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Overheating temperature of 7B04 high strength aluminum alloy

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Abstract: The microstructure and overheating characteristics of the direct chill semicontinuous casting ingot of 7B04 high strength aluminum alloy, and those after industrial homogenization treatment and multi-stage homogenization treatments, were studied by differential scanning calorimetry(DSC), optical microscopy(OM) and scanning electron microscopy with energy dispersive X-ray spectroscopy(SEM-EDX). The results show that the microstructure of direct chill semicontinuous casting ingot of the 7B04 alloy contains a large number of constituents in the form of dendritic networks that consist of nonequilibrium eutectic and Fe-containing phases. The nonequilibrium eutectic contains Al, Zn, Mg and Cu, and the Fe-containing phases include two kinds of phases, one containing Al, Fe, Mn and Cu, and the other having Al, Fe, Mn, Cr, Si and Cu. The melting point of the nonequilibrium eutectic is 478 ℃ for the casting ingot of the 7B04 alloy which is usually considered as its overheating temperature. During industrial homogenization treatment processing at 470 ℃, the nonequilibrium eutectic dissolves into the matrix of this alloy partly, and the remainder transforms into Al_2CuMg phase that cannot be dissolved into the matrix at that temperature completely. The melting point of the Al_2CuMg phase which can dissolve into the matrix completely by slow heating is about 490 ℃. The overheating temperature of this high strength aluminum alloy can rise to 500−520 ℃. By means of special multi-stage homogenization, the temperature of the homogenization treatment of the ingot of the 7B04 high strength aluminum alloy can reach 500 ℃ without overheating.

Key words: 7B04 aluminum alloy; overheating temperature; nonequilibrium eutectic; homogenization treatment; constituent

1 Introduction

The 7B04 alloy is a kind of high strength aluminum alloys that have wide applications in aerospace industry [1−2]. During the direct chill semicontinuous casting processing of this kind of alloys, a great deal of nonequilibrium eutectic forms in the ingots[3−4], which has low melting temperature and dendritic networks morphology, and thus seriously deteriorates the properties of the alloys. In order to improve the composition homogeneity and the properties, the ingots of this kind of alloys need homogenization treatment after casting[5−7]. It is generally considered that the melting temperature of the nonequilibrium eutectic in the ingots of this kind of high strength aluminum alloys is below 480 ℃[8], so the temperature of their industrial homogenization is usually at 470 ℃ in order to prevent overheating[2, 9−10]. However, nonequilibrium eutectic that contains many alloying elements in the ingots cannot dissolve completely during homogenization at this temperature, which can result in many residual coarse constituents in the matrix of the alloys. In this case, the alloying elements cannot completely play their role in improving the properties of this alloy[11−12]. In order to dissolve the nonequilibrium eutectic into the matrix more sufficiently, the homogenization temperature should be risen as high as possible, giving an assurance that the ingot is not overheated. The overheating temperature could be increased considerably by preheating the ingots at temperatures below the melting point of the as-cast structure[13−14], so it is necessary to understand the overheating temperature of this alloy in detail.

The objective of the present work is to determine the melting temperature of the nonequilibrium eutectic in the direct chill semicontinuous casting ingot of 7B04 aluminum alloy, and the equilibrium melting temperature of this alloy that is its overheating temperature. This

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work also aims to develop a new homogenization treatment with the temperature above 480 ℃ to improve the properties of 7B04 aluminum alloy.

2 Experimental

The 7B04 aluminum alloy ingot with thickness of 440 mm was prepared by direct chill semicontinuous casting, and the chemical composition is given in Table 1. The specimens with the size of 50 mm×50 mm×20 mm were cut from the half position between the surface and the center of the ingot.

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

Zn	Mg	Cu	Si	Fe
6.00	2.43	1.61	0.048	0.15
Mn	Cr	Ni	Ti	Al
0.31	0.16	<0.01	0.025	Bal.

All the specimens were homogenized in an air circulation furnace. At first, they were treated at 470 ℃ for 48 h, and some of them were taken out from furnace and cooled in the air, which was usually called industrial homogenization. The specimens left in furnace were step-heated slowly from 470 ℃ to 500 ℃ with every 5 ℃ holding for 3 h, and then held at 500 ℃ for 10 h, among which a few specimens were taken out from furnace and cooled in air, which was called multi-stage homogenization up to 500 ℃ (called MH500 ℃ treatment for short). Then the specimens left in furnace were still step-heated respectively up to 520 ℃ or 540 ℃ from 500 ℃ by the same way as heating to 500 ℃, held at these temperatures for 4 h, and then cooled in the air, which were called corresponding MH520 ℃ or MH540 ℃ treatments, respectively. The specimens were examined by DSC, OLYMPUS GX71 optical microscopy(OM) and SSX-550 SEM-EDX. The DSC analysis was performed using DSC131 with aluminum crucible from room temperature to 550 ℃ with a heating rate of 10 ℃/min.

3 Results and discussion

3.1 Microstructure of as-cast 7B04 aluminum alloy

The microstructures of the as-cast 7B04 aluminum alloy are shown in Fig.1. As shown in Fig.1(a), besides the matrix of the alloy, its microstructure consists of the network in dark gray solid block and grayish eutectic in lamellar structure. Dark gray solid block of constituents in Fig.1(a) corresponds to dark gray phases in Fig.1(b),

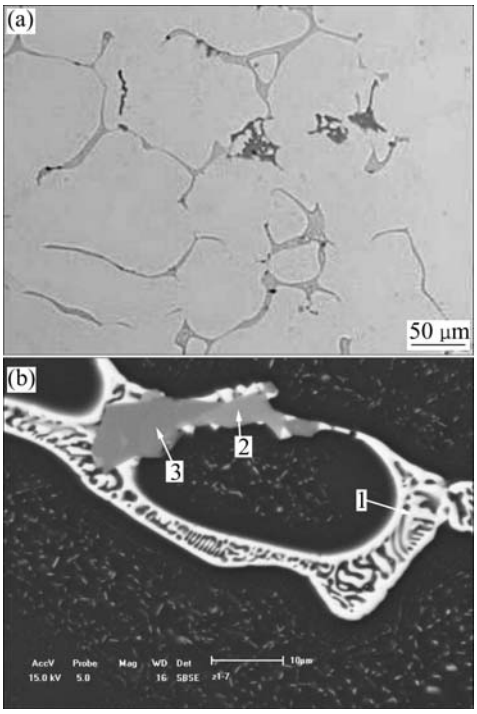


Fig.1 Microstructures of as-cast 7B04 aluminum alloy by OM (a) and SEM (b)

and grayish eutectic to bright one. EDX analysis verifies that the bright eutectic as shown by the arrow 1 in Fig.1(b) contains Al, Zn, Mg and Cu, as seen in Fig.2(a), which has the same result in Ref.[15]. The dark gray phases are Fe-containing phases, which is also in agreement with the result in Ref.[16]. However, the Fe-containing phases include two different ones that contain different elements. The grayish Fe-containing phase as shown by the arrow 2 in Fig.1(b) contains Al, Fe, Mn and Cu, whose EDX result is shown in Fig.2(b), and the darker gray Fe-containing phase as shown by the arrow 3 in Fig. 1(b) contains Al, Fe, Mn, Cr, Si and Cu, whose EDX result is shown in Fig.2(c).

3.2 Microstructures of alloy after homogenization treatment

The microstructure of the specimen after the industrial homogenization treatment at 470 ℃ for 48 h is shown in Fig.3(a). It can be seen that many constituents remain in the matrix of the alloy, which consist of darker gray and gray ones. The darker gray constituents in Fig.3(a), that is, the dark gray ones in the microstructure of the as-cast alloy in Fig.1(a), almost remain the same during homogenization treatment. But the gray ones in Fig.3(a) are not same as the grayish ones in Fig.1(a). The grayish eutectic in Fig.1(a) vanishes after industrial homogenization, which partly dissolves into the matrix of the alloy. The remainder transforms to gray constituents as shown in Fig.3(a), which appear as white phases in backscattered image of SEM, as shown

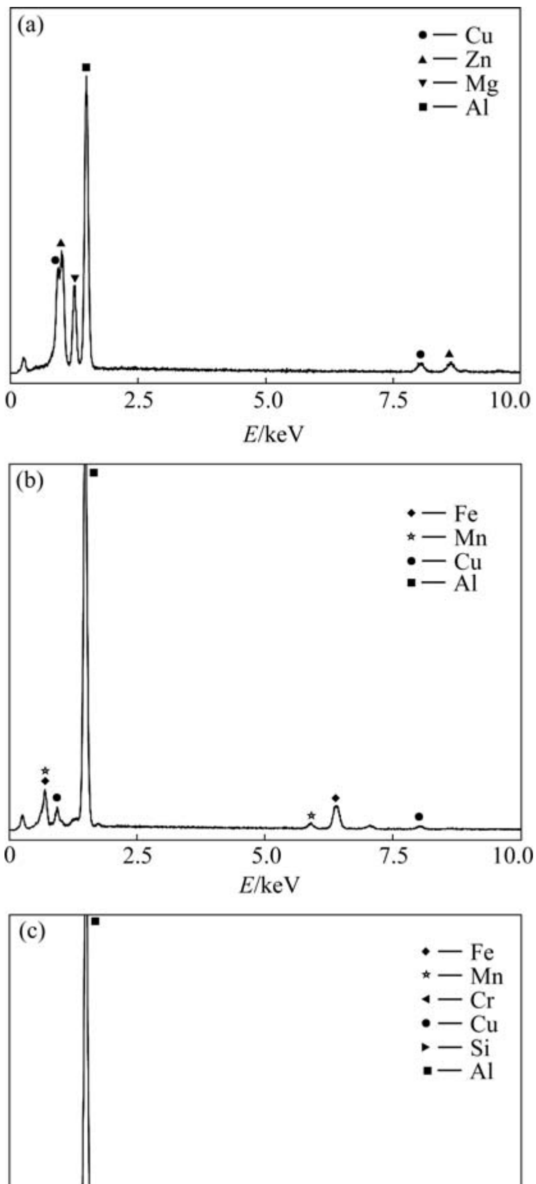


Fig.2 EDX spectra of phases in Fig.1(b): (a) Arrow 1; (b) Arrow 2; (c) Arrow 3

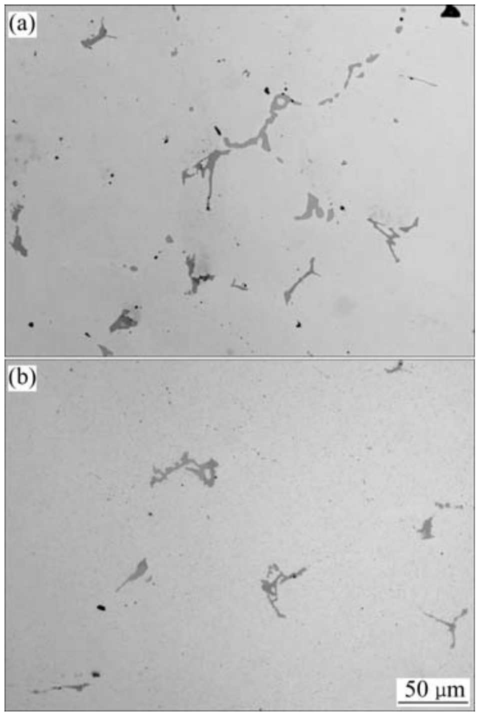


Fig.3 Microstructures of speci mens after homogenization treatments: (a) Industrial homogenization; (b) MH500℃ treatment

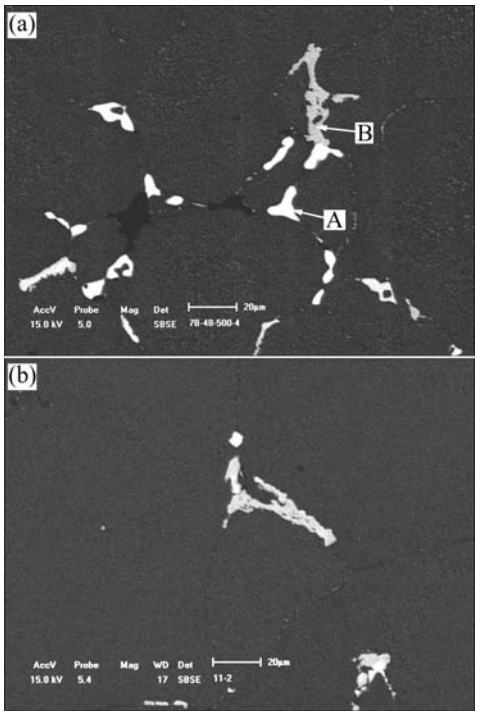
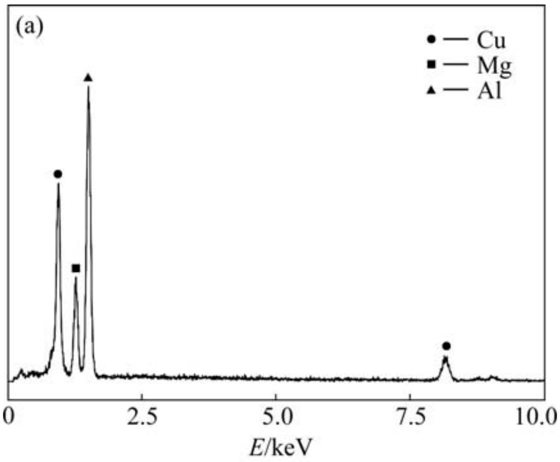


Fig.4 SEM backscattered images of speci mens after homogenization treatments: (a) Industrial homogenization; (b) MH500℃ treatment

by the arrow A in Fig.4(a). The EDX result indicates that the white phases in Fig.4(a) contain 57.8%Al, 21.2%Mg, and 21.0%Cu (mole fraction), as shown in Fig.5(a), and they should be considered as Al_2CuMg phases. The results suggest that the zinc atoms in the nonequilibrium eutectic containing Al, Zn, Mg and Cu can dissolve into the matrix of the alloy after industrial homogenization. The result of the nonequilibrium eutectic of the alloy transforming to the Al_2CuMg phases during the industrial homogenization process is in agreement with the result in Ref.[17]. However, the Al_2CuMg phases in the alloy cannot dissolve into the matrix completely under this process. The darker gray constituents in Fig.3(a) also appear as gray phases in the SEM back-



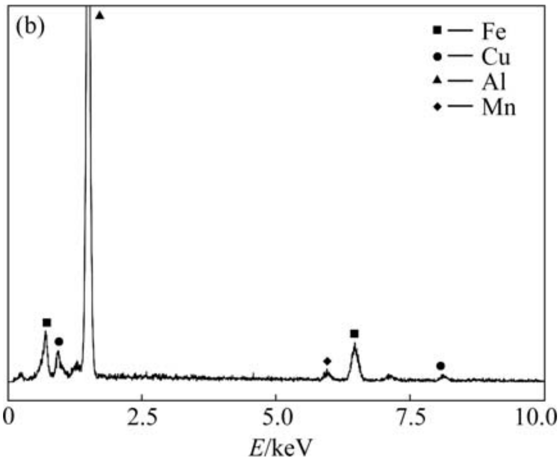


Fig.5 EDX results of phases in Fig.4(a): (a) Arrow A; (b) Arrow B

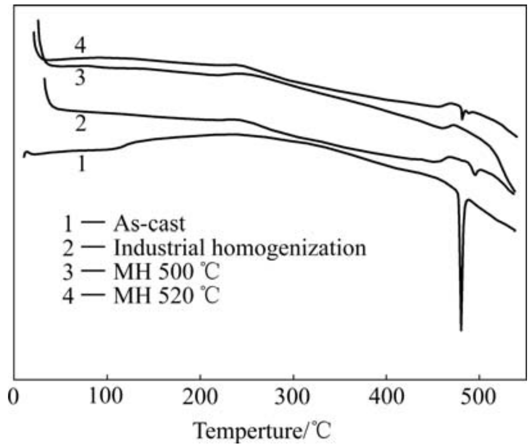


Fig.6 DSC curves of as-cast 7B04 aluminum alloy after different homogenization treatments

scattered image as shown by the arrow B in Fig.4(a), which contain Al, Fe, Mn and Cu, as shown in Fig.5(b).

There are only a few residual constituents in the alloy after MH500℃ treatment, as shown in Fig.3(b). In SEM backscattered image in Fig.4(b), the residual phases in the alloy are dark gray. The EDX results show that all of the residual phases in the alloy are Fe-containing phases. It is clear that if controlling the heating rate to 500 ℃ and holding proper time after industrial homogenization, the strengthening elements in the alloy can dissolve into its matrix sufficiently.

3.3 DSC analysis of specimens as-cast and after homogenization treatment

The DSC curves of the specimens of as-cast 7B04 aluminum alloy, after industrial homogenization, MH500℃ and MH520℃ treatments are shown in Fig.6. There is a sharp endothermic peak at 478 ℃, as shown on the curve 1 in Fig.6, which indicates that the nonequilibrium eutectic in this specimen melts at 478 ℃. This is generally considered as the overheating temperature of direct chill semicontinuous casting ingots of the 7B04 high strength aluminum alloys, so the temperature of the industrial homogenization treatment of the ingots of this kind of alloys is always below 478 ℃, usually at 470 ℃. Although the endothermic peak of the alloy at 478 ℃ almost vanishes after the specimen is homogenized at 470 ℃ for 48 h, a new small endothermic peak appears at about 490 ℃ as shown on the curve 2 in Fig.6, indicating that the nonequilibrium eutectic in the 7B04 aluminum alloy can dissolve into matrix, but a new product with the melting temperature of 490 ℃ forms during the industrial homogenization process. Due to the formation of this new product, the overheating temperature of the alloy increases after industrial homogenization. The EDX result confirms that this new product is Al_2CuMg phase. So it can be concluded that the melting temperature of Al_2CuMg phase in 7B04 aluminum alloy is about 490 ℃.

The curve 3 in Fig.6 is the DSC curve of the specimen of the alloy after MH500℃ treatment, on which there is no endothermic peak below 500℃. It is verified that both of the phases with melting temperatures of 478 ℃ and 490 ℃ can dissolve completely into the matrix of 7B04 aluminum alloy during the MH500℃ processing, and the alloy after this treatment is not overheated below 500 ℃.

The curve 4 in Fig.6 is the DSC curve of the specimen of the alloy after MH520℃ treatment, on which a small new endothermic peak appears again at 478 ℃. This small new endothermic peak is the same one on DSC curve of the specimen of as-cast 7B04 aluminum alloy, and only difference is that the endothermic peak on the curve 4 in Fig.6 is smaller. This shows that the product at the melting temperature of 478 ℃ appears again after MH520℃ treatment.

3.4 Overheating temperature of 7B04 aluminum alloy

Fig.7(a) shows the SEM image of the 7B04

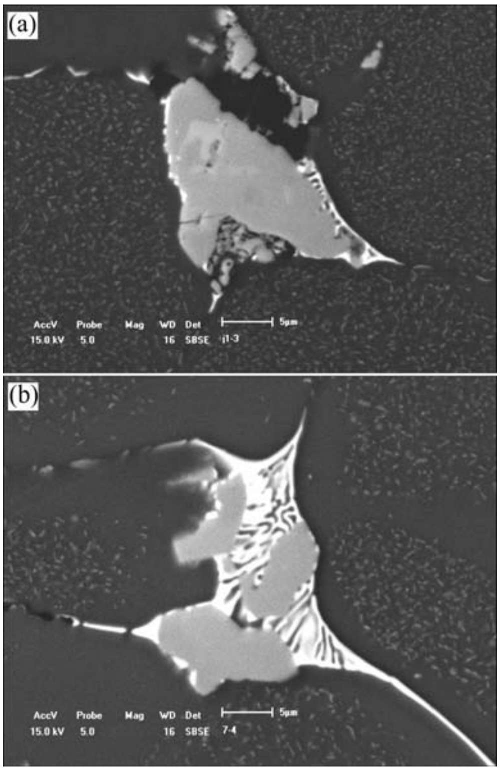


Fig.7 SEM backscattered images of specimens after multistage homogenization treatments: (a) MH520℃ treatment; (b) MH540℃ treatment

aluminum alloy after the MH520℃ treatment, in which there are some white phases around gray ones at the grain boundaries, which present lamellar structure sometimes. The EDX results show that the gray phases contain Al, Fe, Mn and Cu that are residual Fe-containing phases in the alloy after MH520℃ treatment, while the white phases contain Al, Zn, Mg and Cu in both composition and morphology as same as the nonequilibrium eutectic of the as-cast 7B04 aluminum alloy. This shows that the interface between Fe-containing phase and the matrix of the alloy and its grain boundary melt when it is heated slowly from 500 ℃ to 520 ℃ and hold at that temperature, and the molten product forms the nonequilibrium eutectic again when it is cooled in the air from 520 ℃. Because of the existence of nonequilibrium eutectic, the DSC curve of the 7B04 aluminum alloy after the MH520℃ treatment has a small endothermic peak at 478 ℃, as shown in curve 4 of Fig.6. From the backscattered SEM image of the specimen after the MH540℃ treatment, as shown in Fig.7(b), the quantity of the nonequilibrium eutectic increases further as compared with MH520℃ treatment.

The results indicate that the interface between the Fe-containing phase and matrix of the 7B04 aluminum alloy and its grain boundaries melt, which cannot be avoided by means of slow heating from 500 ℃ to 520 ℃ after the MH500℃ treatment. Therefore, it can be concluded that the overheating temperature or equilibrium temperature of the 7B04 aluminum alloy is 500−520 ℃.

4 Conclusions

1) The microstructure of direct chill semicontinuous casting ingot of the 7B04 high strength aluminum alloy contains a large number of nonequilibrium eutectic and Fe-containing phases constituents. The nonequilibrium eutectic in the alloy contains Al, Zn, Mg and Cu, and the Fe-containing phases include two kinds of ones, one containing Al, Fe, Mn and Cu, and the other containing Al, Fe, Mn, Cr, Si and Cu.

2) The melting temperature of nonequilibrium eutectic in the direct chill semicontinuous casting ingot of the 7B04 high strength aluminum alloy is about 478 ℃. They can partly dissolve into the matrix of the alloy and the remainder transforms into Al_2CuMg phase during industrial homogenization treatment at 470 ℃.

3) The melting temperature of the Al_2CuMg phase in the 7B04 high strength aluminum alloy is about 490 ℃, which can dissolve into its matrix completely by slow heating, and the overheating temperature of 7B04 aluminum alloy can rise to 500−520 ℃.

4) By means of special multi-stage homogenization, the temperature of the homogenization treatment of the ingot of the 7B04 high strength aluminum alloy can reach 500 ℃ without overheating.

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