Microstructure modification by La$_2$O$_3$ and its effect on wear resistance properties of as-cast ZL107 alloy

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Abstract

Modification of ZL107 aluminum alloy has been successfully achieved by using La$_2$O$_3$. The different casting parameters, including casting temperature as well as holding time and modifier content, were carried out to investigate the modification effects. The results show that the best modifier content is 1.0 wt.%, and the casting temperature has little effect. In addition, the wear behavior of modified and unmodified ZL107 has been compared. The wear resistance of as-cast ZL107 aluminum alloy can be significantly improved after modification.

Keywords: aluminum alloys; lanthanum oxides; modification; microstructure; wear resistance

1. Introduction

The Al-Si casting alloy is one of the traditional materials owing to its good casting, mechanical properties, etc., and it is widely used in aviation, aerospace, automotive, and other industrial fields [1-2]. However, the mechanical properties and cutting performance are poor when the alloy contains coarse silicon phases. Therefore, the Al-Si alloy must be modified before it is used in the practical production [3-4].

Up to now, there are many modifiers to the Al-Si system, which have their own advantages and disadvantages. Rare earth metals or related modifiers have the potential advantage of long modified time, with the additional advantages of high resistance to corrosion and good weldability, to which more and more attention is being paid [5-9]. However, pure rare earth metals are rarely directly used as modifiers due to their high oxidation tendency at high temperature. Hence, the rare earth metal related compound is often used as a modifier. In this paper, an investigation of a novel effective modifier La$_2$O$_3$ under different casting parameters on the microstructure and wear behavior of ZL107 aluminum alloy has been carried out.

2. Experimental

The base alloy used in the experiment was ZL107 hypo-eutectic alloy. The chemical composition of the experimental alloy is shown in Table 1. La$_2$O$_3$ was selected as the modifier. An ingot was produced in the unmodified condition. Various modified ingots were produced under different modifying conditions. The alloys with or without modification were all smelted in an electric resistance furnace and then poured into a cast iron mould, which had been already preheated up to 200°C. The molten metal was stirred at 700°C for approximately 2-5 min before pouring.

| Table 1. Chemical composition of ZL107 alloy wt.% |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Si              | Cu              | Mg              | Fe              | Mn              | Al              |
| 6.82            | 3.51            | 0.051           | 0.012           | 0.021           | Bal.            |

Casting temperature, holding time, and modifier content were the main parameters used to study the modification effects. The samples cut from the unmodified and modified alloys were etched with 0.5 wt.% NaOH solution for 5-10 s before microstructure observation. The optical microscope was used to characterize silicon morphology and its distribution. Lastly, the wear resistance properties of ZL107 aluminum alloys with or without modification were tested.

3. Results and discussion

3.1. Effects of La$_2$O$_3$ content on the modified microstructure

To explore the effect of modifier content on the microstructure, 0.5 wt.%, 1.0 wt.%, and 2.2 wt.% La$_2$O$_3$ were used, respectively. Fig. 1 shows the microstructures of as-cast
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Fig. 1. Effect of La$_2$O$_3$ content on the modified microstructure of ZL107 aluminum alloy: (a) without La$_2$O$_3$; (b) 0.5 wt.% La$_2$O$_3$; (c) 1.0 wt.% La$_2$O$_3$; (d) 2.2%La$_2$O$_3$.

ZL107 with or without modification. As shown in Fig. 1(a), the unmodified silicon phase has coarse flakey morphology and agglomerates heavily. In terms of the modified silicon phase as shown in Figs. 1(b) and 1(c), however, the dimension has been reduced greatly and the silicon phase distributes uniformly; moreover, the morphology has been changed from the coarse flake to broken rod-like one. Generally, the effect of modification increases with an increase of La$_2$O$_3$ content. However, a phase with needle-like morphology has been obtained in Fig. 1(d), which may be due to an intermetallic compound formed for the excessive amount of La$_2$O$_3$ (2.2 wt.%). This indicates that the alloy has been over-modified. Yi has also confirmed that La containing compounds could be formed with the addition of 3% La to the A390 alloy [10].

3.2. Effect of casting temperature on the modified microstructure

Three different pouring temperatures (700, 750, and 800°C) were used to investigate the influence of pouring temperature on the modified microstructure. Fig. 2 shows the microstructures of as-cast ZL107 modified by 1.0 wt.% La$_2$O$_3$ but casting at different temperatures. It can be seen that the silicon phase emerges with broken rod-like morphology at casting temperatures of 700°C and 750°C; however, it returns to the flake morphology again for casting at 800°C. This is mainly because a part of La$_2$O$_3$ was volatilized and burned; thus, its modification effect is weakened. Casting temperatures ranging from 700 to 750°C are suitable.

3.3. Effect of holding time on the modified microstructure

Generally, the modifier has a certain incubation time; therefore, it is necessary to know the suitable holding time for La$_2$O$_3$. The predetermined 30 min, 2 h, and 4 h were selected to explore the holding time effect. The casting temperature was 700°C and the modifier content was 1% during investigating the holding time effect. Fig. 3(a) shows that the dimension of the silicon phase is still large with the holding time of 30 min compared with Fig. 3(b), suggesting that the alloy is not completely modified. The modification