Microstructure and microhardness of a melt spun Al-Mg alloy with exceptionally high content of Mg

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Abstract. Supersaturated Ribbons of the Al-12Mg alloy are prepared by melt spinning. The objective of this work is to explore the microstructure and microhardness of these ribbons. The results show that each Ribbon is a nearly single-phase solid solution containing a high density of dislocation, and there is few precipitation detected; Grains of the ribbon are equiaxed and the average size of them is 2.51μm; During crystallization, {111} plane of the alloy grows preferentially parallel to the surface of the ribbon; The ribbons exhibit a relatively high microhardness of 113 HV. The feasibility of using these ribbons to prepare supersaturated Al-12Mg bulk alloy is discussed.

1. Introduction
In recent years, Supersaturated high-Mg Al alloy has been attracted wide attention due to its low density, high strength and significant work hardening response[1-4]. However, it’s hard to prepare this alloy by traditional casting method, because Al₃Mg₂ phase would precipitates during the solidification process, which reduce the solubility of the alloy. Thus, how to prepare supersaturated high-Mg Al alloy has become a new research orientation.

At present, solid solution treatment can effectively eliminate the second phase in high-Mg Al alloy. Liu Zhibo[5] et al. increase the solid solubility of a high-Mg Al alloy ingot by controlling the solution temperature and time. Li Xinyu[6,7] et al. obtained complete dynamic recrystallization structure and excellent properties by means of solid solution and high strain rate rolling.

Melt spinning is one of a rapid solidification techniques, and its cooling rate can be up to 10⁵-10⁷ K/s. Alloy prepared by this method has the characteristics of small grain size, less segregation of composition and high degree of solid solution[8,9]. Therefore, it is an ideal preparation method of supersaturated high-Mg Al alloy. But up to now, there is few report on the preparation of supersaturated high-Mg Al alloy by melt spinning. In this work, firstly, Supersaturated Ribbons of the Al-12Mg alloy are prepared using melt spinning. Secondly, their microstructure and microhardness are characterized. Finally, the feasibility of using these ribbons to prepare supersaturated Al-12Mg bulk alloy is discussed.

2. Materials and Methods
The Al-12wt.% Mg ingot used in this study was made of 99.9wt.% industrial pure aluminum and 99.9wt.% industrial pure magnesium by vacuum smelting and casting. Before the experiment, the ingot was cut...
into multiple blocks of 15 mm×20 mm×25 mm, and then the blocks were placed into the quartz tube 
with a hole at the bottom, and fixed to the melt spinning machine. The metal was melted by 
electromagnetic induction heating, and then the molten metal was sprayed onto a high-speed rotating 
copper wheel in an argon atmosphere using different injection pressures. The obtained ribbons were 
characterized by bright surfaces and no burr. The diameter of the hole at the bottom of the quartz tube 
was φ1.5 mm, the injection pressure was 0.05 MPa, and the linear velocity of the copper wheel was 40 
m/s.

Phase composition was characterized by X-RAY diffraction(XRD) using a Panalytical XPert power 
diffractometer equipped with a Cu target at a speed of 0.1 ° and a count time of 3 s per step. The 
microstructures of the ribbon were examined by electron back-scattering diffraction(EBSD) and 
transmission electron microscopy(TEM). For preparation of EBSD samples, the samples were 
mechanically polished and then ion milled using a Leica EM TIC 3X ion milling machine. TEM sample 
were firstly cut into discs shape and then ion thinned. Microhardness of the ribbons was measured using 
a Vickers microhardness tester with a load of 100 g and a loading time of 15 s.

3. Result and discussion

Fig.1 shows the XRD pattern of the melt spun ribbon. It indicates that the ribbon contains only single- 
phase α-Al. This suggests that during the melt spinning process, the Al-Mg stabilized compound Al3Mg2 
was not able to precipitate due to extremely fast speed of solidification, and almost all the Mg atoms 
exists in the alloy in the form of solid solution. According to the Nelson-Riley fitting function\(^{[10]}\), the 
lattice constant of the tested sample can be calculated by using the XRD results. The lattice constant of 
Al-Mg solid solution has a linear relationship with the atomic fraction of Mg, it increases by 0.0046 Å 
for every 1at.% increase of Mg. Therefore, the solid solubility of magnesium in the tested alloy can be 
calculated. The result can be seen in table 1.

| Status             | Lattice constant (Å) | Solute Mg concentration at.% | Solute Mg concentration wt.% |
|--------------------|----------------------|------------------------------|------------------------------|
| Melt spun ribbon   | 4.1109               | 13.34                        | 12.01                        |

Fig. 1. XRD pattern of melt spun ribbon.

To further investigate the morphology and grain size of the melt spun ribbon, EBSD was carried out. 
Fig.2 (a)-(c) are EBSD image, grain size distribution and inverse pole figure of melt spun ribbons. As 
can be seen from Fig. 2(a), the grain morphology of the ribbon is equiaxed and the grain size is relatively 
uniform, with an average size of 2.30µm (Fig. 2(b)). By analyzing the IPF of the ribbon (Fig. 2(c)), it 
can be concluded that the \{111\} plane of the strip grows preferentially parallel to the ribbon surface 
during crystallization.
Fig. 2. EBSD image, grain size distribution and inverse pole figure of melt spun ribbons.

In order to further explore the microstructure, phase composition and the density of dislocation, the melt spun ribbon was examined by TEM. Fig. 3 is the TEM plane view of the ribbon. As Fig. 6(a) shows, the ribbon is approximately a single-phase solid solution, and no obvious precipitation of the second phase is detected. Fig. 3(b) shows a typical diffraction pattern obtained by selective electron diffraction (SAED) on a large number of randomly selected grains. Only the diffraction points of aluminum are observed in the figure, but not those of other phases. The above results are in good agreement with the XRD results. Fig. 3(c) shows the high-density dislocation within the grain of the strip. It can be speculated that due to the high cooling rate in the stripping process, the time for atoms to switch from disorder to order is very short, so a large number of dislocations are generated in the crystallization process.

Fig. 4 is the microhardness distribution of the melt spun ribbons. It shows that the melt spun ribbons exhibit a relatively high microhardness. This can be explained by the forementioned: (1) high degree of solubility, (2) small grain size, (3) high density of dislocation.
Fig. 3. The planar view TEM microstructure of melt spun ribbon: (a) TEM BF image showing a single phase solid solution, (b) a typical SAED pattern, (c) TEM BF image of high density of dislocation.

Fig. 4. The microhardness of the melt spun ribbon.

4. Conclusions
(1) The melt spun ribbon of Al-12Mg alloy consists of a nearly singlle phase α-Al solild solution containg a high density of dislocation. During crystalization, the \{111\} plane grows prefertially parallel to the surface of the ribbon. The average grain size of the ribbon is 2.51 \(\mu m\).

(2) The microharness of the ribbon is 113 HV, which is relatively higher than other Al-Mg alloys. This can be explained by its high degree of solubility, small grain size and high density of dislocation.

(3) The melt spun ribbons of Al-12Mg Al alloy have the above advantages that a supersaturated high-Mg Al alloy requires. Thus, It has a large potential to prepare High-Mg Al bulk alloy.

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