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Pnina Ari-Gur

*Western Michigan University, pnina.ari-gur@wmich.edu*

Andreas Quojo Quainoo

*Western Michigan University*

Shubram Subramanyam

*Western Michigan University*

Ashkan Razania

*Western Michigan University*

Sven Vogel

*Los Alamos National Laboratory*

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**Authors**

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# An Investigation on Formability and Crystallographic Texture in Novel Magnesium Alloys

**Pnina Ari-Gur<sup>1</sup>, Andreas Quojo Quainoo<sup>1</sup>, Shubram Subramanyam<sup>1</sup>,  
Ashkan Razania<sup>1</sup>, Sven Vogel<sup>2</sup>, Wei Gao<sup>3</sup>**

<sup>1</sup>Department of Mechanical and Aerospace Engineering, Western Michigan University, Kalamazoo, MI 49008, <sup>2</sup>Materials Science and Technical Division, Los Alamos National Laboratory, MST-8, MS G755, Los Alamos, NM 87545, <sup>3</sup>Department of Chemical and Materials Engineering, Faculty of Engineering, The University of Auckland, Auckland 1010, New Zealand  
Email: [pnina.ari-gur@wmich.edu](mailto:pnina.ari-gur@wmich.edu)

## Abstract

Magnesium alloys offer many advantages. They offer very low density and good strength. They also offer good damping properties. One of the industries where reducing component weight is the automotive industry. That makes the magnesium alloys good candidates for these applications. Reduced weight of an automobile means also lower fuel consumption. The hexagonal closed packed structure of magnesium, lends itself to strong mechanical anisotropy. In the current work, neutron diffraction was used to study the crystallographic texture developed in novel magnesium alloys during cold rolling operations. The texture was compared with that developed in the commercial AZ-31 magnesium alloy. Tests were run at the High-Pressure-Preferred-Orientation (HIPPO) beam line at Los Alamos National Lab. The texture was then analyzed using pole figures, created using the Material Analysis Using Diffraction (MAUD) software.

## Introduction

Magnesium alloys have high strength-to-weight ratio and that makes them an attractive substitution to heavier alloys, including the light-weight aluminum. In addition, magnesium alloys offer good damping properties [1, 2]. Plastic deformation in Mg alloys is strongly affected by the initial texture, and by process conditions, since the operation of non-basal slip systems require thermal activation [3]. The insufficient number of slip and twinning systems, results in the magnesium alloy demonstrating poor formability at room temperature. This low ductility has prevented their wide-spread application as cold-formed components [4]. The hexagonal closed packed (HCP) structure of magnesium, lends itself to strong mechanical anisotropy, especially when a significant crystallographic texture is present. Other properties, such as damping strongly depend on the texture [1, 2]. *HCP* metals can be classified into two groups according to their principal slip systems: basal slip metals (e.g. Mg and Zn), and prismatic slip metals (e.g. Ti and Zr). When the *c/a* ratio of the *HCP* lattice differs from the ideal value (1.633), the relative close packing of the crystal planes will vary. These changes influence the slip behavior during plastic deformation [5]. In some *HCP* metals like Mg, with limited ductility, twinning only works by the most common types of twins [6]. Operating a particular twinning system depends not only on the magnitude of the shear stress, but also on the *c/a* ratio. For pure Mg the ratio is 1.624 (close to the ideal 1.633). The *c/a* ratio may be altered by alloying elements; and this may change the active slip systems at RT. Work by Gao and Liu [7] on AZ-31 alloyed with small addition of Sn and Pb showed improved ductility. The present work was aimed at

analyzing the crystallographic texture developed in these novel magnesium alloys during cold rolling operations. The baseline for comparison was commercial AZ-31.

### Experimental description

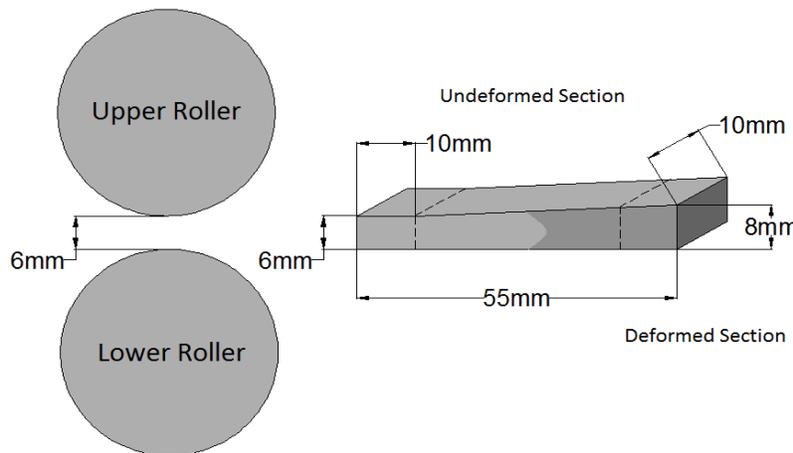
The alloys were prepared at the Light Metal Centre, University of Auckland, New Zealand. [Gao et al. Private communications]. They were made by melting commercially pure metals in a low carbon steel crucible under RJ-2 fusing agent. The melt was stirred to ensure homogeneity and cast into pre-heated (523 K) iron molds. The casting temperature was 983 K.

Three Mg alloys were studied; their compositions are described in Table 1.

**Table 1:** Alloys composition

Alloy	Composition
<b>AZ31 (reference)</b>	96%Mg-3%Al-1%Zn
<b>AZ31-2Sn</b>	94%Mg-3%Al-1%Zn-2%Sn
<b>AZ31-2Sn-1Pb</b>	93%Mg-3%Al-1%Zn-2%Sn-1%Pb

The geometry and procedure for cold rolling of the samples is described in Fig. 1



**Figure 1.** Sample geometry prior to the cold-rolling process

**Table 2:** Samples nomenclature

Alloy	Section No.	Sample ID	% RA
<b>AZ31</b>	1	R-1	8.80
<b>AZ31</b>	10	R-10	23.19
<b>AZ31-2Sn</b>	1	Sn-1	7.85
<b>AZ31-2Sn</b>	10	Sn-10	21.10
<b>AZ31-2Sn-1Pb</b>	1	Pb-1	7.20
<b>AZ31-2Sn-1Pb</b>	10	Pb-10	21.11

X-ray diffraction was conducted on the surface perpendicular to the RD-TD plane (i.e. on the RD-ND plane). Panalytical X-ray diffractometer with CuK $\alpha$  radiation was used. The system

is equipped with a monochromator, a stepping motor and an MDI control and digital output.

Neutron diffraction tests were conducted at the High-Pressure-Preferred-Orientation (HIPPO) beam line at Los Alamos National Laboratory. It is designed to collect data for texture analysis. The crystallographic preferred orientation was analyzed using pole figures, created from the data using the Material Analysis Using Diffraction (MAUD) software [8].

## Results and discussion

X-ray diffractograms of the samples are shown in Fig. 2 (a-c). Comparison was made between the diffractogram of the slightly deformed alloys and the highly deformed ones, as well as between the different alloys. Most notable in all is the absence of the basal plane reflection in the highly deformed sample. This is a result of the strong texture developed that causes the basal plane to rotate to the rolling plane. Some small differences between the three alloys can be seen too. Most notable is the strengthening of the pyramidal plane in the RD-ND plane in the reference alloy (AZ-31). Because the information obtained from the X-ray diffraction is limited to some 50  $\mu\text{m}$  under the surface, and it provides data only about crystallographic planes parallel to the surface, neutron diffraction was performed that provides information over the whole volume as well as complete pole figures.

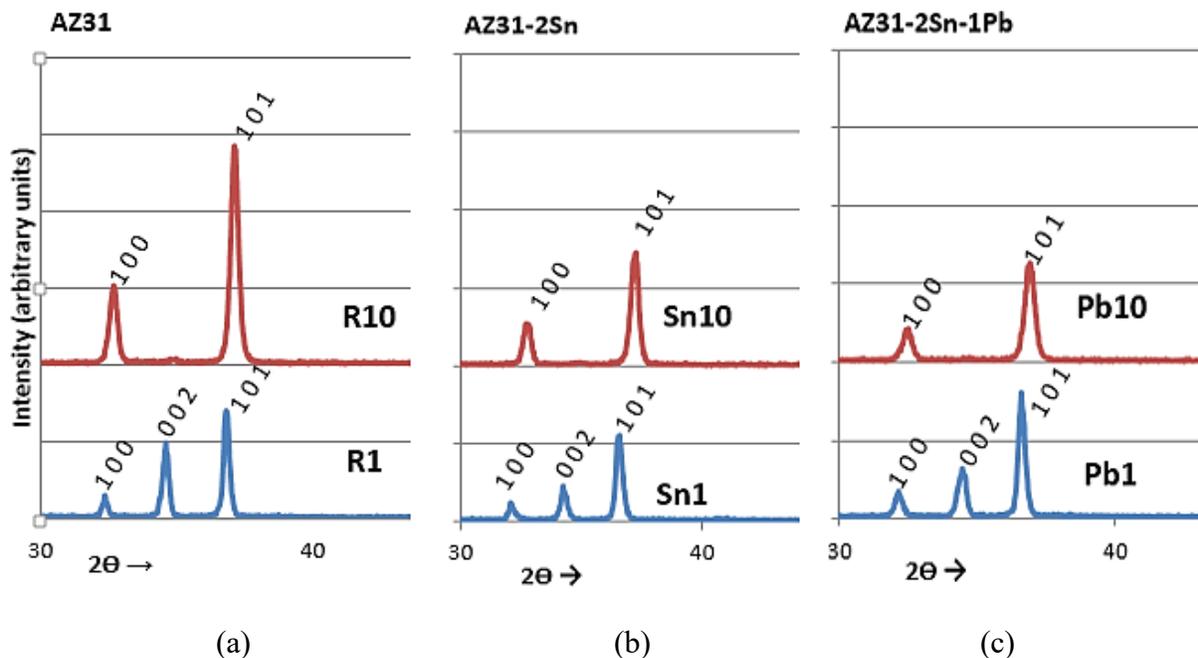
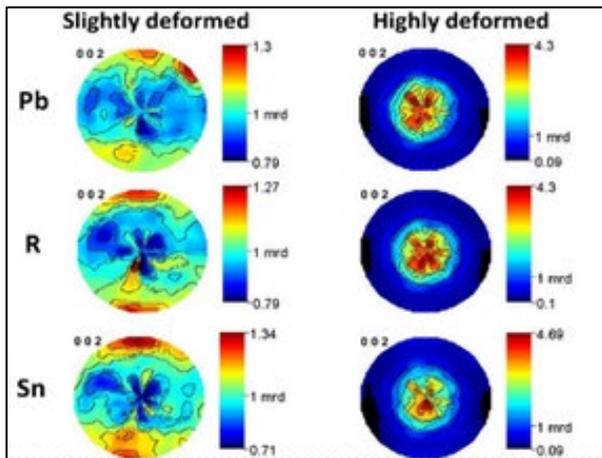
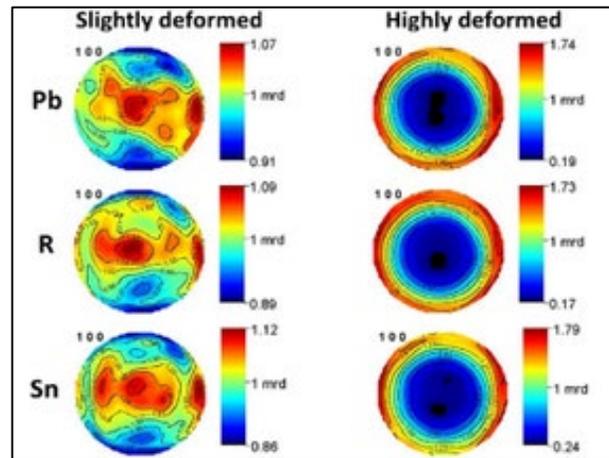


Figure 2. X-ray diffraction of the three alloys before rolling and after heavy deformation

Pole figures of the three alloys are shown in Fig. 3 (basal plane  $\{0001\}$ ) and in Fig. 4 (prismatic plane  $\{10\bar{1}0\}$ ).



**Figure 3.** Basal plane pole figures  
(For sample nomenclature refer to  
Table 1)



**Figure 4.** Prismatic plane pole figures  
(For sample nomenclature refer to  
Table 1)

From the pole figures, it is evident that the initial texture is far from being random. Comparing with Fig.1 at Wang and Huang [9], it is seen that after more than 20% engineering strain (“highly deformed”), the texture of the three alloys is mostly a  $\{0001\}$  fiber texture. The strength of the texture somewhat differs between the three alloys, but its nature remains the same. The slight deviation from a perfect fiber texture, results from the initial texture at the “slightly deformed” state. At that state, it can be characterized as a weak  $\{10\bar{1}0\}\langle 0001\rangle$  texture. During rolling, this texture is first “destroyed” and then the fiber texture gradually develops.

## Conclusions

Rolling ductile Mg alloys (AZ31 plus Sn and Pb), develops  $\{0001\}$  fiber texture similar in nature to the one found in unalloyed Mg [2]. It is concluded that the same slip systems and twinning mechanism operate, and the source of the observed difference in mechanical behavior [10] has other sources, such as microstructure and precipitates formed with the addition of the new elements.

## Acknowledgements

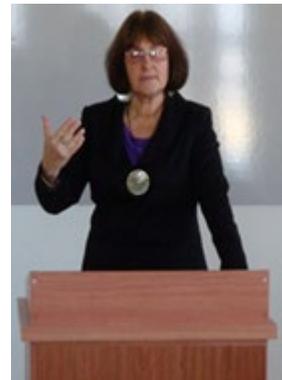
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## Biographical Information

*Professor Pnina Ari-Gur*, received her Doctor of Science degree in Material Engineering from the Technion, Israel Institute of Technology. After a post doctorate research at the University of British Columbia, as well as R&D at the aerospace industry, she started her career at WMU engineering. She has active research collaboration around the globe. Her work is published in engineering and science journals. In addition to her basic research, she conducts some applied projects for the benefit of providing experience to her students.



*Andreas Quojo Quainoo*, *Shubram Subramanyam*, and *Ashkan Razania* are students in the Mechanical and Aerospace Department at Western Michigan University. They came to WMU from Ghana, Malaysia and Iran.