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Biaxial deformation behavior of AZ31 magnesium alloy at high temperatures

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Abstract

The evaluation of plastic deformation processing of materials has been based mainly on uniaxial tensile tests. However, for the analysis of multiaxial stress conditions in sheet-metal plastic forming, more complex tests, such as the controlled biaxial test with cruciform specimens, are required. In this report, we examine the relationship between the biaxial deformation behavior and microstructure of AZ31 magnesium alloy for initial strain rates of 3.0×10^{-3} s^{-1} and 2.8×10^{-4} s^{-1} at 573 K and 623 K using cruciform specimens. The results show that the flow stress increases with decreasing sheet thickness, and the occurrence of tensile twins is confirmed during biaxial tensile deformation at an elongation of 30 % in a cross-section of a specimen under 623 K for a strain rate of 2.8×10^{-4} s^{-1} . This deformation behavior and evolution of the microstructure is unique in biaxial tensile tests, and is not recognized in uniaxial tensile tests with the same elongation. Since this controls the width direction of the specimen during deformation, we can only guess that the plate thickness direction can be deformed freely and without restraint. In other words, for biaxial tensile test conditions, the transition point of the microstructure under the influence of the constraint of grain boundary sliding is at 623 K for a strain rate of 2.8×10^{-4} s^{-1} .

Introduction

Magnesium alloys are the lightest metals in practical use with strong specific strengths. In recent years, these alloys have begun to find application in auto parts to address environmental issues and to achieve weight reduction of the vehicle [1]. However, because of the crystal structure of these alloys, only the basal plane of the slip system at room temperature, the material is known as a difficult work forming. Therefore, for the improvement of the strength and plastic workability of magnesium alloys, the structural refinement, texture control by thermomechanical treatment, and high-temperature deformation behavior of many slip systems are being actively studied [2-5]. However, evaluation of the strength, ductility, and plastic processes at room temperature and high temperatures was carried out under uniaxial stress. Considering the actual manufacturing process, the strength, ductility, and structural changes under biaxial stress should be examined [6-9]. Such analysis methods allow the plastic stress–strain components to be separated. Therefore, it is possible to create biaxial stress and separate the stress–strain components; thus, a biaxial tension test is required on cross-shaped specimens.

In this report, biaxial tensile tests were conducted at a high temperature using the magnesium alloy AZ31 by rolling processing and structural refinement MAF. We investigated the relationship between the mechanical properties and structural changes, and compared the results with those of plastic processing and the evaluation of uniaxial deformation.

Experimental Procedures

Material and structure refinement forming

The materials used were commercially extruded AZ31 Magnesium alloys. The chemical composition was as follows: Al 3.02, Zn 0.92, Mn 0.38, Fe 0.0035, Si 0.023, Mg bal (mass%). A cubic block of length 80 mm was cut out from the extruded AZ31 Mg alloy and subjected to MAF(Multiaxial Alternative Forging) processing at a high temperature. Figure 1 shows the schematic illustration of the working process for MAF [10]. In addition, this block was cut parallel to the extrusion direction to give a sheet with a thickness of 2 mm, and rolling was performed.
Subsequently, recrystallization annealing was carried out at 473 K for 1.2 ks to make the fine-grained structure.

In forging, the pressed sides of the cube were extruded sequentially from the surface. The forging temperatures were 573, 543, and 513 K, the press speed was 1 mm/min rolling speed, and the reduction ratio was 30%. The material was cooled with water after forging in each pass. The rolling conditions were a temperature of 493 K and holding for 0.6ks, and two - pass rolling was performed; the final sheet thickness was 1 mm. Herein, this material is referred to as fabricated material processing material processing rolling after MAF.

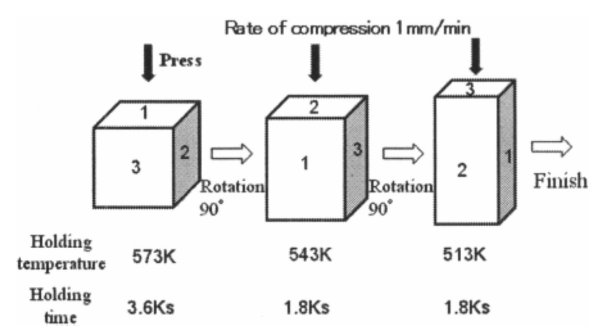

Fig. 1 Schematic illustration of the working process for the multiaxial alternative forging.

Experiment method

The uniaxial tensile specimen consisted of a parallel portion with a width b of 6 mm, gauge length l of 6 mm, and thickness t of 1 mm. Figure 2 show the cruciform specimen geometry. The center of the cruciform shaped specimen represents, has been pocketing at 0.25 mm increments from each φ6 mm back. Thus, the observed thickness at the center of the test section is 0.5 mm, and the others are 1 mm.

The test temperature was 523 – 623 K, the strain rates were 2.8×10^{-4} s^{-1} and 3.0×10^{-3} s^{-1}, and holding tests were performed under each set of test conditions 10 min after the set temperature was reached. The sample was heat - treated at 493 K for 1.2 ks prior to testing.

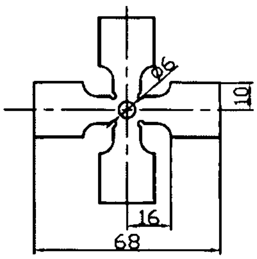

Fig.2 Shape and dimension of cruciform specimen.

Results and Discussions

Effect of pretreatment on structure

Figure 3 shows optical micrographs of the structure of the extruded AZ31 Mg alloy and the fabricated material (rolling after MAF processing). As shown in Figure 3, the extrusion material had an average grain size of 16 μm containing coarse grains, whereas in the rolled material, the structure showed a relatively uniform average particle size of 4 μm. This is due to the hot rolling and MAF processing, which causes dynamic recrystallization. Table 1 shows the mechanical properties of these materials at room temperature. For the extruded material, the proof stress showed a remarkable difference in the tension and compression sides, indicating a large anisotropy. In contrast, for the fabricated material, the difference in the proof stress according to direction was small, and the strength and growth improved.

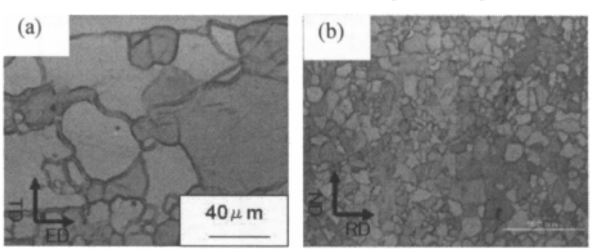

Fig. 3 Optical microstructure extruded material (a) and processing material by forging and heat-treatment (b) of AZ31 magnesium alloy.

Table 1 Mechanical properties of used materials at room temperature.

Extruded material

	Proof stress/MPa			Tensile strength/MPa			Nominal strain(%)		
Direction	0°	45°	90°	0°	45°	90°	0°	45°	90°
	180	80	60	255	277	229	24	31	24

MAF+Rolling material

	Proof stress/MPa			Tensile strength/MPa			Nominal strain(%)		
Direction	0°	45°	90°	0°	45°	90°	0°	45°	90°
	210	180	180	290	270	280	28	34	23

Tensile properties at high temperatures

The nominal stress – strain diagram and the equivalent stress–strain diagram obtained from the biaxial and uniaxial tensile tests are shown in Figure 4.

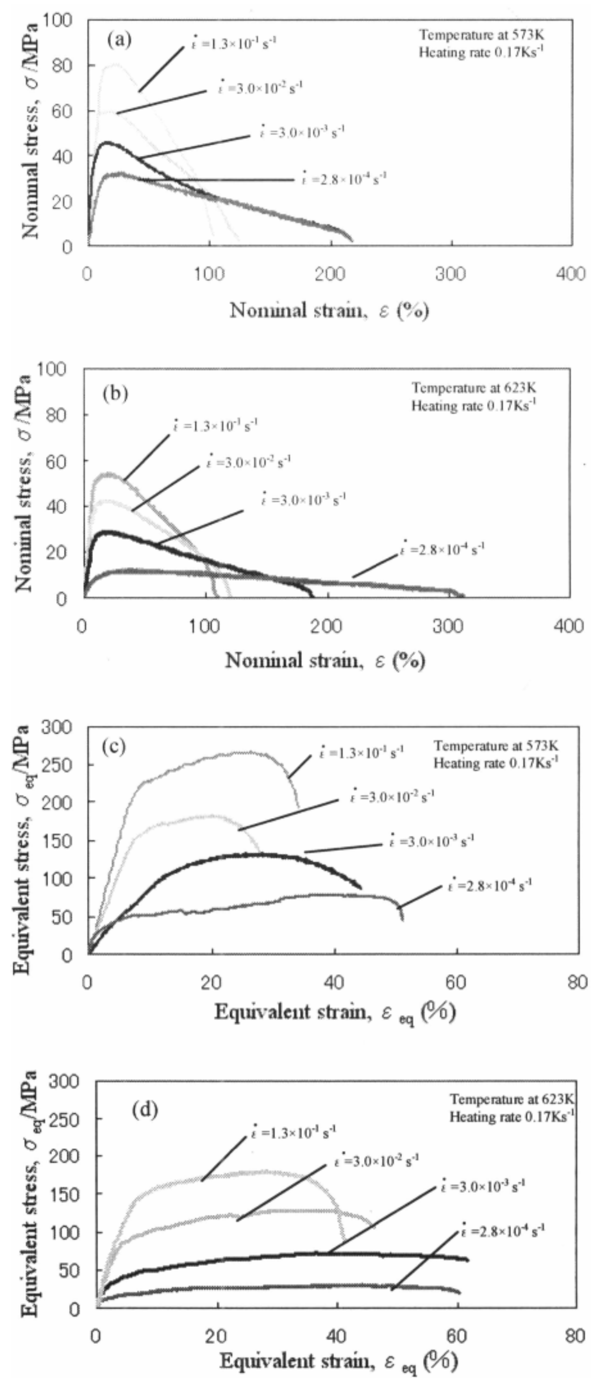

Fig. 4 Nominal stress - strain curves of uniaxial deformation at 573K (a) and 623K (b). And biaxial deformation at 573K (c) 623K (d).

A comparison of uniaxial and biaxial deformation shows that, in uniaxial deformation, after reaching the maximum stress, the stress decreases, and the fracture extends by more than 60%. In particular, at 623 K, the strain of 2.8×10^{-4} s^{-1} has increased by more than 200%. In the biaxial deformation, it can be seen that the flow stress is higher than in uniaxial deformation. In addition, the biaxial deformation is lower compared to the elongation. Figure 5 shows the relationship between the maximum stress and the strain rate. The strain-rate sensitivity of the biaxial deformation indices tends to have a higher value than for the uniaxial deformation.

For a temperature of 623 K and a strain rate of 2.8×10^{-4} s^{-1}, in uniaxial deformation, superplastic deformation was observed. However, despite the fact that the biaxial deformation had a value of 0.3, a large elongation was not obtained. This uniaxial deformation proceeds by a reduction in the width direction and thickness. In biaxial tensile deformation, the deformation is in the direction of the tensile stress, and although it acts from two directions it will decrease in the thickness direction only. Because of the poor plastic flow, the low elongation results in a higher flow stress.

The relationship between the strain rate and n value is shown in Figure 6. The n value in uniaxial deformation at a slow strain rate tends to be lower. At 623 K, with a strain rate of 2.8×10^{-4} s^{-1}, it takes a higher value. Under these conditions, superplastic deformation occurs. Sliding occurs because of the large grain boundary, almost without having to act on the grain deformation, which indicates that the hardening values do not increase. In biaxial deformation, a strain rate of 3.0×10^{-3} s^{-1} has a peak value of n.

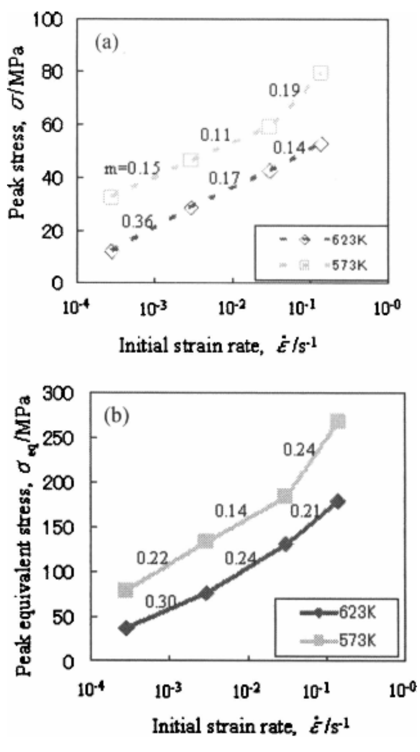

Fig. 5 Relation of peak stress and initial strain rate under uniaxial deformation (a) and biaxial deformation (b).

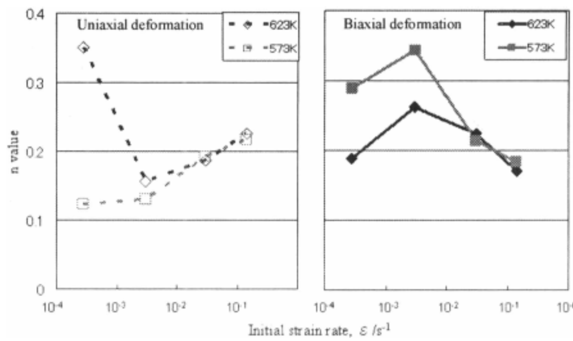

Fig. 6 Relationship between n value and initial strain rate under uniaxial deformation and biaxial deformation.

Structure after uniaxial and biaxial deformation

Figure 7 shows the SEM microstructure of the plate surface structure for an applied strain of 30% on a single axis. Uniaxial deformation is understood that a cavity is formed with biaxial deformation.

A comparison of the structures at a strain rate of 3.0×10^{-3} s^{-1} and those at strain rate of 2.8×10^{-4} s^{-1} reveals that a larger cavity is formed at a slower strain rate. In addition, the cavity grows in the direction perpendicular to the tensile direction. In biaxial deformation, cavity growth can be observed in many directions.

Deformation under biaxial tensile stress is applied in two directions subject to the grain - boundary sliding resistance caused by grain-boundary segregation.

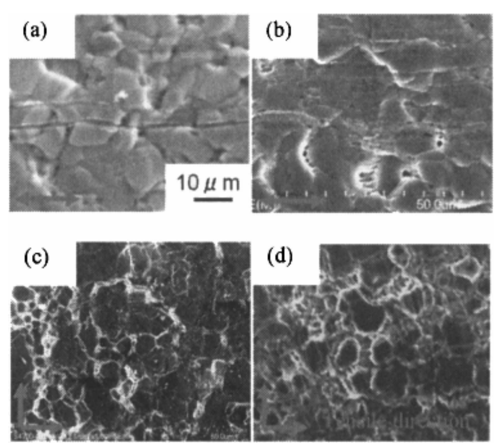

Fig. 7 SEM microstructure at 623K under uniaxial deformation for initial strain rate 3.0×10^{-3} s^{-1} (a) and 2.8×10^{-4} s^{-1} (b). Biaxial deformation 3.0×10^{-3} s^{-1} (c) and 2.8×10^{-4} s^{-1} (d).

The IPF maps from the EBSD analysis are shown in Figure 8. Figure 8 is an IPF map in cross-section from the results at 30% strain. Under uniaxial deformation, the twinning formation is not seen for any conditions. However, under biaxial deformation at a test temperature of 623 K, and strain rates of 3.0×10^{-3} s^{-1} and 2.8×10^{-4} s^{-1}, the formation of {10-12} twins occurred. Under uniaxial deformation, since the unconstrained plane tensile deformation can be reduced in the width and thickness directions, there is good plastic liquidity deformation compared to that found with the lower grain-boundary sliding resistance of the biaxial deformation, and the occurrence of twins is not observed. With the biaxial deformation, the surface contribution to the tensile deformation is constrained only by the reduction in thickness. Because of the poor plastic flow, it is believed that the formation of deformation twins in the grains increases with increasing grain-boundary sliding resistance. The conditions under which twins occur are: 623 K, strain rate 3.0×10^{-3} $s^{-1}$and 2.8×10^{-4} s^{-1} . The incidence of twins is 27% at 3.0×10^{-3} s^{-1} and 30% at 2.8×10^{-4} s^{-1} . At this strain rate, the average grain size is larger. Therefore, the results are considered high-frequency results.

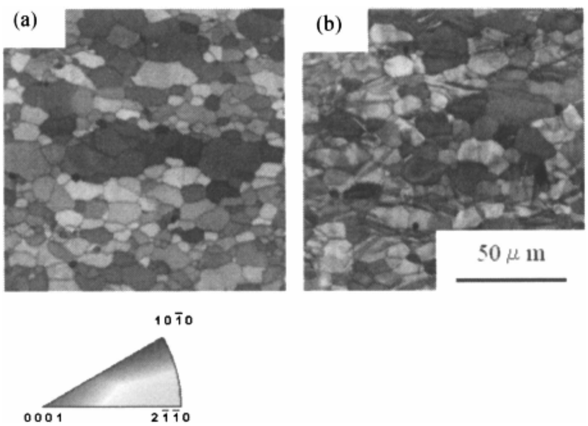

Fig. 8 IPF map of AZ31 magnesium at 623K. Under uniaxial deformation (a) and biaxial deformation (b) on initial strain rate 2.8×10^{-4} s^{-1} .

Conclusion

Biaxial tensile tests at were conducted at high temperatures using a magnesium alloy AZ31 by rolling processing and structural refinement MAF, and the relationship between the mechanical properties and structural changes were investigated and compared with those of plastic processing and uniaxial deformation. The following conclusions were obtained:

In biaxial deformation, for surface constraints, plastic flow is deteriorated only by the decrease in the thickness. The flow stress is high, and the growth is low.

In biaxial deformation, grain-boundary separation occurs much more in the direction of cavity growth, and slip deformation is constrained at the grain boundary.

In biaxial deformation, the formation of tensile twinning occurs only at 623 K for strain rates 3.0×10^{-3} s^{-1} and 2.8×10^{-4} s^{-1} .

Acknowledgment

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