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THE MICROSTRUCTURE FEATURES AND THE DEFORMATION MECHANISM OF A FINE GRAINED MAGNESIUM ALLOY UNDER DYNAMIC LOADING

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Abstract. The relationship between the dynamic mechanical properties of a fine grained magnesium alloy and its microstructure is investigated. The deformation behavior under dynamic loadings of the fine grained Mg alloy is analyzed and the feature of the dynamically deformed microstructure of the material is discussed. The result shows that the dynamic compressive strength of the fine grained Mg alloy is much higher than the quasi-static compressive strength and it marks a significant strain rate strengthen effect in the material. Few twinning is found in the dynamically deformed microstructure of the fine grained alloy; hence the dominant dynamic plastic deformation mechanism of the fine grained magnesium alloy should be the dislocation slips.

1. INTRODUCTION

The magnesium alloy is the lightest structural material combined with the properties of low density, high specific strength, high specific modulus and good damping property and high energy absorption up to now. And it has been used widely in the fields including aeronautics and astronautics, automobile industry and electronic products [1]. With the expansion of magnesium application in many fields, the alloyencounters very severe impacts and dynamic loads in many environments [2].

The deformation behavior of material under dynamic loading is quite different from that under quasi-static loading because of the adiabatic effects, strong shockwave effects and localized deformation under dynamic loading [3]. For example, the usually untwinning material under quasi-static loads may twin under dynamic loads. The metal material often partly molts under high velocity impacts because of the severe thermal effect and the following rapid cooling may transform the molten metal into metallic glass. Furthermore, the dynamic loading will induce higher crystal defects density in the material [4].

The microstructure feature of the dynamic deformed fine-grained AZ31 magnesium alloy is investigated. The mechanism of dynamic plastic deformation of the material is discussed too.

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2. EXPERIMENT MATERIAL AND METHOD

The material studied here is a die-cast AZ31 rod and the chemical composition of the alloy is shown at Table 1.The alloy is annealed at 400 °C for 12 hours firstly and processed by Equal Channel Angular Pressing (ECAP) for four passes to refine the microstructure. The die channel angular used here is 90°.The processing route is B_c and the operating temperature is 300 °C. The pressing speed is 30 mm/min and the pressure is 7.5 MPa [5]. The appearance of the rod specimens processed by four passes ECAP is shown in Fig. 1.

The dynamic mechanical properties of the fine-grained Mg ally are determined by the Split Hopkinson Pressure Bar (SHPB) system, which is known as the most reliable testing system up to now. The range of the strain rate applied here is from 1500 s^{-1} to 4000 s^{-1}. 5 ~ 7 specimens are tested under each strain rate. The specimen shape is column, the diameter of the specimen is 7 mm, and the length of the specimen is 7 mm. The microstructure of the dynamically deformed specimen is investigated by the Olympus PME-3 optical microscope. The deformation feature of the material is discussed.

Fig. 1. The view of AZ31 magnesium alloy processed by 4 passes ECAP.

3. RESULTS AND DISCUSSIONS

3.1. Grain size refinement of the AZ31 magnesium alloy processed by ECAP

The microstructures of the AZ31 annealed at 400 °C for 12 hours and 4 pass ECAP processed are shown in Fig. 2. The microstructure of the annealed AZ31 is coarse grain with clear and completed grain boundary. The microstructure of AZ31 after 4 passes ECAP process is all equal-axis crystal in three dimensions and the microstructure is fine and uniform. The average grain size is 120 μm and 6.5 μm for anneal AZ31 magnesium alloy and 4 pass ECAP processed AZ31 magnesium alloy respectively.

In the process of ECAP deformation of AZ31 magnesium alloy, the microstructure of the material is refined partly in the first pass and uniformly refined in the coming pass. The law of the refinement process can be found as such: the first pass of ECAP makes many small grains in the boundary of the initial large grains but the coarse grain are still left in the material. The microstructure of the material becomes finer and more large grains are into fine grains when the ECAP pass number increases. The experiments results prove that the fine grain microstructure can be obtained when the ECAP pass number exceeds 4.

3.2. The compressive mechanical properties of the fine-grained magnesium alloy under dynamic loading

Fig. 3 shows the true strain-stress curve of the alloy at different strain rates. The strain rates vary from the quasi-static condition (0.0005 s^{-1}) to high strain rate condition (4000 s^{-1}). It can be seen that the true strain-stress curve is higher under higher strain rate than those under lower strain rate and the phenomenon marks a significant strain rate hardening effect. And it proves that the fine grained AZ31 magnesium alloy prepared by ECAP is a strain rate sensitive material and it has a positive strain rate effect.

The strain rate hardening effect of material is related to thermal activating mechanism of dislocation movement. In the quasi-static state the plastic deformation of metal material is controlled by the

Table 1. Nominal composition of the AZ31 magnesium alloy.

Element	Al	Zn	Mn	Si	Fe	Cu	Ni	Mg
wt.%	2.82	0.97	0.29	$3.06 \cdot 10^{-2}$	$0.19 \cdot 10^{-2}$	$0.17 \cdot 10^{-2}$	$0.05 \cdot 10^{-2}$	the rest

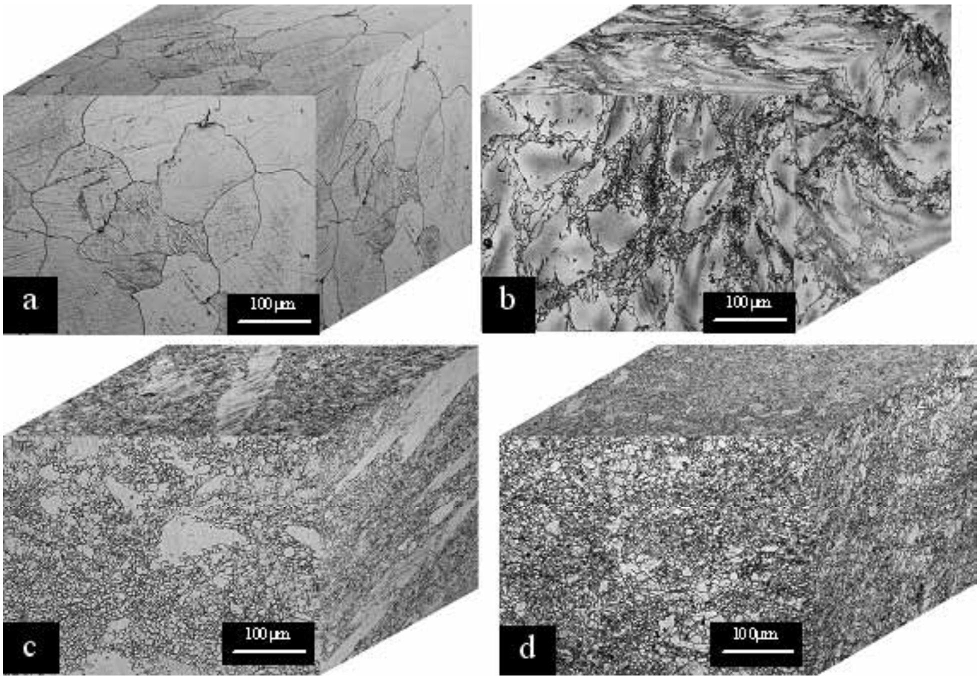

Fig. 2. Optical microstructure of the annealed and 4 pass ECAP processed AZ31: (a) Annealed, (b) 1 pass ECAP processed, (c) 2 pass ECAP processed, (d) 4 pass ECAP processed.

thermal activating mechanism of dislocation movement and the mechanism works only when the strain rate is not very high. When the strain rate is too high the dislocation movement will be unable to conquer the short distance obstacles by thermal activating mechanism and the thermal activating mechanism becomes less and less powerful. The dislocation movement controlling mechanism may transform to the viscose slipping. The crystal defects density of the material is higher and the distribution of dislocation is more uniform in the material under dynamic loading. It has been studied widely

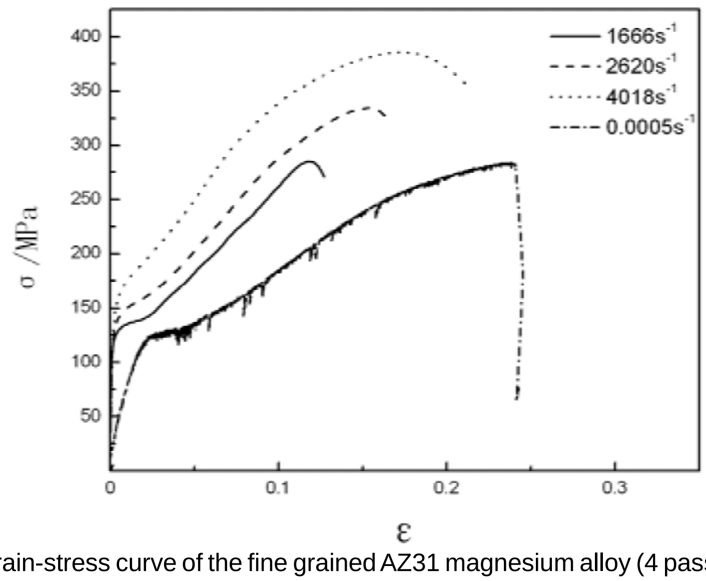

Fig. 3. The true strain-stress curve of the fine grained AZ31 magnesium alloy (4 pass ECAP processed) at different strain rate.

Table 2. The compressive properties of the fine grained AZ31 under different strain rate.

Strain-rate, s^{-1}	*Yield strength*, MPa	*Compressive strength*, MPa	*Uniform reduction*,%
0	118	265	25
1666	123	285	12
2620	134	334	17
4018	156	385	20

that the FCC metal is tend to have cell dislocation structure under dynamic loading and the BCC metal is tend to have the tangling dislocation structure. But the dislocation structure of HCP metals under dynamic loading has not been focused very much.

The mechanical property values calculated from the true strain stress curve of the fine grained AZ31 is listed in Table 2, in which the yield stress is calculated by the 0.2% proof strain stress and the compressive strength is calculated by the peak point of the curve. The ultimate strain volume is marked when the strain-stress curve significantly declines. It can be seen that the compressive strength increases as the strain rate enhances and it indicates a strain rate harden effect of the material.

3.3. The microstructure of the fine grained magnesium alloy dynamic compressively deformed

Fig. 4 shows the microstructure of the fine grained AZ31 plastic deformed by quasi-static compressive loads. Many shear bands parallel to the fracture plane can be seen in the structure. The grains are severely shear-deformed in the shear bands. A lot of twin formed in the grains in and near the shear bands. No significant shear deformation is observed in the grains away from the shear bands. It is analyzed that the micro-crack formed and grow in the shear bands at the end of the plastic deformation progress which results the fracture of the alloy finally. The formation of shear bands in the alloy should be responsible for the decline of the plastic deformation ability of the material.

Fig. 5 shows the microstructure of the fine grained AZ31 plastic deformed by the compressive dynamic load. It can be seen that many adiabatic shear bands which lay parallel are formed in the sample. Large amount of twins are formed in the shear bands and obvious cracks can be found in the shear bands, while nearly no twinning is found out of the shear bands. It is clear that the plastic deformation mechanism of the fine grained magnesium alloy shows "slip" feature under dynamic loads and the adiabatic shear bonds are formed under higher stain rate (the shock pressure is above 4 GPa).

The time that material experiences in the dynamic deformation process is very short and it is impossible for the heat which is converted from plastic work to dissipate from the material, so the dy-

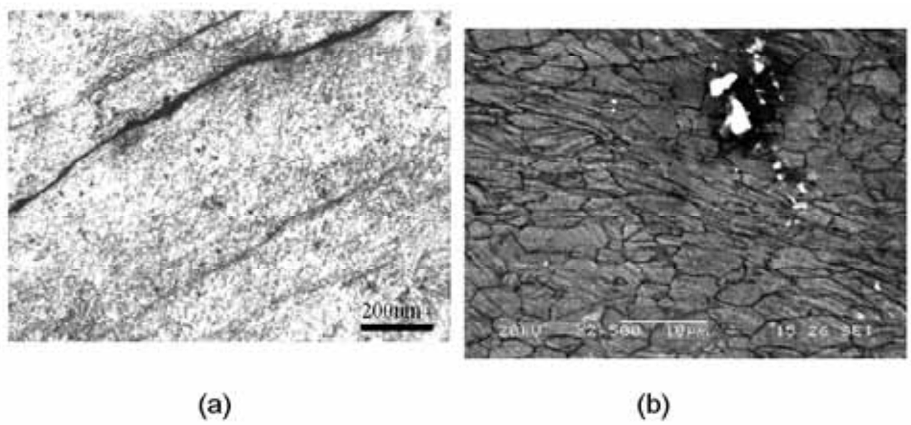

Fig. 4. The microstructure of the fine grained AZ31 after plastic deformation under quasi-static compressive loading: (a) the isothermal shear bands (b) microstructure of the shear band.

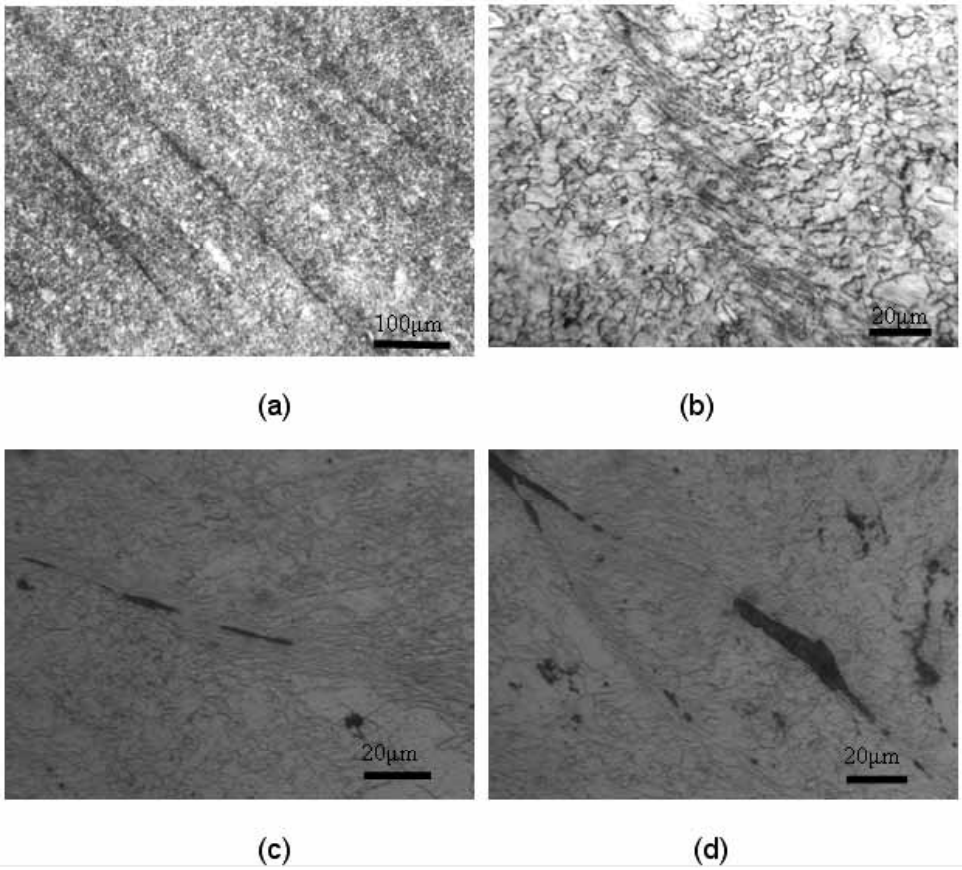

Fig. 5. The microstructure of the fine grained AZ31 after plastic deformation under dynamic compressive loading: (a) adiabatic shear bands, (b) microstructure of the adiabatic shear bands, (c) crack-cores in the adiabatic shear bands, (d) cracks along the adiabatic shear bands.

namic deformation process can be seen as an adiabatic one. It is found in the experiment that a lot of adiabatic shear bands have been formed in the fine-grained AZ31 under high strain rate (4018) of dynamic loading. The formation of adiabatic shear bands is closely related to the strain volume under dynamic loading. No re-crystallization microstructure is found in the adiabatic shear bands while large amount of shear twins are found in the shear bands [2]. The adiabatic shear band is distinguished from the isothermal shear band (shear band formed under quasi-static loading) for the thermal effect under dynamic loading. The material heated by the plastic work under dynamic loading is in a softer state compared with the material at room temperature, so more shear bands are formed and they lies straighter than the isothermal shear bands (Fig. 5). Meanwhile more crack-cores are formed in the adiabatic shear band than in the isothermal shear band because of the heat effect (Fig. 4).

4. CONCLUSIONS

(1) The coarse and large grains of the cast AZ31 can be refined to be uniform and fine grains with equal-axis of few micrometers after several passes of ECAP deformation.
(2) The fine grain AZ31 prepared by ECAP is a kind of strain rate sensitive material with the strain rate strengthen effect.
(3) The plastic deformation mechanism of the fine grained magnesium alloy shows “slip” feature under dynamic loading and the adiabatic shear bands are formed under high stain rate loading.
(4) The microstructure of the adiabatic shear bands is featured by the sheared twins and grains in the band and it is deduced that the adiabatic shear bands are formed by the grains that have preferential twin orientation under dynamic loading.

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