Proof of the potential of new non-heat treated aluminum high-pressure die-cast alloys for crash-impact areas

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Andreas Harborth, Dr. Stuart Wiesner, Rheinfelden ALLOYS GmbH & Co Kg
Overview

- Aluminum high-pressure die-cast
  - Analysis of current trends
  - Casted structural components and research projects at DLR
  - Challenges

- New high-pressure die-cast aluminum alloys
  - Castaduct®-42
  - Magsimal®-plus

- Methodology

- Proof of potential in strut tower

- Proof of potential in A-pillar cast node

- Summary
Aluminum high-pressure die-cast
- Analysis of current trends

• Structural die cast components:
  – Bigger, more complex components
  – Optimization of wall thickness along load path
  – Functional integration

• Electrification
  – New components
  – High potential of functional integration

• Globalization
  – Manufacturing around the globe
  – Same standard

source: VW AG / AUDI AG

source: www.ZF.com
Strut tower
• High fatigue strength
• Optimization of wall thickness along load path
• Weight reduction up to 45 % in comparison to conventional design

A-pillar cast node
• Example: A-pillar cast node of Audi A8 consisting of two half-shells

source: RHEINFELDEN ALLOYS GmbH
source: own photo @ EUROGUSS 2018
source: Audi AG
SuperLightCar (SLC)
- Strut tower made of cast Mg
- Lightweight potential of 63%
- Additional costs of ~1.80 $ per kg saved weight

DLR A-pillar cast node
- Integrates up to 20 parts
- Optimization of additional costs through smart functional integration
- Lightweight potential > 40% possible
Aluminum high-pressure die-cast
- Challenges

- Structural components:
  - High mechanical properties
  - High ductility during crash

- Bigger, complex components:
  - Close tolerances
  - Large flow length
  - Same structure during solidification
  - Warping

- Joining

- Global aspects:
  - Reduction of costs
  - Reduction of global CO₂-footprint

- How can these challenges be addressed?

- Common project with Rheinfelden Alloys GmbH & Co. KG
  - Investigation of two new high-pressure die-cast aluminum alloys
  - No heat treatment needed
New high-pressure die-cast aluminum alloys
- Castaduct®-42

**Castaduct®-42** *(AlMg4Fe2)*

- High mechanical properties in as cast state (F)
- Simple handling in casting process
- Excellent corrosion resistance
- High dimensional stability
- Weldable

<table>
<thead>
<tr>
<th>cast state</th>
<th>wall thickness [mm]</th>
<th>YS$_{0.2%}$ [MPa]</th>
<th>UTS [MPa]</th>
<th>ε [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>2-4</td>
<td>120-135</td>
<td>240-280</td>
<td>11-22</td>
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</tbody>
</table>

source: RHEINFELDEN ALLOYS GmbH

source: D. Quitter/konstruktionspraxis | RHEINFELDEN ALLOYS GmbH
New high-pressure die-cast aluminum alloys
- Magsimal-plus

**Magsimal®-plus** (AlMg6Si2MnZr)

- High-strength Al-alloy in as cast state (F)
- Excellent corrosion resistance
- High dimensional stability
- Weldable

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<th>UTS [MPa]</th>
<th>$\varepsilon$ [%]</th>
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</thead>
<tbody>
<tr>
<td>F</td>
<td>2-3</td>
<td>200-220</td>
<td>340-360</td>
<td>9-12</td>
</tr>
<tr>
<td>T5</td>
<td>2-3</td>
<td>230-250</td>
<td>350-380</td>
<td>8-12</td>
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</tbody>
</table>

source: RHEINFELENDEN ALLOYS GmbH

battery compartment
source: VW AG/Audi AG | +GF+

strut tower with integrated brace
source: Porsche Automobil Holding SE | +GF+
Methodology
- Methodology for predicting the lightweight potential

1. Basic understanding of the material
2. Calibration of material model
3. Validation of material model
4. Proof of lightweight potential through validated simulations
Methodology
- Methodology for predicting the lightweight potential

- Test data of tensile test and fatigue tests
- Three-point-bending flexural tests (3PBFT) of top-hat profiles

- With test data from 3PBFT: Reverse engineering of
  - Young's modulus
  - Stress-strain curve
  - Rate dependent failure strain

- Simulation of three-point-bending flexural tests of flipped top-hat profiles
- Three-point-bending flexural tests of flipped top-hat profiles

- Project SLC: validated simulation model for strut tower
- Project A-pillar cast node: validated simulation model for cast node
Methodology
- Testing of three-point-bending flexural tests of top-hat profiles

quasi-static

high-speed

Cc-42

<table>
<thead>
<tr>
<th>Force [kN]</th>
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<tbody>
<tr>
<td>12</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>displacement [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

- quasi-static
- 1 m/s
- 5 m/s
Methodology
- Testing of three-point-bending flexural tests of top-hat profiles

- Conclusion:
  - High reproducibility of force-displacement curve
  - Similar force level after crack
  - No decrease of failure stress
  - No brittle behaviour, but increase of ductility

→ Static dimensioning leads to higher safety in high-speed applications like crash
Methodology
- Calibration of material model with 3PBFT of top-hat profiles
Methodology
- Calibration of material model with 3PBFT of top-hat profiles

\[ \text{Cc-42 material model has been calibrated} \]
\[ \text{Ma-plus material model was calibrated analogously} \]
Methodology
- Validation of material model with 3PBFT of flipped top-hat profiles
Methodology
- Validation of material model with 3PBFT of flipped top-hat profiles

→ **Cc-42** material model has been validated
→ **Ma-plus** material model was validated analogously
SLC strut tower
• Structural die cast component made of AM50 with mounting parts
• Operational stability: 80 MPa
• Weight of AM50 cast only: 2.110 kg

Material substitution with Al-alloy
• Commonly used AlSi10MnMg T7
• Operational stability 80 MPa
• Weight of AlSi10MnMg cast: 3.130 kg

Load Case:
• static load of 12 kN in z-direction
**Cc-42 strut tower:**

- Initial weight: 3.130 kg
- Operational stability (5%/10^7 cycles): 103 MPa
- Iterative dimensioning between static simulation, adjustment of wall thickness and full-vehicle crash simulation

- Weight analysis:
  - **Castaduct-42:** 2.520 kg
  - Difference to AM50: +0.430 kg **+19.4 %**
  - Difference to AlSi10MnMg: -0.620 kg **-19.5 %**
Ma-plus strut tower:

- Initial weight: 3.100 kg
- Operational stability (5 %/10^7 cycles): 112 MPa

- Iterative dimensioning between static simulation, adjustment of wall thickness and full-vehicle crash simulation

- Weight analysis:
  - Magsimal-plus: 2.430 kg
  - Difference to AM50: +0.370 kg, +15.2%
  - Difference to AlSi10MnMg: -0.680 kg, -22.4%
<table>
<thead>
<tr>
<th><strong>Castaduct®-42</strong></th>
<th><strong>Magsimal®-plus</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Good-natured failure behavior due to high elongation at break</td>
<td>• Elongation at break just enough for this component</td>
</tr>
<tr>
<td>• No cracks between strut tower and connection to A-pillar</td>
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</tr>
<tr>
<td>• Failure in wheel arch not critical</td>
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</tr>
<tr>
<td>→ Structural integrity maintained</td>
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</tr>
<tr>
<td>• Lightweight potential compared to:</td>
<td>• Lightweight potential compared to:</td>
</tr>
<tr>
<td>– AM50: +19.4 %</td>
<td>– AM50: +15.2 %</td>
</tr>
<tr>
<td>– AlSi10MnMg: -19.5 %</td>
<td>– AlSi10MnMg: -22.4 %</td>
</tr>
<tr>
<td>→ Characteristics of Cc-42 better suited for strut tower</td>
<td>→ Potential of Ma-plus not fully exploitable due to castability</td>
</tr>
</tbody>
</table>
A-pillar cast node (DLR)

- Structural die cast component made of AM50
- Operational stability: 80 MPa
- Tensile strength: 210 MPa
- Compressive strength: 130 MPa

- Weight analysis:
  - **Steel** sheet metal assembly: 10.390 kg
  - **A-pillar cast node (AM50)**: 5.920 kg -43.0 %
Magsimal-plus A-pillar cast node:

- **Initial weight:** 8.690 kg

- **Load Case 1:**
  - Static load of 12 kN in z-direction
  - Operational stability of 112 MPa relevant
  - Minimum wall thickness reduction by 1.4

- **3 areas:**
  - Red: reduction only by 1.4 possible
  - Green: reduction by more than 1.4 possible
  - Blue: not needed for this load case

- **But:** LC2 and **castability** not considered
Magsimal-plus A-pillar cast node:

- **Initial weight:** 8.690 kg

- **Load Case 2:**
  - Static substitute load of 50 kN in x-direction
  - Tensile/compress. strength of 380 MPa relevant
    → Minimum wall thickness reduction by 2.9

- **3 areas:**
  - Red: reduction only by 2.9 possible
  - Green: reduction by more than 2.9 possible
  - Blue: not needed for this load case

- **But:** LC1 and **castability** not considered
Castability of **Ma-plus**

- Small ribs with 2.1 mm thickness at head found in reference CAD-model
- Minimum castable wall thickness 1.8 mm

→ Maximum wall thickness reduction by 1.15
→ Potential not fully utilized here

Proof of potential in A-pillar cast node
- Castability of Ma-plus
Estimated weight reduction for Ma-plus

- Initial weight: 8.690 kg
- Total reduction red areas: -0.696 kg
- Total reduction green areas: -1.469 kg
- Total reduction blue areas: -0.120 kg
- Final estimated weight: 6.405 kg

- Difference to AM50: +0.485 kg +8.2%
- Difference to steel sheet metal assembly: -3.985 kg -38.4%

Magsimal-plus model with load case 1
Proof of potential in A-pillar cast node
- Overview of findings

• Failure stresses and strains taken into account
• Castability taken into account
• Most relevant load cases taken into account

→ **Magsimal®-plus** can be used in A-pillar cast node

• **Lightweight potential** compared to:
  – magnesium AM50 casted node: +8.2 %
  – steel sheet metal assembly: -38.4 %

→ Proof of lightweight potential through simulation for **Magsimal®-plus**
**Methodology**

- Basic understanding of the material
- Calibration of material model
- Validation of material model
- Proof of lightweight potential through validated simulations

**Non-heat treated Al-HPDC alloys**

- Proof of lightweight potential
- No heat treatment
  - Reduction of process steps
  - Minimal/no straightening needed
    → Easier, faster production
    → Reduced production costs
- Reduction of used energy
  - Smaller carbon footprint
  - Reduced energy costs
- **Simulation method for structural components available at DLR**
Thank you

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