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Microstructure and properties of AZ80 magnesium alloy prepared by hot extrusion from recycled machined chips ①

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[Abstract] AZ80 magnesium alloy was prepared by hot extrusion of recycled machined chips and its microstructure and mechanical properties were investigated. Hot pressing was employed to prepare extrusion billets of AZ80 chips, then the billets were hot extruded at 623 K with an extrusion ratio of 25:1. The extruded rods show a high ultimate tensile strength of 285 MPa and a high elongation of 6%. Due to grain refinement by extrusion, mechanical properties of the extruded rods are much higher than those of as-cast AZ80 alloy. Process technique and chips densification mechanism were also studied. Results show that hot extrusion is an efficient method for AZ80 alloy chips recycling.

[Key words] hot extrusion; magnesium alloy; chip; recycle

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1 INTRODUCTION

Magnesium alloys have many advantages such as low density, high specific strength, good electromagnetic shielding characteristics, excellent castability and machinability etc. Magnesium is an abundant element since about 1.93% (mass fraction) of earth crust consist of magnesium. Magnesium alloys are potential materials in aerospace, automobile and electronic device applications[1, 2]. On the other hand, recycling of materials draw more and more attention in order to ensure the sustainable development of society. Zero waste has been put forward as one of ultimate aims for materials processing and application. Many researches were carried out to find efficient and cheap way to recycle metallic materials including steels, aluminium alloys etc[3]. However, studies on the recycling of magnesium alloys are comparatively less enthusiastic because the application of magnesium alloys is not as wide as that of steel and aluminium alloys. Since the demand of magnesium alloys increase rapidly, researches on the recycling of magnesium alloys should be taken into account.

Machined chips are one of the main sources of wastes in magnesium alloys production. Recent investigations show that the chips could be made into bulk materials with high mechanical properties through large plastic deformation technologies, especially hot extrusion. Researches in this field are mostly carried out in Japan, and the alloy system is mainly AZ91[4~7]. Nakanishi et al prepared ZK60 magnesium alloy from machined chips[8]. Wantabe studied superplastic and non-superplastic hot extrusion of AZ31 alloy chips[9]. In this paper, microstructure and properties of AZ80 prepared by hot extrusion from machined chips are investigated. Extrusion of chips is similar to but not exactly as same as powder extrusion since chips are materials in pieces form and size of chips is generally lager than that of powders. Densification mechanism of chip extrusion is also discussed.

2 EXPERIMENTAL

Chemical composition of the experimental materials is Mg-8.0%Al-0.5%Zn(mass fraction). Cast ingot were machined to prepare chips. Alloy chips were collected and hot pressed at 598 K under a pressure of 200 MPa for 5 min to fabricate extrusion billets. Then the billets were hot extruded into rods at 623 K with an extrusion ratio of 25:1. Diameter of extruded rods is 10 mm. The maximum extrusion pressure is about 410 MPa. The extruded rods were aged at (463 ±5) K for 8 h(T5 treatment).

Density of samples was measured by Archi method on an electronic balance. Oxygen content of AZ80 chips was tested on TC-30 oxygen-nitrogen analyzer. Tensile properties of experimental materials were determined at room temperature on SANS CMT5000 Universal Testing Machine. Round tensile test samples were machined from extruded rods. Microstructures of experimental materials were examined on MeF3 optical microscope and PHILIPS XL30 scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS).

3 RESULTS AND DISCUSSION

3.1 Microstructure of material

Fig. 1 shows microstructure of as-cast AZ80 alloy. It mainly consisted of α(Mg) and $Mg_{17}Al_{12}$

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phase, with a few AlMgMnFe intermetallic compounds dispersing on α(Mg). The grain size of α (Mg) is about 100 mm.

Fig. 2 shows the morphology of AZ80 chips. Most of the chips are in short flake form with the length ranging of 2~ 5 mm. This size and form is easy for the chips to fill into the hot-pressing mould. Fig. 3 shows the microstructure evolution of alloy chips during densification. It can be seen that after hot pressing, the chips are compacted together (as shown in Fig. 3 (a)). However, the chips can be distinguished from each other, which means that metallurgical bonding of chips is not formed yet. Fig. 3 (b) shows that the primary chip boundaries disappeared, suggesting that the bonding quality is improved after hot extrusion. After hot extrusion, relative density of extrusion rods increased to 98%, which implies near full density materials were prepared. Fig. 4 shows the XRD pattern of hot-extruded material from chips. It can be seen that the main phases are α(Mg) and $Mg_{17}Al_{12}$. However, compared to the microstructure of as-cast alloy (as shown in Fig. 2), both α(Mg) and $Mg_{17}Al_{12}$ of extruded materials are refined greatly. The grain size of α(Mg) is 15~ 50 μm, which is much smaller than that of as-cast materials.

3.2 Mechanical properties of material

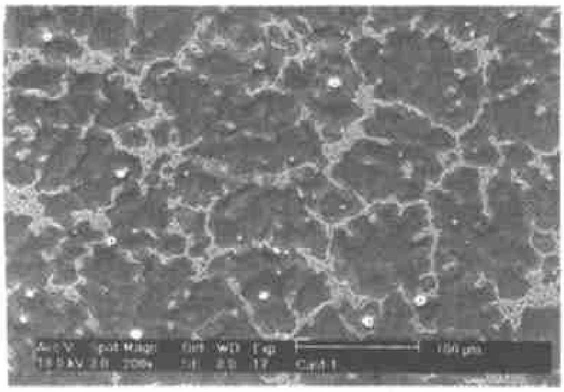

Fig. 1 Microstructure of as-cast AZ80 alloy

Fig. 2 Morphology of AZ80 chips

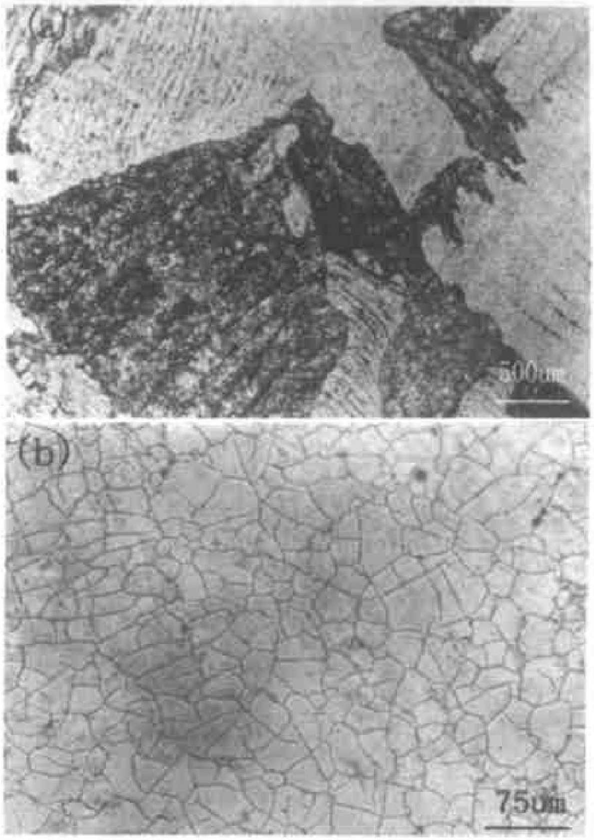

Fig. 3 Optical microstructure of densified AZ80 chips
(a) —After hot pressing; (b) —After hot extrusion

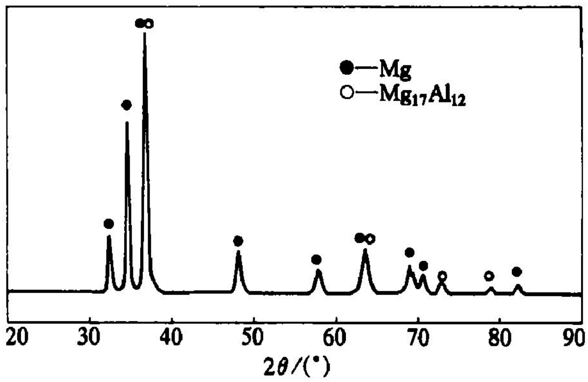

Fig. 4 XRD pattern of hot-extruded material from chips

Table 1 lists the mechanical properties of extruded rod made from AZ80 chips, and properties of AZ80 cast materials are also given for comparison. It can be found that the ultimate tensile strength and elongation of extruded rods made from AZ80 chips is much higher than those of as-cast materials. The most important reason for the mechanical properties improvement is grain refinement caused by hot extrusion. However, compared with extrusion rods processed by hot extrusion from cast alloy under the same condition, the mechanical properties of extruded rods made from chips are a little lower, which is different from Mabuchi's experimental results. Mabuchi prepared AZ91 alloys from chips and as-cast material with an extrusion ratio 100:1, and the results show that the strength of the former one is higher[4]. In general, with increasing extrusion ratio, porosity will decrease. Since there are still some voids in our chip extrusion materials, its mechanical properties are lower than that of extrusion material from as-cast billet, which is in full density. After T5 heat-treatment, the ultimate tensile strength and elongation of chip-extruded rods increase to 310 MPa and 7%, respectively.

Table 1 Mechanical properties of AZ80 alloys prepared by different methods

Sample	Processing	σ_b/MPa	δ/%	σ_s/MPa
1	Cast	145	3	–
2	Cast+ Extrusion	300	14	180
3	Chip extrusion	285	6	165
4	Chip extrusion+ T5	310	7	230

3.3 Discussion

Magnesium alloy chips are easy to form oxide film soon after they are cut off from cast materials because magnesium is chemically sensitive to oxygen in air. Oxygen content of experimental AZ80 chips is 0.04% (mass fraction). The oxide films will hinder the chips from adhering to each other. Since extrusion can provide large shear stress during the deformation process, the oxide film will be broken and chips can adhere to each other by fresh metal surface. Thus the chips bonding strength by extrusion is higher than those of chips by hot pressing. Mabuchi compared the ultimate tensile strength of AZ91 made by chip extrusion and hot-pressing/sintering, and the results show that the former one is about 3 times higher than the later one. Except grain refinement, he pointed out that homogeneously dispersed fine oxide films are also attributed to the strength improvement[4]. This kind of oxide must be broken up firstly. Macro-hardness test results in this study show that hardness of hot-pressing and hot extrusion samples was HB53 and HB62, respectively. It is confirmed that bonding between chips can be enhanced by extrusion. The large shear stress provided by extrusion can also break the coarse intermetallic phases into fragments, thus $Mg_{17}Al_{12}$ phases are refined too.

Bonding between chips includes physical bonding and chemical (metallurgical) bonding, and the later one depends on the diffusion of the alloy elements. It is the main factor that influences the materials properties. Extrusion process is finished in a short period of time, but diffusion takes much longer time to complete. Therefore, the extruded rod has not attained the optimal microstructural state after extrusion. Fig. 5 shows the tensile fracture surface of AZ80 chip hot-extruded material. It can be found that chip interface breaking plays an important role on material fracture. From Table 1, it can be found that strength of sample 3 is lower than that of sample 4. Except enhancing chip bonding, T5 heat-treatment can also eliminate the remnant stress caused by hot extrusion. Therefore, by proper heat-treatment, the mechanical properties of chip extrusion materials can be improved, especially its tensile strength. Effects of heat-treatment on the microstructure and properties of chip hot-extruded materials will be reported later in a separate paper.

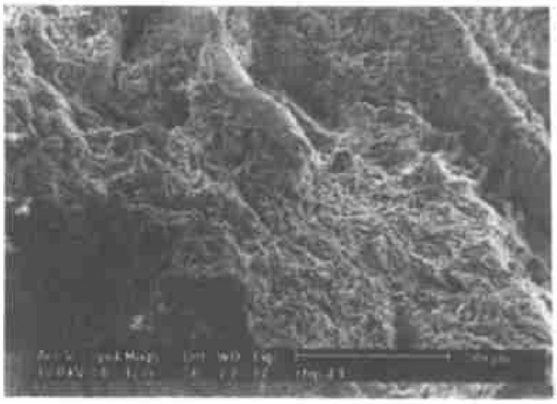

Fig. 5 Fractograph of chip hot-extruded material

Since HCP structure has a large Taylor factor, grain refinement has a strong effect on its strength at room temperature[4, 9]. The constant K_y of magnesium in Hall-Petch relationship is about four times that of aluminium[10]. Thus mechanical properties of magnesium alloy can be improved greatly through extrusion, which has a strong ability of grain refinement.

Magnesium alloy chips could be recycled by many methods including re-melting, burning, thixoforming and hot extrusion[9, 11, 12]. Compared with the former three methods, hot extrusion has some advantages: 1) extrusion has strong ability of grain-refining; 2) extrusion is a solid-state technology in which processing temperature is lower than that of re-melting or thixoforming, thus it is more safe and more energy-economical; 3) extrusion is an efficient way to recycle magnesium alloy chips since few pre-treatments of the chips are required before extrusion. It should be mentioned that AZ80 chips in this study were directly used to prepare bulk materials without any pre-treatments, such as smashing, weeding out oil and contaminants etc. Through hot extrusion, experimental materials show good combination of strength and plasticity. That is to say, hot extrusion is an efficient method for AZ80 magnesium alloy chip recycling.

4 CONCLUSIONS

1) AZ80 magnesium alloy from machined chips

were hot extruded to prepare bulk materials. The relative density of chip-extruded rods is about 98%, and nearly full density can be attained under an extrusion ratio of 25:1 at 623 K.

2) The ultimate tensile strength and elongation of chip-extruded rods is about 285 MPa and 6% respectively, which is much higher than those of as-cast materials due to grain refinement by extrusion. After T5 heat-treatment, its σ_b and δ increase to 310 MPa and 15%.

3) The breaking of chip interfaces plays an important role on material fracture. Heat-treatment can improve the mechanical properties of chip-extruded materials by enhancing the bonding.

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