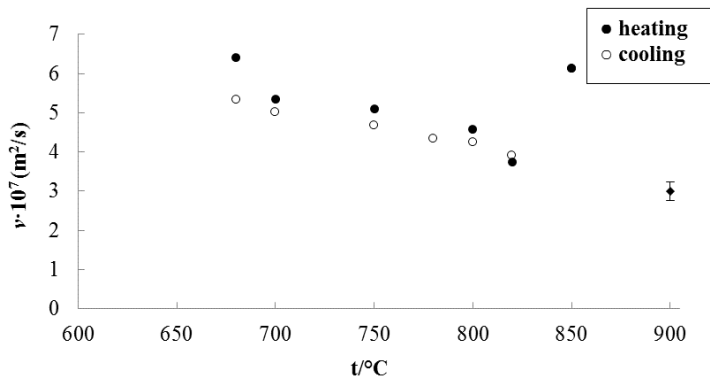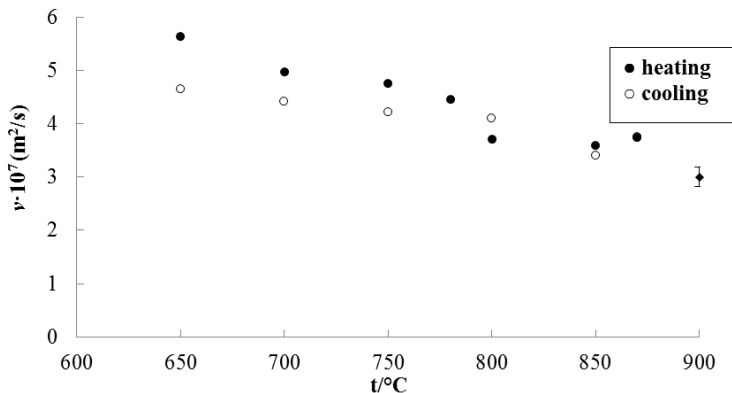
Fig. 3 The temperature dependence of kinematic viscosity of liquid alloy 01421 (5.29% Mg; 2.20% Li; 0.06% Mn; 0.14% Si; 0.11% Fe; 0.15% Zr; 0.21% Sc; the rest is aluminium)
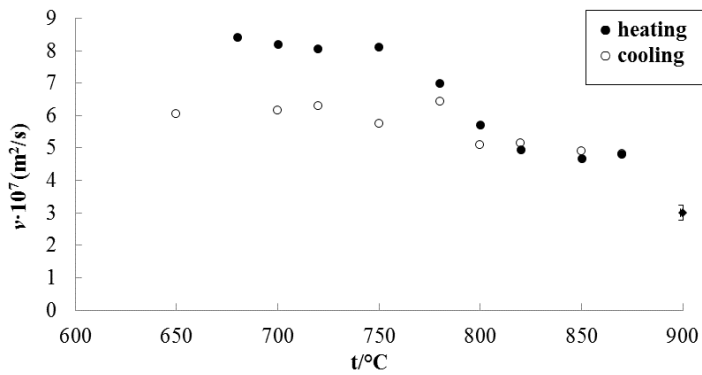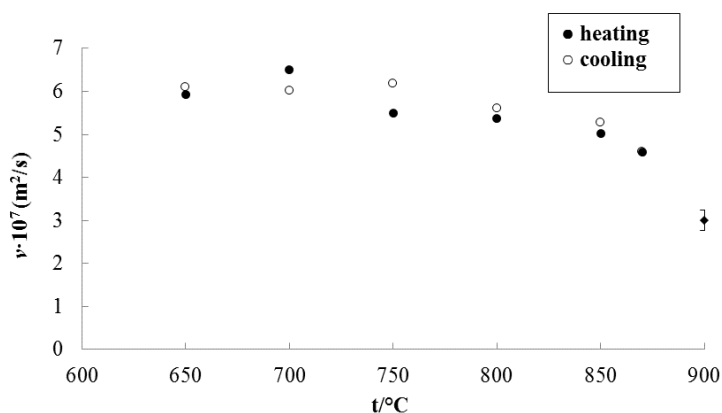

Fig. 4 The temperature dependence of kinematic viscosity of liquid alloy AlMg6Li2Sc0.1

Fig. 5 The temperature dependence of kinematic viscosity of liquid alloy AlMg6Li2Sc0.2

Fig. 6 The temperature dependence of kinematic viscosity of liquid alloy AlMg6Li2Sc0.3

Fig. 7 The temperature dependence of kinematic viscosity of liquid alloy AlMg6Li2Sc0.4

According to numerous experimental data [12], the micro-inhomogeneities of hereditary nature can exist in multi-component aluminum melts in a wide temperature range above liquidus. The micro-inhomogeneities possess different elemental composition and break down under heating to a certain temperature. Such inhomogeneities may be presented by particles close in composition to compounds resulted from phase analysis of 01421 alloy: S_1-phase (Al_2MgLi), β'-phase Al_3(Sc, Zr) δ'-phase (Al_3Li). It was previously established that micro-inhomogeneities of hereditary nature in Al-Sc system melts close in composition to Al_3Sc compound irreversibly break down after heating of a liquid metal to 900°C [14]. According to the data of theoretical analysis of diffusion processes occurring during melting of aluminium alloys, it is most likely that the refractory inclusions Al_3(Sc,Zr) remain in AlMg6Li2Sc(0-0.4) melt at temperatures above liquidus. It can be assumed that the inclusions close in composition to the main strengthening phase S_1-phase (Al_2MgLi) will break down at T* not only through diffusion interaction with surrounding melt, but also through spontaneous dispersion as a consequence of decrease of the free internal energy at the boundary of micro-inhomogeneities and the surrounding melt through the presence of scandium additives.

Thus, the heating of the liquid alloy 01421 AlMg6Li2Sc0.2Zr0.1 up to 700°C ensures melt homogeneity and dissolution of inclusions close in composition to the main strengthening phase S_1-phase (Al_2MgLi).

4   Conclusions

1) The study viscosity of liquid alloys AlMg6Li2Sc(0-0.4)and 01421 under heating of metal from 650°C to 900°C and subsequent cooling was conducted. It was found that temperature dependencies of kinematic viscosity corresponding to heating and cooling regimes for AlMg6Li2 and AlMg6Li2Sc0.1 have branchings. Temperature dependencies of kinematic viscosity differ in the temperature range from liquidus to 750°C and 780°C, i.e. temperature, which causes destruction of micro-inhomogeneities of hereditary nature in a melt, at $T^* = 750$ and 780°C respectively.

2) The content of scandium in alloy 01421 was scientifically grounded. It was demonstrated that introduction of scandium into AlMg6Li2 melt in quantity of 0.2wt.% allows to decrease T^* to the liquidus temperature, which meets industrial composition of 01421 alloy.

3) The results of viscosity studies were discussed according to the concept of presence of micro-inhomogeneities of hereditary nature in multi-component aluminum melts in a wide temperature range above liquidus. Particles close in composition to S_1-phase (Al_2MgLi) break down under heating of melt to T^*, the micro-inhomogeneities with elemental composition close to β'-phase $Al_3(Sc, Zr)$ apparently remain in the melt and under overheating up to 900°C.

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