

Constituents evolution of LFEC 7050 aluminum alloy during processing

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Received 15 July 2007; accepted 10 September 2007

Abstract: The ϕ 120 mm ingots of 7050 aluminum alloy were made by low frequency electromagnetic casting (LFEC) and conventional DC casting process, respectively. After homogenization treatment the ingots were extruded to rods and the solution and aging treatment were carried out for the rods. Constituents evolution during processing and effects of LFEC on constituents and remnant constituents were studied. The results show that 7050 aluminum alloy mainly contains Al-Zn-Mg-Cu type and Al-Cu-Fe type constituents. Al-Zn-Mg-Cu type constituents dissolve during homogenization, while Al-Cu-Fe type constituents could not dissolve. After homogenization treatment, the main remnant constituent is Al_7Cu_2Fe which crushes and orients along the extrusion direction after extrusion. Compared with DC process, by the process of LFEC, the constituents or remnant constituents are smaller in size and less in content. The LFEC process shows significant improvement in elongation by LFEC in both as-cast state and final state.

Key words: 7050 aluminum alloy; low frequency electromagnetic casting; microstructures; constituents

1 Introduction

7050 aluminum alloy is the premier choice for aerospace applications requiring the best combination of strength, stress corrosion cracking resistance and toughness[1–3]. 7050 aluminum alloy contains high content alloying elements, so, it has severe segregation tendency, which leads to eutectic phases and coarse constituents formed at the grain boundaries. Coarse constituents not only cause hot-tearing during casting but also decrease strength, plasticity, fracture toughness and fatigue strength after heat treatment[4–8]. In order to obtain good combined properties, the coarse constituents have to be controlled. It has been reported[9] that for aluminum alloy ingot, several benefits such as better metal fluidity, finer dispersed porosity and second phases, higher resistance to hot tearing, higher fatigue strength, and better pressure tightness arise from the formation of a fine equiaxed microstructure rather than a coarse dendritic structure. The master alloys based on the Al-Ti-B system have been used extensively for refining

aluminum alloy grain structure. But, 7050 aluminum alloy contains Zr, and Zr poisons Al-Ti-B system grain refiners[10–12]. It is necessary to find a new way to refine 7050 aluminum alloy grains. Using external field such as ultrasonic[13–14], electromagnetic field[15–20] to refine aluminum alloy structure attracts much attention. Based on CREM[15–16], a new technique, low frequency electromagnetic casting (LFEC) process was developed by CUI and his co-workers[17–20]. In the previous work, the studies were focused on the refining effect of LFEC on as-cast structures, but effects on the structures during processing such as homogenization, deformation attract little attention. In this work, LFEC was used to make 7050 aluminum alloy ingots and the effects of low frequency electromagnetic field on the constituents not only in as-cast state but also after homogenization and deformation were studied.

2 Experimental

Al-6.1%Zn-2.3%Mg-2.2%Cu-0.13%Zr was used as the experimental material.

The ϕ 120 mm ingots were made by LFEC (30 Hz, 120 A) and conventional DC casting process, respectively. The schematic of the LFEC process is shown in Fig.1.

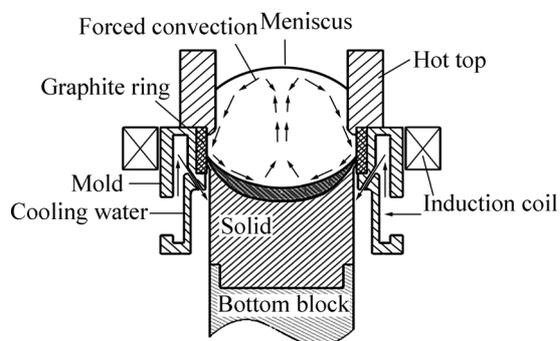


Fig.1 Schematic of LFEC process

After casting process, the ingots were homogenized at 420 °C for 12 h and then at 465 °C for 36 h. Subsequently, the ingots were extruded to rods of 17 mm in diameter, with an extrusion ratio of 28. Solution treatment (470 °C, 3 h) and ageing treatment (120 °C, 12 h) were carried out for the rods.

The samples obtained from the ingot and rods were ground and polished, then were etched with Keller's reagent (2 mL HF, 3 mL HCL, 5 mL HNO₃ and 190 mL H₂O). Microstructures were observed under optical microscope (Leica DMR). Scanning electron microscope (SEM) SSX-550, energy dispersive spectrometer (EDS) and X-ray diffraction (XRD) instrument D/Max-Ra were used for observing microstructures and analyzing constituents. The mechanical tests were conducted at room temperature. The average value of three test results was used as the final value.

3 Results and discussion

3.1 Major constituents in 7050 aluminum alloy ingots

The results of X-ray diffraction, in Fig.2, show that there are mainly MgZn₂(η), Al₂CuMg(S) and Al₇Cu₂Fe constituents in 7050 aluminum alloy ingots. No difference in constituent type between DC and LFEC ingots was found.

The microstructures and constituents observed by SEM are shown in Fig.3. There are massive constituents (Fig.3, points 1, 3) and eutectic structures at grain boundaries (Fig.3, points 2). As shown in Table 1, energy dispersive spectrometry (EDS) reveals that the constituents like point 1 are Al-Zn-Mg-Cu type phases, the constituents like point 3 are Al-Cu-Fe type phases, and the eutectic contains α (Al) and T (Al-Zn-Mg-Cu) type phases.

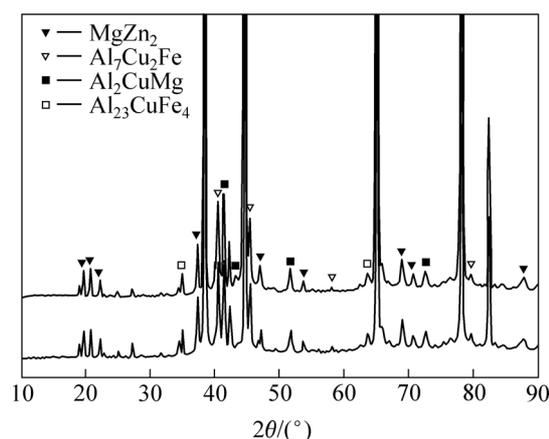


Fig.2 XRD pattern of 7050 aluminum alloy ingots

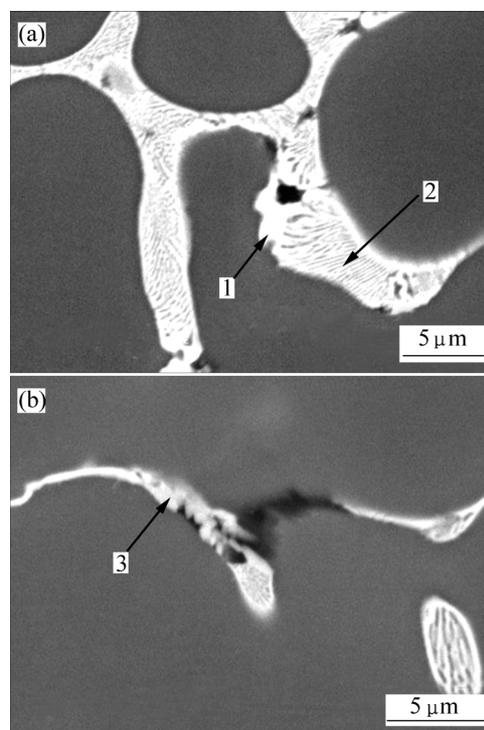


Fig.3 Major constituents of 7050 aluminum alloy

Table 1 Composition of constituents of 7050 aluminum alloy (mass fraction, %)

Point in Fig.3	Al	Zn	Mg	Cu	Fe
1	36.907	35.644	12.214	15.235	
2	47.669	30.140	9.573	12.618	
3	68.252			19.988	11.760

It has been reported that the η (MgZn₂) phase dissolves some aluminum and copper, and then Mg(Al, Cu, Zn)₂ [21–22] is formed. In the same way, the S phase is found to be associated with zinc in the range of 25%–30%. So in 7050 aluminum alloy ingots both the η

phase and *S* phase contain Al, Zn, Mg, Cu elements. The XRD distinguishes constituents by structure, while the EDS distinguishes constituents by composition. This is believed to be the reason why there are difference in results between XRD and EDS.

The microstructures of 7050 alloy ingot are shown in Fig.4. As shown in Fig.4, the constituents of LFEC ingot are smaller than that of DC ingot. The quantitative analysis of constituents and eutectic phase area fraction was carried out with software SISCAS8.0. The statistical value of area fraction of constituents and eutectic structures in LFEC ingot (7.2%) is less than that of DC ingot (8.1%).

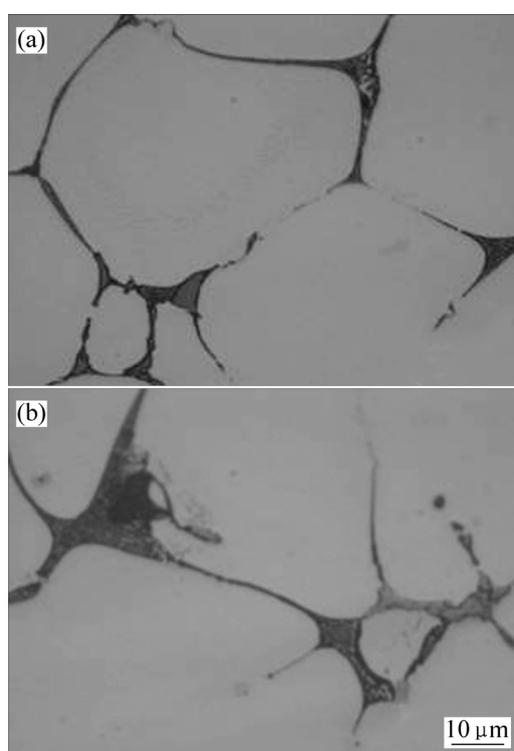


Fig.4 Microstructures of 7050 aluminum alloy ingots: (a) LFEC; (b) DC

3. 2 Constituents evolution during processing

As shown in Fig.5, for the LFEC ingot, the XRD results show that the η (MgZn₂) phase dissolves during homogenization, precipitates during extrusion and redissolves during solution treatment. While, Al₇Cu₂Fe phase does not dissolve during homogenization, extrusion and solution treatment.

After homogenization, the eutectics disappear and the constituents become much less in content than that of as-cast ingot. The remnant constituents of LFEC ingot are smaller in size and less in area fraction than those of DC ingot. The EDS results show that the main remnant constituents are Al-Cu-Fe type phases and they are believed to be Al₇Cu₂Fe.

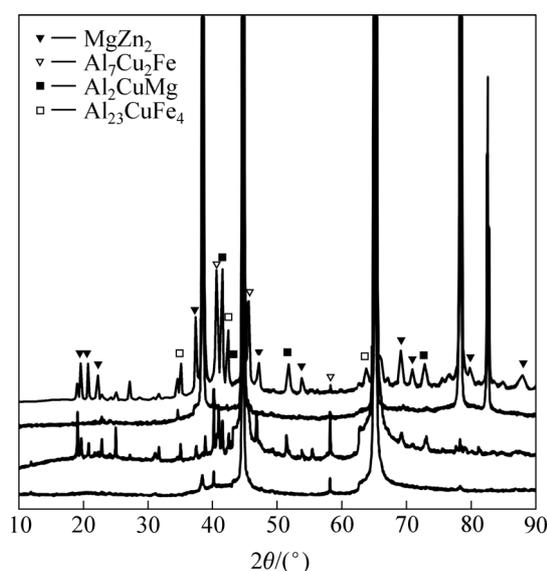


Fig.5 XRD patterns of LFEC 7050 aluminum alloy

The remnant constituents of 7050 aluminum alloy were also observed by SEM. Back-scattered electron images of the microstructures in the state of homogenization, extrusion and solution treatment are shown in Fig.6. The remnant constituents marked in Fig.6 were analyzed with energy dispersive spectrometry (EDS) and the results are listed in Table 2.

Table 2 Composition of remnant constituents of 7050 aluminum alloy (mass fraction, %)

Point in Fig.6	Al	Zn	Mg	Cu	Fe
1	52.980			33.090	13.930
2	53.863			32.287	13.850
3	56.082	2.383	1.107	27.665	12.763
4	52.870			32.873	14.257
5	58.783	2.051	0.601	26.126	12.439
6	62.098	7.720	4.472	21.431	4.279
7	57.862	1.971	0.712	26.207	13.248

During extrusion, there are two phenomena in the constituent evolution. On one hand, the Al-Cu-Fe type remnant constituents crush and orient along the extrusion direction. On the other hand, many precipitate phases which are smaller in size than remnant constituents were formed. So after extrusion the alloy mainly contains crushed remnant constituents and newly formed precipitate phases.

After solution treatment, almost all the newly formed precipitate phases dissolve, while the crushed remnant constituents could not dissolve. So, after solution treatment, the main remnant constituents are the

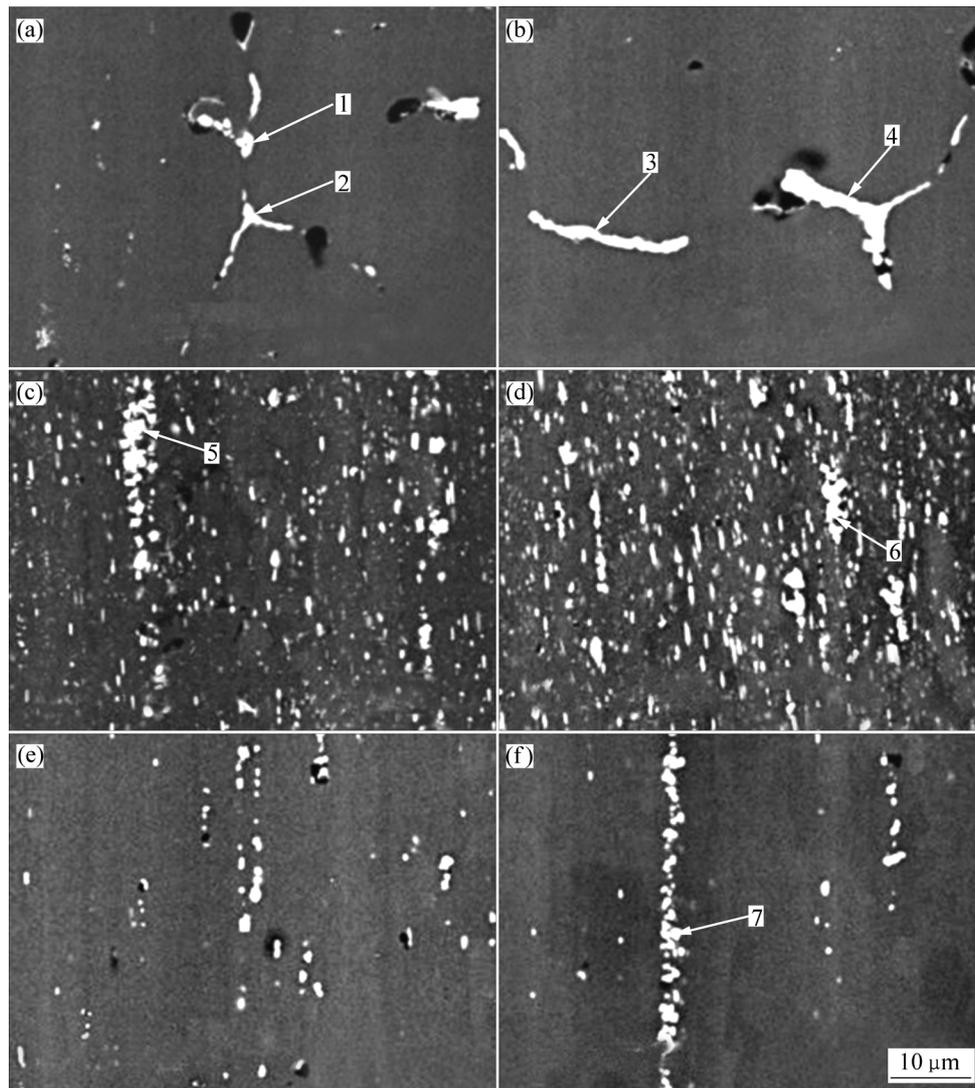


Fig.6 Remnant constituents of 7050 aluminum alloy: (a), (b) Homogenization; (c), (d) Extrusion; (e), (f) Solution treatment; (a), (c), (e) LFEC; (b), (d), (f) DC

crushed Al-Cu-Fe type phases. The statistical analysis shows that the area fraction of the remnant constituents in rod made by LFEC ingot (1.1%) is less than that of rod made by DC ingot (1.3%), which is helpful for improving mechanical properties.

3.3 Mechanical properties of 7050 alloy

The as-cast tensile strength and the elongation of LFEC ingots (292.5 MPa, 2.3%) are higher than those of DC ingots (274.0 MPa, 1.67%). It is believed those the improvement of as-cast mechanical properties results from finer microstructures and constituents of LFEC ingots.

After homogenization, extrusion, solution treatment and artificial ageing treatment, the LFEC process do not show significant improvement in final tensile strength (from 676.5 to 677.5 MPa), but the improvement in elongation is very remarkable (from 11.23% to 13.20%).

It is believed that the improvement of final elongation results from finer and less remnant constituents.

4 Conclusions

1) 7050 aluminum alloy mainly contains Al-Zn-Mg-Cu type and Al-Cu-Fe type constituents. Al-Zn-Mg-Cu type constituents dissolve during homogenization, while Al-Cu-Fe type constituents could not dissolve. After homogenization treatment, the main remnant constituents are Al_7Cu_2Fe phases which are crush and orient along the extrusion direction after extrusion. Compared with the DC process, by the LFEC process, the constituents or remnant constituents are smaller and less in the states of as-cast, homogenization, extrusion, and solution treatment.

2) For the 7050 aluminum alloy, the as-cast mechanical properties of LFEC ingot are higher than

those of DC ingot. The LFEC process does not show significant improvement in final tensile strength (from 676.5 to 677.5 MPa), but the improvement in elongation is very remarkable (from 11.23% to 13.20%).

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(Edited by CHEN Ai-hua)