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GRAIN EVOLUTION DURING HIGH TEMPERATURE NECKING OF MAGNESIUM ALLOYS

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Abstract

Magnesium sheet materials AZ31, AM50, ZM21, ZK10, and ZK30 were tested to failure at 450C at a strain rate of 0.001/s. Each of these materials exhibit significant changes in grain structure during deformation, especially in the necked regions of the failed samples. Grain size in the neck is shown to vary with thickness strain and strain rate. Some materials exhibit significant coarsening along the necked region while others show very little change. The results of this work can be used to help validate models for dynamic recrystallization in magnesium.

Introduction

Magnesium sheet can provide significant lightweighting for automobile applications. A key limitation of magnesium sheet is its lower formability compared to steel and aluminum. This has necessitated the use of thermal assisted forming techniques to make parts [1, 2]. The combination of strain and temperature during forming can lead to significant microstructural changes, including grain growth and dynamic recrystallization. These changes in microstructure can affect both forming and the final performance of the formed part. Previous research on 5xxx series aluminum alloys at elevated temperature demonstrated that recrystallization in the necked region of tensile samples can occur both dynamically [3] and with post deformation static aging [4]. This can lead to significant changes in microstructure including dramatic increases in grain size. The present paper describes a preliminary look the microstructural evolution in five different magnesium alloys, AZ31, AM50, ZM21, ZK10, ZK30 after elevated temperature tensile testing at 450C, by characterizing the static vs. dynamic change in grain size, as well as the effect of strain.

Experimental Procedure

Five magnesium materials were used in the present study: AZ31, AM50, ZM21, ZK10, and ZK30. The materials were provided by Alubin as extruded plates which were 175 mm x 175 mm x t mm where t is shown in Table 1 below. The extrusions were straight, smooth, and had no visible cracks. Thechemical composition of the materials is shown in Table 1.

Elevated temperature tensile samples were extracted using water jet cutting. All tensile specimens were aligned with the extrusion direction parallel to the testing direction. Specimen dimensions were 25.4 mm wide x 63.5 mm long with a 6.4-mm-wide x 25.4-mm-long gage section following ASTM E 2448-06. An Instron, model 5568, screw-driven, test frame, with an Instron 3119-007 furnace and Bluehill 2, version 2.4 data acquisition system were used for all testing. Samples were allowed to equilibrate in the furnace at 450C for 15 min. prior to testing. Testing was performed at a constant strain rate of 0.001/s. Total elongation was measured after fracture.

Metallographic sample preparation was performed using standard procedures, including the use of cold mounting rather than hot compression mounting to avoid creating artifact twins in the microstructure. Acetic-picric etchant (10 ml acetic acid, 4.2g picric acid, 70ml 95% ethanol, 10 ml water) was used to reveal grain boundaries.

Results and Discussion

Tensile Results – Total elongation to failure for the five different magnesium materials at 450C and 0.001/s is summarized in Figure 1. All materials exhibited over 150% elongation which is very good considering they were in the as extruded condition with no additional thermal mechanical processing. The AZ31 material exhibited the lowest ductility of the five materials tested. The ZK30 material exhibited almost 300% elongation which is close to the General Motors specification for hot blow formed material [5]. Additional results on elevated temperature tensile testing of these materials can be found elsewhere [6].

Microstructural Analysis - The grain structure of each of the five materials tested is presented in Figures 2-6 below by showing a micrograph of the following four conditions: (a) as-extruded, (b) taken from the grip section after testing, therefore seeing thermal exposure without strain, (c) fracture tip, and (d) failed tensile sample away from fracture region. The grain sizes for the as-extruded and exposed conditions are shown in Table 2.

AZ31– The grain structure in the various conditions for AZ31 are shown in Figure 2. The as-extruded material has a relatively homogenous grain structure. After thermal exposure at 450C, very little change in structure is observed, with only a small increase in grain size from 12.8 μm to 15.1 μm. After the thermal exposure, the grain structure appears even more homogeneous. The failed samples, shown in Figure 2 (c) and (d) show significant changes in microstructure. At the fracture tip, the grains are extremely large, over 200 μm across. This has been observed previously in AZ31 [7]. Away from the fracture tip, the grain size is closer to the starting material, however the grains appear to be a bit more angular with a few local grains that are 2 -3 times the size of neighboring grains.

AM50– The grain structure in the various conditions for AM50 are shown in Figure 3. The as-extruded material is less homogeneous than the AZ31 exhibiting regions of fine grains and coarse grains in bands along the extrusion direction. After thermal exposure, the grain size has increased significantly from 8.7 μm to 12.9 μm and become much more homogeneous both in morphology and average size. At the fracture tip, very large grains are observed, but not greater than 100 μm, and they are much more uniform than in the AZ31. The "large" grains are also smaller than those observed in AZ31. Away from the fracture edge, the grain structure is more uniform without a significant bimodal distribution.

ZM21– The grain structure in the various conditions for AM50 are shown in Figure 4. The as-extruded grain structure is very uniform in size and grain morphology. After thermal exposure, the grain size has increased modestly from 18.1 μm to 22.8 μm, and the grain boundaries are a bit straighter than in the as-extruded material. In the region near the fracture tip, a very large grain is present which runs the full width of the fracture surface which is almost 250 μm across. Remote from the fracture surface, the grains are slightly coarser than in the exposed material.

ZK10– The grain structure in the various conditions for AM50 are shown in Figure 5. The as-extruded microstructure of the ZK10 material is very uniform in both size and morphology. Very little change in structure is observed after thermal exposure, with only slight coarsening from 12.8 μm to 14.4 μm. In the fracture region, the grain structure is very similar to the starting and exposed materials. There are two very small regions where a coarse grain is observed right at the tip of the failure zone. Everyplace else, the grain structure remains uniform and relatively fine across the necked region.

ZK30– The grain structure in the various conditions for AM50 are shown in Figure 6. The grain structure of the as-extruded material is very bimodal with a network of sub 10 μm grains surrounding some 20-30 μm grains. After thermal exposure, the grain structure is coarser and much more uniform almost doubling from an average size of 9.4 μm to 16.4 μm. In the necked region, very little change in grain structure is observed compared to the exposed material, and there are no extremely large grains present.

Discussion- The grain structure of the five materials tested showed varied response in the necked region after testing at 450C and 0.001/s. The materials which exhibited the largest grains in the neck after testing, AZ31 and ZM21, exhibited the lowest total elongation values. The material which showed no coarse grains in the necked region and likely had the most stable microstructure, ZK30, exhibited the highest total elongation. Figure 8 shows the effect of both material and strain in the neck on grain size after testing. The data is limited, but clearly shows that the grain structure in the ZK materials was very stable, while it varied significantly in the AZ31, AM50 and ZM21 materials. These preliminary results demonstrate that the microstructural evolution in the necked region may correlate with tensile ductility. However, additional work is required to characterize the structure including evaluating different temperatures and strain rates, as well using electron backscatter diffraction (EBSD) to interrogate texture evolution.

Conclusions

The elevated temperature tensile behavior and necking behavior of five magnesium extruded sheets was characterized at 450°C and 0.001/s. Specific conclusions are given below:

1. The as-extruded materials exhibited very good elongation, with almost 300% for the ZK materials at strain rates of 0.001/s.
2. All materials exhibit some level of static grain coarsening during testing.

3. AZ31, AM50, and ZM21 materials exhibited significant grain coarsening in the necked region with grains over 100 microns.
4. The ZK materials exhibit very stable microstructures in the necked region without the presence of large grains.

References

1. P.E. Krajewski, S. Kim, J.T. Carter, R. Verma, "Magnesium Sheet: Automotive Applications and Future Opportunities", Korean Institute of Metals and Materials: Trends in Metals & Materials Engineering, vol. 20, no. 5, (2007) 60.
2. J.T.Carter, P.E. Krajewski, and R. Verma, "The Hot Blow Forming of AZ31 Mg Sheet: Formability Assessment and Application Development", JOM, vol 60 no 11, (2008)77.
3. S. Agarwal, P.E. Krajewski, and C.L. Briant, "Dynamic Recrystallization of AA5083 at 450C: The Effects of Strain Rate and Particle Size," Met. Mat. Trans. A., Vol. 39, no. 6, (2008) 1277.
4. J-K Chang, K. Takata, K. Ichitani, and E.M. Taleff, "Abnormal Grain Growth and Recrystallization in Al-Mg Alloy AA5182 Following Hot Deformation", Met. Mat. Trans. A, Vol 41A, (2010) 1942.
5. J.R. Bradley. "Bulge Testing of Superplastic AA5083 Aluminum Sheet", in *Advances in Superplasticity and Superplastic Forming*, Ed. E.M. Taleff, P.A. Friedman, P.E. Krajewski, R.S. Mishra, and J.G. Schroth, TMS, (2004) 109.
6. P.E. Krajewski and A. Ben-Artzy, "Elevated Temperature Tensile Behavior of Extruded Magnesium Plates," Magnesium Technology 2010: Proceedings of a symposium sponsored by the Magnesium Committee of the Light Metals Division of The Minerals, Metals, & Materials Society, (2010) 221.
7. P.E. Krajewski, "Elevated Temperature Behavior of Sheet Magnesium Alloys," *Magnesium Technology 2002*, Ed. H.I. Kaplan, The Minerals, Metals, and Materials Society, (2002)175.

Table 1: Chemical composition of extruded magnesium sheets used in the present study.

Alloy	*t* (mm)	Al	Mn	Si	Zn	Zr	Fe	Mg
AZ31	1.65	2.9	0.34	<0.5	0.97	<0.01	<0.005	Bal.
AM50	1.75	4.9	0.33	<0.5	<0.01	<0.01	<0.005	Bal.
ZM21	1.43	0.03	1.0	<0.03	2.10	<0.01	0.03	Bal.
ZK10	2.93	<0.01	<0.003	<0.03	1.10	0.6	0.003	Bal.
ZK30	2.93	<0.01	<0.003	<0.03	3.10	0.5	0.003	Bal.

Table 2: Grain size of magnesium materials in as-received and thermally exposed condition.

Alloy	*Grain Size As-received (μm)*	*Grain Size Exposed (μm)*
AZ31	12.8	15.1
AM50	8.7	12.9
ZM21	18.1	22.8
ZK10	12.8	14.4
ZK30	9.4	16.4

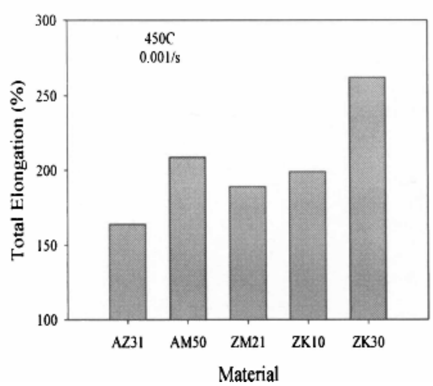

Fig 1: As-extruded microstructure of (a) AZ31, (b) AM50, (c) ZM21, (d) ZK10, and (e) ZK30.

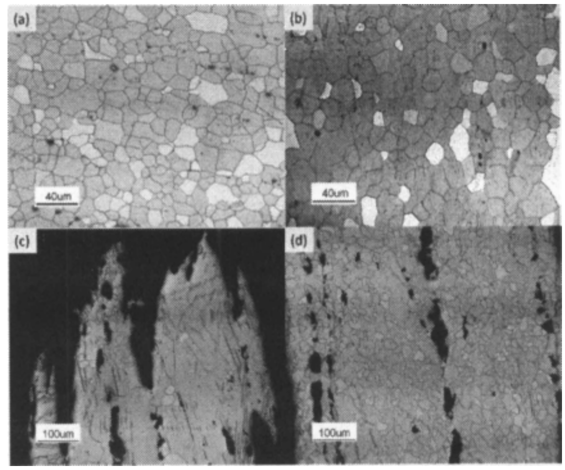

Fig 2: Grain structure of AZ31(a) As-received, (b) From grip section – thermal exposure without strain, (c) fracture tip, and (d) failed tensile sample away from fracture region.

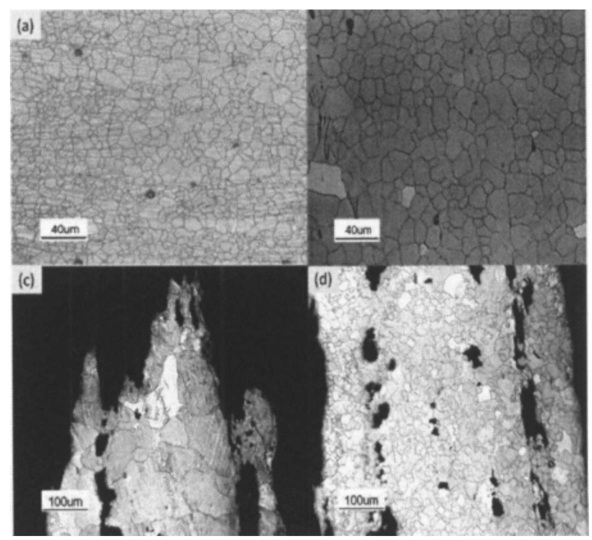

Fig 3: Grain structure of AM50(a) As-received, (b) From grip section – thermal exposure without strain, (c) fracture tip, and (d) failed tensile sample away from fracture region.

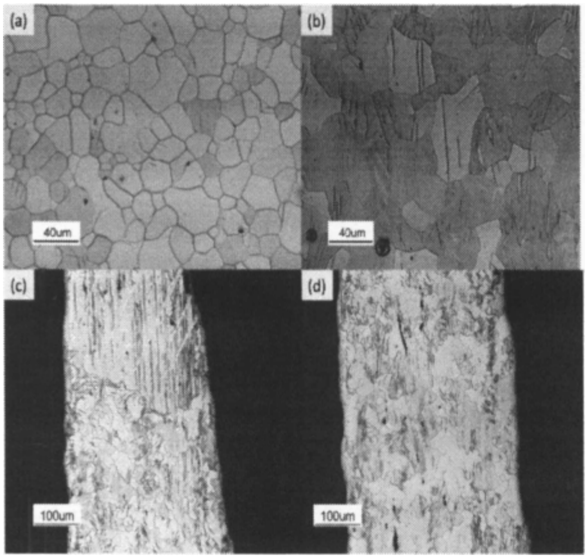

Fig 4: Grain structure of ZM21(a) As-received, (b) From grip section – thermal exposure without strain, (c) fracture tip, and (d) failed tensile sample away from fracture region.

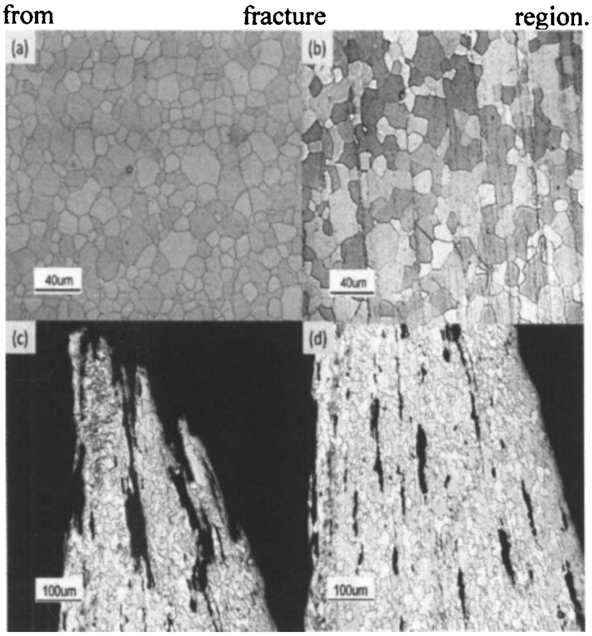

Fig 5: Grain structure of ZK10 (a) As-received, (b) From grip section – thermal exposure without strain, (c) fracture tip, and (d) failed tensile sample away from fracture region.

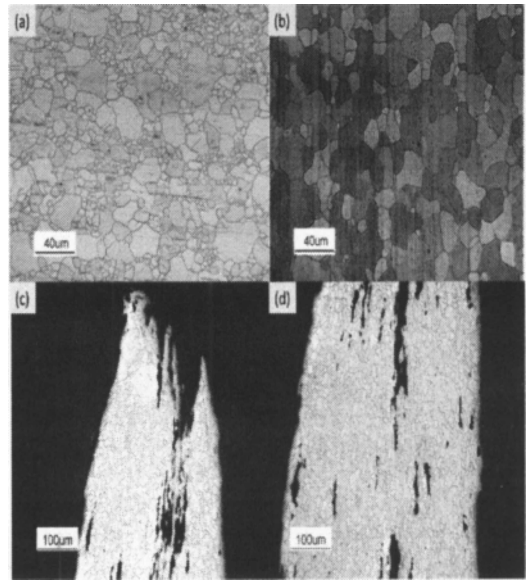

Fig 6: Grain structure of ZK30 (a) As-received, (b) From grip section – thermal exposure without strain, (c) fracture tip, and (d) failed tensile sample away from fracture region.

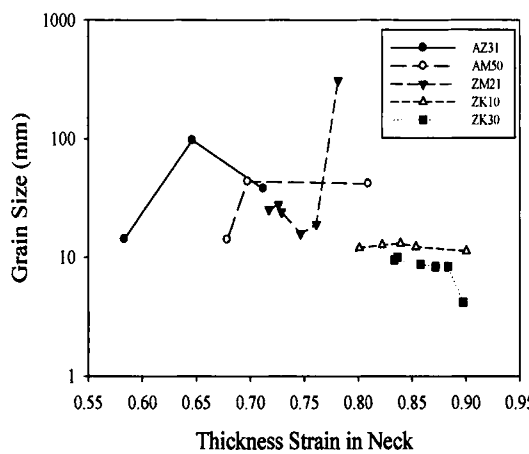

Fig 7: The effect of alloy composition and thickness strain in the necked region on grain size.