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Evolution of secondary phases and properties of 7B04 aluminum alloy during DC homogenization

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Abstract: The effects of the direct current (DC) on the evolutions of hardness and morphology of the secondary phases in 7B04 aluminum alloy homogenized at 380−465 °C for 2 h were investigated in detail by electric conductivity measurement, hardness test, X-ray diffraction analysis, field emission scanning electron microscopy and energy dispersive spectrometry. The results show that with increasing temperature from 380 to 465 °C, the electric conductivity of normal homogenized sample decreases from 34.9%IACS to 28.7%IACS, the hardness increases from HV 96 to HV 146, and the area fraction of secondary phase reduces from 4.5% to 1.89%. While, DC homogenized sample has a higher hardness, a lower electric conductivity and a smaller area fraction of secondary phases at the same temperature. The DC enhances the homogenization process by promoting the diffusibility of the solute atoms and the mobility of vacancy.

Key words: 7B04 aluminum alloy; direct current; homogenization; hardness; secondary phase; elemental diffusion

1 Introduction

7B04 aluminum alloy has high strength, low density and good corrosion resistance, and is widely used in aircraft industries [1]. The high mole ratios of Zn to Mg, Cu to Mg and alloying element content of 7B04 alloy endow its attractive combinations of properties, while in turn lead to the difficulty of processing it. The commonly observed secondary phases in as-cast Al−Zn−Mg−Cu alloy are *η* ($MgZn_2$), *T* ($Al_2Mg_3Zn_3$) or *T* ($Al_{32}(Mg,Zn)_{49}$), *M* ($Mg(Zn_2AlCu)$), *S* (Al_2MgCu) and $A1_7Cu_2Fe$ [2−4]. A lot of secondary phases remaining in the alloys after the subsequent heat treatment and processing [5−8], approaching to the proximity of composition to the limit of solid solubility in those alloys, could assist the crack initiation, propagation and induce variable properties. FAN et al [6] revealed that a phase transformation of major elements from $Mg(Zn, Cu, Al)_2$ phase to Al_2CuMg phase was found in Al−Zn−Mg−Cu alloy homogenized at 460 °C. The *η* phase dissolved completely, while *T* and *S* phases remained in 7055 alloy heat-treated at 450 °C for 35 h [7].

The electric and magnetic fields provide us new approaches to material preparation and property control. LIU and CUI [8] discovered that the electric field accelerated the dissolution of secondary phase and the decrement in the interdendritic segregation during homogenization, and even suppressed the nucleation of δ' phase during artificial aging. CONRAD [9] demonstrated that an electric current density (>1 kA/cm^2) promoted the transformation of the solid state phase in metals and enhanced the recrystallization rate of cold worked metals, but retarded the subsequent grain growth. ZHOU et al [10] detected that the electric field accelerated the transformation of *S* phase from type I to type II. HE et al [11] found that the high magnetic field of 12 T promoted the dissolution of both *T* and *S* phases in Al−Zn−Mg−Cu alloy during homogenization.

It can be seen that the previous studies mainly focused on magnetic or electric fields, little information on the effects of electric current on mechanical properties and microstructures of aluminum alloy is available. In present work, evolution of the conductivity, hardness and chemical composition of secondary phase in 7B04 alloy during homogenization with applying a DC of 1 kA was

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studied in detail by XRD, FESEM and EDS, and the mechanisms of effects of the DC on the dissolution of secondary phases in 7B04 alloy during homogenization were discussed. The purpose of present work is to find a new heat treatment method for Al−Zn−Mg−Cu alloy.

2 Experimental

The composition of 7B04 alloy is: Al−6.06Zn−2.44Mg−1.57Cu−0.07Si−0.17Fe−0.31Mn−0.14Cr−0.05Ni−0.05Ti (mass fraction, %). The semi-continuous cast ingots with dimensions of 600 mm × 400 mm × 1400 mm were provided by Northeast Light Alloy Co., Ltd., China. Samples with dimensions of 10 mm × 20 mm × 580 mm were sliced from the ingots along the casting direction, and then homogenized at 380, 420, 440 and 465 °C, respectively, for 2 h without or with applying a stable DC of 1 kA, and followed by air cooling. In present work, the homogenization without DC is called normal homogenization, and the homogenization with DC is called DC homogenization. The heating rate was 5 °C/min. A wind bellowing device was used to maintain the temperature variation of sample within ±3 °C. The electric conductivity and hardness of alloy in each condition were the average values of five specimens and measured using a Fischer Sigmascope SMP10 type machine and a 452SVD type hardness tester, respectively.

The secondary phases in as-cast and homogenized alloys were examined by X-ray diffraction analysis (XRD) with Cu $K_{\alpha1}$ radiation on a PW 3040/60 X diffractometer. Samples for microstructural observations were prepared by the standard metallographic methods and examined on a Zeiss Ultra Plus 60 type field emission scanning electron microscopy (FESEM) equipped with an Oxford AZTEC 50 type energy dispersive X-ray analyzer having an image resolution of 0.8 nm. The area fraction of the secondary phases in as-cast and homogenized alloys was measured by the average of 15 SEM photographs and calculated using Image J software.

3 Results

3.1 Evolution of electric conductivity and hardness during DC homogenization

The electric conductivity and hardness of normal and DC homogenized 7B04 alloys at 380−465 °C for 2 h are displayed in Fig. 1. The hardness and electric conductivity of as-cast alloy are HV 80 and 43%IACS, respectively. The electric conductivity decreases to 34.9%IACS and 33%IACS, respectively, after the as-cast alloy is homogenized at 380 °C for 2 h without and with direct electric current, and then decreases progressively with increasing temperature, and finally achieves 28.7%IACS and 27.7%IACS, respectively, when the alloy is homogenized at 465 °C without and with DC. The hardness increases to HV 96 and HV 106.4, respectively, when the as-cast alloy is homogenized at 380 °C without and with DC, and then increases progressively with increasing temperature, and finally achieves HV 137.5 and HV 146, respectively, when the alloy is homogenized at 465 °C for 2 h without and with DC.

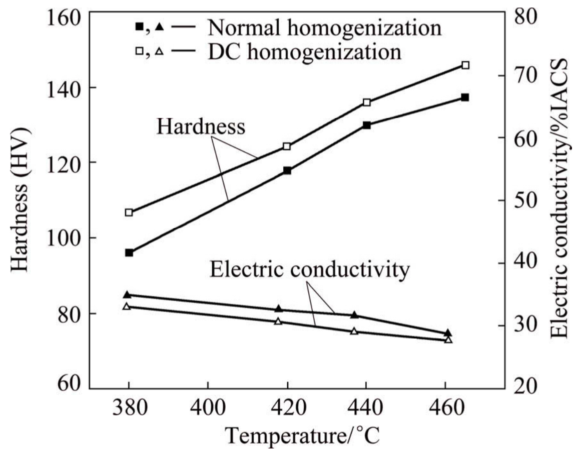

Fig. 1 Electric conductivity and hardness of normal and DC homogenized alloys at 380−465 °C

3.2 Evolution of morphologies of secondary phases during DC homogenization

3.2.1 XRD patterns

The XRD patterns of as-cast and homogenized alloys are shown in Fig. 2. The XRD peaks of α(Al), $MgZn_2$(T), Al_2CuMg(S) and Al_7Cu_2Fe are detected in as-cast 7B04 alloy. With increasing temperature, the amount and height of diffraction peaks of T phase decrease, while those of S phase increase when the

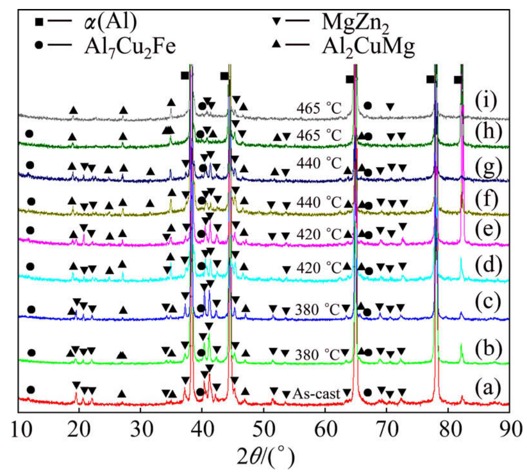

Fig. 2 XRD patterns of as-cast (a) and homogenized alloys (b−i): (b, d, f, h) Normal homogenization; (c, e, g, i) DC homogenization