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Effect of high magnetic field on phase transformation of 7055 alloy during homogenization

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The microstructural evolutions of 7055 aluminum alloy after single and two-step homogenization with or without applying 12T high magnetic field were investigated. The as-cast microstructures of 7055 alloy consist of α+AlZnMgCu eutectics, Al_7Cu_2Fe phase and AlTiCuFe phase. During homogenization, coarse α+AlZnMgCu eutectics located at interdendritic region become smaller, discontinuous and spheroidized, some of them transform into Al_2CuMg (S) having a higher melting point. High magnetic field significantly accelerates the dissolution of α+AlZnMgCu eutectics and S phase. The least amount of α+AlZnMgCu eutectics and S phase is obtained when the alloy homogenized at 465^0C/10h+485^0C/8h under 12T high magnetic field.

Keywords: *high magnetic field, 7055 alloy, homogenization, phase transformation*

1. Introduction

7055 alloy has a combination of high strength and fracture toughness, low density and good corrosion resistance, and is widely used in aerospace industries [1]. The attractive combination of properties of 7055 alloy is attributed to high ratios of Zn/Mg, Cu/Mg and alloying element content, which in turn lead to the difficulty of processing the alloy. The commonly observed precipitate phases in 7000 series alloy are S-Al_2MgCu orthorhombic phase, the $Mg(Zn_2AlCu)$ M or η hexagonal phase and T-$Al_{32}(Mg,Zn)_{49}$ [2]. Many soluble constituents remain in the alloy after subsequent heat treatments and processing, owing to the proximity of composition to the limit of solid solubility in these alloys [3], which can deteriorate the age hardenability, aid crack initiation and propagation and cause variable properties [4]. K.H. Chen et al [5] revealed that η phase dissolved completely and T and S phases still remained in 7055 alloy after pretreatment at 450^0C for 35h. A phase transformation of primary particle from $Mg(Zn,Cu,Al)_2$ phase to Al_2CuMg phase was found in Al-Zn-Mg-Cu alloy during homogenization at 460^0C [6].

Many researches have verified that magnetic field, as an effective external field, can be applied not only to ferromagnetic but also to non-ferromagnetic materials, and provide us a new approach to material preparation and property control. The present works of high magnetic field have mainly studied the phase transformation of ferrous alloys on: (1) phase stability [7-11], (2) phase morphology [12,13], (3) grain refinement [14]. Molodov et al [15] found the recrystallization incubation time significantly decreased in cold-rolled 3103 alloy by a 17T high magnetic field. X. T. Liu et al [16] discovered that the alternating magnetic field accelerated the nucleation and growth of intemetallic compounds in Al-Cu diffusion couple. W. Liu et al [17,18] found that electric field promoted the dissolution of second-phase particles and the removing of dendritic segregation during homogenization, and even suppressed the nucleation of δ' phase during artificial ageing treatment. However, few investigated effects of high magnetic field on phase transformations during homogenization in Al-Zn-Mg-Cu alloy. In present work, the microstructural changes of 7055 alloy during high magnetic field homogenization were studied in detailed by DSC, XRD, SEM and EDS analysis, and hope to provide an insight into mechanisms of high magnetic field on phase transformation in Aluminum alloys.

2. Experimental

The 7055 alloy used in present work is Al-6.2Zn-4.25Mg-2.3Cu-0.12Si-0.12Zr, was produced from semi-continuous cast ingots with size of Φ100mm×1000mm. The homogenization procedures were divided into two types: (1) 465^0C/12h, air cooling, (2) 465^0C/10h+485^0C/8h, air cooling. The conventional homogenizations were carried out on a Lenton AWF12/12 type furnace, the temperature variation was controlled within ±1^0C. The apparatus of high magnetic field homogenizations is illustrated in Fig.1, which consists of a superconducting magnet and a vacuum resistance furnace. The superconducting magnet can generate an axial static uniform magnetic field with a maximum magnetic flux density of 12T. Samples were put into a crucible with size of Φ10mm×50mm at center of magnetic field. A stable magnetic intensity of 12T was applied during homogenization.

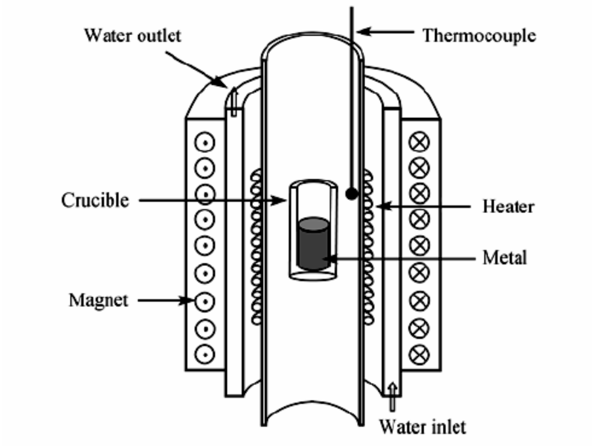

Fig.1 Schematic diagram of high magnetic filed system

Samples for microstructural observations were prepared by standard metallographic method and chemical etched in a solution of 1mlHF+1.5mlHCl+2.5mlHNO_3+95mlH_2O, and then examined on a Jeol SSX550 type scanning electron microscopy equipped with a DX-4EDAX type Energy Dispersive X-ray analyzer. Differential canning calorimetry (DSC) analyses were carried out in a purified argon atmosphere using MDSCQ100 instrument with a scanning rate of 10^0C/min from room temperature to 550^0C. The heat effects associated with transformation reactions were isolated by subtracting a baseline of a high purity aluminum-aluminum run. Phase identifications were examined by X-ray diffraction (XRD) with CuKα_1 radiation on PW3040/60X diffractometer.

3. Results and discussions

DSC curves of 7055 alloy at different conditions are illustrated in Fig.1. Two exothermic reactions a and b happen at 481^0C and 490^0C in DSC curve of as-cast 7055 alloy, respectively. The exothermic reaction a is ascribed to the dissolution of eutectic α+AlZnMgCu, and the exothermic reaction b is caused by the melting of Al_2CuMg (S) [5].

When homogenization at 465^0C/12h, peak a reduces indicating the decrease in fraction of α+AlZnMgCu, while peak b enlarges demonstrating the increase in fraction of S phase. The sizes of peak a and b decrease further when homogenization at 465^0C/10h+485^0C/8h, and become remarkable small when homogenization under 12T high magnetic field.

The XRD analysis results of 7055 alloy at different conditions are shown in Fig.2. The as-cast 7055 alloy contains $MgZn_2$ and Al_7Cu_2Fe. No peak associated with S phase can be observed. The peak of S phase arises in the alloy homogenized at 465^0C for 12h. The amount of peak for S phase decreases further when the alloy homogenized at 465^0C/10h+485^0C/8h, and becomes least when the alloy homogenized at 465^0C/10h+485^0C/8h under 12T high magnetic field.

The as-cast microstructures of 7055 alloy (Fig.3a) reveal a mixture of dendritic α-Al and lamellar eutectic formed between dendrites. From EDS results, point 1 is eutectic α+AlZnMgCu and has a composition of 2.97wt.%, 36.13wt.%Cu, 42.87wt.%Zn and 8.02wt.%Al. The point 2 contains 1.24wt.%Mg, 22.69wt.%Al, 31.82wt.%Cu, 6.3wt.%Zn, 31.01wt.%Fe, 5.58wt.%Si and 1.35wt.%Ti. Because of the small size of phase 2, the electric beam is easy to detect the matrix during the procedure of EDS analysis, and then the composition of matrix (point 3) is given as: 1.33wt.%Mg, 85.98wt.%Al and 12.7wt.%Zn. So, the phase 2 is determined to be AlTiCuFeSi. The point 4 is Al_7Cu_2Fe and has a composition of 24.79wt.%Al, 32.25wt.%Cu, 6.61wt.%Zn and 36.36wt.%Fe. Plenty of eutectic α+AlZnMgCu without $MgZn_2$ are observed in as-cast microstructure of 7055 alloy, it is because that the high cooling speed of semi-continuous casting causes the non-equilibrium solid solution of element Al and Cu in $MgZn_2$ phase and thus results in the formation of eutectic α+AlZnMgCu.

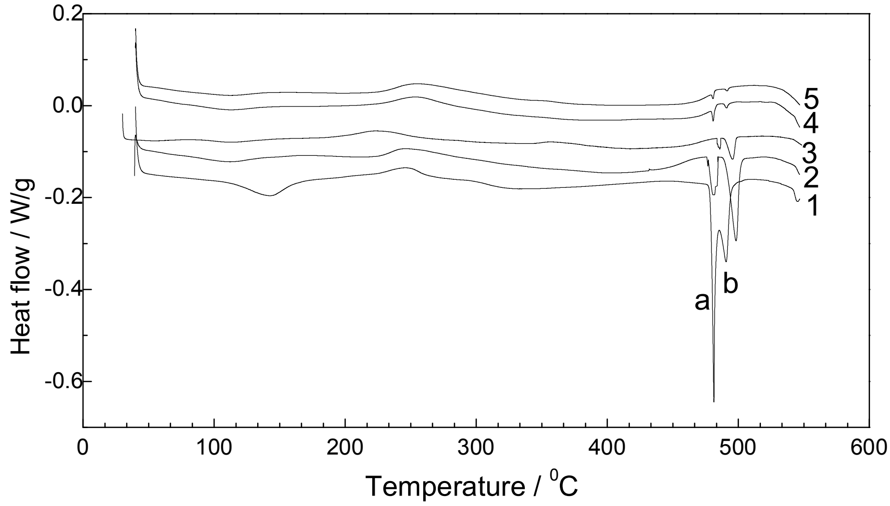

Fig.1 DSC curves of 7055 alloy at different homogenization conditions: 1-as-cast, 2-465⁰C/12h, 3-465⁰C/10h+485⁰C/8h, 4- 465⁰C/12h under 12T high magnetic field, 5- 465⁰C/10h+485⁰C/8h under 12T high magnetic field

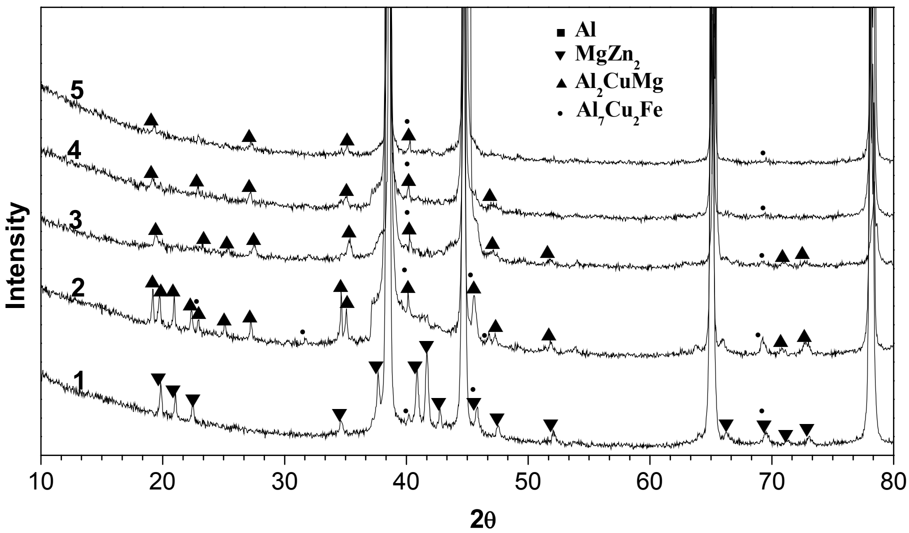

Fig.2 XRD results of 7055 alloy at different homogenization conditions: 1-as-cast, 2-465⁰C/12h, 3-465⁰C/10h+485⁰C/8h, 4- 465⁰C/12h under 12T high magnetic field, 5- 465⁰C/10h+485⁰C/8h under 12T high magnetic field

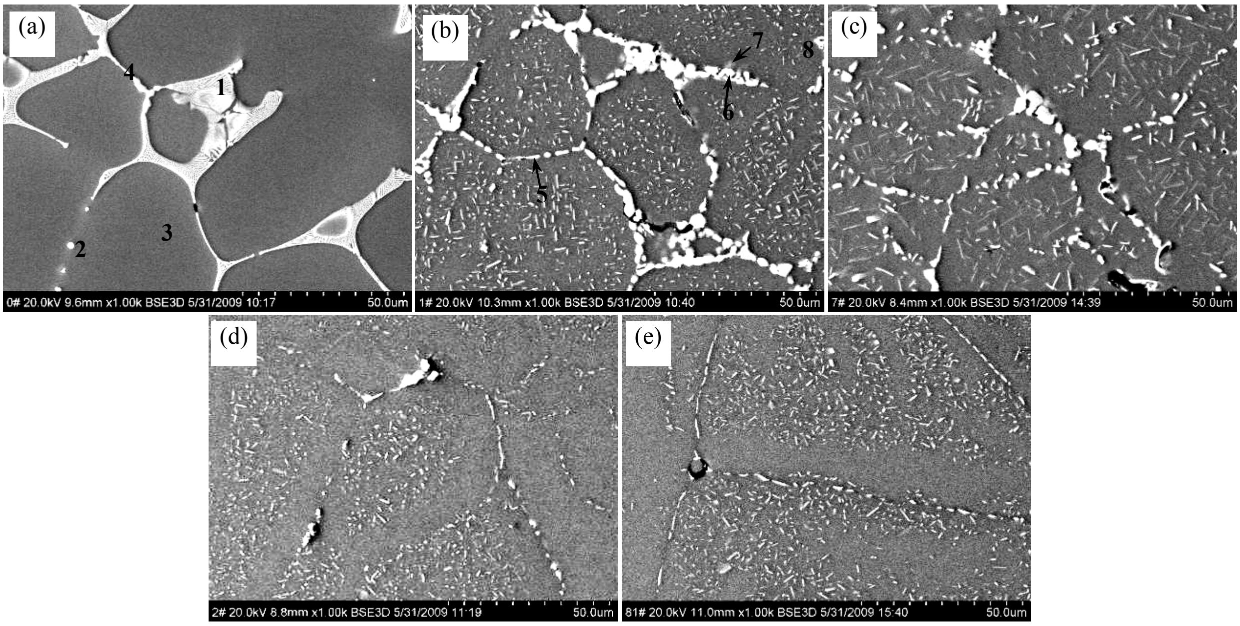

Fig.3 SEM microstructures of 7055 alloy at different homogenization conditions: a-as-cast, b-465^0C/12h, c-465^0C/10h+485^0C/8h, d-465^0C/12h under 12T high magnetic field, e-465^0C/10h+485^0C/8h under 12T high magnetic field

After the alloy homogenized at 465^0C/12h (Fig.3b), the coarse eutectics become smaller, discontinuous and spheroidized, and appears necklace-like distribution at grain boundaries. From EDS results, besides of AlTiCuFe (point 5) and eutectic α+AlZnMgCu (point 6), a new phase (point 7) having a dark gray is detected at margin of eutectic α+AlZnMgCu and contains 22.8wt.%Mg, 48.6wt.%Al, 23.3wt.%Cu, 5.3wt.%Zn. While the matrix (point 8) contains 75.87wt.%Al and 24.13wt.%Zn, so it can be determined that the phase 7 is Al_2CuMg (S) phase. The size and volume of eutectic α+AlZnMgCu and S phase decrease continuously when the alloy homogenized at 465^0C/10h+485^0C/8h (Fig.3c), and show remarkable reduce when the alloy homogenization under 12T high magnetic field (Fig.3d and Fig.3e).

The observed phases in as-cast microstructures in 7055 alloy are eutectic α+AlZnMgCu and Fe-bearing phases (AlTiCuFe or Al_7Cu_2Fe). It should be pointed out that S phase could not be observed in as-cast microstructure by using SEM, EDS and XRD measurements, which is different from results made by Xie [19]. This may result from the differences in alloy composition or casting conditions. The detected exothermic reaction caused by melting of S phase in DSC curve of as-cast 7055 alloy could result from the formation of S phase during the heating procedure of DSC experiment [20]. During homogenization, AlZnMgCu dissolved into matrix, at the same time, Al_2CuMg phase forms at the edge of AlZnMgCu which indicates that the transformation from AlZnMgCu to S phase occurs. The alloying elements in eutectic structures diffuse into matrix, so the AlZnMgCu phase dissolves gradually during homogenization. The diffusion velocity of Cu is lower than Zn and Mg, which results in the higher concentration of Cu in these regions. The driving force for the phase transformation from AlZnMgCu to S must be supersaturation of Cu in eutectic structures, which makes S a stable phase. The volume of AlZnMgCu decreases, and while the volume of S phase increases with the application of homogenization at 465^0C/12h, which is in agreement with the results of DSC and XRD analysis. The size and volume of AlZnMgCu and S phase decrease continuously after the alloy homogenized at 465^0C/10h+485^0C/8h, indicating the dissolution of the newly formed S phase. This is due to the alloying elements from the interdendritic regions to the matrix, and the decreasing of supersaturation extent of alloying elements in eutectic regions. With the application of 12T high magnetic field, the amount of AlZnMgCu and S decreases significantly comparing to the conventional homogenization with the same conditions, demonstrating that the high magnetic field can effectively accelerate the dissolution rate of AlZnMgCu and S phase, and may suppress the transformation from the AlZnMgCu to S phase that needs to be verified.

4. Conclusions

1. The as-cast microstructures of 7055 alloy consist of eutectic α(Al)+AlZnMgCu, Al_7Cu_2Fe and AlTiCuFe. The incipient temperature of 7055 alloy is 481^0C. S phase has a melting temperature of 490^0C.
2. During homogenization, the transformation from AlZnMgCu to S phase occurs. The amount of AlZnMgCu and S phase decrease among the four-homogenization conditions in the following sequence: 465^0C/12h, 465^0C/10h+485^0C/8h, 465^0C/12h under 12T high magnetic field, 465^0C/10h+485^0C/8h under 12T high magnetic field.
3. The high magnetic field obviously accelerates the dissolution rate of AlZnMgCu and S phase during homogenization.

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