PLASMA ARC LAMP PROCESSING OF MAGNESIUM ALLOY SHEET

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Abstract

Use of high density infrared (HDI) processing of magnesium alloy sheet has the advantage of a very rapid anneal coupled with rapid cooling as compared to conventional annealing. Preliminary experiments on wrought commercial sheet, AZ31B-H24, resulted in complete recrystallization through the thickness of the sheet. Tensile tests gave equivalent stress strain curves as compared to specimens conventionally annealed 1 hr at 300 to 500°C. Texture measurements showed a complete elimination of the rolling texture near the surface while the center of the 3 mm thick wrought sheet was similar to that after a conventional 1 hr anneal at 500°C.

Introduction

Use of high density infrared (HDI) processing of magnesium alloy sheet has the advantage of a very rapid anneal coupled with rapid cooling as compared to conventional annealing. In the ORNL experimental setup a plasma arc lamp is rapidly translated across the specimen. In an industrial setting a strip of material would move past the lamp. HDI processing in conjunction with horizontal direct casting and use of pinch rollers closely following the plasma arc lamp has the potential for reducing the number of processing steps thereby saving costs and altering the final crystallographic texture as compared to current processing methods for rolled sheet. Texture control has been shown by Mukai [1] to lead to ductility improvements.

In this study, preliminary experiments using HDI on commercial wrought AZ31B sheet with a thickness of ~3 mm (1/8 inch) were performed. Optical micrographs, tensile tests, and x-ray crystallographic texture plots are compared for HDI processing of as-received material, as-received material with normal 1 hr anneals from 300 to 500°C, and AZ31B material that was recast into a copper mold.

Experimental Procedure

Commercial magnesium sheet, ~3 mm thick of alloy AZ31B, with composition Mg- 3 Al-1 Zn (wt.%) and with the H24 temper was used as the starting material. Square pieces, 50 × 50 mm, were cut for the HDI processing. The surface was cleaned and lightly sanded with 600 grit paper. Other pieces were conventionally annealed for either 1 hr at 300, 400, or 500°C for the purpose of comparison experiments. Some material was recast by simply melting and pouring into a copper mold. Slabs, 3 mm thick, cut from this casting were also processed by HDI.

HDI processing was done under an argon atmosphere using a single 300 kW plasma arc lamp that is continuously variable with power densities up to 3.5 kW/cm^2 [2-3]. A translation speed of 15 mm/s was used with a distance of 1 cm from the lamp to the specimen. The width of the lamp was 1 cm which then results in a given region of the specimen heated for 1.5 s. No evidence of evaporation or smoking was observed. Experiments were conducted with current levels from 350 A to 900 A. A current of 500 A corresponds to a power density of 1050 W/cm^2 and 900 A corresponds to 2350 W/cm^2.

Specimens were prepared for metallography by polishing in diamond slurries (3 and 1 μm) in a Hyprez oil media. The specimens were etched in a solution of 4.2 g picric, 10 ml acetic acid, 70 ml ethanol, and 10 ml water for approximately 5 seconds. The etched specimens were also analyzed by energy dispersive spectroscopy (EDS) in a scanning electron microscope (SEM).

Tensile specimens were cut by electrodischarge machining with a 12 mm long gage length with a cross section of 3.17 × 2.54 mm. Strain rate utilized for testing was 5 x 10^{-3} s^{-1}. Specimens were ground from both sides from 3.17 mm to a final thickness of 2.54 mm. Due to the short specimen length, crosshead displacements were used in lieu of extensometry. This introduced some error due to deformation of the shoulders of the specimens.

Texture measurements were performed with a Picker 4 circle diffractometer at 30 kV and 10 mA with specimen oscillation using the Schultz reflection method on a 5 deg grid with CuKα radiation. The 0002, $10\bar{1}1$ and $10\bar{1}1$ reflections were recorded. Results were plotted on an equal angle area projection. For this preliminary examination, no attempt was made to correct the data for defocusing.

Results and Discussion

Optical metallography and SEM were used to survey the microstructures of both plan view and edge view. Optically, the as-received wrought material, Fig. 1a, showed a very fine and complex microstructure that was difficult to characterize. After a 1 hr anneal at 500°C, fine grain boundaries were evident as in Fig. 1b with grain

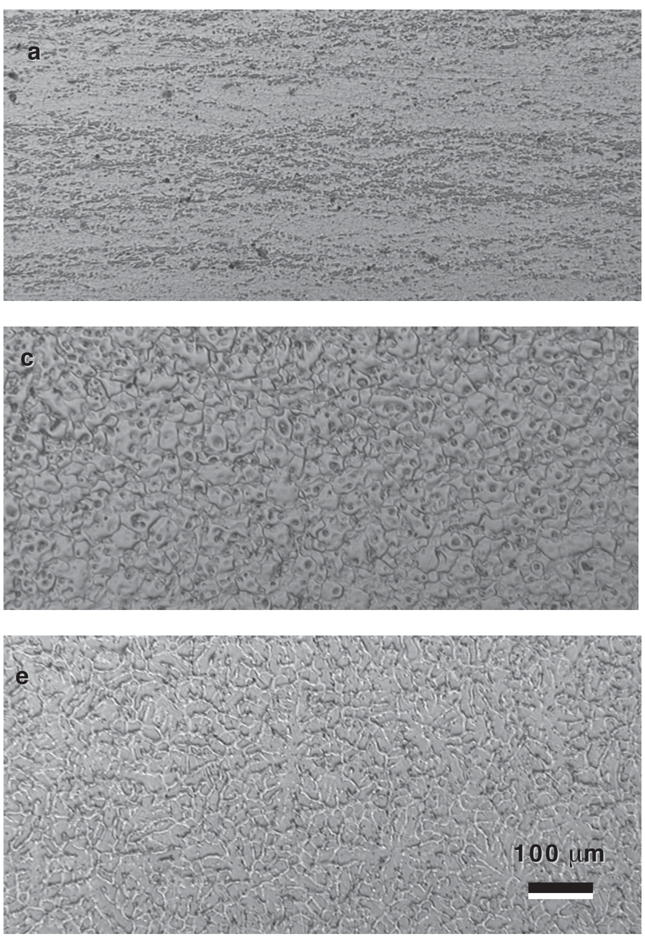
Magnesium Technology 2003
Edited by H. I. Kaplan
TMS (The Minerals Metals & Materials Society), 2003

sizes around 20 µm. Arc lamp treatment at 500 A, which corresponds to 1050 W/cm² yielded grain sizes of 25 to 40 µm, see Fig. 1c. The recast material shown in Fig. 1d showed a dendritic structure which was somewhat coarsened by an arc lamp treatment as shown in Fig. 1e. Figure 2 shows at a higher magnification, cross section views of the near top region, center, and bottom of the as-received specimen treated with the arc lamp at 500 A. The center and bottom images showed 25 to 50 µm grain sizes while the Fig. 2a micrograph near the surface showed grains of 50 to 100 µm. The cross section views show how evenly the plasma arc lamp recrystallized the microstructure through the ~3 mm thickness of the sheet. Figure 3 shows a side view of an annealed specimen at the same magnification as Fig. 2 to provide a direct comparison.

The enhanced etching effects in Fig. 1c as compared to 1b suggests more segregation or particle coarsening and even the possibility of melting. Scanning electron microscopy imaging and EDS analysis in Fig. 4 showed similar Mg-Al-Mn precipitates in all the specimens. The matrix analysis showed Al and Zn levels below the detection limits. Only in the arc lamp treated specimen were a few Mg-Al-Zn precipitates detected. Based on the similarity of the SEM images between the arc lamp material and the annealed material, it appears that the arc lamp treatment at 500 A did not melt the material.

Tensile test results are shown in Fig. 5. The tensile specimen thickness was nearly the full thickness of the sheet material used in the anneals and arc lamp treatments. Two specimens for each condition were tested. Little variation was noted. The 3 anneals of 1 hr at 300, 400, or 500˚C resulted in almost overlapping stress-strain curves. Only one is shown. Likewise the stress-strain curves from the arc lamp treatments from 350 to 500 A also overlapped and only one is shown. Both the conventional anneal and the HDI anneal reduced the yield stress to around 125 MPa and increased the ductility to around 25%. The arc lamp treatments of 600 and 900 A also almost overlapped and only the 900 A is shown. The arc lamp treatments from 350 to 500 A reproduced the results of annealing from 300 to 500˚C. The slight slope difference in the elastic region presumably arose from deformation on the shoulders in the holding fixture.

Crystallographic texture that develops during rolling operations has a major effect on mechanical properties in a hexagonal material. Pole figures of 0002 poles are presented in Fig. 6 for each of the conditions shown in the earlier figures. The plots show intensity distributions as shades of gray with black having the greatest intensity and thereby the greatest volume fraction of grains with this orientation. The center of the plot is normal to the plane of the specimen while the edge of the plot is the plane of the specimen. In Fig. 6a of the as-received material, a large number of 0002 plane normals is centered in the figure indicating that a large volume fraction of grains with basal planes are parallel to the plane of the rolled sheet. The intensity of the black region was 7.1 times that of the intensity of a perfectly random plot. Few 0002 plane normals are found near the edge of the pole figure indicating a very small volume of grains with basal planes perpendicular to the sheet. The dumbbell shape in Fig. 6a indicates a smearing of the 0002 texture in the rolling direction. Earlier studies have correlated this texture to the in-plane plastic anisotropy of AZ31 sheet material [4]. Annealing the material for 1 hr at 500˚C results in the texture shown in Fig. 6b with a peak intensity of 10.2. The dumbbell distribution is eliminated and the area of greatest number of plane normals (the black region) is substantially reduced indicating a sharpening of the texture. The arc lamp treatment at 500 A mostly removed the texture



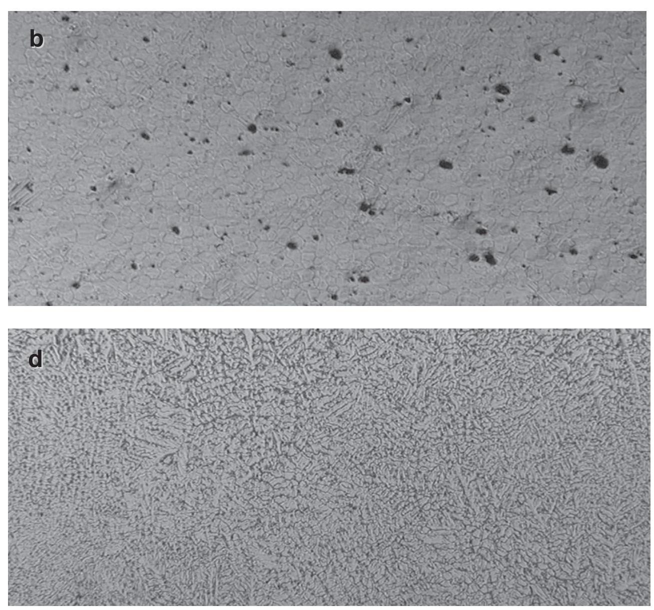


Figure 1: Optical micrographs of a) AZ31B as received, b) annealed 1 hr 500˚C, c) as received plus arc lamp at 500 A, d) recast, e) recast plus arc lamp at 450 A. All are cross sectional views.

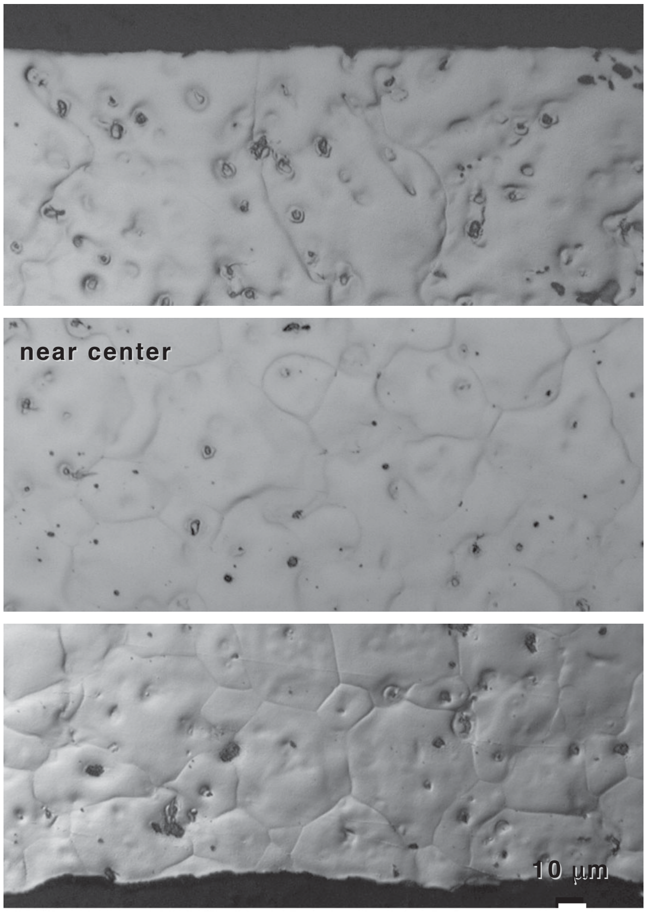


Figure 2: Optical micrographs across the ~3 mm thickness of the AZ31b sheet after treatment by the arc lamp at 500A showing how uniform the grain size is through the thickness

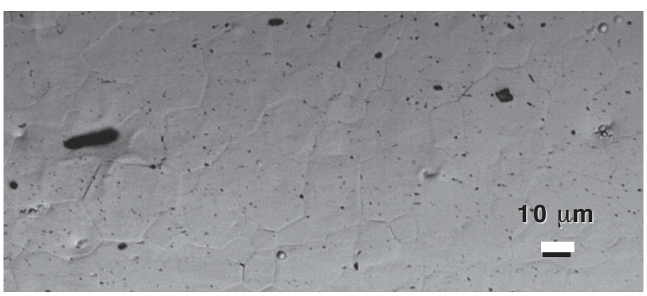


Figure 3: Optical micrograph, side view, of the as-received plus 1 hr 500˚C material to directly compare to Fig. 2.

near the top surface as seen in Fig. 6c with a peak intensity of the black regions of 3.15. However, near the center of the specimen, the texture resembled that of the annealed material. The peak intensity was 7.7. Even with rolling texture left in the center of the specimen, reduction of the near surface texture might play an important role in ultimately improving the formability during sheet bending operations. The recast material, as expected, showed little texture as shown in Fig. 6e and the arc lamp treatment of this material also showed little texture.

Removal of the surface texture suggests that the near surface region was actually melted. However, melting was not apparent from the optical and SEM results. If the near surface region did melt, it also underwent fairly rapid solidification which may have resulted in similar microstructures to the unmelted region.

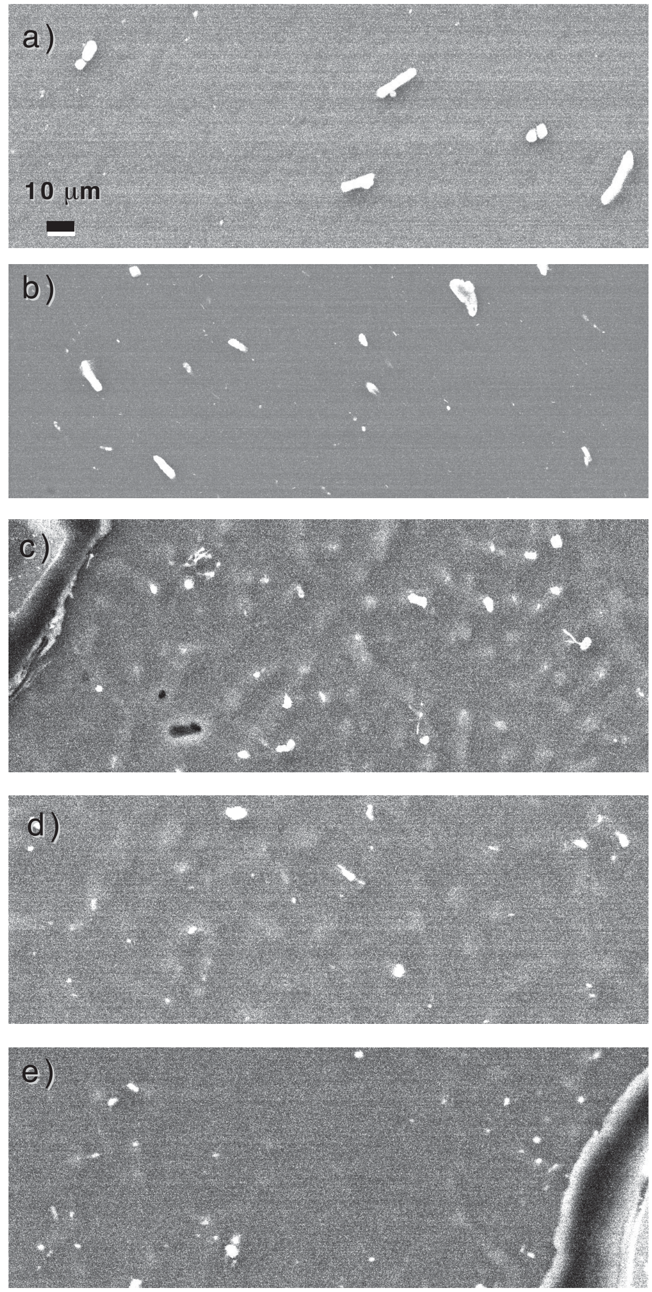


Figure 4: SEM images of polished and etched specimens. a) as received, b) annealed 1 hr 500˚C, c) arc lamp treated at 500A- near surface, d) near center, and e) near the other edge. EDS showed that most white precipitates in all the images are Mg-Al-Mn inclusions. Matrix in all specimens showed no detectable Al and Zn, only Mg. A few Mg-Al-Zn precipitates were found in the arc lamp treated specimens.

Future studies will incorporate a follow-on pinch roller. The lamp-roller combination could be used early in the processing so the material is rolled in the partially melted condition. The lamp-roller combination could also be used at the end of a processing route to

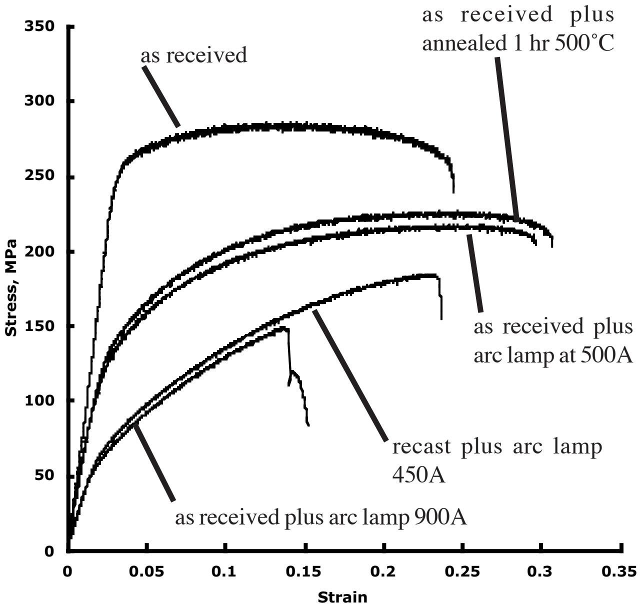


Figure 5: Tensile Tests of AZ-31B. As received is wrought ~3 mm thick commercial sheet. Anneals from 1 hr at 300˚C and 1 hr at 400˚C were similar to the 1 hr at 500˚C curve shown. As received plus arc lamp at 300 thru 500 A were all similar to the one shown while the arc lamp at 600 A was similar to the arc lamp at 900 A curve shown. Likewise the recast plus arc lamp treatments from 300 A to 450 A were similar to the one shown. The arc lamp treatments from 300 thru 500 A resulted in similar mechanical properties as annealling 1 hr from 300 to 500˚C.

improve the surface finish and provide dimensional control of the HDI processed sheet.

Summary and Conclusions

HDI is a viable processing technique for magnesium alloy sheet resulting in equivalent mechanical properties and similar microstructures as compared to standard 1 hr anneals at 300 to 500˚C. The reduced surface texture might prove useful for forming operations that require bending. The reduced time and energy consumed during the heat treatment could result in substantial improvements in the efficiency of processing wrought magnesium.

Acknowledgments

The authors wish to thank D. C. Harper for the HDI processing, H. F. Longmire for optical metallography, C. A. Carmichael and J. L. Wright for technical support and E. D. Specht for assistance with the texture measurements. Research sponsored by the U.S. Dept. of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of FreedomCAR and Vehicle Technologies, as part of the High Strength Weight Reduction Materials Program, and by the Division of Materials Sciences and Engineering at Oak Ridge National Laboratory, operated by UT-Battelle, LLC, under contract DE-AC04-00OR22725.

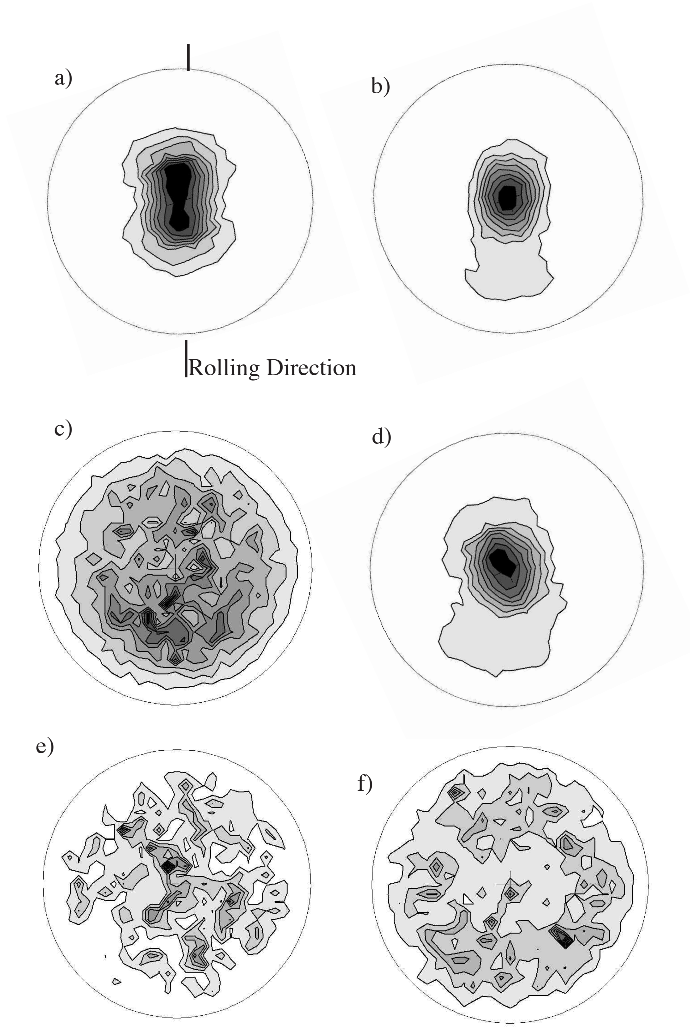


Figure 6: 0002 pole figures showing raw data with a linear scale of intensity gradations of a) as-received, b) as-received plus 1 hr 500˚C, c) top surface of as-received plus arc lamp at 500 A, d) center of as-received plus arc lamp at 500 A, e) recast, f) recast plus arc lamp at 450 A. The arc lamp treatment in c) strongly reduced the rolling texture near the surface and in the center of the specimen in d) matched the texture of the 1 hr anneal at 500˚C .

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