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INFRARED PROCESSING OF MAGNESIUM WROUGHT ALLOYS

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Abstract

High density infrared (HDI) processing of magnesium alloy sheet allows rapid heat up and cool down and may facilitate a continuous cast/roll process, thereby reducing costs. In a previous study, a plasma arc lamp resulted in an anneal in seconds that compared well to a normal 1 h 500°C anneal. The current study on AZ31 used a bank of quartz infrared lamps both in a lab setting and in a demonstration test at a commercial facility (Manufacturing Sciences, Inc.). Typical reheats and anneals between rolling passes required 2 to 5 minutes for rolling 6 mm sheet down to 1 mm. Tensile tests showed comparable results to normal processing. The near surface microstructure was similar to the center of the sheets. No gross progressive or cumulative effect on mechanical properties was observed from pass to pass. Good surface quality with minimal edge cracking was produced.

Introduction

Use of HDI processing [1-2] of magnesium alloy sheet has the advantage of a very rapid anneal coupled with rapid cooling, compared to conventional annealing. HDI processing, in conjunction with horizontal direct casting, has the potential to reduce the number of processing steps compared to current processing methods for rolled sheet, thereby reducing costs and possibly altering the final crystallographic texture.

Previous studies [3] using a 300 KW plasma arc lamp on 3 mm thick magnesium alloy sheet resulted in equivalent mechanical properties and similar microstructures compared to standard 1 h anneals at 300 to 500°C. The lamp translation speed was 15 mm/s at a distance of 1 cm from the specimen resulting in 1.5 s duration of specimen heating. The current studies extended these results to a simpler bank of quartz infrared lamps both in our lab setting and at a commercial rolling facility (Manufacturing Sciences, Inc of Oak Ridge, TN, USA).

Experimental Procedure

Commercial AZ31B magnesium tooling plate, ~6 mm thick, with composition Mg- 3 Al-1 Zn (wt.%) was used as the starting material. Laboratory scale tests were first performed using a setup that provided 20 watts/cm^2. For example, the lab setup required 40 s for 3 mm sheet to heat to 400°C. Pieces, 40 × 40 cm, were cut for the infrared processing at Manufacturing Sciences, Inc.

The quartz infrared bank at Manufacturing Sciences, Inc. delivered 12 W/cm^2 in a bank of lamps approximately 1 × 3 m, located 2 m from a reversing mill. Several changes could be made to their design to increase the heating rate. The number of lamps can be doubled yielding 24 W/cm^2. This installation used a water cooled reflector that is not used in later installations. This installation also used an unusually large airflow which limited the maximum temperature to ~425°C.

Specimens were prepared for metallography by polishing in diamond slurries (3 and 1 μm) in 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.

Tensile specimens with a 12 mm long gage length and a cross section of 3.17 × 2.54 mm were cut by electro-discharge machining. Specimens were ground from both sides from 3.17 mm to a final thickness of 2.54 mm. Strain rate utilized for testing was 5×10^{-3} s^{-1}. Due to the short specimen length, crosshead displacements were used in lieu of an extensometer. 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 $10\bar{1}0$ 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

Four sets of rolling experiments were performed. The first rolling set was carried out at 400°C, required 10 passes to go from the 6 mm starting thickness to the final 1 mm, averaging 16.5% thickness reduction per pass. Infrared heating was used before each pass. Heating to 400°C typically required 5 minutes for the first heating of the 6 mm plate down to less than 2 minutes for the last pass. The second rolling set, also at 400°C, averaged 23% reduction per pass and required 6 passes. The third set was intended to be at 450°C but the high airflow rate did not allow 450°C to be reached and so the rolling was performed at 425°C at an average reduction of 44% and required three passes to go from 6 mm to 1 mm. The final roll was a single pass at 425°C with a 66% reduction to go from 6 mm to 2 mm.

Table 1 summarizes the rolling parameters and for a particular pass shows the ultimate tensile strength (UTS) and elongation at failure for

Table I. Mechanical Properties as a Function of Rolling Conditions

Temp, ˚C	Average Reduc-tion, %	Thickness, mm	Pass #	UTS, MPa RD	Strain, % RD
400	16.5	2.1	6	275	6
		1.3	9	285	5
		1.0	10	307	4
400	23	1.5	5	298	6
		1.0	7	404	7
425	44	1.1	3	363	3
425	66	2.1	1	265	5

Table II. Mechanical Properties after Annealing

Condition	YS*, MPa	UTS*, MPa	Strain, %
as rolled	262 ± 57	312 ± 49	5 ± 2
2 hr 185˚C	185 ± 11	269 ± 6	18 ± 2
2 hr 345˚C	141 ± 14	247 ± 6	24 ± 2
after 66% reduction, 2 hr 345˚C	131	234	22

*6 sets of rolling conditions averaged

the as rolled material with the tensile specimen oriented in the rolling direction. The transverse specimens had slightly higher ductilities but similar UTS. A small increase in UTS and a small decrease in elongation occurred as the sheet became thinner and therefore lost more heat to the rolls and presumably received more cold work. Note that the cold work did not progressively accumulate, suggesting that the 5 to 2 min "anneal" was sufficient to allow multiple passes.

Anneals of these as-rolled tensile specimens increased the ductility to more normal numbers for commercial AZ31. Specimens from six sets of rolling conditions were annealed either for 2 h at 185˚C or for 2 h at 345˚C. The six sets of rolling conditions are the first 6 from Table 1. Because there was no pattern in the data as a function of pass number, the yield stress, ultimate tensile stress and elongation at failure were simply averaged. The results are presented in Table 2, along with data for the single pass 66% reduction at 425˚C annealed for 2 h at 345˚C. This expected increase in ductility from the anneals suggests that no microcracking occurred during the rolling operation, even for the most severe roll of 66% at 425˚C.

Optical metallography showed uniform results thru the thickness. The example shown in Fig. 1 is from the first set of rolling after reheats to 400˚C and after the 10th pass resulting in a thickness of 1 mm. The side views show both edges and an image from the center. Also shown is a top (plan) view. The multiple rolls of the second and third sets gave similar images. Only the 4th experiment that consisted of one pass at 66% reduction at 425˚C showed a non-uniform microstructure through the thickness with some suggestion of dynamic recrystallization, see Fig. 2.

Figure 3 shows an actual rolled sheet. The sheets had a good surface quality with minimal edge cracking.

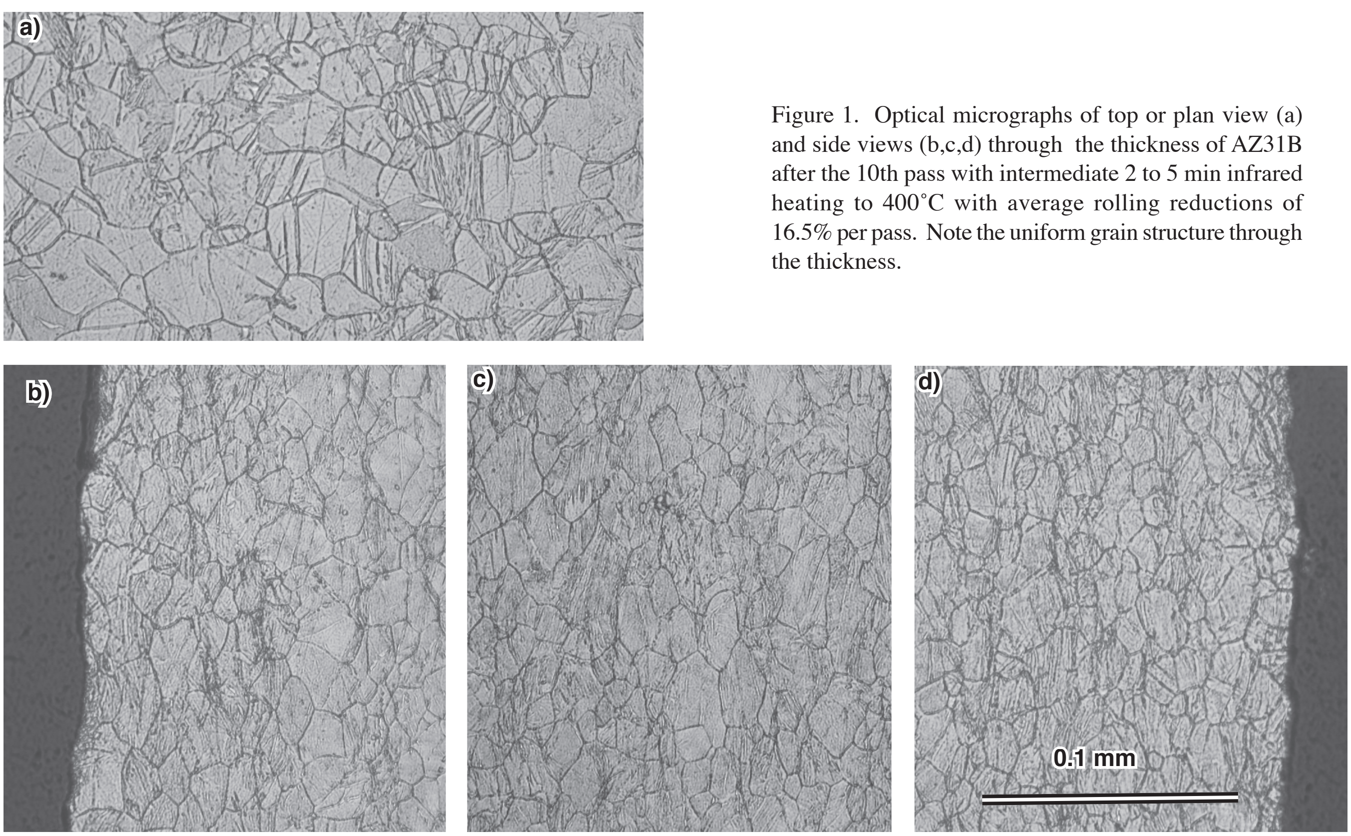

Figure 1. Optical micrographs of top or plan view (a) and side views (b,c,d) through the thickness of AZ31B after the 10th pass with intermediate 2 to 5 min infrared heating to 400˚C with average rolling reductions of 16.5% per pass. Note the uniform grain structure through the thickness.

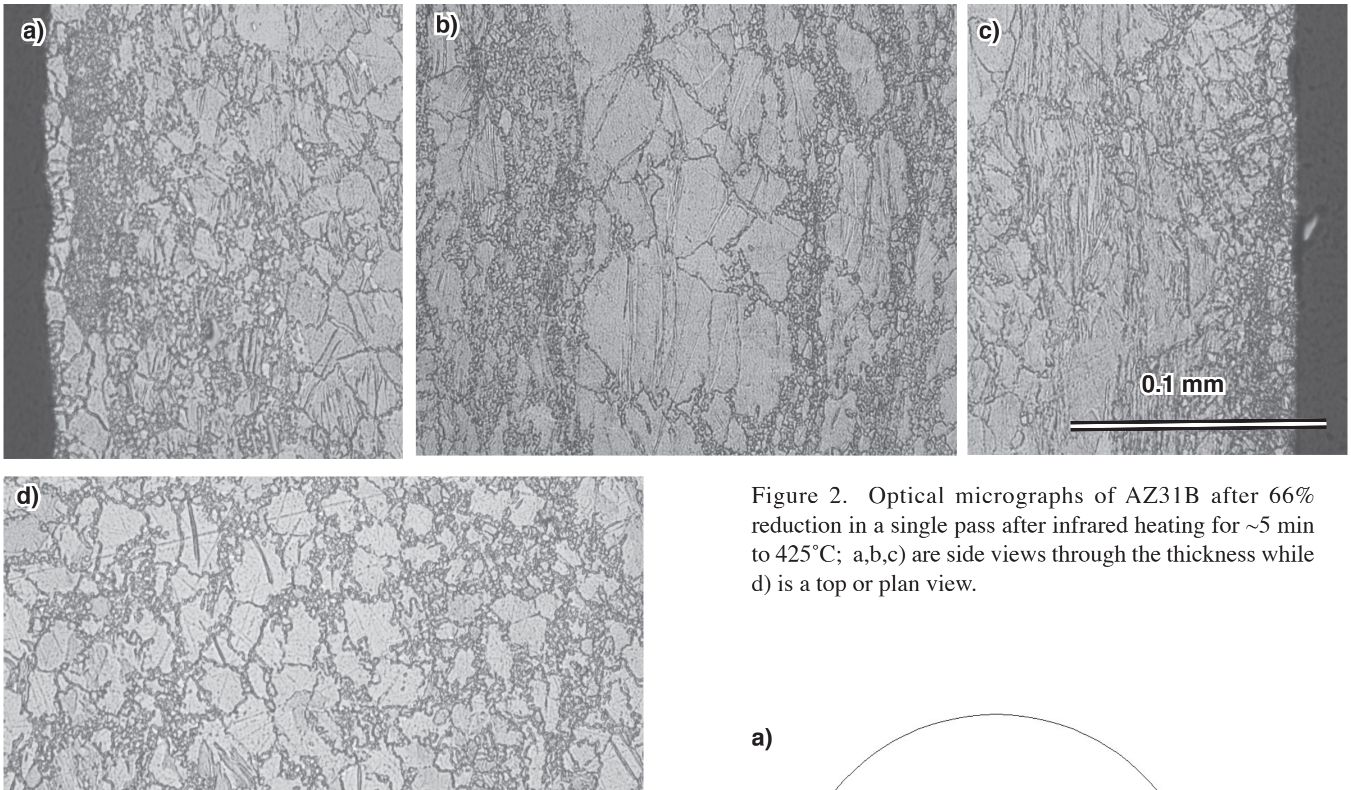

Figure 2. Optical micrographs of AZ31B after 66% reduction in a single pass after infrared heating for ~5 min to 425˚C; a,b,c) are side views through the thickness while d) is a top or plan view.

Crystallographic texture that develops during rolling operations has a major effect on the mechanical properties in a hexagonal material [4]. To increase our understanding of processing, texture, and formability, the crystallographic texture was measured for these trials. Little change was found even in the single pass at 66% sheet. A before and after 0002 pole figure is shown in Fig. 4. 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 are directions in the plane of the specimen. In Fig. 4a of the as-received material, a large number

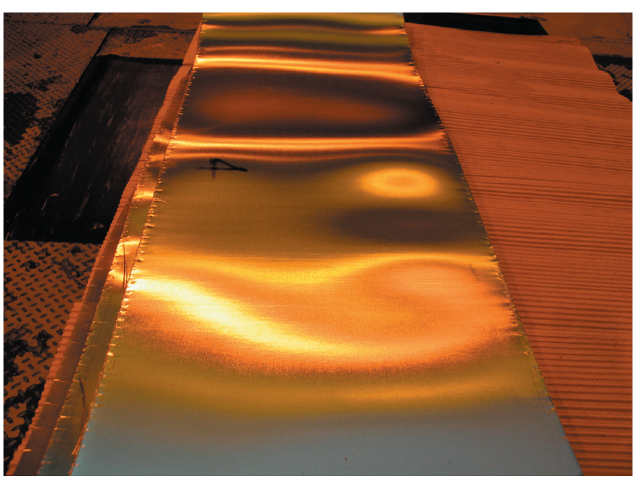

Figure 3. As rolled sheets approximately 45 cm wide. Note good surface finish and minimal edge cracking.

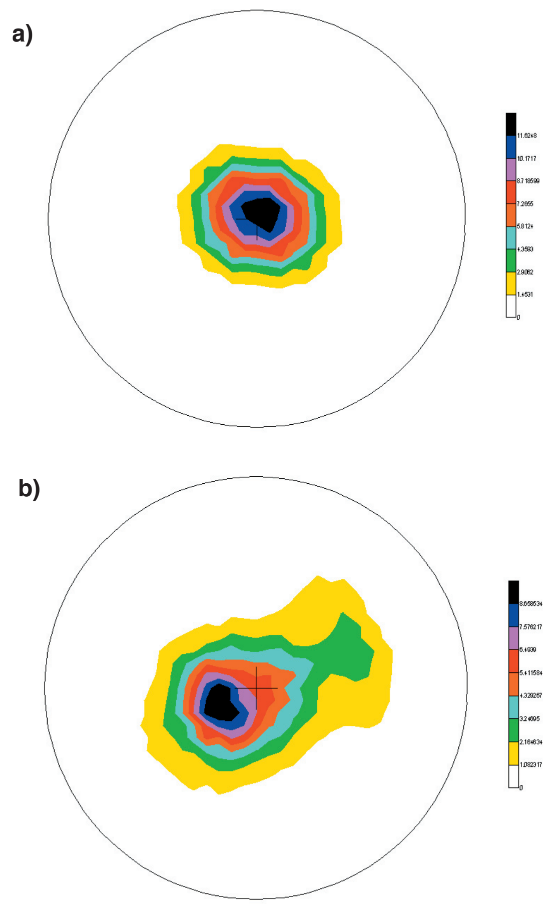

Figure 4. 0002 pole figures showing raw data with a linear scale of intensity gradations of a) as received AZ31 tooling plate and b) after rolling at 425˚C with a 66% reduction.

of 0002 plane normals are 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 11.6 and 8.6 for Figs 4a and 4b respectively, 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. 4b 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 [5].

Summary and Conclusions

Rolling operations on AZ31 using a bank of quartz infrared lamps for anneals and preheats was studied. Typical heat up and anneals between rolls required 2 to 5 minutes for rolling 6mm sheet down to 1 mm. Tensile tests showed comparable results to normal processing. The near surface microstructure was similar to the center of the sheets. No gross progressive or cumulative effect on mechanical properties was observed from pass to pass. Good surface quality with minimal edge cracking was produced. The reduced time and energy consumed during the heat treatment could result in substantial improvements in the efficiency of processing wrought magnesium.

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