# *Formability and Crystallographic Texture in Novel Magnesium Alloys*

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**Abstract**

By looking into the crystalline structure of magnesium alloys, one can have a better understanding of the properties of these alloys. These alloys have a number of advantages such as high strength, low density and good damping properties. Magnesium has a hexagonal close-packed (HCP) crystalline structure, making it a complex and not so ductile alloy. Using neutron diffraction to study the crystallographic texture, 3 different magnesium alloys were tested and all results were compared with each other. Prior to the start of this research testing was run at Argonne National Laboratory. These diffraction results are then compared to a simulation from the software program PowderCell 2.4.

## Introduction

The very low density of Mg alloys may make them an attractive substitution to heavier alloys including even aluminum. However, due to its poor ductility has prevented their wide-spread application as cold-formed components [1]. Ductility refers to the amount of deformation (or change) a material can undergo under tensile stress. High ductility would make a material be able to survive under a high tensile stress and vice versa with a low ductility.

In the family of Mg alloys, AZ31 is an important one because it is the most widely used commercial magnesium alloy. It can be rolled at elevated temperatures, but have insufficient ductility at room temperature. Rolling is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce the thickness and to make the thickness uniform, as shown in Fig.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]. If a material undergoes plastic deformation, this means that the material, under some force, has changed its shape from its initial stage, without undergoing any failure or fractures. The insufficient number of slip and twinning systems, results in the magnesium alloy demonstrating poor formability at room temperature. Formability is the ability for a metal to go through plastic deformation without being damaged. The small addition of Sn and Pb as alloying elements improves the ductility of magnesium alloys [3]. 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). Slip systems describe the slip plane or slip direction within the crystalline structure where a dislocation motion is most likely to happen. This dislocation motion is also

**Figure 1: Rolling Process**

likely to lead to plastic deformation. 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 [4]. In some HCP metals like Mg, with limited ductility, twinning only works by the most common types of twins [8]. Operating a particular twinning system depends not only on the magnitude of the shear stress, but also on the c/a ratio of an HCP metal. This ratio for pure Mg is 1.624 (close to the ideal value of 1.633). The c/a ratio may be altered by alloying elements; and this may change the active slip systems at room temperature.

**Testing**

Three alloys, AZ-31 and two modified alloys ("Sn" and "Pb") were tested using the Advanced Photon source at Argonne National Laboratory. The Advanced Photon Source is a synchrotron radiation that produces high-energy, high-brilliance x-ray beams. The source is optimized to put large quantities of high-energy photons into a very small area in a very short time [6]. The photons are beamed onto the surface of the alloys and are diffracted. For the PCW testing, the software prompts the user to define the alloy in terms of lattice parameters as well as type of atoms being used. Once the parameters of the crystalline structure are defined the software renders a 3-D model of the molecule as well as a diffraction graph that is supposedly the same graph that would be measured if done experimentally. Comparing the 4 different graphs can tell if there are any differences between an experimental value vs the theoretical values. Differences that would be noted when comparing the diffraction graphs would be the location of the peaks and/or the intensity of the peaks. Taking note of the differences between the peak's intensity and location is essential because the differences can tell about the crystallographic structure. If a

difference is found between the real vs the PCW in the peak's location, this would say that there is a difference in the atomic structure's lattice parameters. If the difference is found within the intensities of the peak, this indicates that the crystallographic texture is different. Another comparison done was the spacing between the lattice planes (d). Using known values of the lattice parameters a theoretical d was calculated. The $d_{theory}$ was compared to d values that were calculated from the results of the synchrotron diffraction results.

**Results & Discussion**

It is important to take note which plane are the most interesting in a HCP structure in terms of plastic deformation. It is also important to only look at a unit cell within the HCP crystal, which is highlighted in Fig. 2. Within this unit cell the planes most interesting are the (100) and (110) planes. The synchrotron diffraction results were analyzed and only the values relating to the peaks were taken. The results can be seen in Tables 1-4.

In the tables, values highlighted in blue were d values that matched the $d_{theory}$ values that were calculated. Values highlighted in orange are d values that matched PCW simulation d values. Values highlighted in red were d values that did not match either the PCW or $d_{theory}$ values. These values were matched with a plane by comparing the peaks of the experimental diffraction graphs with the diffraction graph of a standard Mg sample. Taking these values and graphing the results where the graph shows intensity of the peaks vs. the location of the peaks was done which is shown in Fig. 5. The values highlighted in red are the most interesting due to the fact that these d values did not match either a $d_{theory}$ or a simulated lattice spacing value. Because of this, the focus turned to these values specifically, as well as the family of planes in this system.

Upon analyzing the graphs it is noticed that the location of the peaks is the same for all three magnesium alloys, indicating no change in lattice constants. On the other hand, from examination of the intensity of the Sn and Pb peaks on the graphs and comparing them to both a Mg standard and to the alloy AZ31, which is shown in Table 5, the hkl values that gave the most significant intensity differences were planes parallel to the c-axis. This indicates that the crystallographic texture of these modified alloys is different indicating that alloying the magnesium will have an impact on their formability. (PCW work is currently being done and results will be included in the final draft).

| Pb | | | | |
|---|---|---|---|---|
| Peaks | Intensity | 2Theta | d1 | |
| 2.23 | 6.48E+04 | 32.31242 | 2.7683034 | 100 |
| 2.38 | 4.52E+03 | 34.52308 | 2.5959284 | |
| 2.53 | 1.51E+05 | 36.74701 | 2.4437658 | 101 |
| 3.26 | 7.44E+03 | 48.01708 | 1.8932205 | 102 |
| 3.86 | 3.38E+04 | 57.56287 | 1.5998929 | 110 |
| 4.22 | 4.51E+03 | 63.50105 | 1.4638317 | 103 |
| 4.46 | 6.28E+03 | 67.56661 | 1.3852984 | 200 |
| 4.54 | 1.85E+04 | 68.94309 | 1.3609616 | 112 |
| 4.62 | 2.14E+04 | 70.33099 | 1.3374655 | 201 |
| 5.06 | 4.26E+03 | 78.19207 | 1.2214922 | 202 |
| 5.72 | 3.83E+03 | 90.95621 | 1.0803911 | 203 |
| 5.90 | 3.39E+03 | 94.73257 | 1.047032 | 210 |
| 6.02 | 1.06E+04 | 97.28563 | 1.0262388 | 211 |
| 6.14 | 2.51E+03 | 99.77857 | 1.0071902 | |
| 6.37 | 3.31E+03 | 105.103 | 0.9702734 | 212 |
| 6.69 | 3.01E+03 | 113.0963 | 0.9232345 | 300 |
| 6.91 | 3.52E+03 | 118.7685 | 0.8950709 | 213 |

**Table 1: Pb-Mg Results**

| Sn | | | | Plane |
|---|---|---|---|---|
| Peaks | Intensity | 2Theta | d1 | |
| 2.23 | 6.85E+04 | 32.31242 | 2.768303 | 100 |
| 2.38 | 4.33E+03 | 34.52308 | 2.595928 | |
| 2.53 | 1.51E+05 | 36.74701 | 2.443766 | 101 |
| 3.26 | 7.10E+03 | 48.01708 | 1.893221 | 102 |
| 3.87 | 3.31E+04 | 57.65577 | 1.597536 | 110 |
| 4.22 | 4.68E+03 | 63.40536 | 1.46581 | 103 |
| 4.46 | 6.32E+03 | 67.56661 | 1.385298 | 200 |
| 4.54 | 1.83E+04 | 68.94309 | 1.360962 | 112 |
| 4.62 | 2.23E+04 | 70.33099 | 1.337466 | 201 |
| 5.06 | 4.10E+03 | 78.19207 | 1.221492 | 202 |
| 5.72 | 3.70E+03 | 90.95621 | 1.080391 | 203 |
| 5.91 | 3.26E+03 | 94.85274 | 1.046023 | 210 |
| 6.03 | 1.08E+04 | 97.40881 | 1.025269 | 211 |
| 6.14 | 2.37E+03 | 99.90489 | 1.006256 | |
| 6.37 | 3.26E+03 | 105.103 | 0.970273 | 212 |
| 6.69 | 3.00E+03 | 113.0963 | 0.923235 | 300 |
| 6.91 | 3.38E+03 | 118.7685 | 0.895071 | 213 |

**Table 2: Sn-Mg Results**

| AZ31 | | | AZ31 | |
|---|---|---|---|---|
| Peaks | Intensity | 2Theta | d1 | |
| 2.23 | 67399 | 32.31242 | 2.7683034 | 100 |
| 2.38 | 4137 | 34.52308 | 2.5959284 | |
| 2.53 | 160846 | 36.74701 | 2.4437658 | 101 |
| 3.26 | 7277 | 48.01708 | 1.8932205 | 102 |
| 3.86 | 33678 | 57.56287 | 1.5998929 | 110 |
| 4.22 | 4547 | 63.40536 | 1.4658102 | 103 |
| 4.46 | 6148 | 67.56661 | 1.3852984 | 200 |
| 4.54 | 19184 | 68.94309 | 1.3609616 | 112 |
| 4.62 | 22410 | 70.33099 | 1.3374655 | 201 |
| 5.06 | 4131 | 78.19207 | 1.2214922 | 202 |
| 5.72 | 3671 | 90.95621 | 1.0803911 | 203 |
| 5.91 | 3164 | 94.85274 | 1.0460227 | 210 |
| 6.02 | 10689 | 97.28563 | 1.0262388 | 211 |
| 6.14 | 2302 | 99.77857 | 1.0071902 | |
| 6.37 | 3259 | 105.103 | 0.9702734 | 212 |
| 6.69 | 2902 | 113.0963 | 0.9232345 | 300 |
| 6.91 | 3445 | 118.7685 | 0.8950709 | 213 |

**Table 3: AZ31 Results**

| PCW | | | PCW | |
|---|---|---|---|---|
| Peaks | Intensity | 2Theta | d1 | |
| 2.222774 | 1737.13 | 32.182 | 2.77922 | |
| 2.371248 | 1446.889 | 34.396 | 2.605225 | |
| 2.51884 | 3630.128 | 36.61 | 2.452593 | |
| 3.249992 | 2230.226 | 47.81 | 1.900934 | |
| 3.556727 | 411.058 | 52.649 | 1.737042 | |
| 3.850327 | 313.156 | 57.377 | 1.604631 | 110 |
| 4.028725 | 89.007 | 60.302 | 1.533603 | |
| 4.194364 | 912.503 | 63.057 | 1.473065 | 103 |
| 4.446164 | 185.36 | 67.325 | 1.389679 | |
| 4.522348 | 173.101 | 68.637 | 1.36628 | |
| 4.601441 | 651.519 | 70.01 | 1.342808 | |
| 4.743418 | 144.2 | 72.504 | 1.302638 | |
| 5.039245 | 348.668 | 77.834 | 1.226212 | |
| 5.238617 | 415.023 | 81.541 | 1.179575 | |
| 5.69486 | 310.049 | 90.447 | 1.085143 | |
| 5.882905 | 140.937 | 94.324 | 1.050485 | 210 |
| 6.00126 | 202.747 | 96.838 | 1.029786 | 211 |

**Table 4: PCW Results**

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