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Si phase morphology and mechanical properties of ZL107 Al alloy improved by La modification and heat treatment

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Abstract: The phase morphology evolution during the solid solution treatment and then artificial aging of the La-modified ZL107 Al alloy was studied. The results show that when the solid solution was held at 560 °C for 6 h, only partial Si phase dissolved into the matrix; however, the precipitation also occurred during the artificial aging process. The precipitation process in Al−Si alloys with or without La-modification was compared. After modification and heat treatment, the mechanical properties of the alloy were greatly enhanced, due to the modification and uniform distribution of Si phase.
Key words: ZL107 aluminum alloys; modification; heat treatment; microstructure evolution; mechanical properties

1 Introduction

Al−Si alloys have been most widely applied, for they have excellent casting properties, such as good fluidity, air-tightness, low shrinkage and hot-cracking tendency [1−4]. ZL107 has been the potential material of cast aluminum alloy due to its good overall performance. However, the mechanical properties of ZL107 alloy are highly related to the Si phase morphology. Furthermore, Si phase morphology and distribution strongly affect the mechanical properties. In order to improve the mechanical properties of cast components, these alloys can be heat treated [5−8]. It is well known that during the heat treatment, the secondary phase morphology changes dynamically, which provides a direct approach to improve mechanical properties. In Ref. [9], the microstructure modification by addition of La_2O_3 in as-cast ZL107 alloy was studied and it was found that La element plays the actual role in modification. In this work, pure La is selected as a modifier. Moreover, the effects of solid solution treatment and artificial aging on the Si phase morphology evolution and the mechanical properties of Al−Si alloys are subsequently studied. The aim of this work is to explore an effective way to improve the mechanical properties of the ZL107 Al alloy.

2 Experimental

The base alloy used in this work was ZL107 hypoeutectic Al−Si alloy. The chemical composition of the alloy is shown in Table 1. Pure La was selected as modifier. An ingot was produced under the unmodified condition. The alloys were melted in an electric resistance furnace and then poured into a cast iron mould, which had been preheated up to 200 °C. The molten metal was stirred at 700 °C for 2−5 min before pouring.

Table 1 Chemical composition of ZL107 (mass fraction, %)

Si	Cu	Mg	Fe	Mn	Al
6.82	3.51	0.051	0.012	0.021	Bal.

The solid solution treatment (T4) was carried out at 560 °C, and the solution time was 6 h. All the samples were water quenched. The artificial aging (T5) temperature was 200 °C and the holding time was 2, 4, 6 h, respectively. The samples for microstructure observation were cut from the untreated and treated alloys, and etched with 0.5% NaOH solution for 5−10 s.

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Tensile tests were performed using an AG-250KN2SMD tensile testing machine at room temperature. The wear resistance of ZL107 alloys with or without heat treatment was tested. Wear characteristics of the treated and untreated alloys were studied using a wear-testing machine (M−2000). The wear tests were conducted at sliding velocity of 1 m/s and load of 50 N. Wear tests were conducted at dry conditions in order to avoid effect of the lubricating medium. All the specimens were in dimensions of 7 mm × 7 mm × 30 mm. Three samples for each condition were tested and the average of the mass loss was calculated.

3 Results and discussion

3.1 Effect of La modification on microstructure evolution

1% La was employed to modify the ZL107 Al−Si alloy. Figure 1 shows the microstructures of ZL107 Al−Si alloy with or without modification. Figure 1(a) shows that Si phase is bulky and distributes randomly in as-cast ZL107 alloy. However, with the addition of 1% La, the Si phase is refined, and distributes more uniformly than in the unmodified alloy. The modification mechanism is considered that La is adsorbed on the surface of Si embryos and reduces its mobility in the liquid. Hence, the growth rate of Si phase is lower than that of α(Al) phase, which limits the growth of Si phase. In addition, La is one of the surface-active elements, which is able to be adsorbed at the twin valley of Si crystal to prevent the further piling up of Si atom from the excessive growth of the certain crystals. This finally leads to the growth direction shifting, branching, creating fibrosis of the Si crystal [10,11]. Compared with work in Ref. [9], it was found that La can significantly refine not only the eutectic silicon phase but also the primary α(Al) dendrite. Nevertheless, La_2O_3 mainly has a certain function to modify the eutectic silicon phase.

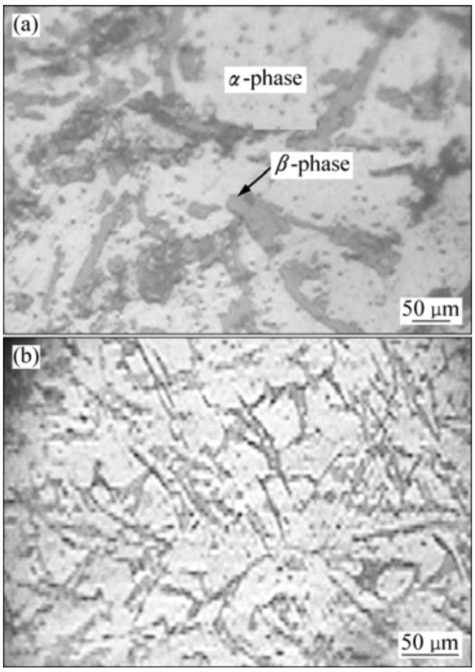

Fig. 1 Effects of La modification on microstructure evolution of ZL107 alloy: (a) Unmodified; (b) With 1% La modification

3.2 Effects of heat treatment on microstructure

Figure 2 shows the effects of heat treatment on the ZL107 alloys. The as-cast alloy mainly consists of α(Al) and β(Si) phases. After solution treatment, the supersaturated solid is in non-equilibrium state, in which the decomposition and precipitation tend to occur. When the solution treatment time is short (6 h), only a part of Si phases dissolve into the matrix, as shown in Fig. 2(a). However, compared to the alloy in as-cast state, the morphology of Si changes greatly, and the contour of the undissolved silicon phase becomes smooth with the size decreasing clearly. As shown in Fig. 2(b), the precipitate is obvious when the aging time is 2 h. The fine precipitation particles uniformly distribute between the undissolved eutectic silicon phases. As the aging time increases, the atom mobility and the diffusion process will be increased, thus a lot of precipitates will disperse in the matrix, as shown in Fig. 2(c); however, as the aging time increases to 6 h, as shown in Fig. 2(d), the β-Si phase precipitates aggregately. It is known that the precipitates are coarsened to decrease the interfacial free energy between the precipitate and the matrix [12].

The effects of modifier on the aging process of the alloys were studied. Figure 3 shows the microstructure of the unmodified alloy under the same heat treatment condition. As for the unmodified alloy, the size of Si phase is obviously larger than that in the modified alloys. The effects of modification on precipitation mainly come from the fact that the modifier will be enriched on the surface of these precipitates, reducing its crystal growth rate. In addition, when the modifier is in the form of replacement in the matrix, there must be a large number of crystal defects, such as dislocations, stacking faults, where Si atoms are more easily absorbed, which increase the number of Si nucleation rate, making more intensive and minor size of Si phase in the matrix [13,14].

3.3 Mechanical properties of ZL107 Al−Si alloy

The addition of modifier increases the tensile strength (σ_b). Such tendency of enhancement for the modified alloy seems to be associated with the increase of obstacles to slip due to the more extensive distribution of α(Al) phase/silicon particles boundaries. It can also be observed from Table 2 that the elongation (δ) decreases slightly with the artificial aging time increasing. Hence, the modification of cast ZL107 Al alloys and then heat

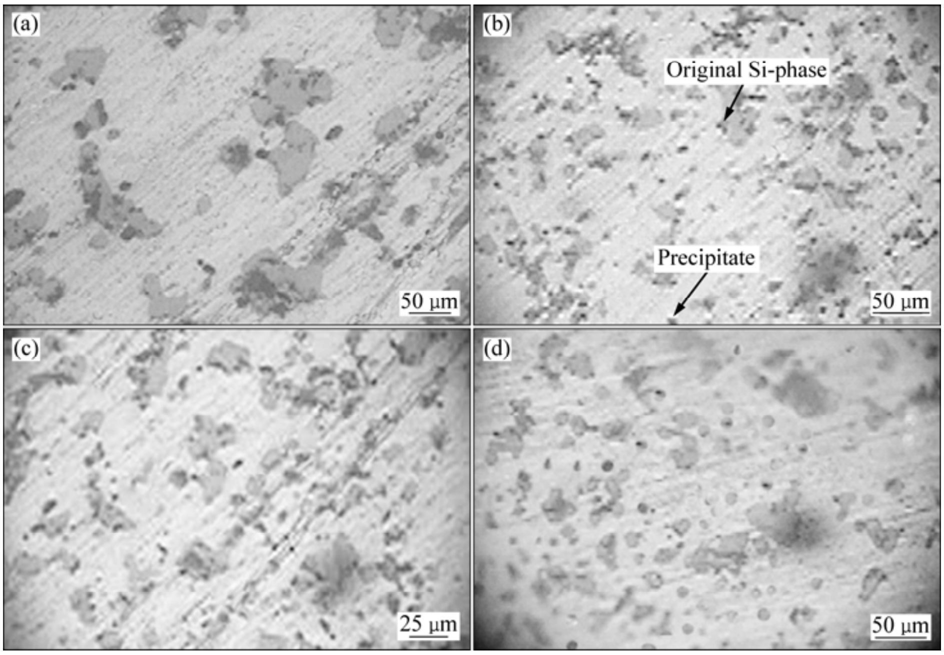

Fig. 2 Effects of heat treatment on ZL107 alloys: (a) Modification+T4; (b) Modification+T5 for 2 h; (c) Modification+T5 for 4 h; (d) Modification+T5 for 6 h

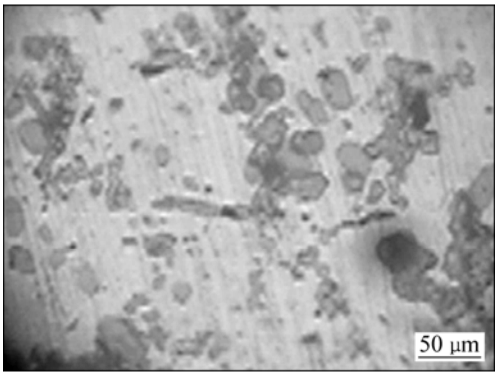

Fig. 3 Microstructure of unmodified alloys after T5 treatment for 6 h

Table 2 Mechanical properties of alloys

Sample	σ_b/MPa	δ/%
Unmodified (as-cast)	170	2.3
Modified (as-cast)	230	2.5
Modified+T4	257	4.6
Modified+T5 for 2 h	290	3.5
Modified+T5 for 4 h	306	3.2
Modified+T5 for 6 h	329	2.9

treatment can provide a better way to improve the tensile properties of the alloy.

As shown in Fig. 4, the wear resistance of the alloys is improved as artificial aging time increases. The wear resistance enhanced by modification obviously comes from the Si morphology change and its size reduction. The improvement of wear resistance mainly comes from two aspects: one is from the matrix improvement; the other is from the Si morphology modification. A part of the solution Si atoms dissolve into the matrix, which could enhance the wear resistance of the matrix.

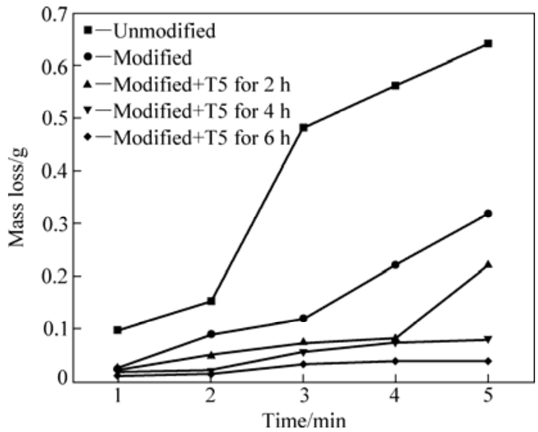

Fig. 4 Wear resistance of ZL107 Al alloy with or without heat treatment

During the solid solution, partial phase formed during solidification can dissolve into the matrix. It is important that Mg- and Cu-containing phases dissolve and the hard phase leaves, which is available to increase the wear resistance [15]. On the other hand, the Si phase morphology modification can improve the wear resistance. WU and WANG [16] investigated the effects of morphology on the wear resistance of the Si_3N_4 ceramic. The results showed that the friction force changed with the surge of surface topography. Thus, the enhanced distribution of refined and spheroidized silicon crystals would retard the crack nucleation and propagation propensities and can be attributed to improvement of wear resistance [17,18].

4 Conclusions

1) When the solid solution was held at 560 °C for 6 h, only partial Si phases dissolved into the matrix; however, the precipitation also occurred during the artificial aging process. The precipitation is obvious when the aging time was 2 h. As the aging time increased to 6 h, β-Si phase precipitated aggregately.

2) The precipitation would be more fine and homogeneous after modification. It was found that after heat treatment, the mechanical properties of the modified alloy were greatly enhanced.

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La 变质和热处理复合作用下 ZL107 铝合金中 Si 相形态演化及其力学性能

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摘　要：研究 ZL107 铝合金经过固溶和时效处理后的 Si 相形态演化及其对力学性能的影响。结果表明，当合金在 560 °C 固溶处理 6 h 后，有部分 Si 相固溶进入基体，但在随后的时效过程中 Si 相会重新析出。比较了变质和未变质 ZL107 合金的固溶时效过程。通过 La 变质处理再固溶时效，ZL107 合金中的 Si 相形态明显细化，合金的力学性能提高幅度更大。

关键词：ZL107 铝合金；变质处理；热处理；形态演化；力学性能

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