Optimization of High-Volume Warm Forming for Lightweight Sheet Alloys

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Ford Motor Company
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Project ID # LM061

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Overview

Timeline
• Project start date: January 1, 2010
• Project end date: September 30, 2012*
• Percent complete: 70%

* Original project proposal end date

Barriers
- Cost: Low cost approach to warm forming
- Performance: Preserving the part complexity when forming an aluminum alloy vs. steel
- Manufacturability: Accounting for die heat-up during continuous production

Budget

<table>
<thead>
<tr>
<th></th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>Total Project Funding</td>
<td>$1,188K</td>
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<tr>
<td>-DOE Share @ 50% Funding</td>
<td>$594K</td>
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<tr>
<td>-USAMP Share @ 50% Funding</td>
<td>$594K</td>
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<td>DOE Funding Received in FY2011</td>
<td>$367K</td>
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<tr>
<td>DOE Funding Received in FY2012</td>
<td>$107K</td>
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Partners/Contributors

Project Lead: Nia Harrison/Peter Friedman
Review Past Warm Forming AMD Projects

**AMD307**
Conventional Stamping Die
Refitted for Warm Forming

**AMD602**
Purpose-Built Integrated
Warm Forming Die

Aluminum Warm Forming
Aluminum Room Temperature

Binder Pressure, psi
Blank Temperature, C

AA5182 Forming Window
Split and Wrinkle
Wrinkle
Split
Review of Warm Forming AMD307/602 Project Accomplishments

- Developed and demonstrated key elements of warm forming technology with the forming of a door inner panel from commodity Al and Mg alloys.
- Developed die architecture and process to provide thermal stability / uniformity to minimize dimensional distortion during steady state production conditions.
- Performed fundamental material characterization work on magnesium sheet from five different suppliers.
- Established forming process limits for both commercial Al and Mg sheet.
- Developed finite element prediction of forming and failure during warm forming.
- Developed fully-automated warm forming cell capable of demonstrating the process under run-at-rate conditions at 5 jobs per minute for both aluminum and magnesium.

AMD307 closed FY2007, AMD602 closed FY2009
Objectives of Current Project – AMD905

- Phase 1: Develop an Optimized Warm Forming Process
  - Investigate the formability limits by producing a more intricate part
  - Lower die temperatures allowing for lower cost heating methods

  **Metric:** Formability of aluminum sheet equivalent to steel at room temperature using a die at lower temperature

- Phase 2: Scale-up and Demonstration of the Optimized Process
  - Design and build full-scale die based on optimized process
  - Conduct forming trials to demonstrate improved WF process

  **Metric:** Successful scale-up and demonstration of repeatability at a production partner
## Milestones

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Milestone</th>
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<tbody>
<tr>
<td>November/2010</td>
<td>Go/No-Go Decision: Optimized process approach decided (Go with non-isothermal for production scale-up).</td>
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<tr>
<td>July/2011</td>
<td>Milestone: FEA sheet formability study, die modifications, die design completed.</td>
</tr>
<tr>
<td>October/2011</td>
<td>Milestone: Die construction completed. Initial target date of August (2011) was missed due to cutting error in one of the four die components.</td>
</tr>
<tr>
<td>November/2011</td>
<td>Milestone: Initial forming trial completed at Vehma–Cosma. This event identified areas of the die that required modifications and initial proof of concept. Upon completion of the trial, the die was modified by Troy Tooling Technologies.</td>
</tr>
<tr>
<td>December/2011</td>
<td>Milestone: Second forming trial completed at Vehma–Cosma. This event established the baseline for forming feasibility. No further die modifications were necessary so the die was shipped from Vehma directly to Promatek.</td>
</tr>
<tr>
<td>January/2012</td>
<td>Milestone: Third forming trial completed at Promatek-Cosma. Formability window with respect to temperature was investigated and the optimal forming parameters established.</td>
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<tr>
<td>March/2012</td>
<td>Milestone: Post forming material properties determined.</td>
</tr>
<tr>
<td>June/2012</td>
<td>Milestone: Project close-out report completed.</td>
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</table>
Objective: Develop an Optimized Warm Forming Process

- Investigate the formability limits by producing a more intricate part
- Lower die temperatures allowing for lower cost heating methods

Approach:

- Modify existing die from AMD602 to add a reverse feature at the bottom of the pan die, simulating a typical automotive panel.
- Investigate non-isothermal processes:
  - Cold die / Cold blank (baseline)
  - Cold die / Warm blank
  - Warm die / Hot blank
Die Modification

Modification of Pan Die to Include Mid-Panel Stretch

New punch with heating and water cooling capability developed

Previous panel design formed in the AMD602 warm forming die

New trial part developed to simulate a typical automotive panel
Cold Die Forming: 71 mm depth

Blanks at RT and 270°C with feature depths of 12 mm and 26 mm, and 25 mm.
Cold Die Forming Limits

Al 5182 / Fuchs lube / Pan Depth 71 mm

- • Successful
- ○ Failed

Feature Depth, mm

Blk Temperature, °C
**AMD905 – Phase 2**

**Demonstration Part**

Benefits of using this part in Phase 2 are that it cannot be formed in aluminum with conventional processes and much of the die engineering is available.
Technical Approach – Phase 2

- **Objective:** Scale-up and Demonstration of the Optimized Process
  - Design and build full-scale die based on optimized process
  - Conduct forming trials to demonstrate improved WF process

- **Approach:**
  - Thermal Simulation – evaluation of die heat-up
  - CAE Simulation – evaluation of sheet formability
  - Die Development – preserving conventional practices
  - Vehma Forming Trial (trial 1) – die performance evaluation
  - Vehma Forming Trial (trial 2) – die performance evaluation
  - Promatek Forming Trail (trial 3) – manufacturing process repeatability
Thermal Simulation

Accomplishments:

- Utilized die heating/cooling lines to attain a steady-state production at start-up.
- Utilized die heating/cooling lines to maintain a steady-state condition during production.
- Minimized distortion within the die.
- Reduce the number of defective panels during forming startup.
CAE Simulation

Accomplishments:

- Performed FEA of the process at room temperature and at elevated temperatures with isothermal assumptions.
- Provided FEA feedback to the die design and modification process.
- Optimized draw bead design and locations.
- Optimized relief window configuration.

Initial die geometry, 20°C

Final die geometry, 180°C
Die Development

Accomplishments:

- Utilized traditional die construction practices that were optimized for aluminum sheet.
- Delivered steel intent design and geometry by limiting the on part radii modifications to specific areas to improve drawability.
- Modified draw beads to assist with material flow.
Promatek Forming Trial

- **Trial Parameters:**
  - Two alloy suppliers of 5182-O: Alcoa & Novelis
  - Two directions: Rolling Direction & Transverse
  - Temperature range: Between 200°C - 300°C

- **Press Parameters:**
  - Press tonnage: 1475 tons
  - Cushion pressure: 270 tons

- **Cycle time:**
  - Pre-heat blank: 180 seconds
  - Furnace to forming: 15 seconds

- **See Movie**
Forming Trial Results:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Alcoa (L)</th>
<th>Novelis (L)</th>
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<tbody>
<tr>
<td></td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>200°C</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>225°C</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>230°C</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>240°C</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td>250°C</td>
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<td>10</td>
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<tr>
<td>260°C</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>270°C</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>275°C</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>280°C</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>300°C</td>
<td>17</td>
<td>18</td>
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</tbody>
</table>

Cracking

Formability Window

Room temperature

Temperature: 250°C
Collaborations/Partners

- **Ford Motor Company**
  - Peter Friedman
  - Nia Harrison
  - Andrey Ilinich
  - George Luckey

- **General Motors Corporation**
  - Paul Krajewski
  - Ravi Verma

- **Chrysler Group, LLC**
  - Jugraj Singh
  - DJ Zhou

- **Troy Tooling Technologies, LLC**
  - Dennis Cedar, tool maker
  - Richard Hammar, thermal analyst for die system

- **Fuchs Lubricants**
  - Jim Wiederholt, lubricant supplier

- **Alcoa**
  - Glen Jarvis, material supplier

- **Novelis**
  - Mike Bull, material supplier

- **Vehma – Cosma**
  - Scott Gayeski, production partner
  - Timothy Skszek, production partner

- **Promatek - Cosma**
  - Jonathan Hook, production partner
  - Jagdeep Jhajj, production partner
  - Darren Womack, production partner
  - Alex Zak, production partner
Proposed Future Work

- **FEA Development**
  - Gap: No established coupled thermo-mechanical simulation model for formability studies.

- **Design Guidelines**
  - Gap: Identifying the radii limitations as a function of temperature for design purposes.

- **Continuous Production**
  - Gap: Run-at-rate production cell has not been established to verify die performance in a non-isothermal environment.
Technical Accomplishments

- Established WF process for Phase 2 for significantly lower cost and enhanced formability.

- Completed die engineering and development for door inner
  - Modified die for aluminum gauge and draw bead design
  - Completed formability simulation
  - Completed thermal analysis of steady state forming process
  - Established heating strategy for the Phase 2 forming trials

- Identified Cosma as the collaboration supplier-partner for Phase 2
  - Defined roles and responsibilities
  - Successfully executed forming trials at Cosma’s Vehma facility (manual load trial)
  - Developed a loading process for repeatable forming trials
  - Successfully executed forming trials at Cosma’s Promatek facility (automated load trial)
Summary

- **Key deliverables of the project:**
  - Established a low-cost warm forming process.
  - Implemented traditional die construction practices which were optimized for aluminum sheet.
  - Demonstrated that the optimized forming process is repeatable.
  - Demonstrated a cycle time consistent with conventional stamping.

- **Significance of the results:**
  - The ability to use aluminum versus steel resulted in a weight savings of ~5 lbs (~40% wt savings).
  - A non-isothermal warm forming process demonstrates a low cost approach to forming aluminum which is consistent with existing conventional stamping practices.