Magnesium Alloy Forgings for Automotive Applications

Mary A Wells
Dean – College of Engineering and Physical Sciences

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THE INCENTIVE OF USING LIGHTWEIGHT MATERIALS FOR AUTOMOTIVE APPLICATIONS

\[ y = -0.006518 \cdot x + 48.746 \]

- CAFE Std. for cars
- CAFE Std. for trucks
- FIT

- Premium Small
- Entry Small
- Midsize
- Near Luxury Midsize
- Luxury Midsize
- Large
- Luxury Large
- Comp. VAN
- Comp. PU.
- STD PU
- Comp. SUV
- Luxury Comp. SUV
- Large SUV
**BACKGROUND – MOTIVATION**

**Optimized Design with 37% Weight Reduction**

**Cast Al - A356-T6 Benchmark Design**
- Mass: 2.431 kg

**Forged Mg - Final Design**
- Mass: 1.534 kg

**Design validation:** The optimized final design of the control arm passes all clearance checking and Ford system-level strength, stiffness and fatigue analysis for the required load cases.
**The Challenge for Wrought Magnesium**

- Knowledge base for magnesium is much smaller than for steel or aluminum
- Intrinsically more complex due to the low symmetry of the crystal structure
- Lack of engineers/scientists with magnesium knowledge
- Education of the industry
- Low cost !!
BACKGROUND – APPLICATIONS OF Mg ALLOYS

Intake Manifold - Audi

Seat Base - Ford

Specific Rotating Bending Fatigue Strength at $10^8$ Cycles

- Aluminum castings
- Magnesium forgings
**EXPERIMENTAL STRATEGY**

Lab Scale uniaxial compression tests → Intermediate scale forging using 110 ton press → Intermediate scale forging using 500 ton press → Forging of actual control arm

- Uniaxial compression: 17.5 mm, 15 mm, 10 mm
- Lab Scale: 45 mm, 20 mm, 15 mm
- Intermediate scale forging using 110 ton press: 66 mm, 110 ton press
- Intermediate scale forging using 500 ton press: 70 mm, 85 mm, 500 ton press
- Forging of actual control arm: 63.5 mm, 500 ton press
EXPERIMENTAL STRATEGY

Forging of actual control arm

400 mm
1500 Tonne Press

280 mm
1500 Tonne Press
## EXPERIMENTAL

<table>
<thead>
<tr>
<th>Die Type</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Die Forging</td>
<td>Feasibility of forging selected alloys.</td>
<td>Forging temperature: 450°C, Forging Speed: 0.6 mm/s</td>
</tr>
<tr>
<td>Semi-Closed Die Forging</td>
<td>Effect of temperature and forging speed.</td>
<td>Forging temp: 250°C-500°C, Forging Speed: 0.4-40 mm/s</td>
</tr>
<tr>
<td>Closed Die Forging</td>
<td>Effect of pre-form (cast and extruded) and temperature.</td>
<td>Forging temp.: 250°C &amp; 375°C, Forging Speed: 20 mm/s</td>
</tr>
<tr>
<td>Full-Scale Forging</td>
<td>Extruded pre-form (AZ80 and ZK60).</td>
<td>Forging temp: 400°C &amp; 450°C, Forging Speed: 8 mm/s</td>
</tr>
</tbody>
</table>
EXPERIMENTAL

Orientations and Locations of Ø10mm x 15mm Compression Samples

- Extruded Mg
  - Extrusion Axis
- Cast Mg
  - Casting Direction

Ø44.0 Billet (Ø63.5)
Ø210.0 Ingot (Ø304.8)
FLOW STRESS MEASUREMENTS (EXTRUDED AZ80)
FLOW STRESS MEASUREMENTS (AS-CAST AZ80)
110 Ton Press At Canmet
110 Tonne Press at CANMET Simulation with DEFORM 3D

400°C, 0.4mm/s
500 Ton Press at CANMET

0.06mm/s

0.6mm/s

6mm/s
FORGING VIDEO (500 TON PRESS AZ80)  
400°C, 0.6 MM/S
500 Ton Press Experiments

0.067mm/s
0.667mm/s
6.667mm/s
SAMPLE EXTRACTION
(MECHANICAL PROPERTY MEASUREMENTS)

Figure 1: I-Beam forging side view.

Figure 3: Specimen Geometry

FD: Forging Direction  LD: Longitudinal Direction  RD: Radial Direction
S-N CHARACTERIZATION (AZ80)

- As-Ext (ED)
- As-Cast (LD)
- 250°C (IF41)
- 250°C (IF44)
- 275°C (IF38)
- 375°C (IF59)
- 375°C (IF62)

Stress Amplitude [MPa] vs. Number of Cycles [N]

- Cast
- Forged
- Ext
- Forged

Graph showing stress amplitude vs. number of cycles for different conditions.
Forging of Control Arms (1500 Ton Press)

Forging Operation

Flattening Operation
Forging of Control Arms (1500 Ton Press)
FORGING OF CONTROL ARMS (1500 Ton Press)

Forging Operation

Flattening Operation
CONTROL ARM COMPARISON SIMULATION TO MEASUREMENT
SUMMARY

• Magnesium alloy AZ31, AZ80 and ZK60 were successfully forged under a range of conditions

• Starting structure has a large effect on microstructure evolution and processing map

• Anisotropic DEFORM 3D model able to capture flow behavior and load during forging
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Forging Foundation

Multimatic

CanmetMATERIALS

Ford