Improvement of ductility in magnesium alloy sheet using laser scanning treatment

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ABSTRACT

This paper suggests a novel method for improving the ductility of magnesium alloy sheets using a laser scanning treatment combined with a defocusing technique. The crystallographic orientation on both surface regions of the AZ31B magnesium alloy sheet processed using this method was changed from a strong basal texture to an almost random texture. The laser-scanned magnesium alloy sheet showed enhanced tensile elongation of up to 50% with a similar tensile strength.

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1. Introduction

Magnesium alloy sheets have potential applications in the automobile and aircraft industry owing to the low density and excellent mechanical properties [1–4]. However, Mg alloy sheets show very limited ductility at room temperature because of the limited number of slip systems in the HCP structure and strong (0002) basal plane texture [2,5,6]. The most effective method for improving the ductility of Mg alloy sheets is by weakening the basal plane texture. Recently, it was reported that the basal plane texture of an Mg alloy sheet can be reduced by asymmetric rolling due to the severe shear deformation, which enhanced the ductility [7]. With equal channel angular pressing (ECAP) or rolling (ECAR), the materials are passed repeatedly through a folded sharp die channel leading to severe shear deformation. This method has also been demonstrated to improve the ductility of Mg alloy sheets through the formation of textures with high Schmid factors for the basal slip. However, methods involving the application of severe shear deformation during processing should require a subsequent heat treatment process to stabilize the grain boundary and allow recovery. In addition, the amount of deviation from the basal plane texture after the process is too low.

In this study, a novel method to supply high energy to both surfaces of an Mg alloy sheet through a laser scanning treatment combined with a defocusing technique was performed to weaken the (0002) basal plane texture on the surface regions. The changes in microstructure and mechanical properties of the Mg alloy sheet by the laser scanning treatment were analyzed by electron backscattered diffraction (EBSD) and microhardness. Tensile tests at room temperature were carried out to confirm the improved elongation of the laser-scanned specimens. This measured mechanical behavior was compared with simulation results obtained from a finite element method (FEM) for the laser-scanned specimens with the layered structure.

2. Experimental

A 1.05 mm thick AZ31B-H24 sheet with 3.27 wt.% Al, 0.96 wt.% Zn and balanced Mg was used in this study. An Ytterbium fiber laser (IPG photonics corp., YLR-1000) in continuous mode was used to scan both surfaces of the Mg sheet. The laser power was 200 W and the laser scanning speed was 10, 15, and 20 m/min. A defocusing technique was applied to obtain a broad laser-treated region over the surface and prevent an excessive concentration of the laser power. The cross-sections of the laser-scanned sheets were polished mechanically using a diamond suspension. A final surface polish by colloidal silica was then carried out. The specimens for the high quality EBSP measurements were etched chemically for 7 to 10 s in a solution of 4.2 g picric acid, 10 ml distilled water, 10 ml acetic acid and 70 ml ethanol. The microstructure and crystallographic orientation of the laser-treated region and base material were analyzed using the EBSD system equipped in a field emission scanning electron microscope (JEOL, JSM-
material was measured, as illustrated in Fig. 2. The fusion zone, basal plane aligned in its normal direction. In the HAZ, the basal plane showed a very strong texture with the (0002) columnar grains in the fusion zone. Fig. 3(b) shows the (0002) pole misorientation angles and crystallographic orientation in CGZ, HAZ and BM, as shown in Figs. 2 and 3 (a). The decrease in microhardness in the HAZ was caused by the effect of grain growth and recovery due to the increase in temperature by the laser scanning.

The microhardness of the cross-section of the laser-scanned material was measured, as illustrated in Fig. 2. The fusion zone, where coarse columnar grains exist, showed a tendency towards the smallest microhardness compared to the base material. The microhardness data confirmed the presence of a heat affected zone (HAZ) between the fusion zone and base material. In HAZ, the microhardness decreased gradually with increasing distance from the base material. The microhardness and microstructure data was used to distinguish the base material (BM), heat affected zone (HAZ), and coarse grain zone (CGZ), as shown in Figs. 2 and 3(a). The decrease in microhardness in the HAZ was caused by the effect of grain growth and recovery due to the increase in temperature by the laser scanning. After the laser treatment at a laser power and scanning speed of 200 W and 15 m/min, respectively, the average grain sizes of the BM and HAZ was 7.5 μm and 8.4 μm, respectively. Since both surface regions of the AZ31B sheet were laser-scanned, the laser-treated sheet showed a layered structure consisting of CGZ, HAZ, BM, HAZ and CGZ.

The EBSD measurements were used to examine the microstructure and crystallographic orientation in CGZ, HAZ and BM, as shown in Fig. 3. The EBSD observations of the grain boundaries with misorientation angles > 15° clarified the grain shape as coarse columnar grains in the fusion zone. Fig. 3(b) shows the (0002) pole figures obtained by EBSD for CGZ, HAZ and BM. The base material of the AZ31B-H24 sheet showed a very strong texture with the (0002) basal plane aligned in its normal direction. In the HAZ, the basal plane texture was maintained despite the effect of the grain growth and recovery. However, in the CGZ, the basal plane texture weakened dramatically after rapid melting and solidification during the laser scanning treatment. This is accordance with some reports showing a fusion zone after laser welding [1,4]. As mentioned above, Mg alloys exhibit an HCP structure leading to low ductility due to the limited number of slip systems. The critical resolved shear stress (CRSS) for basal slip is much lower than non-basal slip or a deformation twin at room temperature [10]. Therefore, the formation of textures with high Schmid factors for basal slip, as shown at CGZ in Fig. 3, might have a positive effect on improving the ductility of Mg alloys at room temperature.

Tensile tests at room temperature were carried out and compared with the calculated results obtained by FEM to confirm the improvement of elongation of the laser-scanned specimens. The layered structure of BM, HAZ and CGZ was considered for the FE simulation. The material properties of HAZ and CGZ were acquired by best fitting to the mechanical behavior for 10 m/min and the indentation hardness in these zones. Mechanical behavior for various scanning speeds was calculated considering the fraction of laser-treated region at each scanning speed. Fig. 4 shows the measured and the calculated engineering stress–strain curves for various laser scanning speeds at the laser power of 200 W. The symbols indicate the measured data while the solid lines represent the calculated ones. The calculated overall stress–strain curves for various scanning speed seemed similar to the experimental results. The elongation tends to decrease with increasing scanning speed in both the measured results and the calculated ones. This is attributed to increasing the average thicknesses of the fusion zone with randomly oriented coarse grains as scanning speed decreases. In the case of a scanning speed of 10 m/min, the laser-scanned magnesium alloy sheet showed enhanced tensile elongation by about 50% comparing to the base material. As for ultimate tensile strength (UTS), it seems to decrease slightly as the portion of laser-treated part increases. However, as a true measure, the UTS values for various scanning speeds including the base material were similar. According to these results, it could be confirmed that laser treatment is a reasonably effective way to improve ductility of magnesium alloy sheets.

3. Results and discussion

Fig. 1 shows the microstructure in the vicinity of the region laser-scanned at a power of 200 W and a scanning speed of 15 m/min. The curved lines from the surface to the inside, which are shown as white arrows in Fig. 1, indicate a trace of a fusion zone due to the laser treatment. Coarse columnar grains can be seen in the fusion zone. The major axes of the columnar grains lean to the inside of the curved lines, which is closely related to the direction of heat flow during the laser treatment. The thickness of the fusion zone decreased with increasing scanning speed at a given laser power due to the decrease in laser power rate. The average thicknesses of the fusion zone at scanning speeds of 10 and 15 m/min were at 100.8 and 78.6 μm, respectively. The thickness in the case of 20 m/min was < 10 μm.

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4. Summary

In summary, a laser scanning method was applied to both surfaces of an AZ31B-H24 Mg alloy sheet to improve the ductility. In the fusion zone, where coarse columnar grains exist, the strong basal plane texture of the base material was changed to an almost random texture after rapid melting and solidification during the laser scanning treatment. The magnesium alloy sheet laser-scanned at a power and
scanning speed of 200 W and 10 m/min, respectively, showed enhanced tensile elongation of up to 50% with a similar tensile strength.

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