



Homogenization treatment of Mg–6Zn–3Sn (wt.%) alloy and its effects on microstructure and mechanical properties

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Abstract: With DSC, OM, XRD, SEM, TEM, Vickers hardness tester, and universal testing machine, the evolution of the microstructure and mechanical properties of Mg–6Zn–3Sn alloy during homogenization was studied, the reason for overburning and diffusion kinetics of the alloy were analyzed, and the homogenization scheme was determined. The results show that the decomposition of the Mg_2Zn_3 phase, accompanied by the precipitation of the Mg_2Sn phase, occurs after the single-stage homogenization. When the homogenization temperature increases to 350 °C, the Mg_2Zn_3 phase leads to overburning. The suitable homogenization scheme for the alloy is (335 °C, 24 h) + (400 °C, 6 h). During the double-stage homogenization, the hardness of the alloy decreases continuously and the mechanical properties show an increase first and then decrease, which is related to the solid solution of Zn and Sn atoms and the precipitation of the Mg_2Sn phase.

Key words: ZT63 magnesium alloy; homogenization; microstructure; diffusion kinetics; mechanical properties

1 Introduction

As instruments and equipment develop toward miniaturization, precision and integration, the demand for low-cost lightweight materials with integrated structure and function is becoming more and more urgent. Magnesium alloys have the advantages of low density, high specific strength and specific stiffness, good damping and electromagnetic shielding properties, and have important applications in aerospace, automotive, and national defense [1–3].

Mg–Zn–Sn magnesium alloys are typical age-hardenable wrought alloys [4]. During aging, a high-density Mg–Zn phase will precipitate, thereby improving the mechanical properties of the

alloy [5–7]. Meanwhile, the thermally stable Mg_2Sn phase will also precipitate in this process, resulting in precipitation strengthening and improving the heat resistance of the alloy [8–10]. In addition, Sn elements can also improve the formability of the alloy [11]. Compared with rare earth magnesium alloy, Mg–Zn–Sn magnesium alloys also have the advantage of low cost, and their research and development are of high significance for broadening the application space of magnesium alloys.

Homogenization treatment is a key step before alloy deformation, which can eliminate the dendritic segregation, reduce the deformation resistance, and prepare the structure for the alloy deformation and the precipitation of the strengthening phase [12,13]. QI et al [14] kept the

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ZTM641 alloy at 330 °C for 24 h and found that only the Mg–Zn phase decomposed, while the Mg_2Sn phase remained in large quantities. WEI et al [15] conducted a two-stage homogenization treatment on ZT43 alloy and achieved a good homogenization effect. In addition, recent studies have shown that Sn-containing magnesium alloys are very prone to overburning during homogenization [16]. At present, the study of Mg–Zn–Sn alloys has focused more on their deformation microstructure, and the systematic study of their homogenization process is relatively rare. Accordingly, it is particularly crucial to study the homogenization process of Mg–Zn–Sn alloys in-depth, optimize their homogenization system, so as to prepare the microstructure for the subsequent deformation of the alloy. On this basis, in this study, Mg–6Zn–3Sn (ZT63) alloy was taken as the research object, the homogenization system of the alloy and the microstructure evolution during homogenization were investigated, the effects of different homogenization treatments on the hardness and mechanical properties of the alloy were explored, and the homogenization diffusion kinetics was analyzed, which presented the data and theoretical support for the homogenization treatment of Mg–Zn–Sn alloys.

2 Experimental

2.1 Material preparation

The Mg–6Zn–3Sn (wt.%) ingot was prepared by melting pure magnesium, pure zinc and pure tin in a medium frequency induction furnace under a mixed atmosphere of R-134a and Ar with the ratio of 1:20, and then cooled in water. The detailed procedures for alloy preparation are shown in Fig. 1, Inductively coupled plasma-atomic emission spectrometry (ICP-AES) was adopted to analyze the composition of the ingot. The designed composition and measured composition of the alloy are listed in Table 1.

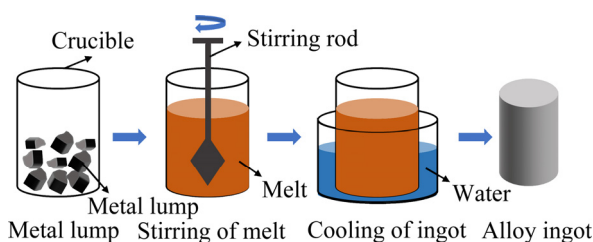


Fig. 1 Schematic diagram of alloy preparation

Table 1 Chemical composition of ZT63 alloy (wt.%)

Zn	Sn	Mg
5.82	3.36	Bal.

2.2 Experimental method

The metallographic etchant for the alloy was 4% nitric acid alcohol. The metallographic photographs of the alloy were observed with a Carl Zeiss Axiovet2000MAT metallurgical microscope, and the grain size was counted with the linear intercept method based on metallographic photographs. A Smartlab X-ray diffractometer was adopted to analyze the phase in the alloy. The microstructure of the alloy was observed on a JSM–7900F scanning electron microscope, and the micro-area composition was examined with EDS. The second phase in the alloy was further studied under the Tecnai–G2–F20 field emission transmission electron microscope. The hardness of the alloy was tested with the Wilson VH1150 Vickers hardness tester. The respective sample was tested five times, and the average value was taken. The tensile properties for the alloy were obtained by a SANS universal testing machine. Cylindrical samples of 3 mm in diameter and 15 mm in gauge length were used for tensile tests. Three tests were performed, and the strength and elongation were taken from the mean values. The DSC was performed on the SDT–Q600 simultaneous thermal analyzer, the protective gas was Ar, the heating rate was 10 °C/min, and the temperature range was 25–600 °C. The DSC curve of the as-cast alloy obtained is presented in Fig. 2.

The DSC curve of the as-cast ZT63 alloy displayed an endothermic peak in the range of

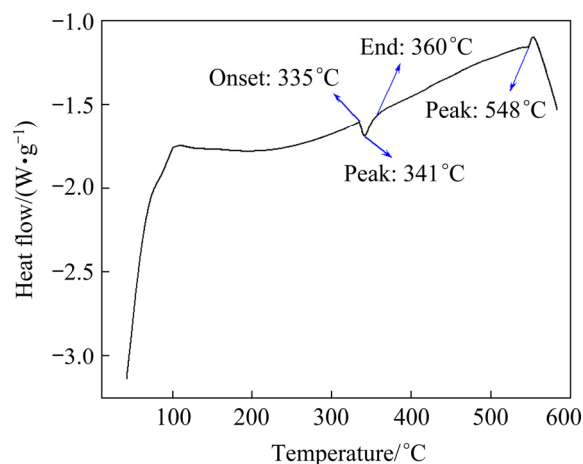


Fig. 2 DSC curve of as-cast ZT63 alloy

335–360 °C, and there was also a slight endothermic peak near 548 °C. Based on the phase diagram of Mg–Zn–Sn ternary alloy [17], the elements Zn and Sn did not form ternary phase with Mg, whereas it formed Mg–Zn binary phase and Mg–Sn binary phase with Mg, respectively. Mg–Zn phase showed a lower melting point, while Mg–Sn phase had a higher melting point. Thus, 335–360 °C corresponded to the phase transition temperature of Mg–Zn phase, and 548 °C was the phase transition temperature of Mg–Sn phase. For an alloy with two endothermic peaks, a single-stage homogenization treatment may not enable the alloy to obtain a good homogenization effect, and overburning was extremely easy to occur. Accordingly, based on the empirical formula $T=(0.9-0.95)T_m$, the homogenization system was preliminarily formulated. First, the first-stage homogenization temperature was set to be 320, 335, 350 and 365 °C, and the holding time reached 12 and 24 h, respectively. Based on the optimization of the single-stage heat treatment system, the second-stage homogenization temperature was set to be 370, 380, 390, 400 and 420 °C, and the holding time reached 2, 6, and 12 h, respectively. Though the phase transition temperature of the Mg–Sn phase was high, the overflow of Sn atoms could cause the oxidation and overburning [16], so the second-stage homogenization temperature should not be overly high. In this study, the highest second-stage homogenization temperature was set to be 420 °C.

3 Results

3.1 As-cast structure of alloy

Figure 3 presents the metallographic photograph and XRD pattern of as-cast ZT63 alloy. According to Fig. 3(a), the as-cast structure of the alloy comprises α -Mg matrix and eutectic structure distributed on the grain boundaries. The grain size of alloy is about 38 μm . XRD pattern in Fig. 3(b) reveals that besides the α -Mg matrix, the phases in the alloy are the Mg_2Zn_3 phase and Mg_2Sn phase.

Figure 4 presents the SEM image and EDS mapping images of the as-cast alloy. As indicated from the figure, the bulk phase (marked as A) is mainly rich in Sn, and the skeletal eutectic structure (marked as B and C) is mainly rich in Zn. Table 2 lists the EDS analysis results of as-cast alloy. The

atomic ratio of Mg to Zn in the skeletal phase is about 2:3, and the ratio of Mg to Sn atoms in the bulk phase is close to 1:2. Figure 5 gives the TEM images of the as-cast ZT63 alloy. As shown in Fig. 5(a), the skeletal phase is the Mg_2Zn_3 phase, which has a triclinic structure. Figure 5(b) reveals that the bulk structure is the Mg_2Sn phase, which has a FCC structure.

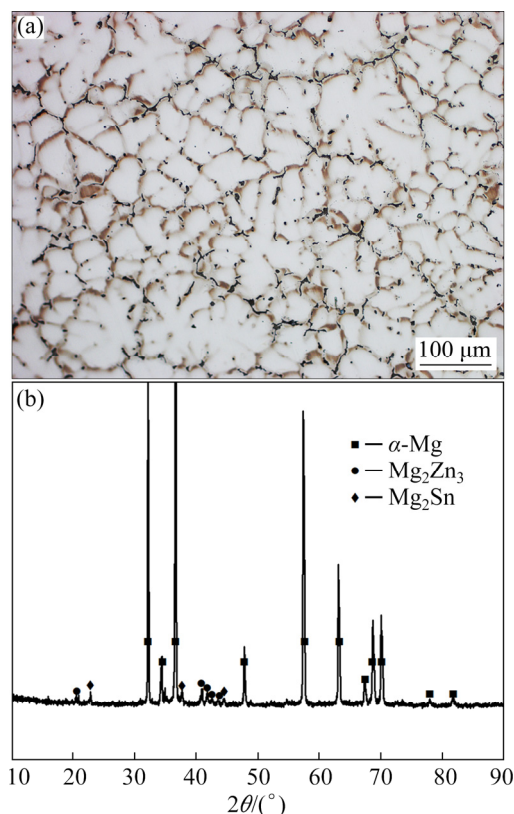


Fig. 3 Metallographic photograph (a) and X-ray diffraction pattern (b) of as-cast ZT63 alloy

3.2 Single-stage homogenization

Figure 6 illustrates the metallographic structure of ZT63 alloy with different single-stage homogenization treatments. As revealed from the figure, after keeping the alloy at 320 °C for 24 h, the coarse eutectic structure is greatly reduced, whereas some unresolved Mg_2Zn_3 and Mg_2Sn phases remain. When the homogenization temperature increases to 335 °C, the Mg_2Zn_3 phase gradually disappears, but some Mg_2Sn phases still fail to decompose. Moreover, during the homogenization process, considerable fine dot-like particles precipitate, which are distributed near the grain boundary. As the homogenization temperature increases, the number and size of precipitates tend to decrease. Since the Mg_2Zn_3 phase can dissolve at

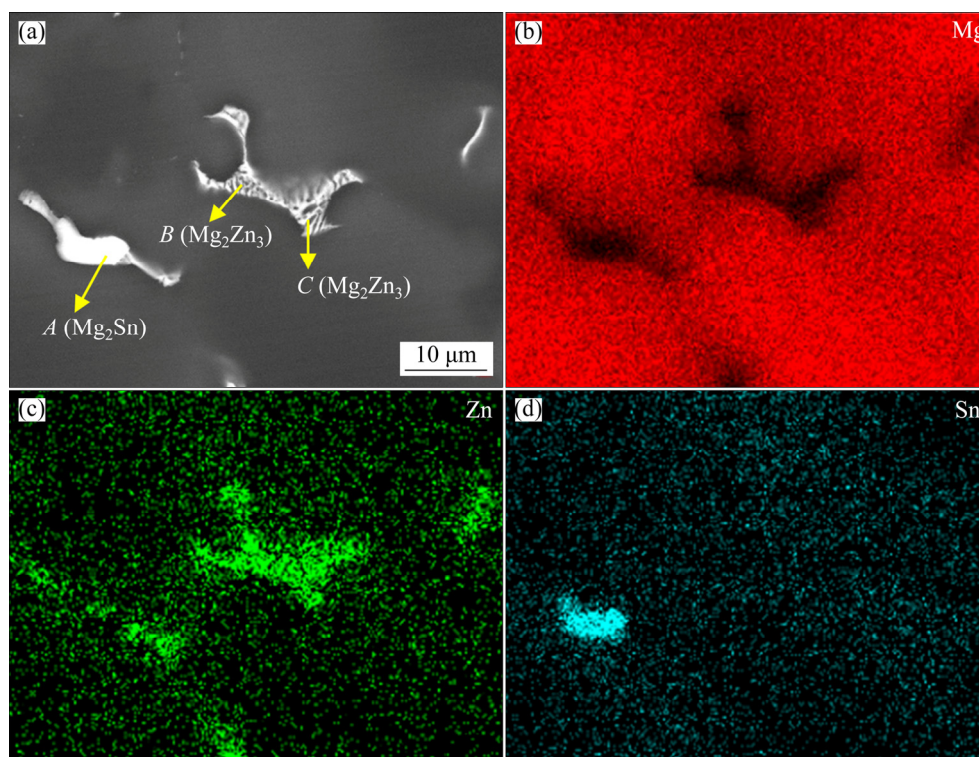


Fig. 4 SEM image and EDS mapping images of as-cast ZT63 alloy: (a) SEM image; (b) Mg; (c) Zn; (d) Sn

Table 2 EDS analysis results of as-cast ZT63 alloy at different positions in Fig. 4(a)

Position	Molar fraction/%			Phase
	Zn	Sn	Mg	
A	0.23	28.66	71.11	Mg ₂ Sn
B	63.12	0.21	36.67	Mg ₂ Zn ₃
C	61.72	0.29	37.99	Mg ₂ Zn ₃

this temperature, the precipitated particle is relatively stable, which is presumed to be the Mg₂Sn phase. When the homogenization temperature rises to 350 °C, with the extension of time, the size of the precipitated phase is reduced, and overburning occurs after the holding time reaches 12 h. As the homogenization temperature increases to 365 °C, serious overburning is found at the eutectic compounds, which becomes severe with the prolongation of holding time.

To further confirm the precipitated phases and the cause of alloy overburning, the microstructure of the homogenized alloy is analyzed by SEM and TEM. Figure 7 shows the SEM image and corresponding EDS mapping images of the alloy after the first-stage homogenization treatment (335 °C, 24 h). According to Fig. 7, Zn elements

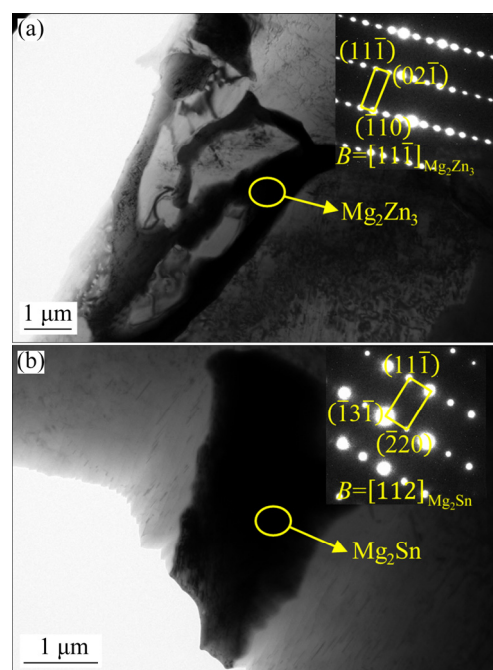


Fig. 5 TEM images of as-cast ZT63 alloy: (a) Mg₂Zn₃ phase (inset: SEAD pattern of Mg₂Zn₃ phase); (b) Mg₂Sn phase (inset: SEAD pattern of Mg₂Sn phase)

are uniformly distributed in the alloy, which demonstrates that the segregation of the Zn elements is eliminated. Moreover, considerable Sn elements are still segregated in the Mg₂Sn phase.

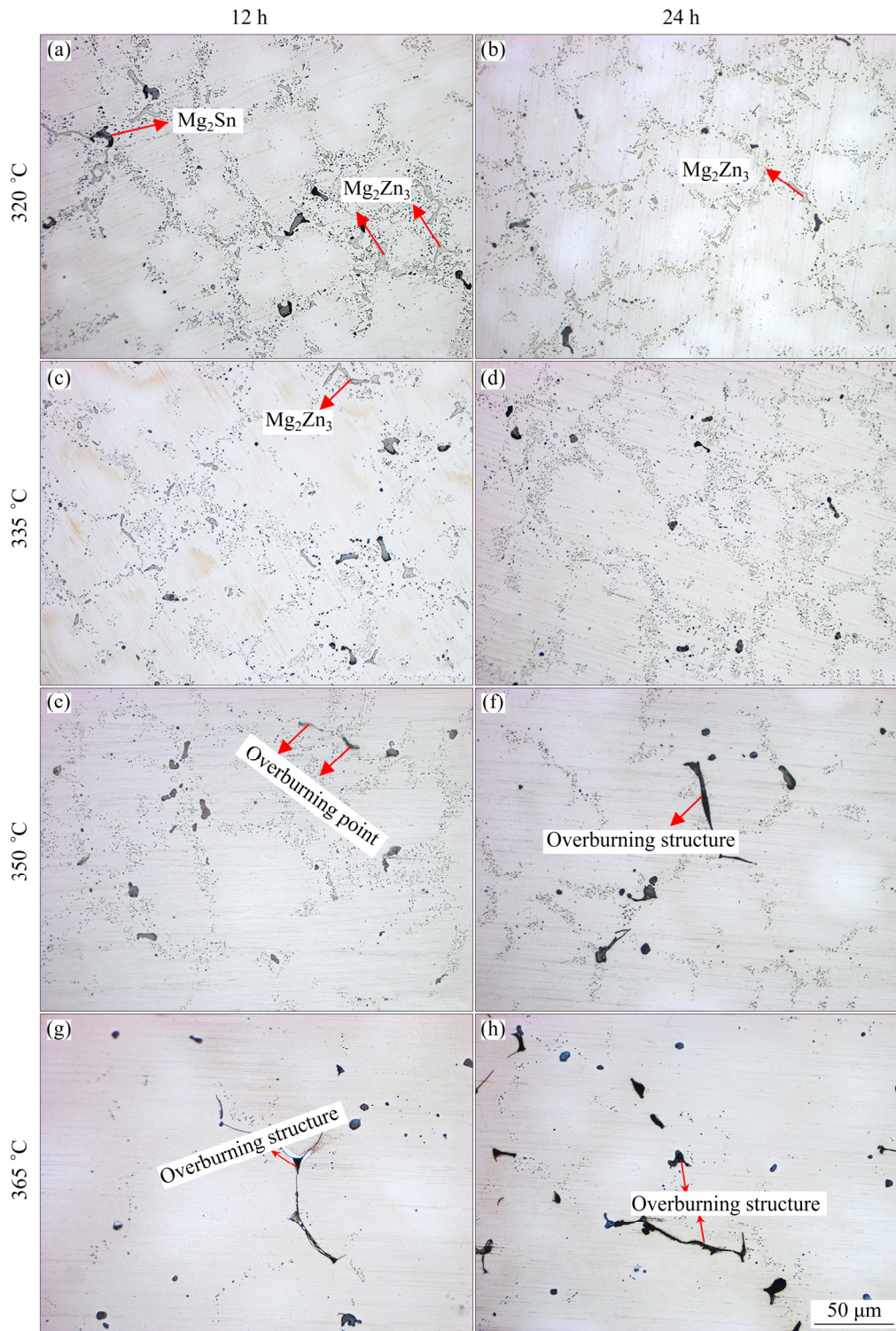


Fig. 6 Metallographic photographs of ZT63 alloy after single-stage homogenization treatment: (a) 320 °C, 12 h; (b) 320 °C, 24 h; (c) 335 °C, 12 h; (d) 335 °C, 24 h; (e) 350 °C, 12 h; (f) 350 °C, 24 h; (g) 365 °C, 12 h; (h) 365 °C, 24 h

Therefore, the homogenization temperature should be continuously elevated to promote the dissolution of the Mg_2Sn phase. According to the high-magnification SEM image in Fig. 7(a), the precipitated phases are rod-shaped with different sizes. Figure 8 presents the TEM bright-field image

of the precipitated phase and its corresponding selected area electron diffraction pattern. The TEM image indicates that the precipitated phases are mainly short rods with different length-to-diameter ratios, and the phase size is roughly on the order of microns. According to the SEAD pattern in

Fig. 8(b), this phase is Mg_2Sn with a cubic structure, and its lattice constant is $a=0.6763$ nm. Such a result is consistent with the research of NIE et al [18] and SASAKI et al [19]. 335°C is relatively low compared with the dissolution temperature of Mg_2Sn phase, so the massive Mg_2Sn phase formed during the solidification process fails to decompose. However, this temperature is sufficient to enable the Mg_2Sn phase to obtain sufficient precipitation driving force. Besides, the precipitated Mg_2Sn phase grows continuously under the influence of temperature, so the phase gradually coarsens and reaches the micron level.

The SEM image and corresponding EDS mapping images of the overburning structure are illustrated in Fig. 9. According to Fig. 9(a), typical overburning structures appear at the original eutectic structure. As revealed from the EDS mapping images, considerable oxygen is enriched at the overburning structure, Zn elements are evenly distributed in the matrix, and Sn elements concentrate in the Mg_2Sn phase. When the homogenization temperature is high, the low melting point Mg_2Zn_3 phase does not have enough time to decompose, thereby causing the occurrence of overburning. The Mg_2Sn phase has a high melting

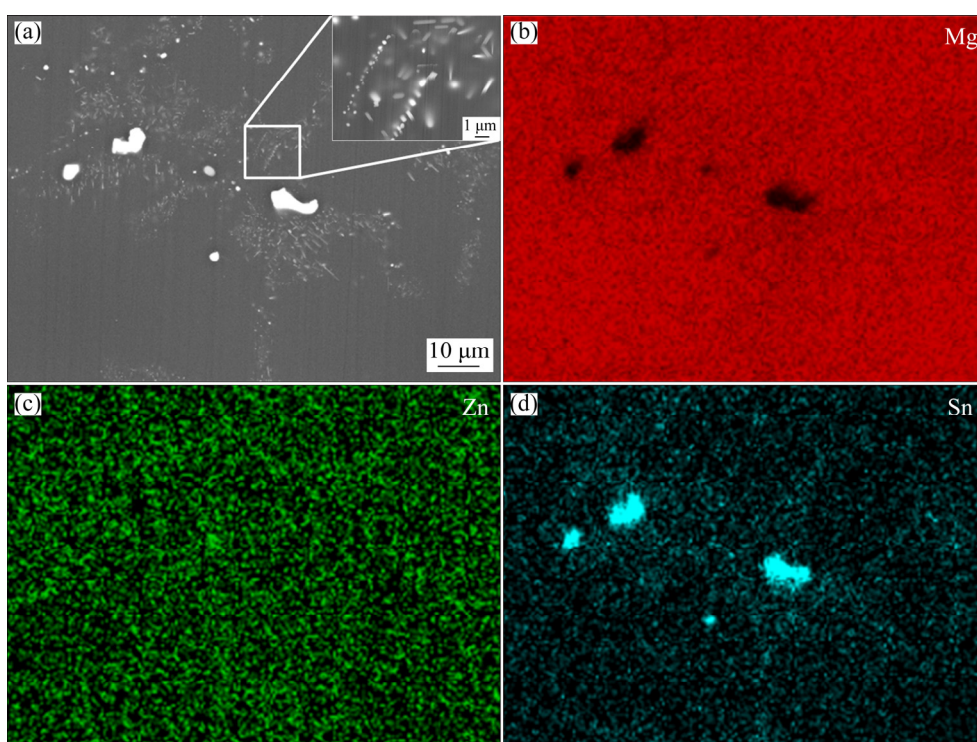


Fig. 7 SEM image and corresponding EDS mapping images of ZT63 alloy after single-stage homogenization (335°C , 24 h): (a) SEM image (inset: high magnification image of Mg_2Sn phase); (b) Mg; (c) Zn; (d) Sn

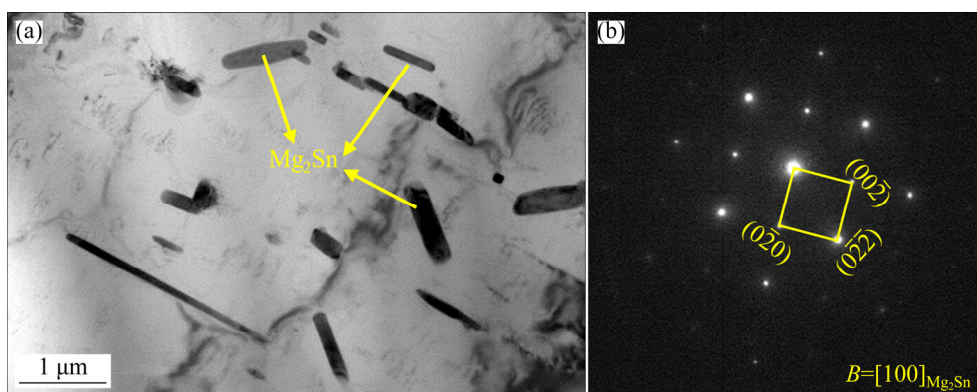


Fig. 8 TEM images of ZT63 alloy after single-stage homogenization treatment (335°C , 24 h): (a) Bright-field image of precipitated phase; (b) SEAD pattern of precipitated phase

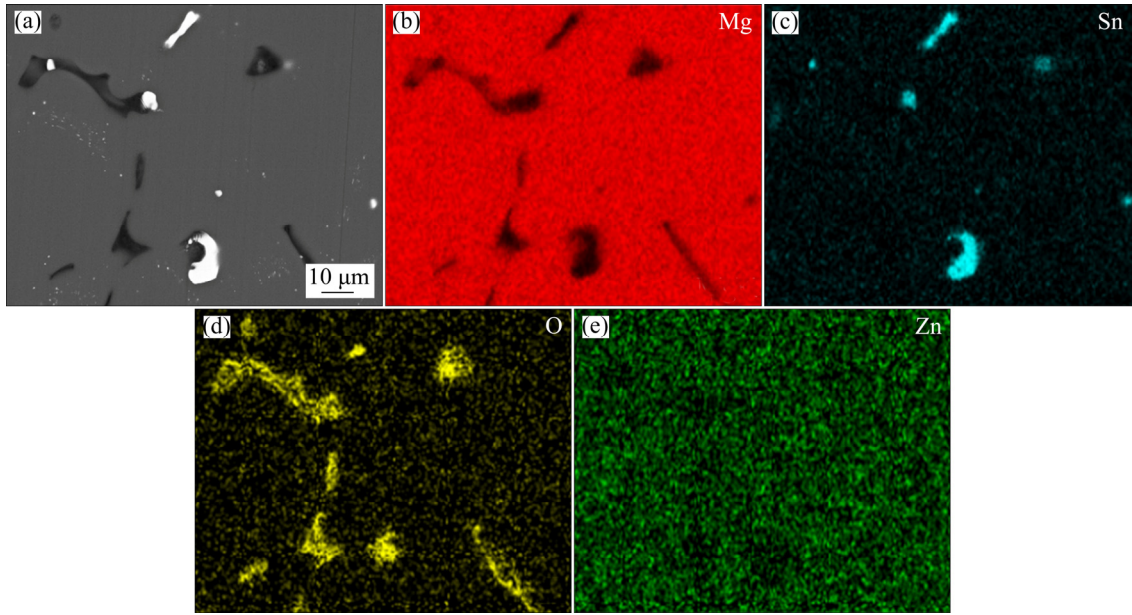


Fig. 9 SEM image and corresponding EDS mapping images of ZT63 alloy after single-stage homogenization treatment (365 °C, 24 h): (a) SEM image; (b) Mg; (c) Sn; (d) O; (e) Zn

point and remains during this process. Thus, the single-stage homogenization treatment can not realize the simultaneous dissolution of the two phases, and improper treatment is easy to cause overburning.

3.3 Analysis of diffusion kinetics

To more effectively optimize the homogenization scheme of the alloy, the homogenization process of the alloy is analyzed from the perspective of diffusion kinetics. In the as-cast structure with segregation, the concentration of alloying elements varies periodically among dendrites. The distribution of segregated elements in as-cast alloys could be approximated by the Fourier series of a cosine function, as expressed by the following equations [20,21]:

$$C(x) = \bar{C} + A_0 \cos(2\pi x/L) \quad (1)$$

$$A_0 = 1/2(C_{\max} - C_{\min}) = 1/2\Delta C_0 \quad (2)$$

where $C(x)$ denotes the element concentration at position x ; $\bar{C}$ represents the average concentration of alloying elements after the complete homogenization; A_0 expresses the initial amplitude of component segregation in the as-cast alloy; ΔC_0 is the element concentration difference between the grain boundary ($C_{\max}$) and the grain ($C_{\min}$) in the as-cast alloy; L denotes the distance between dendrites. According to Fick's second law and the

boundary conditions for the homogenization of component segregation, Eq. (3) is obtained [22]:

$$C(t) = A_0 \exp\left(-\frac{4\pi^2 D t}{L^2}\right) \quad (3)$$

Moreover, diffusion coefficient $D = D_0 \exp[-Q/(RT)]$, and Q is the activation energy of atom diffusion. By substituting the diffusion coefficient D into Eq. (3), it yields:

$$C(t) = A_0 \exp\left(-\frac{4\pi^2 D_0 t}{L^2} \exp\left(-\frac{Q}{RT}\right)\right) \quad (4)$$

It is generally considered that the alloy composition was reduced to 1% A_0 [21,23], i.e., $C(t) = 1/100 A_0$, and the homogenization is completed. Subsequently, Eq. (4) is rewritten as

$$\exp\left(-\frac{4\pi^2 D_0 t}{L^2} \exp\left(-\frac{Q}{RT}\right)\right) = \frac{1}{100} \quad (5)$$

Further simplification can be obtained:

$$T = \frac{Q}{R} \cdot \frac{1}{\ln[2\pi^2 D_0 / (L^2 \ln 10)]} \quad (6)$$

At the initial stage of homogenization, the segregation of Zn elements can be a typical feature in the as-cast structure, and the first-stage homogenization also aims to achieve the uniform dispersion of Zn atoms. Accordingly, the first-stage homogenization of the alloy is assessed by the

diffusion of Zn. As revealed from the literature, the diffusion constant and diffusion activation energy of Zn are $D_0(\text{Zn})=0.41 \times 10^{-4} \text{ m}^2/\text{s}$, $Q(\text{Zn})=119.7 \text{ kJ/mol}$ [24]. By substituting the diffusion constant, diffusion activation energy and the gas constant $R (=8.314 \text{ J}/(\text{mol} \cdot \text{K}))$ into Eq. (6), the relationship between homogenization temperature, time, and dendrite spacing of the cast alloy can be obtained:

$$T = \frac{14397}{\ln(3.5 lt/L^2)} \quad (7)$$

Figure 10 presents the homogenization kinetic curves of ZT63 alloy with different dendrite spacings obtained according to Eq. (7).

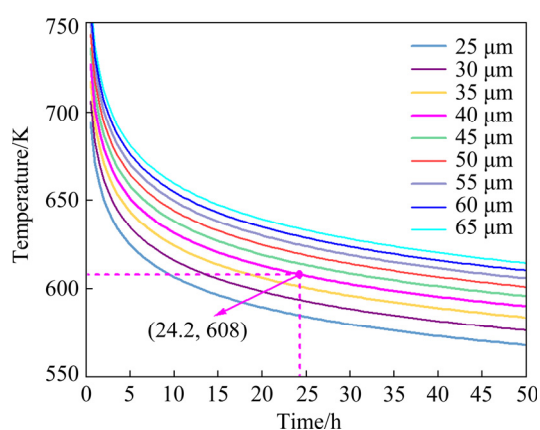


Fig. 10 Diffusion kinetic curves during homogenization of ZT63 alloy

Given the diffusion kinetic curves of the alloy, increasing the homogenization temperature will shorten the homogenization treatment time, and extending the homogenization time can facilitate the elimination of segregation. With the increase in the dendrite spacing, a higher homogenization temperature and a longer homogenization time will be required. The diffusion kinetic curves of ZT63 alloy also indicate that when the grain size of the alloy is about $40 \mu\text{m}$, a good homogenization effect can be obtained by holding the alloy at 335°C for 24 h, which is in good agreement with the experimental results in this work, i.e., the Mg_2Zn_3 phase can be fully dissolved in homogenization treatment at 335°C for 24 h.

3.4 Double-stage homogenization

As suggested from the results above, when the first-stage homogenization scheme was set to be 335°C , 24 h, Mg_2Zn_3 can be fully redissolved, but

considerable Mg_2Sn phases precipitate. To achieve the dissolution of the precipitates, the second-stage homogenization scheme is performed. The microstructures of the alloy obtained after different second-stage homogenization treatments are shown in Fig. 11. According to the figure, with the increase in the homogenization temperature and the extension of the holding time, the size of Mg_2Sn phase turns finer, and the proportion of the massive Mg_2Sn phase formed during the solidification process tends to decrease. When the alloy is homogenized at $370\text{--}390^\circ\text{C}$ for 12 h, a small amount of Mg_2Sn precipitates can still be found at the grain boundaries. When the homogenization temperature increases to 400°C , the precipitates disappear rapidly, and the massive Mg_2Sn phase decreases significantly. When the holding time is 6 h, and the variation is limited with the extension of time. When the homogenization temperature increases to 420°C , the alloy can achieve a good homogenization effect after holding the alloy for 2 h, and after continuing to keep it for 12 h, the massive Mg_2Sn phase cannot completely decompose, and surface oxidation is serious. Some studies suggested that the $\beta\text{-Sn}$ phase is easy to form during homogenization of Sn-containing magnesium alloy, thereby causing oxidation of the alloy surface [16]. Thus, the homogenization temperature of Sn-containing alloys should not be too high. Moreover, the incomplete resolution of the Mg_2Sn phase is also a common phenomenon in Sn-containing alloys. If just considering the microstructure after homogenization, the second-stage homogenization scheme can be set as 420°C , 2 h, which is suitable for small-sized ingots. For large-sized ingots, however, the heat is transferred from the surface to the core, which takes a period of time. When the core of the ingot reaches the temperature, the surface of the ingot has already been kept at a high temperature for some time. So, when the core reaches the best state, the homogenization time of the ingot surface is much longer than 2 h, i.e., the tendency of overburning is increased. Therefore, to ensure the homogenization quality of the ingot, and take into account the economy, the temperature of the second-stage homogenization is determined to be 400°C . On the whole, the suitable homogenization scheme for the alloy is suggested to be $(335^\circ\text{C}, 24 \text{ h}) + (400^\circ\text{C}, 6 \text{ h})$.

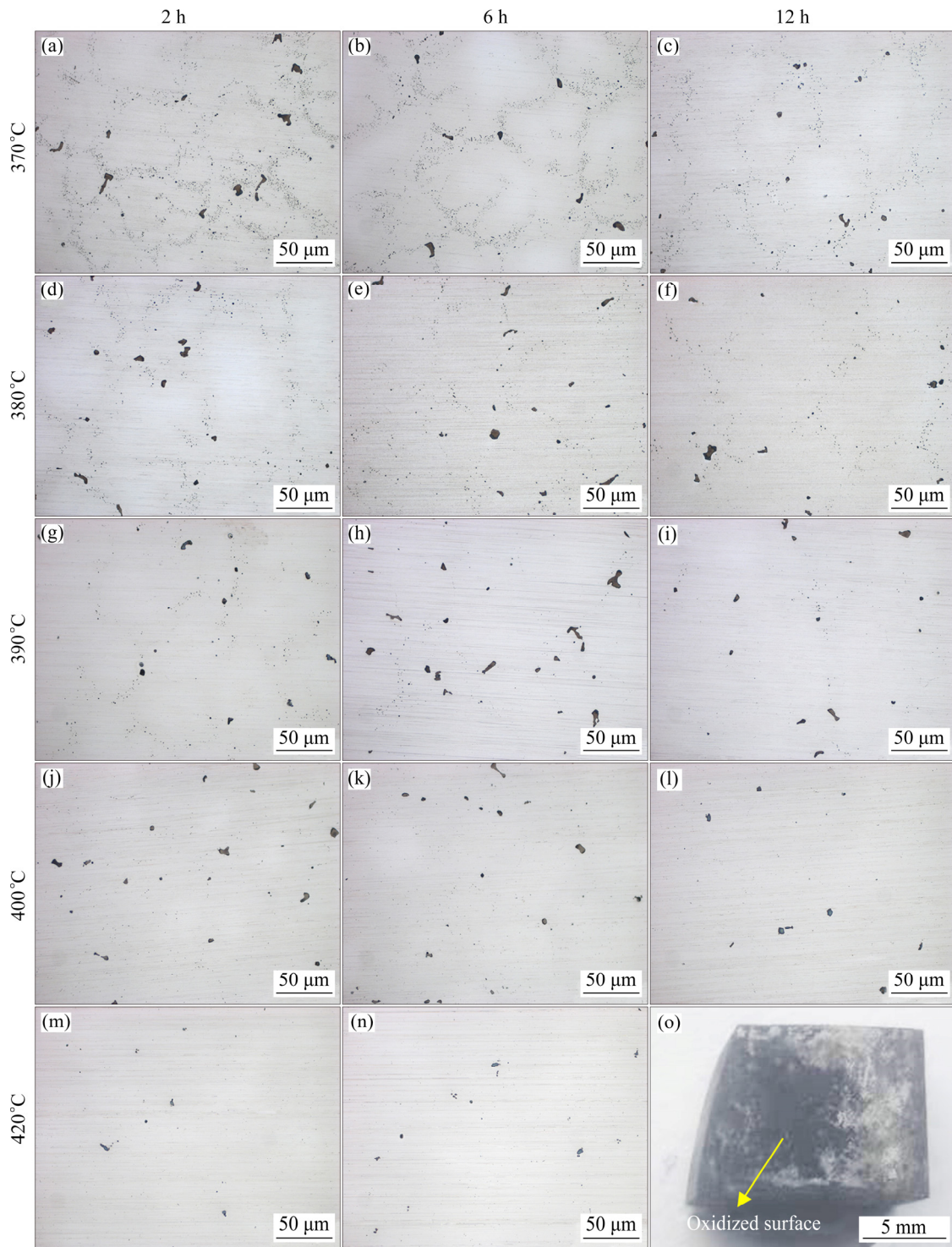


Fig. 11 Metallographic photographs of ZT63 alloy after second-stage homogenization: (a) 370 °C, 2 h; (b) 370 °C, 6 h; (c) 370 °C, 12 h; (d) 380 °C, 2 h; (e) 380 °C, 6 h; (f) 380 °C, 12 h; (g) 390 °C, 2 h; (h) 390 °C, 6 h; (i) 390 °C, 12 h; (j) 400 °C, 2 h; (k) 400 °C, 6 h; (l) 400 °C, 12 h; (m) 420 °C, 2 h; (n) 420 °C, 6 h; (o) Macrostructure photo of sample homogenized at 420 °C, 12 h

3.5 Effects of homogenization on mechanical properties

Figure 12 presents the variation of the alloy hardness during the double-stage homogenization.

After the first-stage homogenization, the hardness of the alloy shows a decrease compared to the as-cast alloy, due to the dissolution of the Mg_2Zn_3 phase. At the same time, the release of casting

stress is also one of the important reasons for the decrease of alloy hardness. Moreover, the precipitation of the Mg_2Sn phase consumes the solid-solution Sn atoms in the matrix, which also results in the decrease of the alloy hardness. In the second-stage homogenization, with the extension of time, the hardness of the alloy continues to decline, and with the increase of homogenization temperature, the tendency for the alloy hardness to decline increases. There are two reasons for this phenomenon. On the one hand, the eutectic structure in the alloy has greatly dissolved at this time, the resistance to the diffusion of Zn and Sn atoms is reduced, and it is easier for the atoms to diffuse to bring the alloy composition into an equilibrium state, resulting in a rapid decrease in alloy hardness; on the other hand, as the homogenization temperature increases, the driving force for the diffusion of Zn and Sn elements increases, and the diffusion rate accelerates, leading to an increasing trend of decline in alloy hardness. After holding the alloy at 420°C for 2 h, the hardness of the alloy drops to a level close to that at 400°C for 6 h. Therefore, 400°C , 6 h can act as an ideal second-stage homogenization scheme.

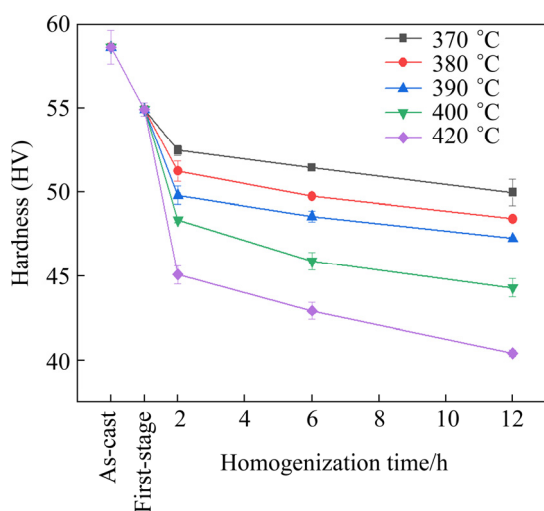


Fig. 12 Hardness variation curves of ZT63 alloy during homogenization

The mechanical properties of the alloy in different states are shown in Fig. 13. After the first-stage homogenization treatment, the mechanical properties of the alloy are improved. This is because the decomposition of coarse eutectic structures reduces the stress concentration. At the same time, the Zn atoms dissolve into the matrix, the rod-like Mg_2Sn phase precipitates, and the

combined effect of solid solution strengthening and precipitation strengthening improves its mechanical properties. After the second-stage homogenization, the mechanical properties of the alloy decrease. During this process, although the solid solution of Sn atoms generates a certain solid solution strengthening effect, the precipitated Mg_2Sn phase decomposes and the hindering effect of the second phase on dislocation movement is weakened, so the mechanical properties of the alloy decrease again.

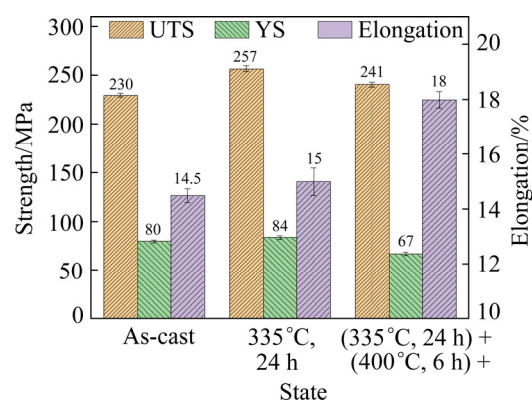


Fig. 13 Mechanical properties of ZT63 alloy in different states

4 Discussion

The schematic diagram for microstructure evolution of the alloy during homogenization is presented in Fig. 14. During the homogenization process of ZT63 alloy, asynchronous re-dissolution of the Mg_2Zn_3 phase and Mg_2Sn phase occurs, due to the large difference in melting point between the two phases. When the homogenization temperature is 335°C , the high concentration of Zn atoms near the grain boundary obtains enough driving force to diffuse into the matrix. With the extension of time, the dynamic equilibrium of Zn elements between the grain boundary and the intragranular zone is gradually achieved. However, the Mg_2Sn phase has a high melting point and exhibits good structural stability [25]. At this temperature, the Mg_2Sn phase cannot be redissolved. In addition, because the diffusion rate of Sn atoms is much slower than that of Zn [26], the content of Sn atoms near the grain boundaries is higher, and coupled with the higher heat treatment temperature, the Mg_2Sn phase precipitates. When there are eutectic phases with different melting points in the alloy, increasing the homogenization temperature or prolonging the

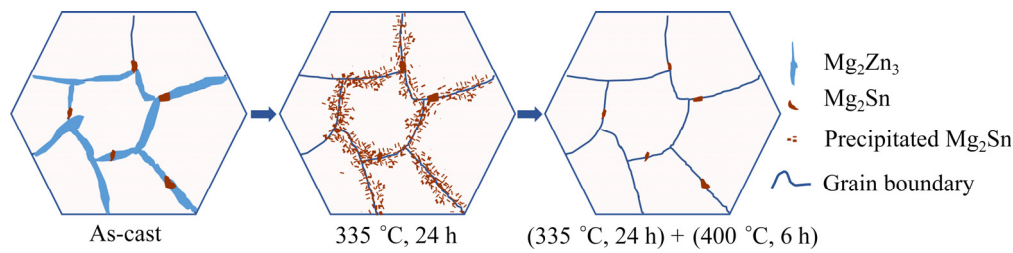


Fig. 14 Schematic diagram for microstructure evolution of ZT63 alloy during two-stage homogenization heat treatment

homogenization time cannot effectively reduce the segregation of the alloy, and even can lead to overburning. Double-stage or even multi-stage homogenization schemes should be developed to achieve a good homogenization effect. In particular, for Sn-containing alloys, promoting the redissolution of Sn atoms as much as possible during homogenization will facilitate the dynamic precipitation of the fine Mg_2Sn phase during extrusion [27], thus improving the mechanical properties of the extruded alloy.

5 Conclusions

(1) The as-cast ZT63 alloy has severe dendrite segregation, and its microstructure comprises α -Mg matrix, Mg_2Zn_3 phase, and Mg_2Sn phase.

(2) Good homogenization effect can be achieved by the double-stage homogenization treatment of (335 °C, 24 h) + (400 °C, 6 h). During the first-stage homogenization, the Mg_2Zn_3 phase is dissolved, and the rod-like Mg_2Sn phase precipitates. The Mg_2Sn phase is greatly reduced during the second-stage homogenization treatment.

(3) During the homogenization process, the hardness of the alloy decreases continuously, and the higher the temperature is, the greater the decreasing trend of the hardness will be.

(4) After the first-stage homogenization treatment, the mechanical properties of the alloy are improved due to the effect of solid solution strengthening and precipitation strengthening. After the second-stage homogenization treatment, the mechanical properties of the alloy are reduced because of the disappearance of precipitation strengthening.

Acknowledgments

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Mg–6Zn–3Sn 合金的均匀化热处理及其对显微组织和力学性能的影响

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摘要: 利用 DSC、OM、XRD、SEM、TEM、维氏硬度计和万能试验机, 研究 Mg–6Zn–3Sn 合金均匀化过程中的显微组织和力学性能演变, 分析合金过烧的原因和扩散动力学, 确定合金的均匀化制度。结果表明, 单级均匀化处理后, Mg₂Zn₃ 相分解, 同时伴随着 Mg₂Sn 相的析出。当均匀化温度上升到 350 °C 时, Mg₂Zn₃ 相导致合金的过烧。合金合适的均匀化制度为 (335 °C, 24 h) + (400 °C, 6 h)。在双级均匀化过程中, 合金的硬度持续下降, 力学性能呈现先升后降的趋势, 这与 Zn 和 Sn 原子的固溶和 Mg₂Sn 相的析出有关。

关键词: ZT63 镁合金; 均匀化; 显微组织; 扩散动力学; 力学性能

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