Deformation and fracture of wrought magnesium alloys AZ31 and AZ61

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OUTLINE

• Microstructure
• Texture
• Deformation Mechanisms
• Tensile Behavior
• High-Cycle Fatigue Behavior
### Chemical composition of As received AZ31 and AZ61 alloys

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Zn</th>
<th>Mn</th>
<th>Fe</th>
<th>Ni</th>
<th>Cu</th>
<th>Si</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ31</td>
<td>3.06</td>
<td>0.80</td>
<td>0.25</td>
<td>0.003</td>
<td>&lt; 0.001</td>
<td>0.001</td>
<td>-</td>
<td>bal.</td>
</tr>
<tr>
<td>AZ61</td>
<td>6</td>
<td>0.72</td>
<td>0.33</td>
<td>0.003</td>
<td>≤ 0.001</td>
<td>≤ 0.01</td>
<td>&lt;0.01</td>
<td>bal.</td>
</tr>
</tbody>
</table>

Compositions in Wt%
Microstructure – Grain size and hardness

Recrystallized equiaxed structure. No annealing twins observed
AZ31 does not show ppt on grain boundaries.

In AZ61 there seems to be a ppt on the g.b’s, most probably β-phase (to be further investigated).
Deformation Mechanisms in Mg-alloys

**Slip Systems**
- Basal slip \{0001\}<-12-10> 2 ISS
- Prismatic slip \{10-10\} <11-20> 2 ISS
- Pyramidal slip \{10-11\} <11-20> 4 ISS

von Mises criterion requires operation of 5 ISS

Pyramidal slip has high CRSS, operates only at high T
Prismatic slip has higher CRSS than Basal slip but could operate at room T
Basal + Prismatic slip cannot accommodate slip in Mg polycrystals (provide only 4 ISS)

Twinning can provide the needed (by the von Mises criterion) independent deformation mechanism
In Mg-alloys \( c/a < 1.732 \), therefore \{10-12\} twinning can be activated only with tension along the \( c \)-axis or in-plane compression of the basal plane (tension twins).

A significant effect of twinning is to re-orient the basal plane (and generally the twinned region of the lattice) so that slip can be activated.
Basic findings

- A near-basal fiber texture with cylindrical symmetry has been found, i.e. the basal \{0001\} plane is parallel to the rolling plane, while the c-axis is perpendicular to the rolling plane.

- The count of (0001) plane intensity comprises 70% for AZ31 and 80% for AZ61 alloy, of total measured counts from the other crystallographic planes.

- The (0001) Pole Figure shows an angular spread of basal poles towards the rolling direction (L).

- This spread is more pronounced for AZ31 alloy.
The higher yield strength in the LT direction is attributed to the angular spread of basal poles towards the rolling direction (L) (see texture analysis) which causes:

- Yielding by activation of basal slip in the L-direction. Yielding in the LT direction requires activation of prismatic slip, which possesses a higher CRSS
- The c-axis is tilted towards the L-direction. Loading in the L-direction generates a tensile stress component along the c-axis which activates twinning. Twinning in the LT direction requires a higher stress
- Anisotropy more pronounced in AZ31 than AZ61

### Tensile anisotropy (AZ31 and AZ61)

<table>
<thead>
<tr>
<th></th>
<th>Rp [MPa]</th>
<th>Rm [MPa]</th>
<th>Af [%]</th>
<th>W [MJ/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ31 - L</td>
<td>165</td>
<td>263</td>
<td>19.45</td>
<td>48.00</td>
</tr>
<tr>
<td>AZ31 - LT</td>
<td>193</td>
<td>264</td>
<td>20.00</td>
<td>50.80</td>
</tr>
<tr>
<td>AZ61 - L</td>
<td>207 (192)*</td>
<td>317 (294)*</td>
<td>20.19 (16.3)*</td>
<td>61.29</td>
</tr>
<tr>
<td>AZ61 - LT</td>
<td>205.6 (202)*</td>
<td>310.6 (291)*</td>
<td>19.64 (19.5)*</td>
<td>57.93</td>
</tr>
</tbody>
</table>

*U. Patras values*  
*SZMT values*
Characteristics of twin formation (AZ31)

Twin habits

{10-12} tension twin

{10-11} contraction twin

Grain subdivision
Stress concentrations at grain boundaries
Obstacles to dislocation slip (dislocation pile ups)
Operation of two dominant habits
Twining observed after In-plane Compression (AZ31)
Twinning during tension testing (AZ31)

Uniform section

Neck section

Neck: co-ordination leading to shear localization
Intergranular fracture promoted by stress concentrations in g.b due to plastic strain incompatibilities, twinning and/or brittle intermetallic β-phase on g.b.
AZ61 Fatigue Specimens - Uncorroded

165MPa / Nf=140550

165MPa / Nf=418630

170MPa / Nf=84000

180MPa / Nf=343000

180MPa / Nf=104382

190MPa / Nf=30615
AZ61: Fractography of Fatigue specimens

Fast fracture: Intergranular

Flakes: Intergranular

Propagation: Flake-like features

Initiation site: striations

165MPa \(/ N_f=140550\)
190MPa / Nf=30615

Secondary fatigue crack

Initiation: Striations

Propagation: Flake-like Intergranular
Fatigue Initiation: Transgranular fracture

FCP: Intergranular-cleavage cracking and crack branching

Twins at grain left

FCP: Intergranular cracking
Crack branching in FCP region – Section through fracture Surface (LS Plane)  AZ31 alloy
Microstructure: equiaxed, no annealing twins present. $\beta$-phase probably present on grain boundaries of AZ61 alloy

Texture / anisotropy: Sheets have a near-basal texture (c-axis perpendicular to rolling plane). However, an angular spread of basal poles towards the rolling direction generates tensile anisotropy, more pronounced in AZ31 than AZ61 alloy.

Tensile deformation and fracture: Two modes of twinning operate (tension and contraction twins) which affect shear localization. Fractography indicated intergranular mode both for AZ31 and AZ61.

Fatigue: Clear distinction between initiation and propagation stages. Different fracture characteristics. Initiation involves formation of striations and shows a transgranular character while propagation exhibits a flake-like fracture surface with intergranular character.

Intergranular mode could be attributed mainly to strain incompatibilities at grain boundaries due to difficulties to satisfy the Mises criterion and additionally to $\beta$-phase grain boundary network (AZ61).