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Research on microstructure in as-cast 7A55 aluminum alloy and its evolution during homogenization

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Abstract

The microstructure of the as-cast 7A55 aluminum alloy and its evolution during homogenization were investigated by means of optical microscopy (OM), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray diffraction (XRD), and differential scanning calorimetry (DSC) analysis. The results indicate that the microstructure of the as-cast 7A55 aluminum alloy mainly consists of the dendritic network of aluminum solid solution, Al/AlZnMgCu eutectic phases, and intermetallic compounds $MgZn_2$, Al_2CuMg, Al_7Cu_2Fe, and $Al_{23}CuFe_4$. After homogenization at 470°C for 48 h, Al/AlZnMgCu eutectic phases are dissolved into the matrix, and a small amount of high melting-point secondary phases were formed, which results in an increasing of the starting melting temperature of 7A55 aluminum alloy. The high melting-point secondary phases were eliminated mostly when the homogenization time achieved to 72 h. Therefore, the reasonable homogenization heat treatment process for 7A55 aluminum alloy ingots was chosen as 470°C/72 h.

Keywords: 7A55 aluminum alloy; as-cast constituents; homogenization

1. Introduction

The high strength (7××× series) aluminum alloys are extensively used in the commercial aircraft structures as well as various critical military bridges and vehicles due to their excellent mechanical properties developed during the age-hardening process, high strength to weight ratio, fracture toughness and SCC resistance [1-3].

The aluminum alloy 7A55 is a descendant of the Al-Zn-Mg-Cu alloys, which is a novel Chinese brand. It is a precipitation hardenable alloy developed recently for aerospace structural applications based on commercial AA (aluminum alloy) 7055 alloy. Nowadays, the 7A55 aluminum alloy was designed as a plate or extrusion for aircraft structural materials. It is well known that the AA 7055-T7751 in plate form offers an increase in strength of 10% and 30% relative to that of 7150-T6 and 7150-T76, respectively [4]. Due to its significance in engineering applications, many investigations have been conducted on the solution treatment [1, 5-6], aging process [4, 7-9] and quench sensitivity [10-12] of high strength 7055 aluminum alloys. The homogenization process is applied in practical production for high alloying elements content 7000, however, the study on microstructure in as-cast 7A55 aluminum alloy and its evolution during homogenization is still very limited [13-14].

Microstructure evolution and phase transformation of aluminum alloys can be changed and controlled by many methods, such as semi-solid cast [15] and heat treatment [16]. Due to containing higher alloying content than other conventional 7xxx series alloys, the 7A55 aluminum alloy will form more non-equilibrium phases during the semi-continuous casting. The homogenization treatment has to be carried out directly after casting to eliminate the majority of eutectic intermetallic particles, which can degrade the plastic deformation and mechanical properties of the alloy. In order to achieve a suitable homogenization treatment, it is necessary to study the constituents in the as-cast microstructure and the evolution during homogenization. The microstructure of the as-cast 7A55 aluminum alloy and its evolution during homogenization were investigated in this work to provide a theoretical guide for processing optimization.

2. Experimental

The composition of 7A55 aluminum alloy is shown in

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Table 1. During the semi-continuous casting, the melt was refined by argon and refinement agent Al-Ti-B wire was used as grain refiners. The impurities were strictly controlled, such as Fe and Si elements. 7A55 aluminum alloy ingots with 440 mm in diameter and 1300 mm in length were prepared by semi-continuously casting technology.

Table 1. Chemical composition of 7A55 aluminum alloy wt %

Zn	Mg	Cu	Zr	Fe	Si	Mn	Cr	Ni	Ti	Al
7.86	2.09	2.06	0.11	0.08	0.04	<0.05	<0.04	<0.05	<0.06	Bal.

The ingots were pre-treated at 300°C for 6 h to avoid the cracking caused by residual stress. Samples cut from the position at 1/2 radius from the center to edge of the ingot were treated at 470°C for 2 h, 12 h, 24 h, 48 h, and 72 h respectively, and then water quenched immediately.

The samples were prepared using the standard metallographic methods for microstructural observation. The samples were polished mechanically and etched in a solution of 2.5 vol% HNO_3 + 1.5 vol% HCl + 1 vol% HF. The microstructures were observed using a Zeiss Axiovert 200 MAT model optical microscope (OM). A HITACHI-S4800 scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) working at 20 kV was used to observe as-cast and as-homogenized microstructures of the samples. The X-ray pattern analysis was carried out by a Rigaku D_{MAX}-RB 12 kW diffractometer equipped with Cu K_α radiation, operating at 40 kV and 150 mA with the scanning rate of 10º/min. Differential scanning calorimetry (DSC) was performed on the TA2010 thermal analyser with a heating rate of 10ºC/min.

3. Results and discussion

3.1. As-cast microstructure

Fig. 1 shows the typical as-cast microstructures of 7A55 aluminum alloy, which consist of primary dendrites of aluminum-rich solid solution and an interdendritic network of intermetallic compounds around the primary grains. It can be seen that the grain boundaries were decorated by large, irregular eutectic phases and intermetallic particles that had a detrimental effect on mechanical properties of the alloy. Plenty of heterogeneous $MgZn_2$ precipitates formed during the cooling of the ingots were mostly observed around the grain boundaries. Therefore, it was necessary to eliminate them effectively through the subsequent homogenization and solution treatment.

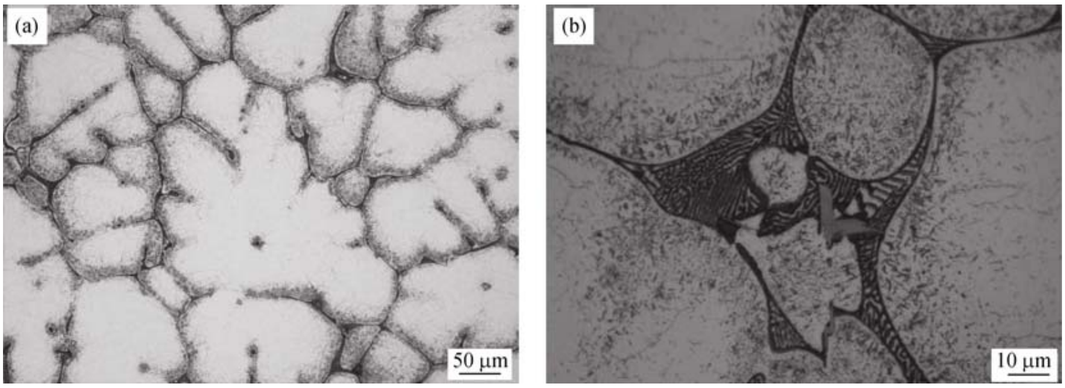

Fig. 1. Microstructures of as-cast 7A55 aluminum alloy: (a) low magnitude; (b) high magnitude.

Fig. 2 shows SEM micrographs of the as-cast 7A55 aluminum alloy. Various coarse intermetallics are observed and their EDS analysis results are listed in Table 2. It can be found that the phases of A and B marked in Fig. 2 were inferred as Al_7Cu_2Fe constituents, and the phases C, D and E should be AlZnMgCu.

The DSC thermograms of 7A55 aluminum alloy samples after homogenization at 470ºC for various times are shown in Fig. 3. The obvious endothermic peak at 478ºC was presented in the as-cast DSC thermogram, corresponding to the eutectic phases melting of Al/AlZnMgCu. Furthermore, the

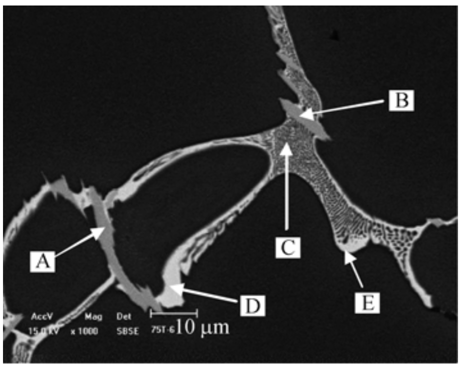

Fig. 2. SEM image of as-cast 7A55 aluminum alloy.

Table 2. Composition of secondary phase marked in Fig. 2 measured by EDS mol%

Marks	Al	Zn	Mg	Cu	Fe
A	73.273	–	–	17.532	7.872
B	72.886	–	–	15.413	9.404
C	58.469	15.213	17.649	8.669	–
D	19.946	32.704	30.316	17.034	–
E	56.753	11.612	17.993	13.642	–

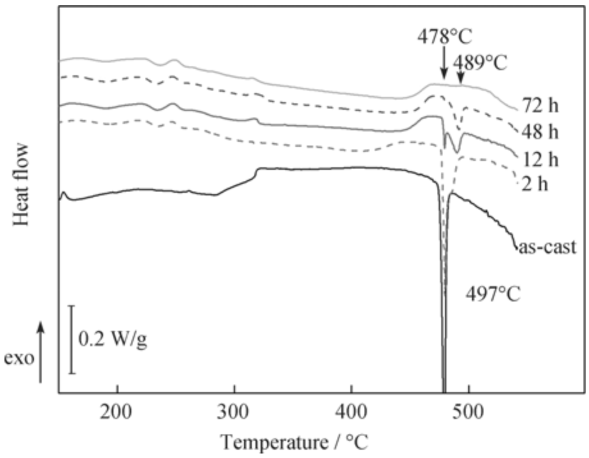

Fig. 3. DSC thermogram of the alloy homogenized at 470°C for various times.

endothermic peak corresponding to the melting of Al/AlZnMgCu disappeared, which indicated that the eutectic Al/AlZnMgCu phase dissolved into the matrix completely after homogenization at 470ºC for 48 h. The endothermic melting reaction at near 489ºC was observed in the Fig. 3, which illustrates transformation from eutectic phases to high-melting point Al_2CuMg phases occurred in the alloy during homogenization at 470ºC. After homogenization treatment at 470ºC for 72 h, the endothermic peak at 489ºC even disappeared, indicating that the high-melting point Al_2CuMg phases were almost dissolved, as shown in Fig. 3.

3.2. Microstructural evolution during homogenization treatment

Fig. 4 shows the optical micrographs of 7A55 aluminum alloy under different homogenization treatment conditions. Compared with the as-cast microstructure in Fig. 1, the eutectic intermetallic compounds distributed at the grain boundaries were dissolved into the matrix with the increasing of homogenization time, resulting in a reduction in amount of eutectic phases apparently. The secondary phases were dissolved more sufficiently, which was in good agreement with the DSC results in Fig. 3. Fig. 5 shows the effect of homogenization time on microstructure of eutectic. Compared with Fig. 5(a), the eutectic phases were dissolved more sufficiently with prolonging of homogenization time. A very small amount of secondary phases are still remained in the microstructure of sample after homogenization treatment at 470ºC for 72 h, and the morphology of residual secondary phases become more smoother.

XRD analysis was carried out to identify the as-cast and as-homogenized 7A55 aluminum alloys, as shown in Fig. 6. For the as-cast alloy, XRD peaks included Al, $MgZn_2$, Al_2CuMg, Al_7Cu_2Fe, and $Al_{23}CuFe_4$, which was in good

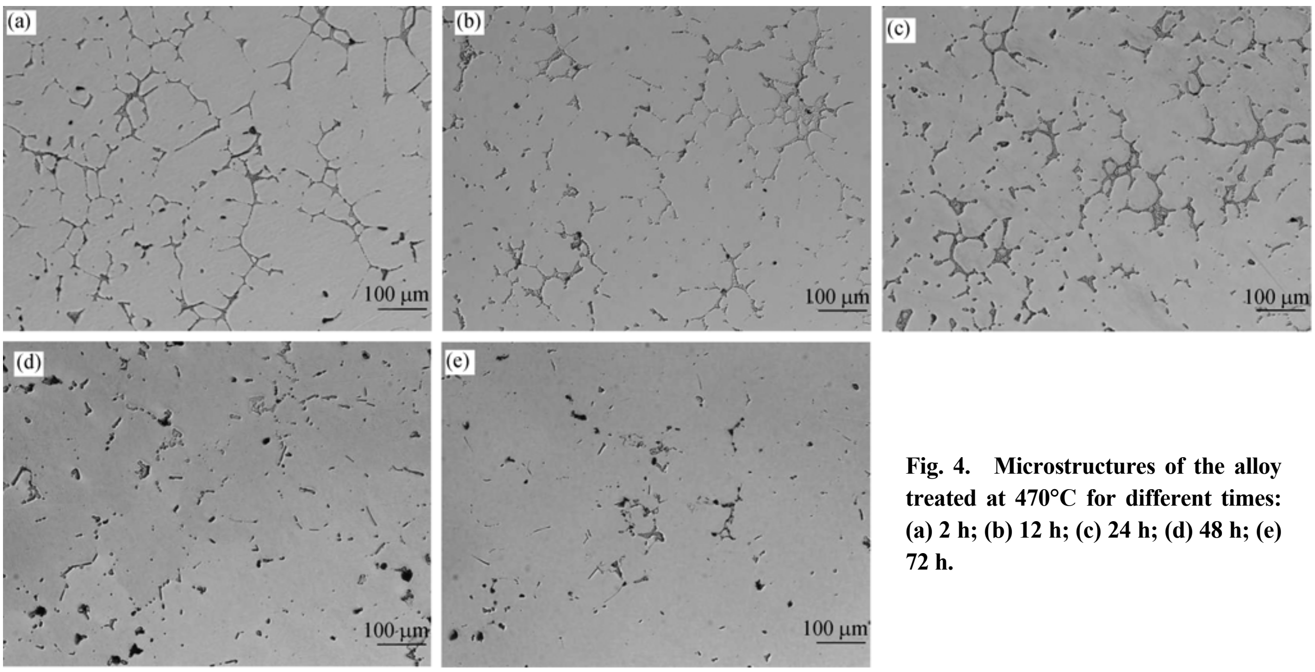

Fig. 4. Microstructures of the alloy treated at 470°C for different times: (a) 2 h; (b) 12 h; (c) 24 h; (d) 48 h; (e) 72 h.

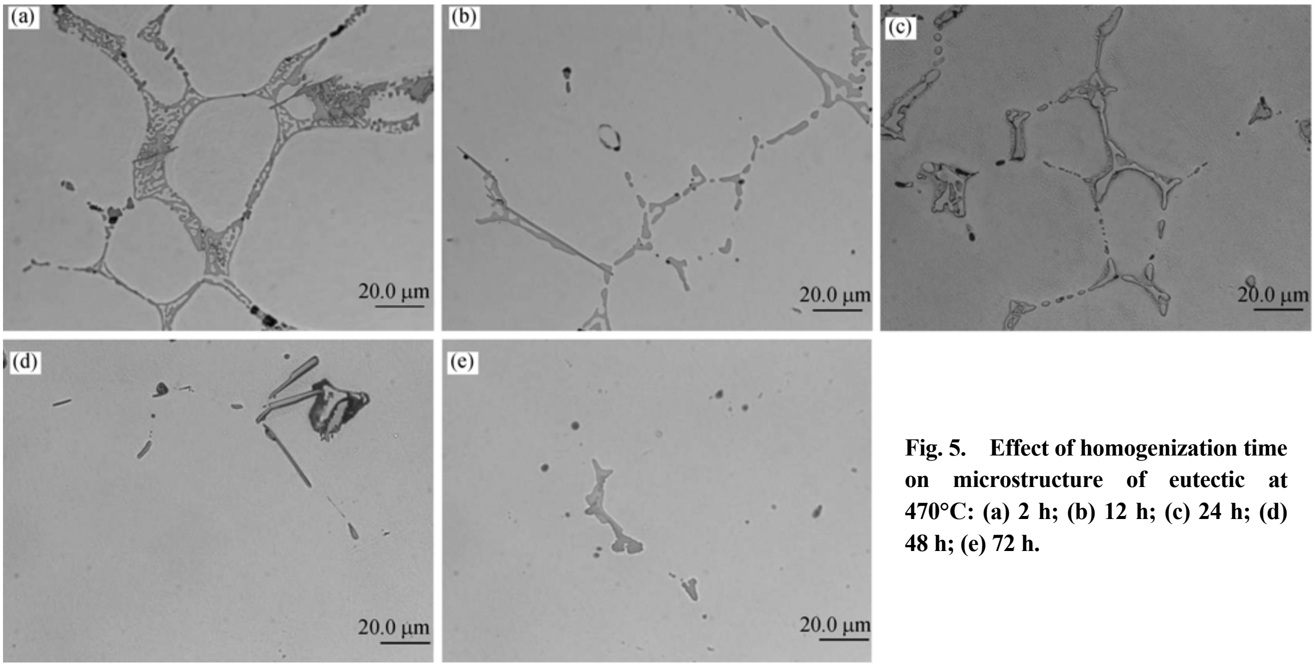

Fig. 5. Effect of homogenization time on microstructure of eutectic at 470°C: (a) 2 h; (b) 12 h; (c) 24 h; (d) 48 h; (e) 72 h.

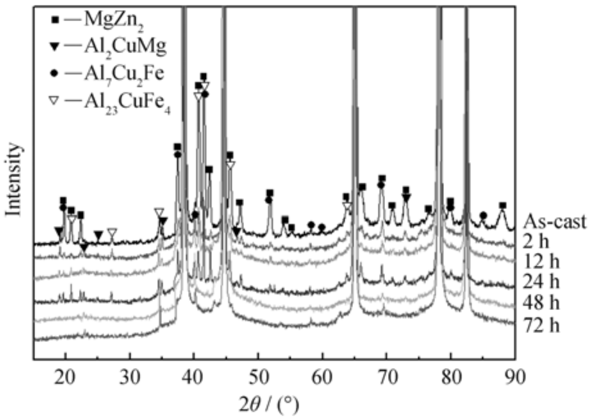

Fig. 6. X-ray patterns of the alloy homogenized at 470°C for different times.

agreement with EDS analysis. It should be pointed out that the peaks of AlZnMgCu eutectic phases were not detected because of their same crystal structure with $MgZn_2$ phases. The diffraction peak of the $MgZn_2$ phase almost disappeared after homogenized for 12 h, and the peaks corresponding to the Al_2CuMg phase were also partly eliminated after homogenization treatment at 470ºC for 48 h, indicating that the Al/AlZnMgCu phase dissolved into the matrix more effectively, which was coincident with the DSC results. Furthermore, some diffraction peaks of intermetallic phases (Al_7Cu_2Fe and $Al_{23}CuFe_4$) kept a little change with prolonging of homogenization time, which illustrates that these secondary particles can not be dissolved into the matrix at all for the homogenization treatment conditions used in the present study.

4. Conclusions

(1) The microstructure of the as-cast 7A55 aluminum alloy is composed of Al matrix, Al/AlZnMgCu eutectic phases, and compounds $MgZn_2$, Al_2CuMg, Al_7Cu_2Fe, and $Al_{23}CuFe_4$.

(2) The Al/AlZnMgCu eutectic phases dissolve firstly during homogenization at 470ºC, and a small amount of eutectic phases transformed to high melting-point Al_2CuMg phases after homogenization treatment at 470°C for 12 h. The eutectic phases were eliminated more sufficiently with the prolonging of homogenization time. The reasonable homogenization heat treatment process for 7A55 aluminum alloy is homogenization treated at 470°C for 72 h.

Acknowledgements

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