Effects of Y, Nd and Sb on microstructure of Mg-6Al alloy

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Abstract: Effects of Y, Nd and Sb on the microstructure of Mg-6Al magnesium alloy were investigated by optical microscope, SEM, EDS, XRD and TEM. The results showed that, with the increase of Sb content from 0.5% to 2.0wt%, the formation of Sb$_2$Y$_3$ (at 1.0% Sb) or YSb (at 2.0% Sb) phase is observed. Sb$_2$Y$_3$ nano-phase and dispersed Al$_2$Y, SbY phases are found in the alloy when the content of Sb reaches 2.0%.

1. Introduction
Magnesium alloy is the lightest metal structural material. It has good properties such as low density, high specific strength and specific stiffness, good cast characteristics and electric conductivity and thermal conductivity, and has been widely applied in automobile industry, electron industry and 3C products. It is important for its wider application to improve the strength and other relating properties of magnesium alloy. At present about 70% of magnesium alloy castings are made for automotive industry. Lowering a car’s weight by 100 kg makes it possible to save 0.5L petrol per 100 km. The application of magnesium alloy in automobile industry has a strong influence on the reduction of fuel consumption. Alloying is an effective way to improve the microstructure and therefore enhance the mechanical properties of magnesium alloy at room and elevated temperatures. Mg-6Al alloy has good comprehensive mechanical properties. In this work the effects of Y, Nd and Sb on the microstructure of Mg-6Al magnesium alloy are studied.

2. Experimental procedure
Chemical compositions of the studied alloys were Mg-6Al-2.1RE-xSb. RE was for rare earth elements including Y and Nd (the mass ratio of Y and Nd was 4:3). The addition amount of Sb was 0, 0.5%, 1.0%, 1.5% and 2.0% respectively (wt.%). Alloy ingots were then prepared from high purity Mg (99.95%), purity Al (99.98%), purity Sb (99.95%), and Mg–18Y (wt.%), Mg–18Nd (wt.%) master alloys in an induction melting furnace under the mixed atmosphere of CO$_2$ and SF$_6$ with the ratio of 100:1. The melts were held for 15 min at 963K, and then poured into a metallic mold which was preheated to 523K. Samples were cut from the casting and covered with MgO powders. Then T6 treatment was made. They were heated for solution treatment at 693K for 20h and then water quenched. Artificial aging treatments were performed at 473K for 10h. Microstructure and compositions of the studied alloys were analyzed by using optical microscopy and scanning electron microscopy (JSM-5610LV) with energy dispersive spectroscopy (EDS). Phase analyses were performed with an X’pertmpdpro X-ray diffractometer (XRD). Phase observation and analysis were carried out by using JEM-2100 high resolution transmission electron microscopy (TEM).

3. Results and analysis
Microstructure of experimental alloys after T6 treatment is shown in Fig.1. And the EDS and XRD
analysis results are shown in Fig.2 and Fig.3. It can be seen that Al₂Y phases in the alloy without Sb distribute in grain and at grain boundaries with the shape of blocky or island-like (shown in Fig.1a). EDS analysis shows that small amount of Al, Y and Nd are dissolved in α-Mg matrix. Furthermore, small amount of Mg₂Al₃ phases are formed in the alloy. Al₂Y phases in the alloy with 0.5 % Sb addition (shown in Fig.1b and Fig.2a) are dispersive in blocky or granular (small amount). The content of rod-like Mg₂Al₃ phase increases and the granular hexagonal Sb₃Y₅ phase is formed. When the content of Sb is 1.0 % (shown in Fig.1c), the amount of rod-like Mg₂Al₃ phase reduces. However, rod-like Mg₂Al₃ phases in the alloy with 1.5 % Sb increases in quantity (shown in Fig.1d and Fig.2b), and a few of them are in long strip shape, which can damage the mechanical properties of Mg-6Al alloy. When the Sb content is 2.0 % (shown in Fig.1e), Sb₃Y₅ phase is not detected in alloy by XRD (shown in Fig. 3b), and granular SbY phase with cubic structure is formed, and short rod-like Mg₂Al₃ phases distribute in the alloy, and granular Al₂Y and SbY phases disperse in the alloy. All these shows that the formation and distribution of the second phases in Mg-6Al alloy are remarkably changed by the addition of Y, Nd and Sb elements. Meanwhile, it is found that Sb has little effect on the grain size of the alloy.

Fig 1. Microstructure of experimental alloys after T6 treatment
(a) Without Sb; (b) with 0.5% Sb; (c) with 1.0% Sb; (d) with 1.5% Sb; (e) with 2.0% Sb

Fig 2. EDS analysis result of alloy after T6 treatment (a) With 0.5% Sb; (b) with 1.5% Sb
According to metallographic theory, the electron-negativity difference of two elements and solidification kinetics of metallic melt are applied to predict the possibility of forming metallic compound. The more the electron-negativity difference of two elements, the stronger the familiarity and the easier the possibility of forming metallic compound. In Mg-6Al alloy with Y, Nd and Sb addition, the electron-negativity difference between Sb and Y is higher than that between Mg and Sb, and higher than that between Y and Al (seen in table 1). It means that Sb-Y compound can be formed more easily than Mg-Sb compound (so the Mg$_3$Sb$_2$ phase mentioned in references [2] can’t be found in the Sb-containing experimental alloys). According to the solidification thermodynamics of metallic melt, Sb-Y and Sb-Nd compounds is formed preferentially. With the increase of Sb content, Sb-containing intermetallic compound in the alloy firstly is Sb$_3$Y$_5$ (1.0 wt.% Sb) or SbY (2.0 wt.% Sb) phase, which is in accordance with the Sb-Y binary alloy phase diagram. In Sb-containing alloys, the amount of Al$_3$Y phase decrease because of the formation of Sb-Y compound. Al and RE atoms in Mg-Al alloy attract each other rather than Al with Mg and tend to form in clusters [3, 4]. When Sb is added to Mg-6Al-RE alloy, Al$_3$Y phases decrease in amount and disperse in the alloy, and the phenomenon of Al-RE phase segregation is reduced.

**Table 1.** Electro-negativity of elements in experimental alloys

| Element | Sb | Y  | Nd | Mg | Al  |
|---------|----|----|----|----|-----|
| **Electro-negativity** | 2.05 | 1.22 | 1.14 | 1.31 | 1.61 |

**Fig 3.** XRD pattern of the alloys after T6 treatment (a) 1.0% Sb; (b) 2.0% Sb

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**Fig 4.** TEM micrograph and SAED pattern of Mg-6Al-2.1RE-2Sb alloy

Fig. 4a is a high resolution image of Mg-6Al-2.1RE-2Sb alloy. By means of Fourier transform and corresponding calculation (Fig. 4b), the nanometer scale Sb$_3$Y$_5$ phase is detected in the alloy. It is found that there is a certain degree of crystal orientation relationship with $\alpha$-Mg phase when the incident direction is along [0260]$_{$\alpha$}$. The presence of rare earth Nd is also detected in the substrate of alloy with 1.5% Sb. The results of
EDS analysis on “C” area in Fig.5 reveal that α phase is a solid solution containing Al, Y, Nd and Sb elements. The influence of Y, Nd and Sb on microstructure of Mg-6Al alloy needs further research.

4. Conclusions
In Mg-6Al alloy containing Y, Nd and Sb, Sb₃Y₅ (at 1.0 wt.% Sb) or SbY (at 2.0 wt.% Sb) phase is found with the increase of Sb content.

Sb₃Y₅ nano-phase and dispersed Al₂Y, SbY phases are detected in the alloy when the Sb content reaches 2.0 wt.%.

Acknowledgements
This research was supported by Taizhou Science and Technology Program (15gy55) for Public Welfare.

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