Effect of Heat Treatment on Microstructure and Dimensional Stability of Y-Modified AlSi7Cu3Mg Alloy

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Abstract. The application of rare earth modified AlSi7Cu3Mg alloy in automobile engine and motor casing has increased. The dimensional stability of this alloy is an important feature. In this paper, the effects of yttrium addition and different heat treatment on the microstructure and dimensional thermal stability of AlSi7Cu3Mg alloy were studied by OM, SEM and dimensional measurement. Research shows that: The dimensional stability of AlSi7Cu3Mg alloy after T6 heat treatment is better than that after T4 heat treatment, and the dimensional stability after T7 heat treatment is the best. The addition of rare earth Y can improve the dimensional stability of AlSi7Cu3Mg alloy.

Keywords. Al-Si7-Cu3-Mg alloy, Y-modified, microstructure, dimensional stability.

1. Introduction
Cast Al-Si alloys such as AlSi7Mg0.3, AlSi7Cu3Mg and AlSi9Cu3, due to the low density, good castability and higher mechanical properties, are extensively used in the aerospace and automotive industries [1, 2]. The usage for automotive components including automotive engine blocks and motor shells of these alloys has greatly increased in the past 2 decades [3]. The addition of rare earth elements, such as Ce, Y, makes aluminium alloy a new kind of material with excellent properties and wide applications. It can not only refine the microstructure, purify melt, reduce the content of gas and inclusions, improve the mechanical properties of the alloy, etc. [4-6].

AlSi7Cu3Mg alloy as a kind of hypo-eutectic cast Al-Si alloys, content of α-Al dendrite, Al-Si phase, Al2Cu, Mg2Si, and Fe-based compounds, etc. [7-9]. AlSi7Cu3Mg alloy will undergo slight dimensional changes if it exposed at certain temperatures for a period of time [3, 7]. Thus, the dimensional accuracy of the casting is reduced, and even the casting cracking occurs. Therefore, dimensional stability, if not effectively controlled, will result in limited applications of this material in engine and motor housing.

In this study, the effect of different wt.% Y added and different heat treatment conditions on microstructure and dimensional stability at different exposure temperatures of AlSi7Cu3Mg alloy are discussed.

2. Experimentation
The composition of AlSi7Cu3Mg alloy is shown in table 1. The experimental cast alloy was heated to 760°C, then the Al-Y master alloy(22 wt.% Y) was added. The rate of burning loss of Y was considered at 5 wt.%. The target amount of rare earth Yttrium added of 1#, 2# 3# and 4# was 0 wt.%Y, 0.1wt.%Y,
0.2 wt.% Y and 0.3 wt.% Y, respectively, and the composition range of yttrium content is controlled within ±0.02% of the target value. The content of main alloy components in each group of tests was detected by direct reading spectrometer. The pouring temperature was 720±2°C.

Table 1. Main compositions of AlSi7Cu3Mg alloys (wt.%).

|   | Si  | Cu  | Mg  | Mn  | Fe  | Zn  | Al  |
|---|-----|-----|-----|-----|-----|-----|-----|
|   | 7.26| 3.14| 0.05| 0.27| 0.18| 0.01| Bal.|

The dimensions of the casting samples were: 100 mm×80 mm×15 mm. The heat treatment types are T4, T6 and T7. The heat treatment process is shown in table 2.

Table 2. Heat treatment process design.

| Heat treatment process | Solution Temperature (°C) | Time (hour) | Quench (30s) Temperature (°C) | Medium | Age Temperature (°C) | Time (hour) |
|------------------------|---------------------------|-------------|-------------------------------|--------|----------------------|-------------|
| As-cast                | --                        | --          | --                            | --     | --                   | --          |
| T4                     | 495                       | 4.0         | 20~25                         | air    | Natural              | --          |
| T6                     | 495                       | 4.0         | 70~80                         | water  | 190                  | 3.0         |
| T7                     | 495                       | 4.0         | 70~80                         | water  | 190                  | 3.0         |

The dimensional stability samples were machined into Φ5 mm×75 mm cylinders by wire cutting. The thermal exposure test was conducted at retention temperature 180 °C and 250 °C respectively. Dimensional stability is measured by dimensional growth rate. The dimensional growth was calculated as follow:

\[
\text{Dimensional growth} = \frac{\Delta l}{l_0} \times 100\% = \frac{l_f - l_0}{l_0} \times 100\% \tag{1}
\]

where \(\Delta l\) is the difference between the length after thermal expose(\(l_f\)) and the length before thermal expose(\(l_0\)) by averaged measurement.

3. Results and Discussion

3.1. Microstructure Analysis
The microstructure of as-cast AlSi7Cu3Mg alloy with different wt.% Y is shown in figure 1. The variation trend of the grain size and SDAS (the secondary dendrite arm spacing) of \(\alpha\)-Al dendrite in AlSi7Cu3Mg alloys by different wt.% Y added is shown in figure 2. The grain size and SDAS of \(\alpha\)-Al dendrite decreases with the increase of wt.% Y. In AlSi7Cu3Mg melt, because of the higher electronegativities between yttrium and oxygen, Y could generate \(Y_2O_3\) by capture O from \(Al_2O_3\). \(Y_2O_3\) could act as the nucleus of \(\alpha\)-Al dendrite. Further more, Y was very easy to accumulate in the solid-liquid interface between dendrite and melt. So, the growth of \(\alpha\)-Al dendrite is impeded, as is shown in figure 3.
Figure 1. Optical microstructures of AlSi7Cu3Mg alloy (a) 1#(Y: 0wt.%); (b) 2#(Y: 0.1wt.%); (c) 3#(Y: 0.2wt.%); (d) 4#(Y: 0.3wt.%).

Figure 2. Grain size and SDAS of α-Al of AlSi7Cu3Mg alloys in different wt.% Y.

Figure 3. Area distribution of each element in AlSi7Cu3Mg alloy with 0.2wt.% Y via EDS.
It can be seen from figure 1 (d) that the eutectic silicon phase in as-cast structure of AlSi7Cu3Mg alloy after rare earth Y modification is obviously fibrous. After T4 heat treatment, the fibrous eutectic silicon phase contracts inward and fuses when passivated at both ends, and its roundness gradually improves, and part of the eutectic silicon phase presents good granular distribution, as is shown in figure 4(a). After quenching and artificial aging, the morphology of eutectic silicon has no obvious change, as is shown in figure 4(b).

Figure 4. Optical microstructures of AlSi7Cu3Mg alloy added 0.3wt% Y (a), T4 (b), T6.

3.2. Thermal Growth
The dimensional growth of AlSi7Cu3Mg alloy under different heat treatment processes, T4, T6 and T7, in 500 hours of thermal exposure is shown in Figure 5 and figure 6. The thermal exposure temperature is 180℃ and 250℃ respectively. The dimensional growth changes significantly in the first 50 hours and gradually slows down in the subsequent thermal exposure in 180 ℃. And, in 250℃, the growth mostly in the first 20 hours. Generally, Al2Cu and Mg2Si, as precipitation of Al-Si-Cu-Mg alloy, are occur by following steps: GP zone $\rightarrow$ $\theta'$ (Al2Cu) and $\beta'$ (Mg2Si) $\rightarrow$ $\theta$ (Al2Cu) and $\beta$ (Mg2Si). For AlSi7Cu3Mg alloy, because that the amount of Al2Cu is much higher than that of Mg2Si, the effect of Al2Cu transition on dimensional stability is more dominant. The dimensional stability of AlSi7Cu3Mg alloy after T6 heat treatment is better than that after T4, and the best heat treatment for dimensional stability of the alloy is T7.

Figure 5. Dimensional growth of AlSi7Cu3Mg after different heat treatment exposed at 180℃.
Figure 6. Dimensional growth of AlSi7Cu3Mg after different heat treatment exposed at 250°C.

Figure 7. Dimensional growth of AlSi7Cu3Mg with different w.t.% Y (T6) exposed at 180°C.

Figure 8. Dimensional growth of AlSi7Cu3Mg with different w.t.% Y (T6) exposed at 250°C.

Figure 7 and figure 8 show the thermal exposure of AlSi7Cu3Mg with different wt.% Y after T6 heat treatment at 180 °C and 250°C. Whether the thermal exposure is 180°C or 250°C, the dimensional stability of AlSi7Cu3Mg alloy is improved by yttrium added.
4. Conclusion

(1) The dimensional growth of AlSi7Cu3Mg alloy is different at 180 °C and 250°C thermal exposure temperatures. And, in the initial stage, the dimensional growth is significant, and tends to moderate in the subsequent time.

(2) The dimensional stability of AlSi7Cu3Mg alloy after heat treatment of T6 is better than that after T4, and the dimensional stability after T7 heat treatment is the best.

(3) The addition of yttrium improves the dimensional stability of AlSi7Cu3Mg alloy.

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