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Compressive deformation behavior of meso pillar fabricated from magnesium alloy AZ 80

T. Nakamura[1], T. Kakiuchi[2*], Y. Yogo[3], T. Suzuki[3], M. Wakasugi[3], Y. Uematsu[2]

[1] Graduate Student, Mechanical and Systems Engineering Division, Graduate School of Gifu University, 1-1 Yanagido, Gifu, 501-1193, Japan
[2] Department of Mechanical Engineering, Gifu University, 1-1 Yanagido, Gifu, 501-1193, Japan
[3] Toyota Central R&D Labs., Inc., 41-1 Yokomichi, Nagakute, 480-1192, Japan

* Corresponding Author: kakiuchi@gifu-u.ac.jp

Abstract. Meso pillar specimens, 100 μm in diameter and 150 μm in height, were fabricated from an extruded plate of magnesium (Mg) alloy AZ 80 by an electrical discharging machining process. Compression tests have been performed using the meso pillars and compressive deformation behavior was investigated. The plate had the strong texture as that the c-axes of the hexagonal close packed (HCP) crystals were nearly parallel to the thickness direction (ND) of the plate. The pillars were taken so that the longitudinal axes were parallel to ND, the extruding direction (RD), the width direction (TD) and some directions between RD and TD. They are denoted as ND, RD, TD and RD-TD, respectively. The bulk pillars, 6 mm in diameter and 9 mm in height, exhibited strong anisotropy: The RD and TD bulk pillars exhibited a bending point in stress – strain curves at almost 1 % of strain while this bending point did not appear in the ND pillar. However, in the case of the meso pillars, this bending point did not appear either in the ND or RD-TD; which indicates that the anisotropy of the meso pillar was weaker than that of the bulk pillar. As for the strength, the nominal compressive strengths of the meso pillars were lower than those of the bulk pillars. These results were attributed to the relaxation of the deformation constraint conditions in the meso pillar due to the increase of the specific surface area ratio to volume and the decrease in the number of the nuclei of dislocations and twinning.

1. Introduction

In recent years, there has been an increasing demand for lightweight structural materials from the viewpoint of improving fuel economy in industrial fields such as automotive and aerospace industries. Magnesium (Mg) has the lowest density in the practical metals and its alloy is superior in specific strength, therefore Mg is promising for such applications. Mg alloy has a hexagonal close-packed (hcp) crystal structure which has few slip systems, which exhibits strong anisotropy. For this reason, it is known that a wrought material of Mg alloy forms texture easily during manufacturing and the bulk sample has strong anisotropy in mechanical properties. In order to promote the use of Mg alloys, it is necessary to understand the anisotropy of the wrought Mg alloy. In the past, many experimental studies have been conducted on the bulk sample of Mg alloy, and much knowledge is obtained about the anisotropy. Recently compression tests using single crystal pillar type specimen (micro pillar) having dimensions of several to tens of micrometers were also performed [1], and the strength and deformation behavior depending on crystal orientation and anisotropy of differences with bulk sample were clarified. However, the transition of the mechanical properties on the scale between the micro sized sample and the bulk sample are not clarified.

In this research, pillar specimens having a mesoscale dimension of about 100 μm (meso pillar), which is between micrometer scale and millimeter scale, were fabricated from an extruded Mg alloy plate. Compression tests were carried out and the effects of size and anisotropy in compressive strength and deformation behavior were investigated.

2. Test material and Sample

2.1. *Test material*

The material used in this study was an extruded Mg alloy, AZ80. The material was received as a plate with thickness of 11.5 mm. In this paper, the extrusion, the width and the thickness directions are denoted as the RD, the TD and the ND directions, respectively. Figure 1 shows the pole figures of the (0 0 0 1) plane obtained by an electron backscatter diffraction (EBSD) analysis on the RD-TD and TD-ND planes. From these pole figures, a strong basal texture in which the c-axis was parallel to the ND direction can be seen while the texture has a scatter.

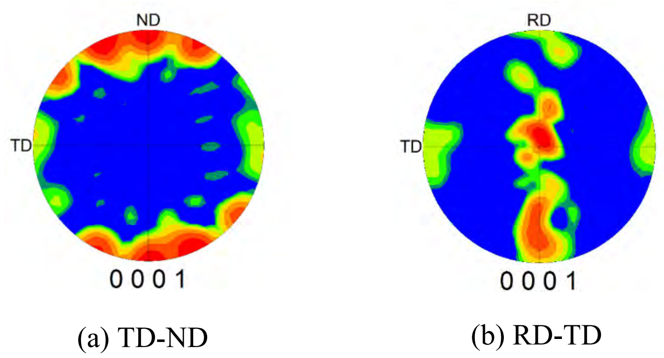

Figure 1. Pole figures of (0 0 0 1) at RD-TD and TD-ND plane with AZ80.

2.2. *Bulk pillar*

The column-shaped specimen, 6 mm in diameter and 9 mm in height, was fabricated from the extruded plate, which is hereafter denoted as the bulk pillar. Figure 2 shows a schematic drawing of

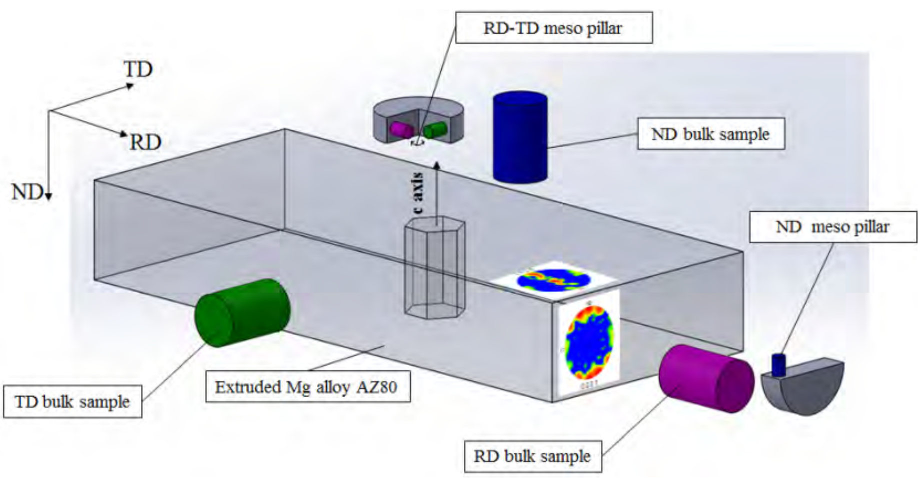

Figure 2. Schematic drawing of sampling bulk specimen and meso pillar from AZ80.

bulk pillar specimen sampling. Meso pillar sampling, described below in section 2.3, is also shown in the same figure. Bulk pillars were sampled in three directions. The bulk pillars in which the height direction was parallel to the RD, TD and ND directions are denoted as the RD, TD and ND bulk pillars, respectively.

2.3. *Meso pillar*
As shown in figure 3, a thin disk, with a diameter of 10 mm and a thickness of 1.0 mm was sampled from the extruded plate and was cut in the thickness direction. And then a meso pillar with a diameter of 100 μm and a height of 150 μm was fabricated with the height perpendicular to the cut surface. Fabrication was carried out by a die-sinking electrical discharge machining using cemented carbide electrodes. The SEM image of the meso pillar sample is shown in Fig. 3. Meso pillars were sampled in two directions; in which the height direction was parallel to the ND direction and vertical (the height direction existed between the RD direction and the TD direction), and are denoted as the ND meso pillar and the RD-TD meso pillar, respectively.

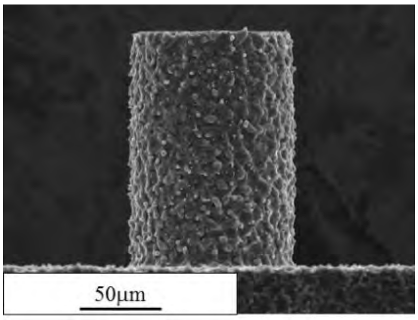

Figure 3. SEM image of meso pillar before compression test.

3. Experimental methods

3.1. *Bulk pillar compression test*
The compression test [3] was performed on the bulk pillars. In this test, grooves were fabricated on the contacting surfaces of the upper and lower dies to prevent slippage between the bulk pillars and the dies. The test condition was at a strain rate of 0.02 / s at room temperature in the laboratory air. In this test condition, the compression axis and the c-axis were parallel in the ND bulk pillar.

3.2. *Meso pillar compression test*
The uniaxial compression test was performed on the meso pillars using a self-made testing machine. The compression was made by an actuator equipped with a steel probe having a diameter of 300 μm and a height of 200 μm. The load was measured by a load cell during the compression tests. The test condition was under actuator rate control at 8 μm / s at room temperature in laboratory air. In this test condition, the compression axis and the c-axis were parallel in the ND meso pillar.

4. Results
Figure 4 shows the compressive nominal stress - nominal strain curves of bulk pillars and meso pillars. The results of the micro pillar [1] are also shown in the same figure. In the micro pillar compression test, compression was performed parallel to the c-axis. The value of the micro pillar in legend indicates the diameter of the micro pillar.

4.1. *Bulk pillar compression test*

In the RD and TD bulk pillars, the stress was linear with the strain up to 110 MPa, and then the stress - strain curve bent. On the other hand, the bending point did not appear in the ND bulk pillar. The compressive strength was about 400 MPa, and no significant difference was observed in the strength.

4.2. *Meso pillar compression test*

From figure 4, the compression strengths of the ND and RD-TD meso pillars were 340 MPa and 420 MPa, respectively, and there was a large difference. The fracture strain was also 0.32 and 0.15 respectively, and a large difference was also observed.

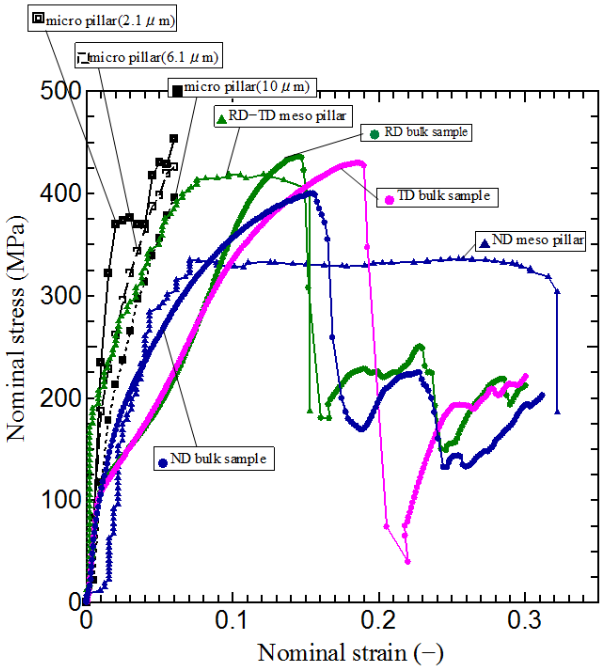

Figure 4. Nominal stress-strain curves of bulk specimens, meso pillars and micro pillars in compression test.

5. Discussions

5.1. *Strength difference of bulk pillar*

The bending point in the stress - strain curve was confirmed at 110 MPa in only the RD and the TD bulk pillars. This is considered to be caused by angular difference between the c-axis and the compression axis. First, when the c-axis and the compression axis are parallel, no shear stress is applied at the basal plane (0 0 0 1), so no basal slip operates. Also, no tensile stress is applied parallel to the c-axis, so tensile twin $(1\ 0\ \bar{1}\ 2)$ does not operate. Next, when the c-axis and the compression axis are perpendicular, the stress projected area for the basal plane (0 0 0 1) is 0, so no basal slip operates. But tensile shear stress is applied parallel to the c-axis, so the occurrence of tensile twin $(1\ 0\ \bar{1}\ 2)$ is promoted. From these results, it is considered that tensile twins did not operate in the ND bulk pillar but tensile twins operated in the RD and TD bulk pillars. As a result, the bending point appeared only in the RD and the TD bulk pillars.

5.2. *Effect of scale on compressive strength*

The results of the micro pillar [1] and the results of this study are compared and discussed. When comparing these three compressive strengths; the micro pillar, the meso pillar and the bulk pillar, the micro pillar was the highest, the next highest was the bulk pillar, and the meso pillar was the lowest. It is considered that the cause of the decrease in strength between the meso pillar and the bulk pillar was less constraint of dislocation due to the increase in the ratio of surface area to volume. Therefore, stress required for plastic deformation decreased and the strength was lowered. On the other hand, the strength of the micro pillar is higher than the others. As a factor of this, reduction of the number of dislocation sources due to volume reduction is conceivable. As the dislocation source decreases, the strength level could be improved by increasing the stress required for plastic deformation.

6. Conclusion

In this study, compression tests using meso pillars were conducted and the test results were compared with those of the bulk pillars and the micro pillars [1]. As for deformation behavior, any meso pillar did not exhibit a bending point in the stress - strain curve, while some bulk pillars, the RD pillar and the TD pillar, exhibited the bending point. As for strength, the scale effect between the bulk and meso, and between the meso and micro, were different. The meso pillar, which was smaller than the bulk pillar, exhibited the lower strength than the bulk pillar, while the micro pillar, which was smaller than the meso pillar, exhibited the higher strength than the meso pillar and the bulk pillar.

References

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