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Structural evolution of ZA27 alloy during semi-solid isothermal heat treatment ①

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[Abstract] The structural evolution of ZA27 alloy modified by element Zr was studied during semi-solid isothermal heat treatment, and its transformation mechanism was also discussed. The results indicate that the primary α phase changes from equiaxed grains to spherical grains gradually at semi-solid temperature of 460 ℃. With increasing isothermal time, the eutectic between boundaries of α phase diffuses toward α phase, and the primary equiaxed grain arms merge and boundaries tend to disappear to form near particle grains. Further, the eutectic left on α boundaries melts to make the near particle grains separate, and form spherical structure at last.

[Key words] ZA27 alloy; semi-solid state; isothermal heat treatment; structural evolution; spherical structure

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1 INTRODUCTION

Semi-solid forming has a wide use for its improving product quality and decreasing costs[1~3]. It is composed of three main processes, such as semi-solid material production, partial remelting and thixoforming. Among those, the semi-solid billet production is the most important one. At present, the methods of obtaining semi-solid billet with non-dendritic microstructure include mechanical stirring (MS)[4], electromagnetic stirring (ES)[5,6], strain-induced melt activation (SIMA)[7], spray deposition (SD)[8] and liquidus cast[9]. MS is easy to cause melt contamination[4], ES needs complicated equipment and high investment[5,6], SIMA can only produce small castings[7], SD has no good serviceability and controllability[8,9], by which their applications in industrial production were limited.

Semi-solid isothermal heat treatment is a new way being found in the middle 1990s, which omitted the special procedure to fabricate the semi-solid billet but fulfil the semi-solid non-dendritic microstructure during heating prior to thixoforming[10,11]; however the details and mechanism of its structural evolution was still unknown[11]. In the present work, experiments on ZA27 alloy modified by element Zr are performed to observe its structural evolution during isothermal heat treatment at semi-solid temperature of 460 ℃, and special attention has been focused on the mechanism of its structure sphericizing.

2 EXPERIMENTAL

The nominal composition of ZA27 alloy used for the experiment was 26%~28% Al, 1.7%~2% Cu, 0.02%~0.04% Mg (mass fraction), with a balance of Zn. ZA27 was remelted and degassed by using C_2Cl_6, and then heated to 640 ℃ to modify with 0.4% Zr, followed to be poured into permanent mold at 550 ℃. Sample was then cut into small specimens and put into a chamber of resistance furnace with a power of 4 kW at 460 ℃ to be held for 5 min, 8 min, 10 min, 13 min, 15 min, 20 min, 30 min, 40 min, 60 min and 80 min respectively, and then taken out for water quenching quickly. These small specimens were polished and etched by 4% HNO_3 aqueous solution to examine the microstructure transformation and composition change using Mef-3 optical microscope and S-520 scanning electron microscope. The composition changes of its structures were also examined by EDAX. Each structure composition was measured for three times and their average value was taken as the final results.

3 RESULSTS AND DISCUSSION

3.1 Structural evolution of ZA27 alloy during isothermal heat treatment

Fig. 1 shows the structural evolution process of ZA27 alloy during isothermal heat treatment at semi-solid temperature of 460 ℃. The primary phase of as-cast ZA27 alloy modified by Zr is small equiaxed

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grains (see Fig. 1(a)). During the initial period of heat treatment, the grain size and morphology have no obvious change, but the white α phase tends to decrease, and this phenomenon is obvious after being held for 8 min. Its arms merged to form near particle grains and boundaries become narrow (see Fig. 1 (b)). When the time reaches 10 min, the boundaries almost disappear and some of α phases occasionally distribute in flat gray structure with a few discontinuous boundaries (see Fig. 1(c)). With increasing isothermal time, the α phase has disappeared completely and the boundaries begin to increase and lead the structure to be separated. In some regions the boundaries link up to form particle grains (as shown in Fig. 1(d)). While the isothermal time reaches 20 min, its structure has separated completely and become independent particles and then transformed into spherical grains which distribute uniformly in melting metal (see Fig. (e)). The size of spherical grain is in the range of 20~ 60 μm and the solid fraction is about 60%. When treated for 40 min, the size of spherical particles increases slightly. For 60 min of treating time, the growing phenomenon is very obvious and even the particle grains turn into irregular big lumps when the temperature holds for 80 min (see Fig. 1 (f)). In addition, when the time reaches 13 min, some black points appear in its structure and they have a tendency to move toward the center of spheroid and then merge to grow up with increasing time.

The above specimens were also examined by SEM in order to analyze the evolution process in de-

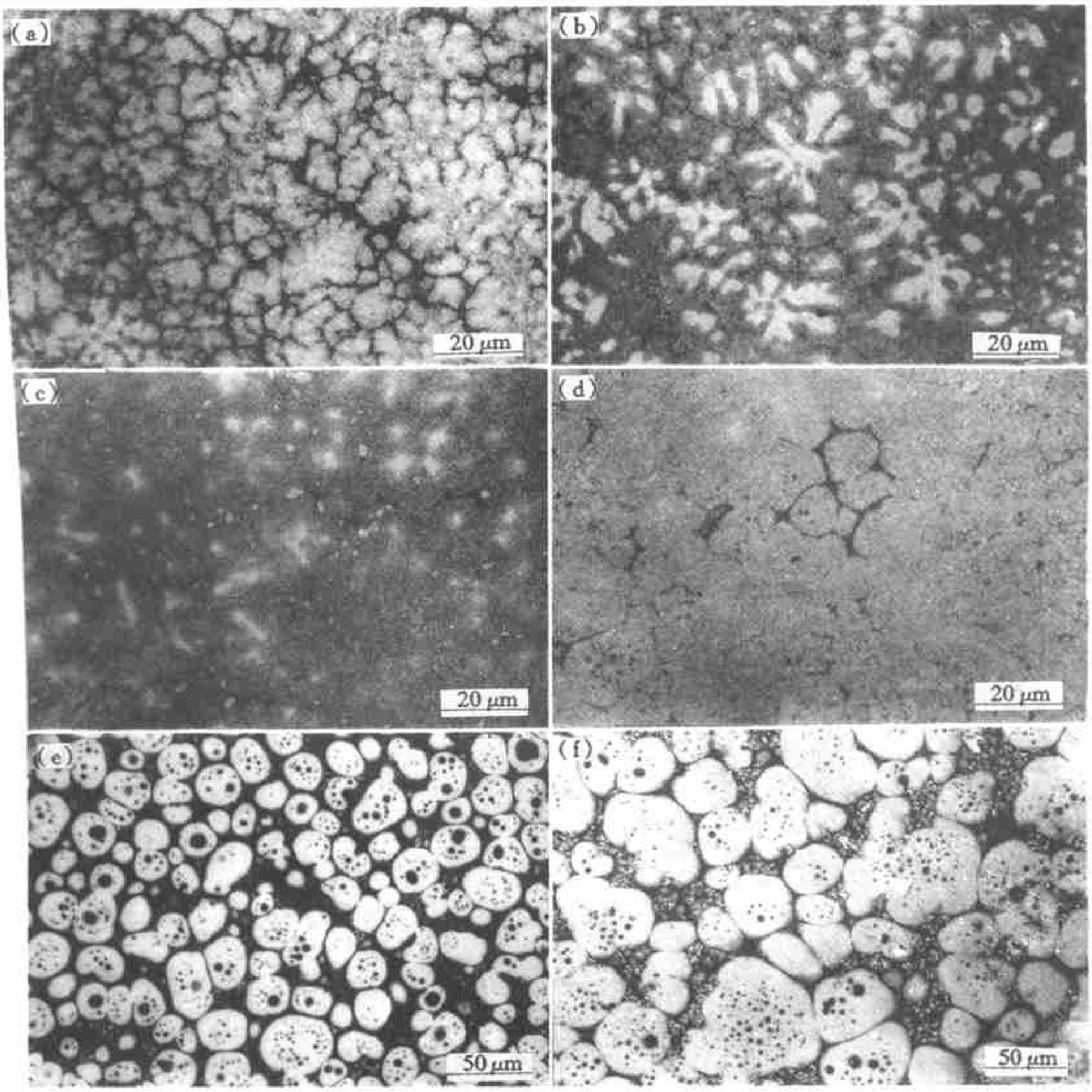

Fig. 1 Structural evolution of ZA27 alloy during isothermal heat treatment at semi-solid temperature 460 ℃
(a) —0 min; (b) —8 min; (c) —10 min; (d) —13 min; (e) —30 min; (f) —80 min

tails. When treated for 8 min, the α grain arms merge, the boundaries become narrow and indistinct, and the equiaxed appearance disappears completely followed by the white α phase decreasing and gray structure increasing (see Fig. 2(a)). While the temperature holds for 10 min, a kind of white discontinuous and bending structure appears (marked *A* in Fig. 2(b)), which is the boundaries indicated in Fig. 1(c). From its appearance, it can be concluded that it is the molten chilled structure. This can demonstrate that the eutectic with low melting point, which exists between α boundaries, starts to melt at this time. In addition, a kind of white bright phase (marked *B*) also appears. With prolonging time, the melting boundaries increase and link up to lead to the formation of spherical structure (see Fig. 2(c)). Finally, the structure becomes spherical grains completely. Therefore, the melting of low melting point structure near the α boundaries is the main reason for the structural sphericizing of ZA27 alloy.

From the above analysis, it can be concluded that the microstructure of ZA27 alloy modified by Zr will be transformed from equiaxed grains in turn into near particles, big lumps, small lumps, particles and spherical grains which will grow up with increasing isothermal time.

3.2 Composition change and phase transformation during semi-solid isothermal heat treatment

The structural evolution of ZA27 alloy is caused by a series of transformation, therefore, it is very important to verify the composition change and ascertain the situation of atom diffusion during the treating to find out the evolution mechanism. The results from EDAX of the present work are shown in Table 1.

The microstructure of as-cast ZA27 alloy consists of primary α phase and eutectic α and β (dark structure between boundaries in Fig. 1(a)); α is Al-rich phase and β Zn-rich phase. When the specimen is treated at 460 ℃, the Zn-rich eutectic begins to dissolve toward α phase. This deduces two phenomena: one is that the content of Zn in α phase increases, the other is that the α boundaries become narrow and indistinct with decreasing eutectic. With increasing temperature in specimen and Zn content in α phase near boundaries, the periphery of α phase is under conditions of transformation and the reaction $\alpha \rightarrow \alpha' + \beta$[12] takes place to form the gray eutectoid α' and β around α phase (see Fig. 2(a)). With prolonging isothermal time, the eutectoid increases while α phase reduces. When held for 10 min, there is only a little α phase which distributes in gray eutectic occasionally and the structure between the grain boundaries starts to melt (indicated by *A* marked in Fig. 2(b)). This demonstrates that the eutectic can not dissolve in α phase due to rapid heating. In addition, a kind of white bright particle phase (marked *B* in Fig. 2(b)) with high Zn content, up to 69.10%, distributes along the indistinct boundaries of raw α grains. It can be concluded that the white bright particles might form from the growing of β phase in the left eutectic, which has low melting point, and the melting of eutectic originates from the melting of the white particle phase.

When the specimens have been treated for 13 min, the eutectoid reaction completes and α phase disappears. In addition, some black points with high amount of Zn appear, simultaneously, the content of Zn in gray structure decreases. It is easy to observe from their appearances that these black points are formed by the melting of β phase in eutectoid (see Fig. 3). The amount of Al increases and Zn decreases in the molten boundaries structure and black points because of the dissolving of α' with high Al content

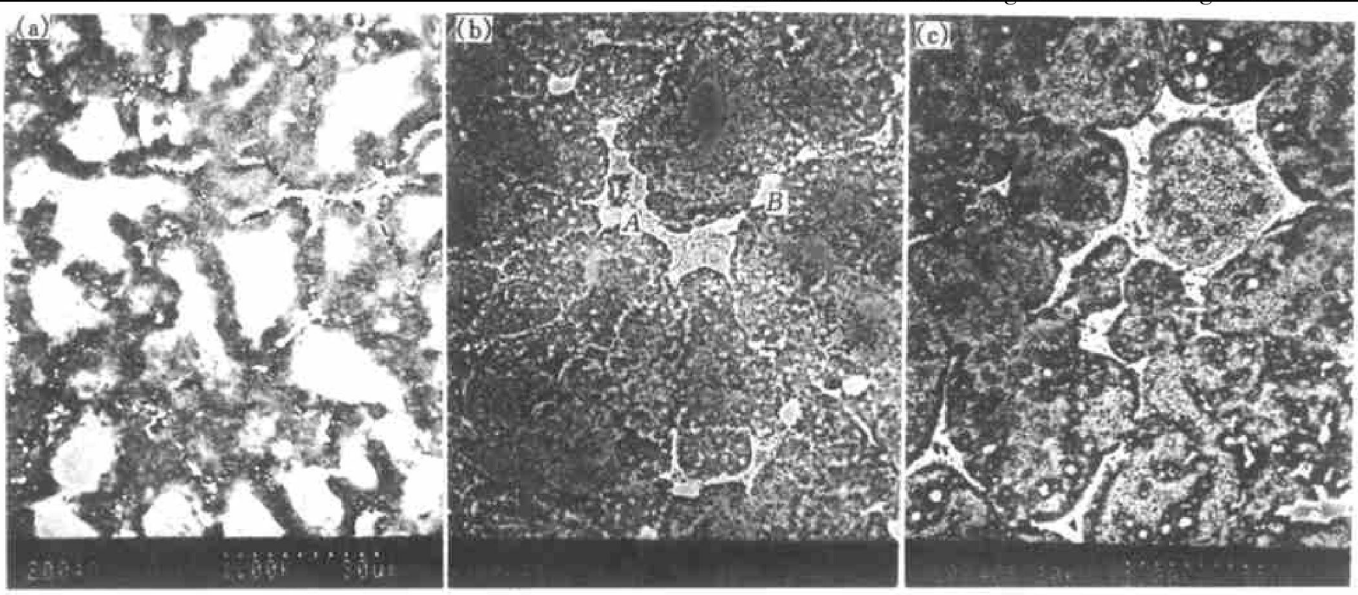

Fig. 2 Microstructures of ZA27 alloy during semi-solid isothermal heat treatment
(a) —8 min; (b) —10 min; (c) —13 min

Table 1 Results from EDXA for different microstructures in ZA27 alloy

Time / min	Photo and microstructure		Element content(w / %)			
			Zn	Al	Cu	Mg
0	Fig. 1(a)	α phase	34.81	53.53	8.05	3.61
5		α phase	43.68	46.34	6.33	3.65
8	Fig. 2(a)	α phase	48.77	45.08	4.25	1.90
		Gray structure	53.08	32.92	10.97	3.03
10	Fig. 2(b)	α phase	49.97	42.38	5.72	1.93
		Gray structure*	55.67	39.36	3.56	1.41
		White bending structure	64.30	23.93	9.88	2.79
		Bright white phase	69.11	23.71	6.62	0.56
13	Fig. 2(c)	White bending structure	65.87	27.54	4.83	1.76
		Gray structure	50.60	41.19	5.84	2.37
15		Gray structure	46.32	48.01	2.08	3.59
		Melted boundaries	66.97	25.42	4.54	3.07
		Black point structure	56.14	37.28	3.81	2.77
20		Gray structure	32.14	60.77	3.41	5.68
		Melted boundaries	60.52	33.93	2.83	2.72
		Black point structure	54.09	41.46	2.09	2.36

* Primary α phase has taken a series of changes, so it is named gray structure.

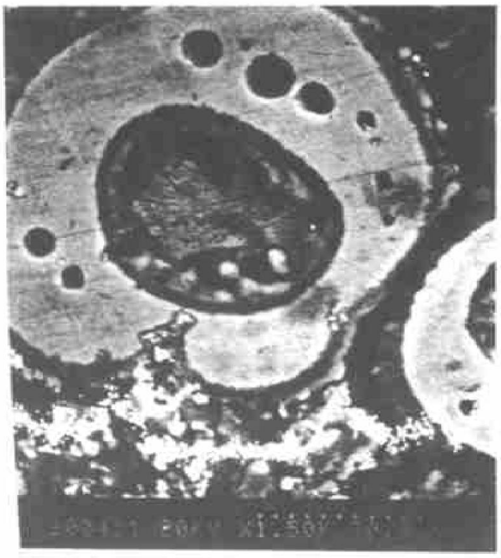

Fig. 3 Appearance of black point in global structure for 40 min

near these molten structures when heated for 20 min. At the same time, this causes the solid fraction to decrease. 30 min later, the compositions of all kinds of structure and solid fraction are steady. Liquid and solid structures are in the dynamic balance without other special transformations.

3.3 Structural evolution mechanism of ZA27 alloy during semi-solid isothermal heat treatment

Based on the structure appearance and transformation of ZA27 alloy, the mechanism can be concluded as: during the semi-solid heat treatment, the eutectic between α grains dissolves into α phase and zinc content in α phase increases. Eutectoid reaction can take place from outside to inside of α grains and the boundaries of α grains become narrow and indistinct, at last even disappear. The disappearance of grain arm boundaries makes each α grain become near particle, and the disappearance of grain boundaries causes each near particle to be connected each other. At the same time, because the temperature in specimens increases rapidly, some eutectic can not be dissolved into α phase in time to be left and some β grains in this eutectic and eutectoid grow up to form white bright lumps (marked B in Fig. 2(b)), and then melt to form molten boundaries (marked A in Fig. 2(b)), thereby, the joining near particles are separated. With increasing time, the molten boundaries increase and link up to form independent particles. It can also be referred that the melting of β phase in eutectoid is beneficial to the joining of molten boundaries, especially the molten grain arm boundaries.

From the analysis above, it can be found that the size of spherical grain, formed by the joining of molten boundaries, is large, about being equal to that of the as-cast equiaxed grain, but the size of spheroid formed by linking of molten grain boundaries and grain arm boundaries is small because one primary α grain can be separated into several particles. Therefore, the size of spheroids is different. When the isothermal time exceeds 40 min, the spheroids merge and grow up because of ripening phenomenon[13].

4 CONCLUSIONS

1) The microstructure of ZA27 alloy modified by Zr may become spherical particles with size of 20~ 60 μm and 60% solid fraction holding at 460 ℃ for 30~ 40 min.

2) The microstructure of ZA27 alloy changed from equiaxed grains in turn to joining near particles, flat big lumps, small lumps, independent particles and spheroids that would merge and grow up later during semi-solid isothermal heat treatment.

3) The structural evolution of ZA27 alloy was caused by a series of transformation: eutectic between boundaries of primary α grains diffused toward α phase to cause the merging of arms and disappearing of boundaries, and then to form joining near particle structure. Finally, the left eutectic near boundaries and inter arms melted to separate its structure into independent particles.

4) The merging of equiaxed grain arms and melting of β phase in left eutectic near boundaries and inter arms are the main reasons for structural sphericizing.

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