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Effect of Titanium on Homogenizing Process and Microstructure of Alloy 2618

Abstract: The effect of titanium on the homogenizing process of alloy 2618 and the microstructure of the Ti-containing alloy before and after homogenization has been investigated using optical microscope (OM), scanning electron microscope (SEM), energy dispersive X-ray (EDX), differential thermal analysis (DTA). The results show that the addition of 1.5 mass% Ti to alloy 2618 could refine its grain size remarkably. A large amount of rod-shape Al_3Ti particles with the size range of 2–12 μm distribute evenly and dispersively in the alloy. It is θ (Al_2Cu) phase instead of S′ (Al_2CuMg) obtained in eutectic structures due to the non-equilibrium solidification in casting of 2618-Ti alloy, which is the same as alloy 2618. The optimal homogenization temperature (773 K) for Ti-containing alloy 2618 (2618-Ti alloy) is the same as that of alloy 2618. Combining the results of kinetic analysis and experiments, the optimized homogenizing time for Ti-containing alloy 2618 at 773 K is only 12 h, which is shorter than that for alloy 2618. The shortening of the optimized homogenizing time results mainly from the decrease of the grain size of 2618-Ti alloy.

Keywords: 2618-Ti alloy, microstructure, grain refinement, homogenization

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1 Introduction

Aluminum alloy 2618 is wildly used for application at elevated temperature up to 573 K due to its aging hardenable property and the formation of thermostable Al_9FeNi phase [1, 2]. Facing the challenge of defense and aviation industries, a lot of researches have been done to further improve both its room temperature and high temperature mechanical properties without sacrificing its ductility [2–5]. Among them, the addition of Ti into the alloy is very attractive due to its favorable grain refining performance and the formation of fine reinforced Al_3Ti phases [2, 6–7]. Acturally, Ti could greatly decrease the grain size of aluminum alloy when its amount reached 0.01–0.06% (mole fraction) owing to very little equilibrium solubility [2]. In order to give full play of the role of Al_3Ti phases, some publications [2, 8–9] pay attention to the fabrication of Al-Al_3Ti composites by adding more Ti. Despite detailed studies having been made on microstructure and mechanical properties of Ti-containing aluminum alloy [2, 8–9], less attention was focused on the effect of titanium on the setup of optimized homogenized parameters and microstructure evolution of the Ti-addition alloy during homogenization.

As is known to all, severe dendrite and grain boundary segregation occurred in the casting process of aluminum alloys due to fast cooling will deteriorate their subsequent extrusion and mechanical properties. Thus, homogenization is an indispensible process for these alloys to remove segregation and dissolve large soluble non-equilibrium eutectic structures [10–13].

In the present paper, the influence of titanium on homogenizing temperature and time of alloy 2618 was studied. Additionally, the microstructure evolution of the Ti-containing alloy 2618 during homogenization was also investigated. The aim of the work could provide valuable reference for following cold/thermal-mechanical process, solution and aging treatment.

2 Experimental procedure

The nominal compositions of the studied alloys are listed in Table 1. Alloy 2618 was used as reference alloy and its fabricating process was the same as that in reference [14].

Table 1: Nominal compositions of the studied alloys (mass%)

Alloy	Cu	Mg	Fe	Ni	Ti	Al
Alloy 2618	2.3	1.6	1.1	1.1	0	Bal.
Ti-containing alloy 2618	2.3	2.3	1.1	1.1	1.5	Bal.

The Ti-containing alloy 2618 (1.5% Ti in mass fraction) was prepared by solid-liquid mixing and near-liquidus casting [15] with industrial pure Al and master alloys of Al-Cu, Al-Mg, Al-Fe, Al-Ni and Al-7 mass% Ti powders with average size of 100 μm produced by gas atomization method. The casting ingots were cut into the specimens with the size of 10 × 10 × 8 mm. The specimens were homogenized at the temperature range of 743–783 K in steps of 10 K for 24 h, respectively, to obtain optimal homogenization temperature. Afterwards, the specimens were homogenized at the optimized temperature for 4–24 h in steps of 4 h, followed by quenching into water at room temperature.

The specimens for observation were prepared through conventional metallographic procedures and followed by etching in a standard Keller's reagent. Then the specimens were observed by Leica DIM 3000 optical microscope (OM) and JSM-6510 scanning electron microscope (SEM). The transition points of the as cast alloy were measured from 573 K to 1073 K with differential thermal analysis (DTA) at a heating rate of 5 K/min.

3 Results and discussion

3.1 Effect of titanium on microstructure of alloy 2618

Figure 1 shows the microstructure of the as cast alloys. The typical dendritic α(Al) matrix can be observed in both 2618 alloy (Fig. 1(a)) and 2618-Ti alloy (Fig. 1(b)) with large amounts of secondary phases existing along grain boundaries owing to severe dendritic segregation. Compared with as cast alloy 2618, the grain size of Ti-containing alloy 2618 is refined dramatically. A large number of short rod-shape reinforcing particles (2–12 μm) distributes evenly within the grain of the alloy. The EDX analysis reveals that the triangle structure is non-equilibrium α-Al + θ (Al_2Cu) eutectic structure (spot A in Fig. 1(c)), while the short rod-shape phase is Al_3Ti (spot B in Fig. 1(c)) and the spot C in Fig. 1(c) is Al_9FeNi phase. The chemical compositions of intermetallic phases existed in Ti-containing alloy 2618 are listed in Table 2. Although the main precipitate is

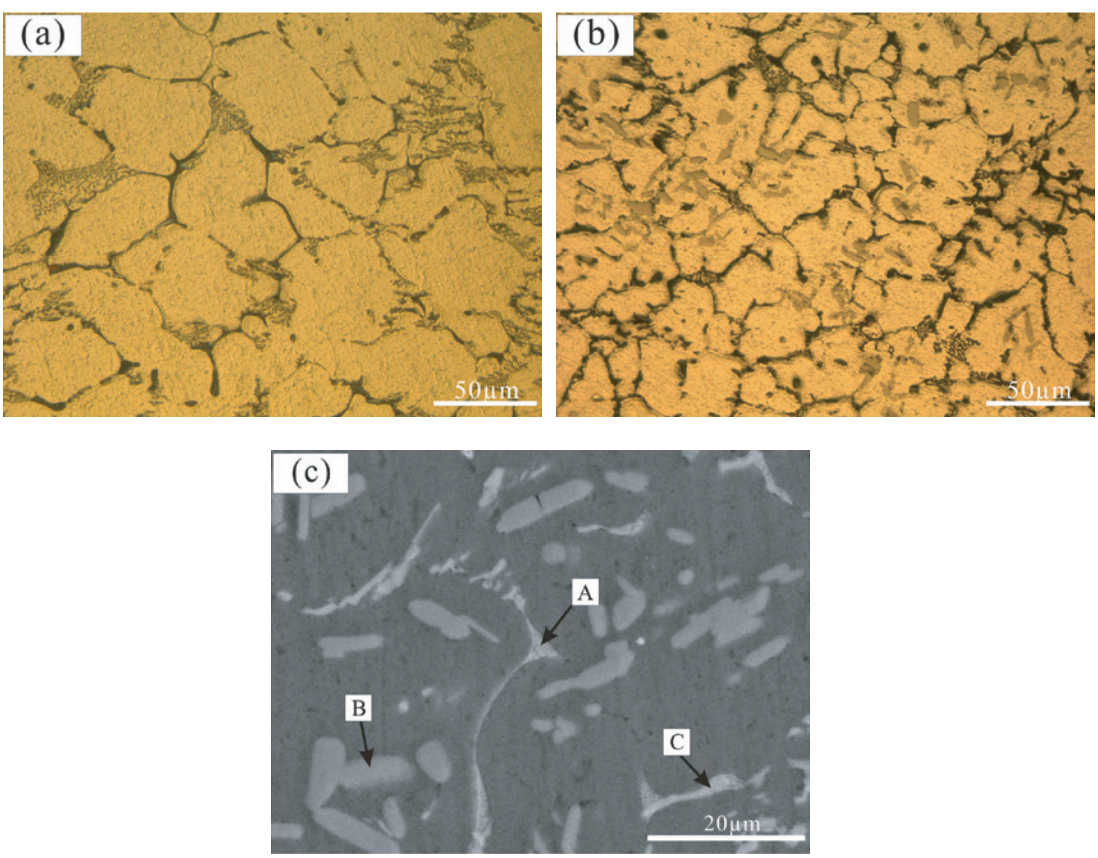

Fig. 1: Microstructures of as cast alloys: Optical microstructure of as cast alloy 2618 (a) and as cast Ti-containing alloy 2618 (b); Backscattered electron image of Ti-containing alloy 2618 (c)

Table 2: Chemical compositions of intermetallic phases existed in Ti-containing alloy 2618 (at.%)

Phase	Al	Cu	Mg	Fe	Ni	Ti
A	80.83	18.85	1.02	–	–	–
B	75.6	–	–	–	–	24.4
C	80.62	1.84	1.62	7.99	7.93	

semi-coherent S′ (Al_2CuMg) phase in 2618 alloy after aging, the formation of θ (Al_2Cu) phase in eutectic structure is not accidental considering the non-equilibrium solidification during casting. Similar results have been found in Ref. [14] and reasonable explanations given.

Fig. 2 gives the SEM microstructure of as-cast alloy 2618 and elements distribution which can also verify the

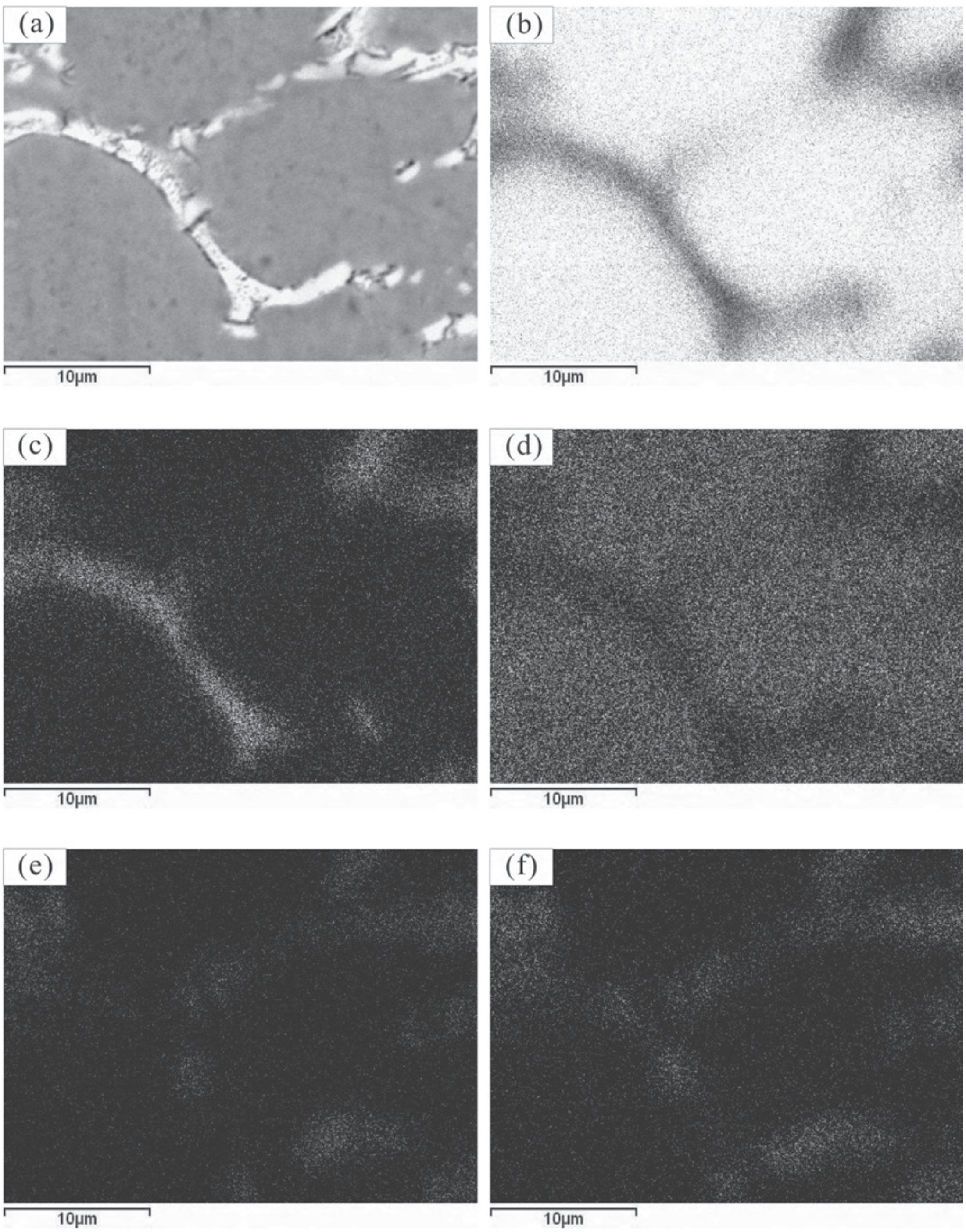

Fig. 2: The SEM microstructure of as-cast alloy 2618 and elements distribution: (a) SEM microstructure; (b) Al; (c) Cu; (d) Mg; (e) Fe; (f) Ni

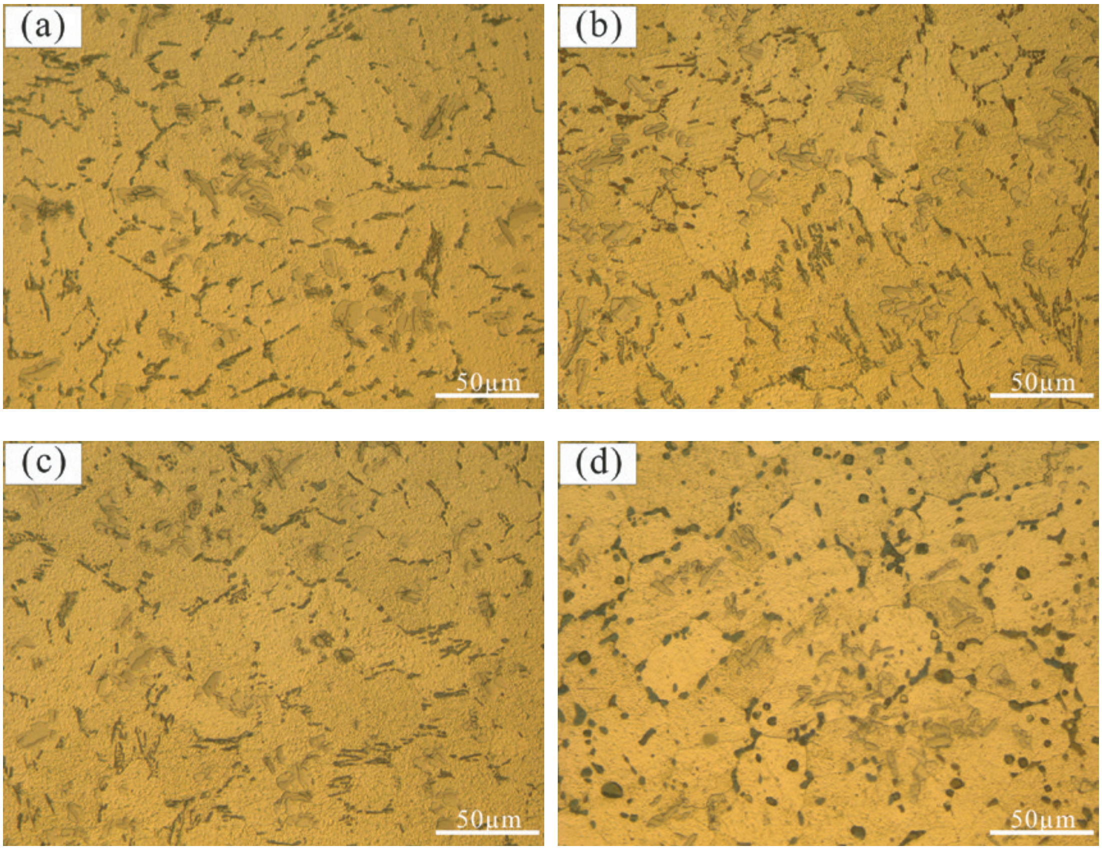

Fig. 3: Microstructures of Ti-containing alloy 2618 homogenized at different temperature for 24 h: (a) 743 K; (b) 763 K; (c) 773 K; (d) 783 K

precipitated phase after casting is not S′ (Al_2CuMg) but θ (Al_2Cu) phase. It can be seen that only the elements Cu, Fe and Ni are enriched in grain boundaries, while Al and Mg is poor. The enrichment of Fe and Ni corresponds to the formation of Al_9FeNi. The enrichment of Cu and the lake of Mg demonstrate the formation of binary Cu-containing phase instead of ternary phase Al_2CuMg. The depletion of Al can be attributed to the formation of secondary phases in grain boundaries.

3.2 Effect of titanium on homogenization temperature of alloy 2618

The microstructures of Ti-containing alloy 2618 homogenized at different temperatures for 24 h are shown in Fig. 3. It can be seen that the microstructure of the alloy is affected remarkably by the homogenized temperature. With the increase of homogenization temperature, the dissolution of non-equilibrium eutectic structures into matrix was more complete and the continuous dendritic network structures were broken, the grain size of the alloy increases and the grain boundaries become blurry (Fig. 2(a)–(c)). However, when Ti-containing alloy 2618 is homogenized at 783 K, slight overburning occurs at grain boundaries, resulting in the formation of large amount of small spherical structures as shown in Fig. 2(d). So the optimal homogenization temperature for Ti-containing alloy 2618 is 773 K, which is the same as that for alloy 2618 [14].

The DTA curves of the studied as cast and homogenized alloys are given in Fig. 4. Two endothermic peaks

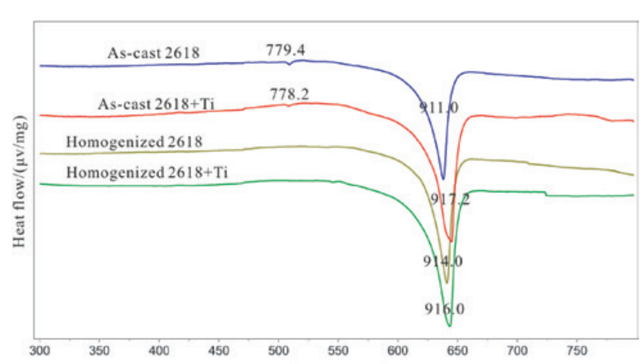

Fig. 4: DTA curves of the as cast and homogenized alloys

are observed in as cast Ti-containing alloy 2618, sited at 778.2 K and 917.2 K, respectively. For as-cast alloy 2618, these two endothermic peaks are 779.4 K and 911 K, respectively. When the as-cast alloys were heated during DTA process, the endothermic peaks at 778.2 K and 779.4 K occur which correspond to the fusion of non-equilibrium eutectic structures in these alloys. The fusion temperatures are generally called the overburnt temperature. After the alloys are homogenized, these two endothermic peaks disappear due to the dissolution of non-equilibrium eutectic structures into matrix during homogenization. The addition of Ti decreases the overburnt temperature slightly, resulting from the formation of multi-component alloy. The endothermic peaks at 917.2 K and 911 K are identified as the liquidus temperature of Ti-containing alloy 2618 and alloy 2618, respectively. The increase of the liquidus temperature in 2618-Ti alloy could be ascribed to the higher melting point of titanium and a little solubility of titanium in aluminum. The homogenization process is actually controlled by the diffusion of solvent elements in matrix and the diffusion coefficient of these elements increases with the increase of homogenization temperature [10, 16]. So, the homogenization temperature should be set as higher as possible, as long as it does not surpass the overburnt temperature of the alloy. Thus, the optimized homogenization temperature based on the DTA analysis of Ti-containing alloy 2618 should be lower than 778.2 K, which is in good accordance with experimental results obtained from homogenization process. Both of Ti-containing alloy 2618 and alloy 2618 have almost the same optimal homogenization temperature owing to their similar overburnt temperatures. Additionally, a new phase formed around Al_3Ti particles was found in Ti-containing alloy 2618 after homogenization, which will be discussed in another article.

3.3 Effect of titanium on holding time of alloy 2618 homogenized at 773 K

Fig. 5 presents the Backscattered Electron Images-BSE images of alloy 2618 homogenized at 773 K for 12 h and Ti-containing alloy 2618 homogenized at 773 K for different times. Eutectic structures existed in grain boundaries of the as-cast alloy could be observed obviously as shown in Fig. 5(b). With the increase of homogenization time, the residual eutectic structures at grain boundaries decrease gradually as shown in Fig. 5(c)–(d). After homogenization at 773 K for 12 h, the continuous dendritic network structures disappear and the volume fraction of residual phases reaches the least. Then with the increase of homogenization time, the grain sizes of Ti-containing alloy increase slightly as shown in Fig. 5(e)–(f) with no further reduction of residual phases. So, when Ti-containing alloy 2618 is homogenized at 773 K, the optimal homogenization time is 12 h, which is shorter than that of alloy 2618 [14]. During the homogenization process, the size and morphology of Al_9FeNi phase have no obvious change, which can be attributed to its higher thermo-stability [1]. Compared with alloy 2618 (Fig. 5(a)), the grain size of Ti-containing alloy 2618 homogenized at 773 K for 12 h (Fig. 5(d)) is still much smaller than that of alloy 2618 (Fig. 5(a)). It can be concluded that the grain refining effect of Ti addition on as-cast alloy 2618 remains after homogenization from as-cast condition.

Fig. 6 gives the line-scan analysis of Ti-containing alloy 2618 before and after homogenization at 773 K for 12 h. It can be seen that the elements of Cu, Mg, Fe and Ni distribute periodically in the as cast alloy as shown in Fig. 6(a). After homogenization, the segregations of Fe and Ni still exist as shown in Fig. 6(b), which can be ascribed to the stable existence of Al_9FeNi phase in grain boundaries. The segregation of Cu at grain boundaries is reduced dramatically owing to the dissolution of eutectic structures into matrix. Besides, the distribution of Mg in matrix becomes much more even. However, it is worth noting that slight segregation of Cu still exists in homogenized alloy due to lower diffusion coefficient of Cu in matrix [10, 16]. Thus, the homogenized process of alloy 2618 is mainly controlled by the diffusion of element Cu. According to Shewmon [17], Xiaoyan Liu [16] and Wenbin Li [10] et al., the homogenization equation of the studied alloy can be expressed as:

$$\frac{1}{T}=\frac{R}{Q}\ln\left(-\frac{4\pi^2 D_0 t}{4.6L^2}\right) \tag{1}$$

with the data of D_0 (Cu) = 0.084 cm²/s, Q (Cu) = 136.8 KJ/mol and R = 8.31 J/(mol · k) [17], where T is the absolute temperature, R the gas constant, Q the diffusion activation energy, D_0 the diffusion coefficient, L the interdendritic spacing and t is the required time. It can be concluded that the decrease of interdendritic spacing is favorable to shorten homogenization time at the same temperature.

Based on quantitative metallographic analysis, the interdendritic space of Ti-containing alloy 2618 could be decreased to about 36 μm. By substituting L = 36 μm into Eq. (1), the corresponding homogenization time is about 9 h for Ti-containing alloy 2618 at 773 K, which is shorter than that (15 h) of alloy 2618 [14]. In order to be homogenized completely, the homogenization time for Ti-containing alloy 2618 should be more than 9 h, which is

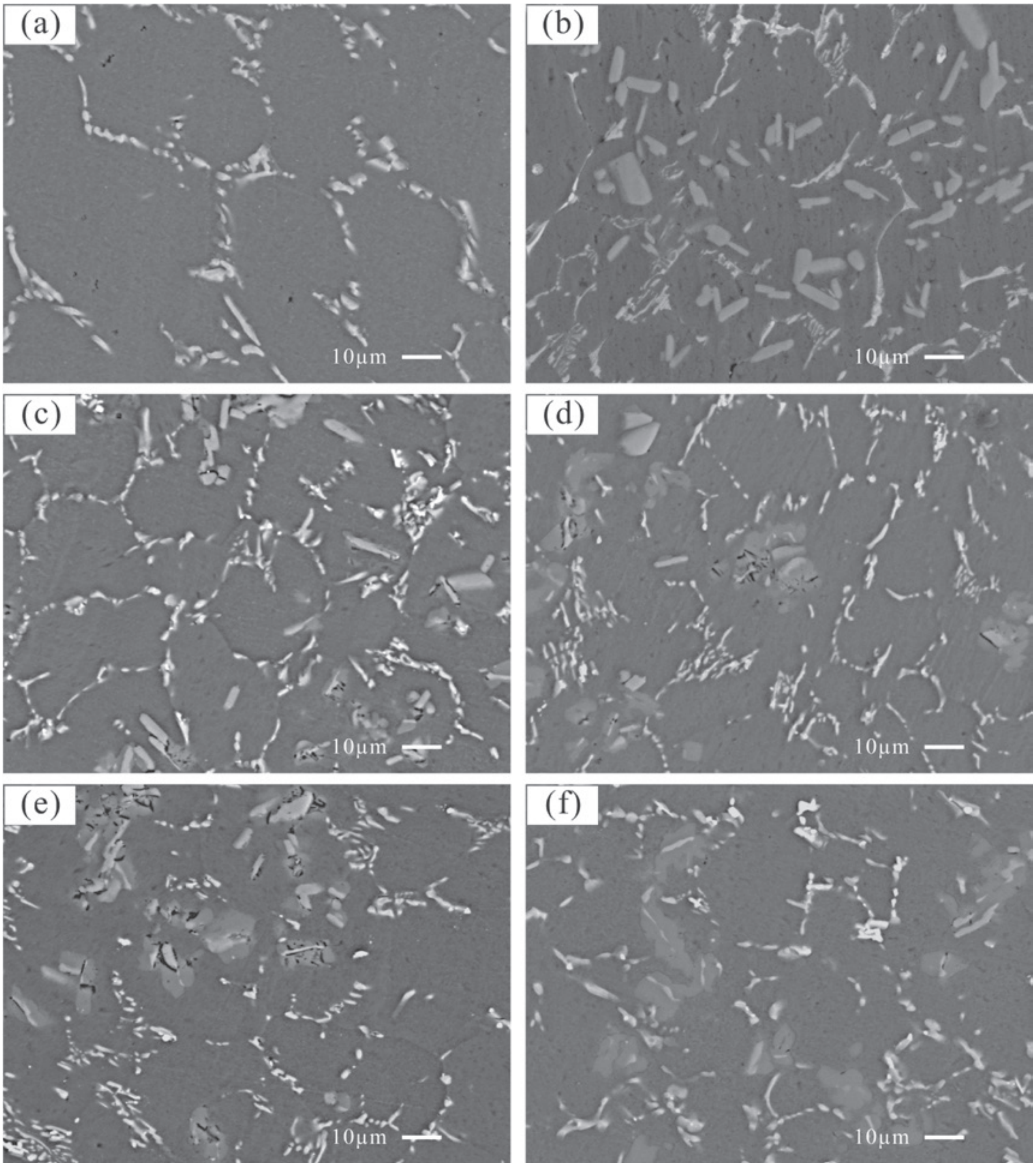

Fig. 5: BSE images of alloy 2618 homogenized at 773 K for 12 h (a) and Ti-containing alloy 2618 homogenized at 773 K for different times: (b) 0 h; (c) 8 h; (d) 12 h; (e) 16 h; (f) 24 h

well consistent with the results obtained from homogenization treatments.

In conclusion, titanium in alloy 2618 could decrease the homogenization time resulting from the decrease of the grain size of the alloy.

4 Conclusion

1. The addition of 1.5 mass% Ti to alloy 2618 could refine its grain size remarkably. A large amount of rod-shape Al_3Ti particles with the size range of 2–12 μm distribute evenly and dispersively in the alloy.
2. It is θ (Al_2Cu) phase instead of S′ (Al_2CuMg) obtained in eutectic structures due to the non-equilibrium solidification in casting of 2618-Ti alloy, which is the same as alloy 2618.
3. The optimal homogenization temperature of Ti-containing alloy 2618 is the same as that of alloy 2618. When homogenized at 773 K, the optimized homogenization time is only 12 h, which is shorter than that of alloy 2618.

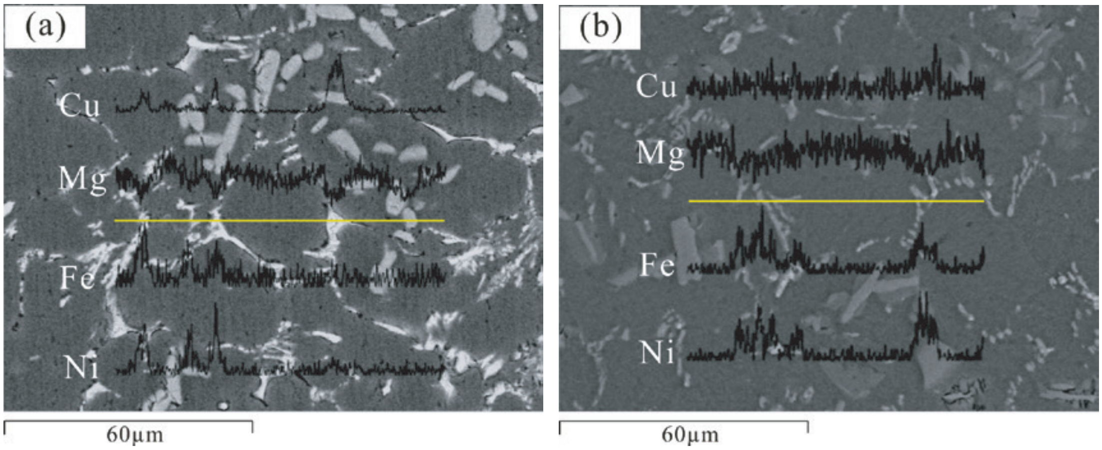

Fig. 6: Line-scan analysis of Ti-containing alloy 2618 before and after homogenization: (a) As cast alloy; (b) The alloy homogenized at 773 K for 12 h

4. The shortened holding time for homogenization of Ti-containing alloy 2618 can be attributed to the grain refining effect of Ti addition to alloy 2618.

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