Aerodynamic Lightweight Cab Structure Components

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Project ID#
LM60
Outline

- Project Overview
- Relevance
- Approach
- Milestones
- Technical Approach
- Results and Accomplishments
- Summary
- Publications/Presentations
Project Overview

Project Timeline
- Start: 10/01/2010
- Finish: 9/30/2013

Budget
- Total project funding
  - DOE – $1220K
  - FY11 Funding - $375K
  - FY12 Funding - $365K
  - FY13 Funding - $480K

Barriers
- Suitable aluminum alloys meeting strength and durability requirements for heavy duty trucks lack formability
- Forming and manufacturing process must be compatible with PACCAR cab assembly and finishing methods
- Moderate production volumes limit tooling options

Partners
- PACCAR Technical Center
- Novelis Aluminum
- Magna International – Stronach Centre for Innovation (SCFI)

PACCAR and Magna SCFI (Stronach Centre For Innovation) providing 50% cost share as in-kind materials and effort
The objective of the project is to develop and demonstrate a thermo-mechanical forming process that will allow a standard aluminum sheet alloy to be formed into complex, aerodynamic shapes and components, reducing component weight by up to 40%.

The development of the hot/cold forming process for aluminum sheet will allow commercial truck designers to replace heavier glass fiber reinforced plastics and sheet steel in complex-shaped components while meeting required strength, durability and finish requirements.
Approach

- Evaluate warm forming process that is compatible with PACCAR-selected 6XXX-series aluminum alloy
- Demonstrate extended formability that will allow forming of aerodynamic body components
- Demonstrate compatibility with PACCAR paint bake cycle and required component property and surface finish requirements
- Form full-scale component using 6XXX alloy and PNNL-developed process and conduct cab durability test evaluation
Complete tensile test-based development of hot/cold forming process sequence demonstrating enhanced tensile ductility and >175 MPa tensile strength for 6000-series sheet alloy. Completed - October 2011
Complete manufacturing process demonstration of Hot/room temperature aluminum sheet forming using prototype 3-dimensional component tooling (March 2012).

Completed - February 2012
Project Background

- Focused on Class 8 Truck cab components that provide weight savings and contribute to aerodynamic optimization
- The Heavy Truck industry can’t amortize stamping dies due to lower production volumes
  - Built-up structures from generic shapes
  - Steel for hard to form body components (single stamping die/weight penalty)
  - SMC for styling, aerodynamic body and hood, and low tooling costs (with weight penalty)
- Aluminum can provide >40% weight savings compared to SMC and steel but:
  - Lacks formability required for aerodynamic panels
  - Must be compatible with established manufacturing and finishing processes
Task 1.1

- Establish as-received (-T4) properties and basic E-coat HT response
- Determine optimum hot forming temperature and formability limits (maximum uniform elongation)
- Determine E-coat HT response for hot formed specimens and optimize
- Simulate RT preforming to strain level (10%) + hot forming additional 10% + E-coat HT
- Simulate hot preforming to strain level (10%) + RT forming additional 10% + E-coat HT

<Results based on optimum tensile “formability” and tensile properties>
Hot Gas Pre-Forming / RT Final Forming Process Schematic

- **X608-T4 Sheet**
- **Hot Gas Preform Sheet Blank @ 450 - 540 C**
- **Tool Removal**
- **Water Quench**

- **Air Cool**
- **RT Stamp Finish Form Single Sheet**
- **RT**
- **E-Coat / Paint Bake Heat Treatment**
  - 180 C / 20 min.
- **Test and Characterize UTS/YS/elong.**
Room Temp. Pre-Forming / Hot Gas Forming Process Schematic

1. X608-T4 Sheet
2. Preform Sheet Blank @ Room Temp.
3. Hot Gas Finish Form Single Sheet 450 – 540 °C
4. Tool Removal / Cooling Fixture
5. Air Cool / Forced Air Cool
7. E-Coat / Paint Bake Heat Treatment 180 °C / 20 min.
8. Test and Characterize UTS/YS/elong.
### As Received Properties for Batch 1 & 2 Novelis X608 Sheet

<table>
<thead>
<tr>
<th>Material ID</th>
<th>Condition</th>
<th>0.2% Yield Strength (MPa)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6XXX-1</td>
<td>As-Received (AR)</td>
<td>120</td>
<td>210</td>
<td>22.1</td>
</tr>
<tr>
<td>6XXX-1</td>
<td>AR + PB</td>
<td>165</td>
<td>241</td>
<td>18.7</td>
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<tr>
<td>6XXX-1</td>
<td>AR + 5%CF + PB</td>
<td>207</td>
<td>255</td>
<td>20.9</td>
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<tr>
<td>6XXX-2</td>
<td>As-Received (AR)</td>
<td>135</td>
<td>228</td>
<td>23.6</td>
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<tr>
<td>6XXX-2</td>
<td>AR+PB</td>
<td>184</td>
<td>260</td>
<td>21.2</td>
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<tr>
<td>6XXX-2</td>
<td>AR + 5%CF + PB</td>
<td>230</td>
<td>274</td>
<td>27.1</td>
</tr>
</tbody>
</table>

AR = As-Received (-T4); PB = Paint Bake (180 C, 20 minutes); CF = Cold Form (Room Temperature Strain)

Test results for shoulder-loaded SPF tensile specimen. Additional comparison tests conducted with ASTM standard and sub-sized E8 specimens have been conducted.
## Summary of simulated forming test results for hot and cold strained specimens. Results for Novelis 6XXX-2 sheet

<table>
<thead>
<tr>
<th>Specimen Group</th>
<th>Forming Condition</th>
<th>Temp. (C)</th>
<th>Hot Strain (%)</th>
<th>Cold Strain (%)</th>
<th>0.2% Yield Strength (MPa)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Total Elongation (%)</th>
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</thead>
<tbody>
<tr>
<td>29</td>
<td>HF/CF</td>
<td>450/RT</td>
<td>19.89</td>
<td>4.17</td>
<td>141.9</td>
<td>184.4</td>
<td>37.89</td>
</tr>
<tr>
<td>26</td>
<td>HF/CF</td>
<td>500/RT WQ</td>
<td>20.11</td>
<td>4.06</td>
<td>179.2</td>
<td>239.7</td>
<td>41.76</td>
</tr>
<tr>
<td>31</td>
<td>HF/CF</td>
<td>540/RT AC</td>
<td>29.38</td>
<td>4.36</td>
<td>201.0</td>
<td>249.0</td>
<td>45.91</td>
</tr>
<tr>
<td>30</td>
<td>HF/CF</td>
<td>540/RT WQ</td>
<td>28.92</td>
<td>4.27</td>
<td>223.1</td>
<td>262.4</td>
<td>45.80</td>
</tr>
<tr>
<td>15</td>
<td>CF/HF</td>
<td>RT/350</td>
<td>5.31</td>
<td>4.90</td>
<td>109.3</td>
<td>158.0</td>
<td>21.37</td>
</tr>
<tr>
<td>17</td>
<td>CF/HF</td>
<td>RT/540 WQ</td>
<td>13.23</td>
<td>4.76</td>
<td>104.0</td>
<td>183.1</td>
<td>31.46</td>
</tr>
</tbody>
</table>

Notes: HF/CF = Hot Form then Cold Form; CF/WF= Cold Form then Hot Finish Form; WQ = Water Quench (from HF step); AC = Air Cool (from HF step). All specimens received standard paint bake (180 C/20 min.) prior to room temperature tensile test.
Task 1.2

- Design and fabricate tooling for 3-D component
- Demonstrate process sequence for three candidate forming methods:
  1. RT preform blank followed by elevated temp final forming
  2. Hot preform blank followed by RT final forming
- Evaluate die lubricants, surface, E-coat process for formed component

< Validate feasibility of forming process sequence and ability to meet strength, dimensional, surface finish and E-coat/paint bake response for simulated component>
• Design of 3-D component for forming process development and validation
  
  • Non-proprietary component that incorporates features of aerodynamic aluminum cab component
  
  • Component configuration requires formability that exceeds room temperature stamping capability
  
  • Designed to demonstrate hot forming application using standard alloy (common to balance of cab)
  
  • Requires compatibility with strength requirements, E-Coat surface treatment, fatigue performance
3-D Component Model Features

- Smooth Transition at Corners
- 10° Draft Angle for Walls
- 9mm Entry Radius
- ~3"
Rigid Die (Half model)
Summary of Cold Forming Limit Analysis

- **Equiv. Plastic Strain**
  - Necking at 20% strain
  - Local Hotspots (Due to local necking)
  - 0.1 Friction Between Sheet and Die

- **Max Depth:** 22.2mm (0.87”)
- **Limit Pressure at 20% strain:** 57atm (~827 psi)

- **Material:** AA6061-T4 Room Temp

**Graph:**
- Stress vs. Strain curve
Selected hot preform with room temperature final forming using second lot of X608 sheet material (nominal 1.3 mm thickness)
- Hot form at 500 C with air cool and with water quench
- Hot form at 540 C with air cool and water quench
- Two trays per condition

Fully-constrained forming of sheet into 38 mm deep tray section requires 50 to 100% transverse elongation of sheet

Forming steps performed without edge constraint/drawbead control

Sheets lubricated with boron nitride (hot preforming step) and Vanish water-based stamping lubricant (room temperature finish forming)

All trays heat treated for simulated paint bake cycle (180 C/20 minute) after final forming

Formed trays sectioned for
- Six longitudinal tensile bars from the bottom of tray
- Samples provided to PACCAR Tech Center for surface finish, E-coat and adhesive bonding test and characterization
Hot Preformed Tray Prior to Room Temperature Final Forming

Picture of bottom of hot preformed X608 aluminum tray showing draw-in of sheet
Room Temperature Final Formed Tray

Picture of bottom of room temperature final formed X608 aluminum tray showing additional material draw-in of the sheet
Room Temperature Final Formed Tray

Picture of top of room temperature final formed X608 aluminum tray
### Room Temperature Tensile Test Results for Hot/RT Formed Trays and Baseline Sheet

<table>
<thead>
<tr>
<th>Forming Conditions</th>
<th>0.2% Yield Strength (MPa)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF 500 C/AC + CF + PB</td>
<td>119.7</td>
<td>210.3</td>
<td>22.9</td>
</tr>
<tr>
<td>HF 500 C/WQ + CF + PB</td>
<td>121.4</td>
<td>211.2</td>
<td>22.8</td>
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<tr>
<td>HF 540 C/AC + CF + PB</td>
<td>140.8</td>
<td>241.8</td>
<td>22.9</td>
</tr>
<tr>
<td>HF 540 C/WQ + CF + PB</td>
<td>144.8</td>
<td>245.0</td>
<td>22.8</td>
</tr>
</tbody>
</table>

HF = Hot Form; CF = Cold Form; AC = Air Cool; WQ = Water Quench; PB = Paint Bake (180 C for 20 min.)
Aluminum Tray Forming Results –
Technical Accomplishments and Progress

• Tensile-based forming process demonstrated high levels of uniform deformation with excellent retained ductility and yield strengths

• Forming experiments focused on hot preforming at 500 to 540 C, followed by room temperature final stamping

• The 3-D tray component that was formed can not be formed in 6000-series sheet at room temperature without significant tears and fractures

• Because of edge draw-in, the actual total strain (hot and RT strain) in the finished trays was generally below 10%

• Tensile properties of the formed trays fall below the tensile properties of the as-received sheet material, but retain excellent ductility

• Effects of hot forming temperatures on surface finishing, coating and adhesive bonding is under evaluation (PACCAR)
• A second phase of forming experiments is underway where the sheet material will undergo significantly higher hot preform strains

• Sheet material used for tray forming was held in freezer, but is beyond recommended shelf life for natural aging

• Discussions have been initiated with Magna SCFI on selection and optimization of the forming process to meet production requirements

• PACCAR and Magna SCFI are evaluating potential truck cab components for demonstration of forming process
Collaboration

- PACCAR Technical Center
  - Principal industry partner – contributing component design, design requirements, material specifications, assembly and testing

- Magna International – Tier 1 supplier to automotive and commercial vehicle OEM’s

- Novelis Aluminum – supply and specification of aluminum sheet materials
Summary

• This is a project with PNNL, PACCAR Tech Center, Novelis Aluminum and Magna SCFI collaborating

• Project is addressing a key challenge of reducing truck cab component weight by >40% through application of aluminum aerodynamic panels in place of steel and SMC

• Warm/cold and cold/warm forming processing sequences have been demonstrated using tensile specimen-based test methods

• Demonstration of a basic production capable warm/cold forming process using a 3-D tool has been completed in Phase 1 forming trials and process optimization trials are underway

• Tensile properties of the formed 3-D trays are somewhat below target goals, and Phase 2 forming demonstrations will focus on generating higher hot and cold strains in the formed materials