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Effect of homogenization treatment on microstructure and hot workability of high strength 7B04 aluminium alloy

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Abstract: The effects of homogenization treatment on microstructure, overburnt temperature and hot rolling plasticity of high strength 7B04 aluminium alloy were investigated. Under the condition of homogenization at 470 ℃, the starting melting temperature of the primary eutectics in ingot of non-equilibium solidified 7B04 alloy is 478 ℃. Using two-step homogenization processing at ultra-high temperature which comprises heating the ingots to 470 ℃ at 10 ℃/h and holding for 64 h, and then heating to 500 ℃ at 1 ℃/h and holding for 10 h, the ingots of 7B04 aluminium alloy could safely pass the sensitive overburnt zone between 480 ℃ and 495 ℃, and the ordinary burnt phenomena of the ingots between 480 ℃ and 495 ℃ does not occur because the excess low-melting point eutectic phases in the as-cast alloy dissolve into the matrix during the two-step homogenization processing. Consequently, the hot rolling plasticity of ingot of 7B04 aluminium alloy is greatly improved.

Key words: 7B04 aluminium alloy; homogenization; low-melting point eutectic phases; overburnt temperature

1 Introduction

High strength aluminium alloys of 7xxx series are widely used in aviation and aerospace because of their high specific strength, good hot workability, resistance to corrosion, toughness and fatigue durability[1−3]. In order to get good processing properties and service performance of aluminium alloys of this series, the cast ingot of the alloy must be homogenization-treated during their processing. The temperature of traditional homogenization treatment for the cast ingot of 7xxx alloys is normally below 470 ℃ because 480 ℃ was considered the overheat temperature of 7xxx alloys [4−7]. According to this kind of homogenization treatment processing, a large number of residual constituents might still remain[8−12]. As a result, not only the strengthening effect of some elements could not adequately develope but also the fatigue lifetime and resistance to corrosion were affected due to the existence of these residual phases[13−14]. In this paper, homogenization processing of 7B04 aluminium alloy was investigated, such as temperature, heating rate and step-heating processing during homogenization. The purpose of this study is to develop a new method of homogenization treatment by which homogenization temperature can be increase over 480 ℃ and overburnt phenomina can also be avoided.

2 Experimental

The 7B04 alloy ingots with the dimension of 440 mm×1 500 mm were prepared by electric furnace melting and semi-continuous casting. The chemical compositions of 7B04 alloy are listed in Table 1.

Under the condition of single homogenization treatment, the samples were treated at 470 ℃ for 0.5, 1, 2, 4, 8, 16, 24, 32, 64 and 128 h, respectively, and then water cooled. In order to study the effect of heating rate on the residual phases, samples were heated to 500−570 ℃ at different heating rates, such as 1, 10 and 25 ℃/h, and then water cooled. Under the condition of step homogenization treatment, two-step homogenization processing is as follows: samples were heated to 470 ℃ at 10 ℃/h and held for 64 h, and than heated again to 500 ℃ and held for 10 h. The microstructures of different

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Table 1 Chemical compositions of 7B04 alloy (mass fraction, %)

Cu	Mg	Mn	Cr	Zn	
1.4−2.0	1.8−2.8	0.2−0.6	0.1−0.25	5.0−6.5	
Fe	**Si**	**Ti**	**Ni**	**Others**	**Al**
0.05−0.25	≤0.1	≤0.05	≤0.1	≤0.1	Bal.

homogenization treated samples were analyzed by an OLYMPUS GX71 optical microscope and Shimadzu SSX-550 SEM. The compositions of constituents were analyzed by EDS. The wedge samples with thickness from 3 mm to 22 mm were used to evaluate the hot rolling plasticity (Fig.1). The deformation in the front of wedge samples was 0, and at the end was 83%. DSC analysis was performed using DSC131, and the heating rate for DSC test was 10 ℃/min.

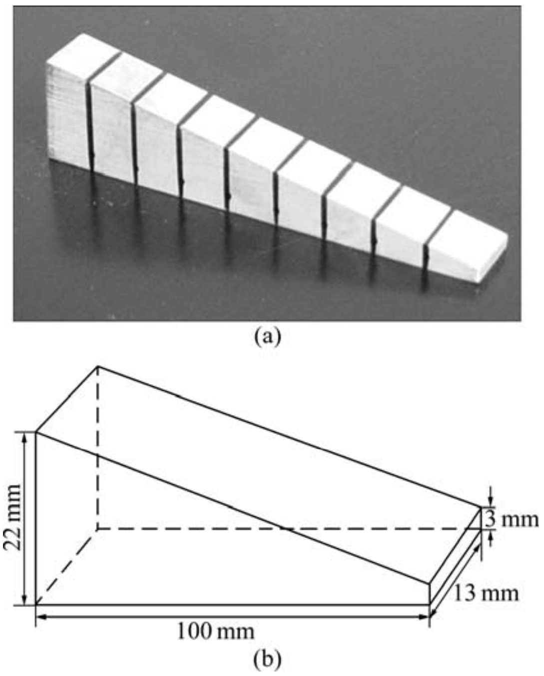

Fig.1 Sketch map of wedge sample of 7B04 alloy: (a) Wedge sample; (b) Size of sample

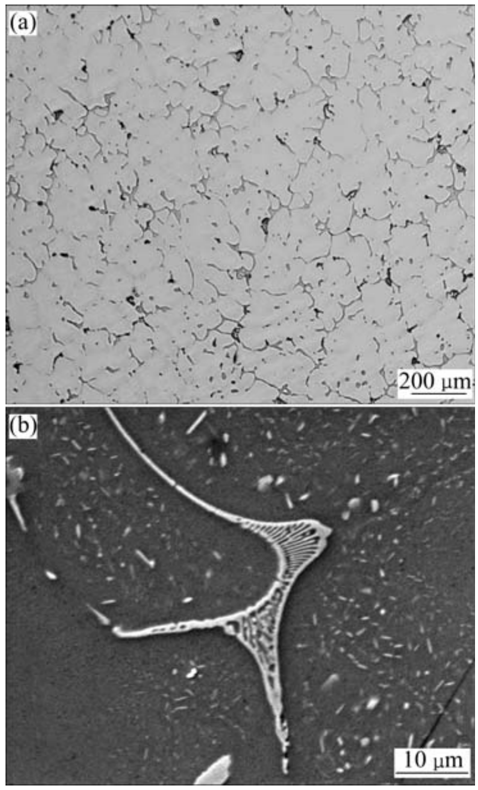

Fig.2 Microstructures of as-cast 7B04 alloy ingot: (a) Optical microstructure, not etched; (b) SEM image

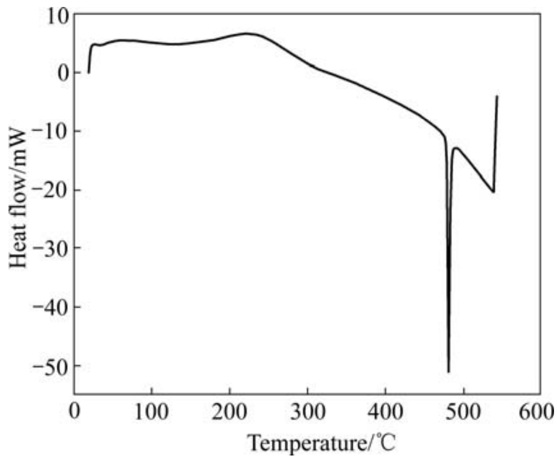

Fig.3 DSC curve of as-cast 7B04 alloy

3 Results and discussion

3.1 Microstructures of as-cast alloy

Fig.2 shows the microstructure of as-cast 7B04 alloy in the middle of the ingot. It can be seen that there are a lot of constituents with forms of dendrite network. The constituents can be divided into deep grey and light grey ones which are separately in forms of pieces and eutectics as seen in Fig.2(b). The energy spectrum analysis of SEM shows that constituents with forms of pieces contain trace Mn and Fe, and ones with forms of eutectics are AlZnMgCu formed from non-equilibrium solidification. Fig.3 shows the DSC curve of as-cast 7B04 alloy in the middle of the ingot. The result of DSC analysis indicates the melting temperature of low melting point constituents in as-cast 7B04 alloy is 478 ℃. It is generally called an overburnt temperature of cast ingot of 7B04 alloy.

3.2 Effect of holding time and heating rates on overburnt temperature

3.2.1 Effect of holding time

Micrographs of cross section of cast ingots treated for different holding time at 470 ℃ are shown in Fig.4. It shows that eutectics from non-equilibrium solidification dissolve obviously at 470 ℃ in the first 8 h. When holding time is extended to 64 h, all of them almost dissolve into the matrix of alloy and residual constituents are mainly ones with deep grey block. Increasing further the time of homogenization treating at 470 ℃, the microstructures of the ingot are not obviously different from that for 64 h. According to energy spectrum analysis, the residual constituents of deep grey block contain Al, Fe, Cu and Mn.

The results of DSC analysis of samples homogenization-treated at 470 ℃ for different holding time are shown in Fig.5. It is clear that with increasing of the holding time at 470 ℃ the endothermal peak of melting of eutectics with low melting point in alloy decreases, and another endothermal peak with higher temperature appears. According to Refs.[15−16], a phase transformation of the primary eutectic structure from $Mg(Zn,Cu,Al)_2$ to Al_2CuMg occurs during homogenization of cast ingot of 7xxx alloys. There is a higher melting temperature between Al_2CuMg and matrix of 7B04 aluminium alloy. The phases corresponding to endothermal peak at higher temperature can not dissolve completely into the matrix of 7B04 alloy, even when the time of homogenization treatment of the alloy ingot at 470 ℃ is 72 h, as shown in Fig.5(d).

3.2.2 Effect of heating rate

Optical microstructures of samples at different heating rates show that the dissolution of the constituents with low-melting point from non-equilibrium solidification increases with decreasing of heating rate for homogenization treatment of the ingot. In the as-cast alloy, there is a lot of eutectic products along grain boundary and interdendrite, whose melting point is lower than 500 ℃. When samples are heated to 500 ℃ at a low rate, the eutectic structures could dissolve into matrix before melting of them. As a result, the phenomena of grain boundary melting could be reduced.

3.3 Ultra-high temperature homogenization treatment

According to a series of homogenization treatment experiments, a new ultra-high temperature homogenization treatment was suggested. It was divided into two steps. At the beginning, the ingot was heated to 470 ℃ at 10 ℃/h and held for 64 h, and then heated to 500 ℃ at 1 ℃/h and held for 10 h. Fig.6 shows the optical microstructure of the sample of this kind of homogenization treatment. It can be seen that only a few of residual constituents and fine precipitates remain. EDS analysis shows that the residual constituents are AlCuFeMn phases.

DSC curve of the sample after the new ultra-high temperature homogenization treatment is shown in Fig.7. It can be seen that the endothermal peak disappears below 500 ℃, which means the eutectic phases with low-melting point below 500 ℃ have dissolved into the matrix during ultra-high temperature homogenization

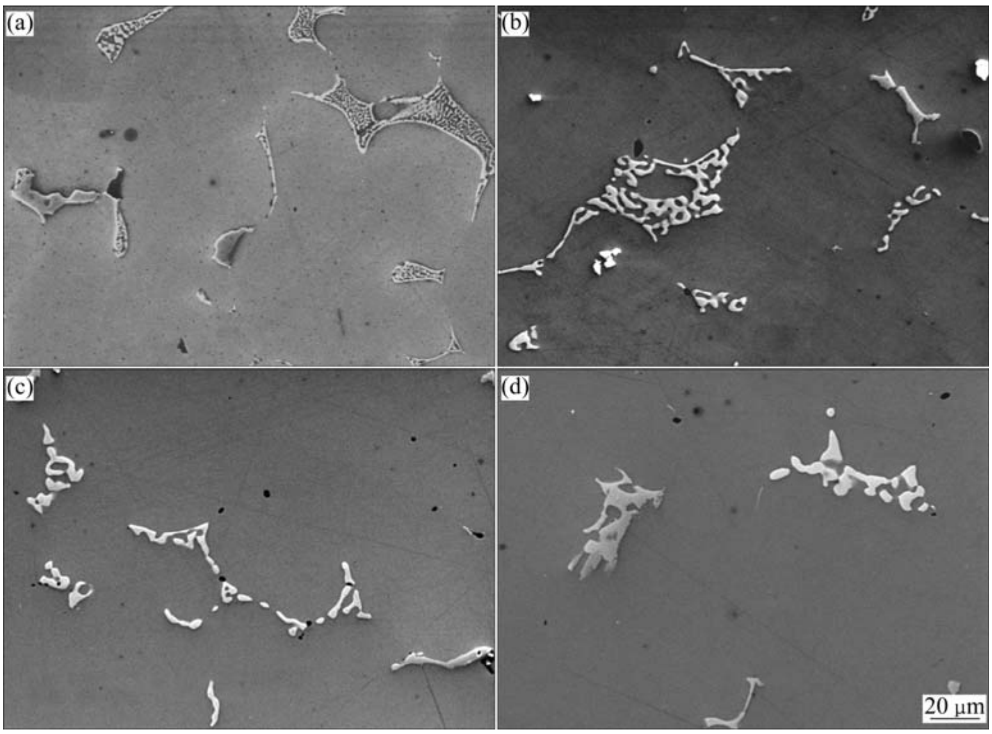

Fig.4 Microstructures 7B04 ingots at 470 ℃ for different holding time: (a) 0.5 h; (b) 8 h; (c) 16 h; (d) 64 h

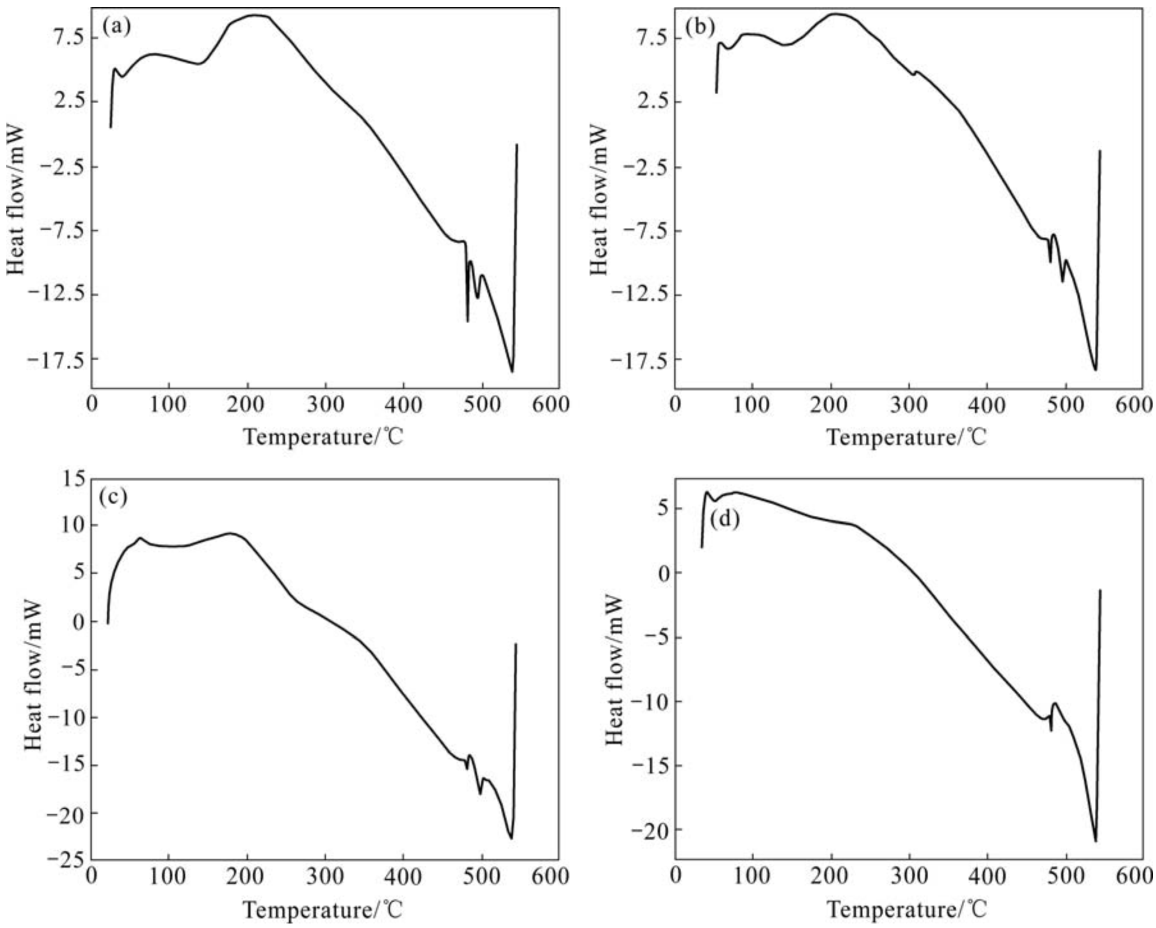

Fig.5 DSC curves of homogenization treated sample at 470 ℃ for different holding time: (a) 4 h; (b) 24 h; (c) 48 h; (d) 72 h

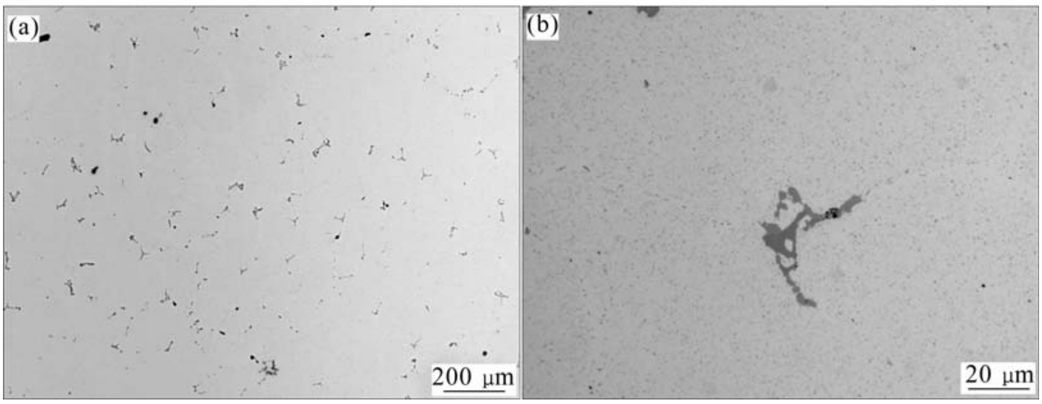

Fig.6 Optical microstructures of homogenization treated sample heated to 470 ℃ at 10 ℃/h and then heated to 500 ℃ at 1 ℃/h (non-etched): (a) Low magnification; (b) High magnification

treatment. The optical microstructures and DSC results show that the temperature of homogenization treatment of ingot of 7B04 alloy can reach 500 ℃ by controlling heating rate between 470 ℃ and 490 ℃.

3.4 Hot-rolling plasticity of alloy ingots after different homogeneous treatment

The wedge samples were hot rolled by one pass of 3 mm gap after being heated at 430 ℃ for 1 h. Under this condition, hot rolling reduction is from 0 to 83%. Fig.8 shows the photograph of hot-rolled wedge samples from ingot after traditional homogenization at 470 ℃ for 48 h and from ingot after two-step homogenization with ultra-high temperature of 500 ℃. It can be seen that there is no cracked edge for the latter. It is proven that the hot-rolling plasticity of alloy ingot after two-step homogenization at ultra-high temperature of 500 ℃ is much better than that of one after traditional homogenization.

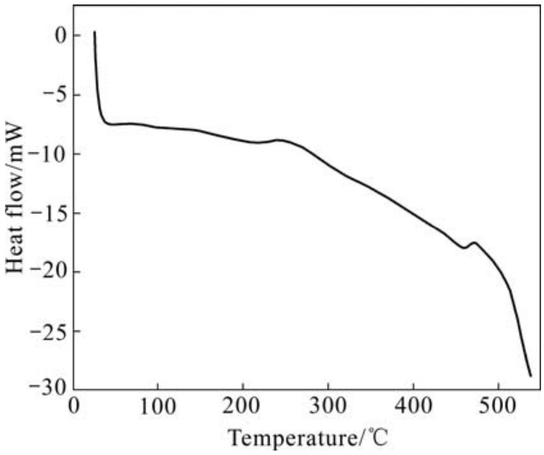

Fig.7 DSC curve for sample after homogenization treatment

Fig.8 Macro-photographs of sample B from ingot after traditional homogenization at 470 ℃ for 48 h and sample A from ingot after two-step homogenization at ultra-high temperature of 500 ℃

4 Conclusions

1) The traditional overburnt temperature of the semi-continuous cast ingot of 7B04 aluminium alloy is 478 ℃. The primary eutectics in the semi-continuous cast ingot dissolve rapidly in 8 h of homogenization treatment at 470 ℃, but the products corresponding to endothermal peak at higher temperature than 478 ℃ can not dissolve completely into the matrix of 7B04 alloy, even when the time of homogenization treatment of the ingot of the alloy at 470 ℃ reaches 72 h.

2) The highest temperature of the new two-step homogenization treatment of ingot of 7B04 aluminium alloy can reach 500 ℃, but no overburnt of ingot appears. The optimum homogenization processing is that the ingot is heated to 470 ℃ at 10 ℃/h and held for 64 h, and then heated to 500 ℃ at 1 ℃/h and held for 10 h.

3) The non-equilibrium solidified constituents in the ingot of 7B04 aluminium alloy after two-step homogenization at ultra-high temperature of 500 ℃ dissolve completely into matrix of alloy and then its hot-rolling plasticity is much better than that of one after traditional homogenization at 470 ℃.

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