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Aerodynamic Lightweight Cab Structure Components

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Project ID#
LM60

Outline

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Project Overview

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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

PACCAR and Magna SCFI (Stronach Centre For Innovation) providing 50% cost share as in-kind materials and effort

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)

Relevance

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- 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

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- 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

Milestones – FY2011

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

Milestones – FY2012

Complete manufacturing process demonstration of Hot/room temperature aluminum sheet forming using prototype 3-dimensional component tooling (March 2012).
Completed - February 2012

Project Background

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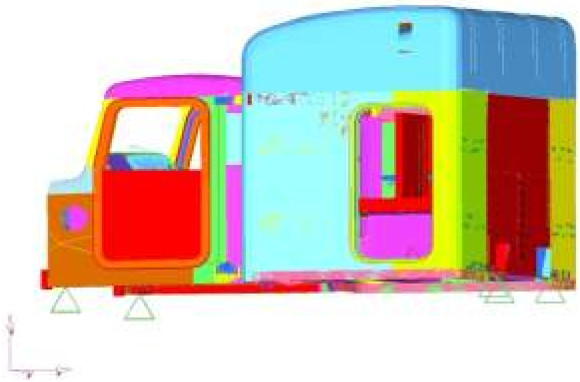
- Focused on Class 8 Truck cab components that provide weight savings and contribute to aerodynamic optimization
- The Heavy Truck industry can't amortize stamping dies due to lower production volumes
  - Built-up structures from generic shapes
  - Steel for hard to form body components (single stamping 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



Material Characterization and Process Validation – Task Plan

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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

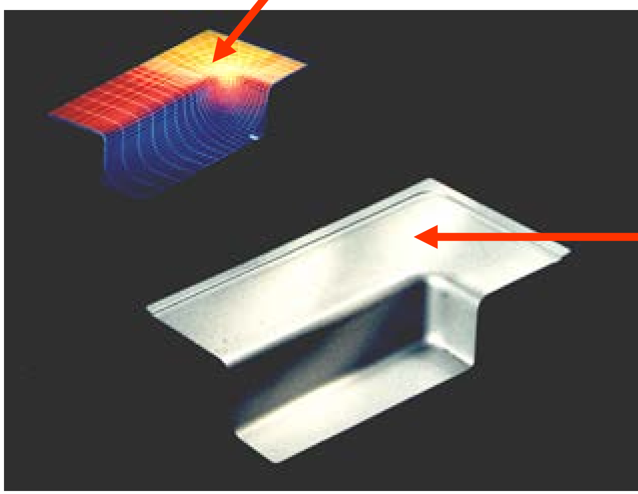
< Results based on optimum tensile "formability" and tensile properties>

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

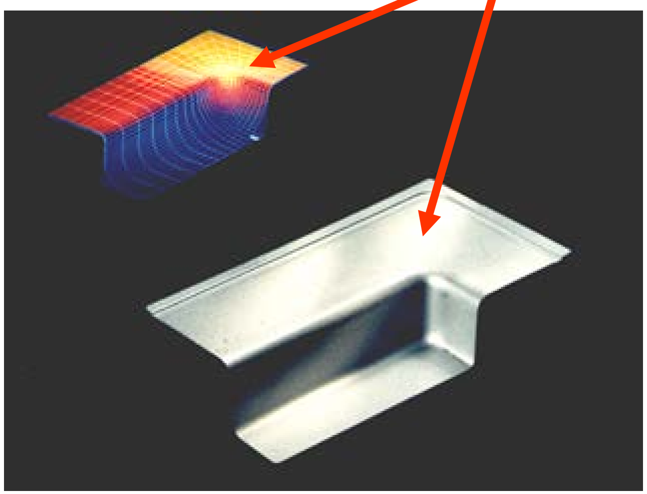
  RT
- E-Coat / Paint Bake Heat Treatment

  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. Solution Heat Treat/Water Quench
   450-550 C – 10 min.
6. 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

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

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

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

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.

Forming Process Validation – Task Plan

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Task 1.2

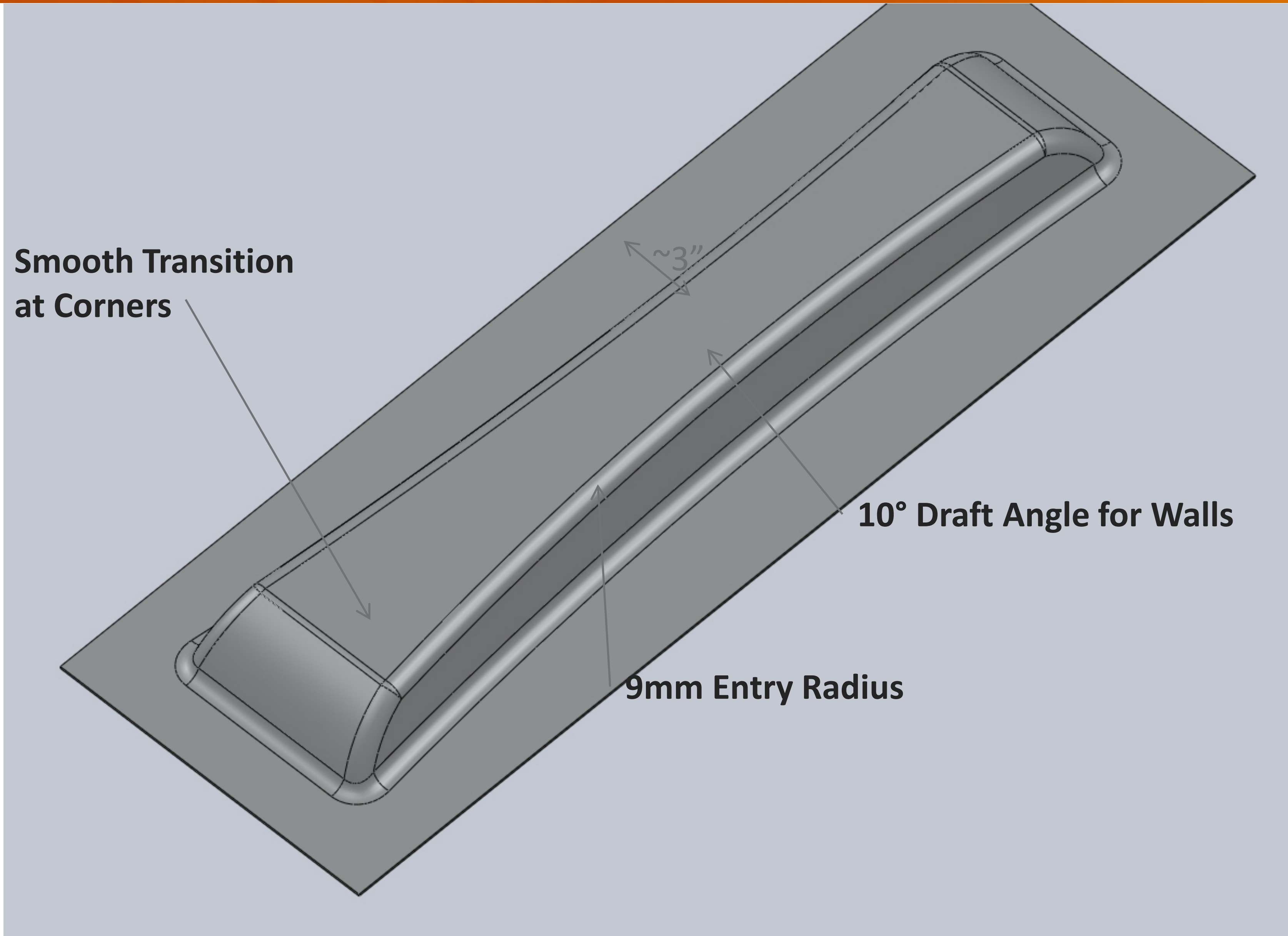
- Design and fabricate tooling for 3-D component
- Demonstrate process sequence for three candidate forming methods:
  1. RT preform blank followed by elevated temp final forming
  2. Hot preform blank followed by RT final forming
- Evaluate die lubricants, surface, E-coat process for formed component

< Validate feasibility of forming process sequence and ability to meet strength, dimensional, surface finish and E-coat/paint bake response for simulated component>

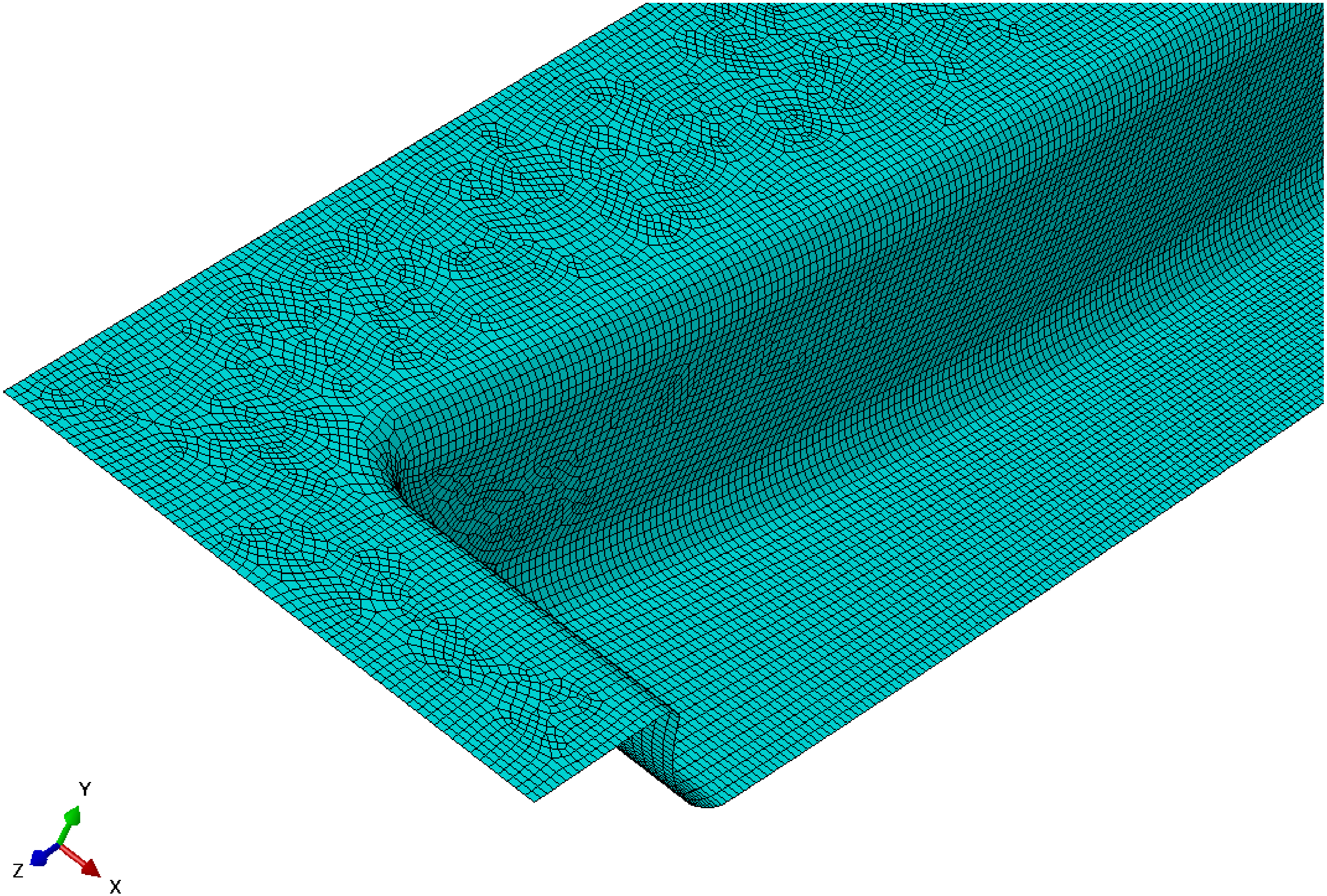
Forming Process Validation – Component Design and Forming Analysis

- 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



Rigid Die (Half model)



Summary of Cold Forming Limit Analysis

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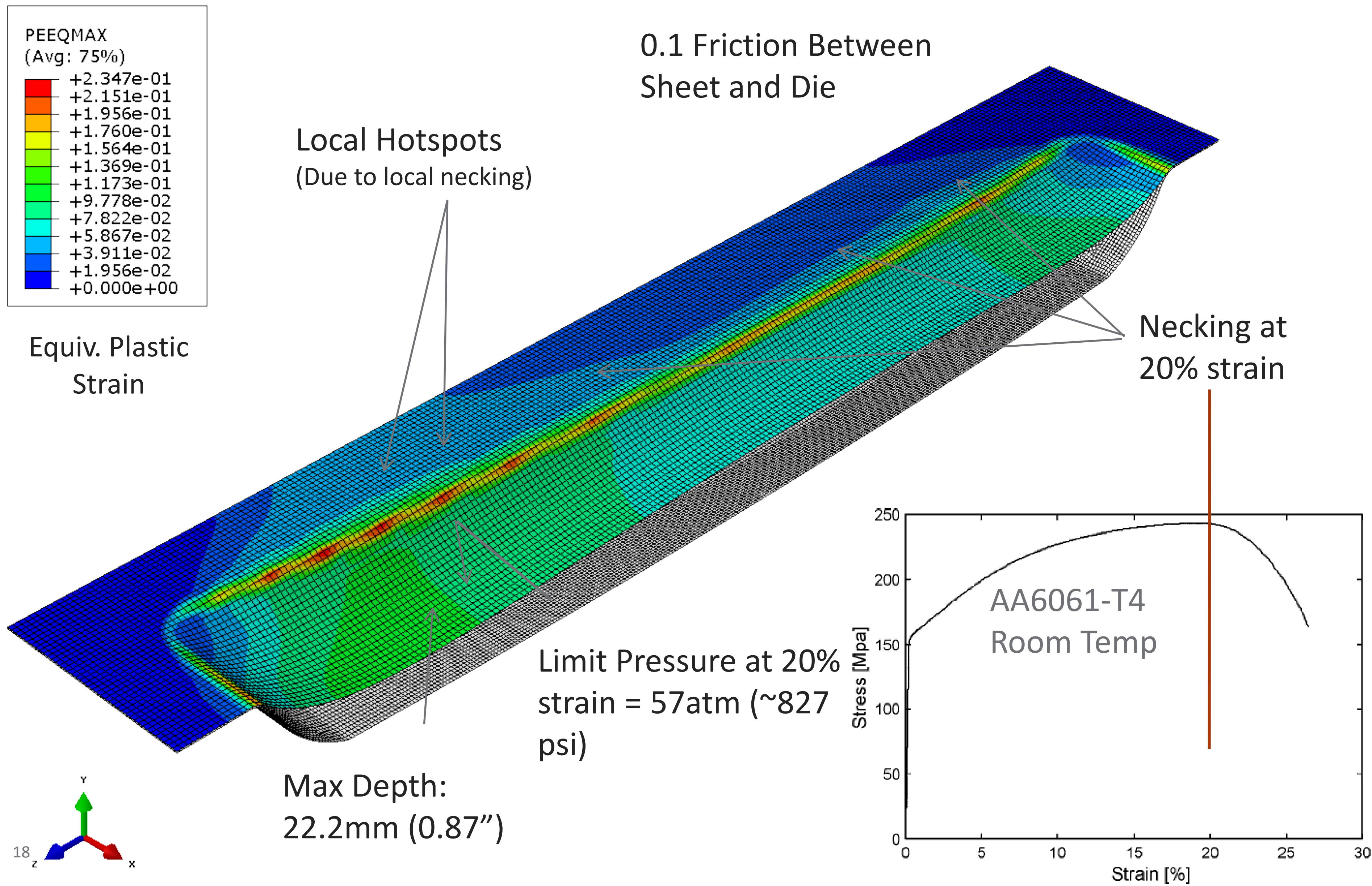

Aluminum Tray Forming Results – Phase I

- 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

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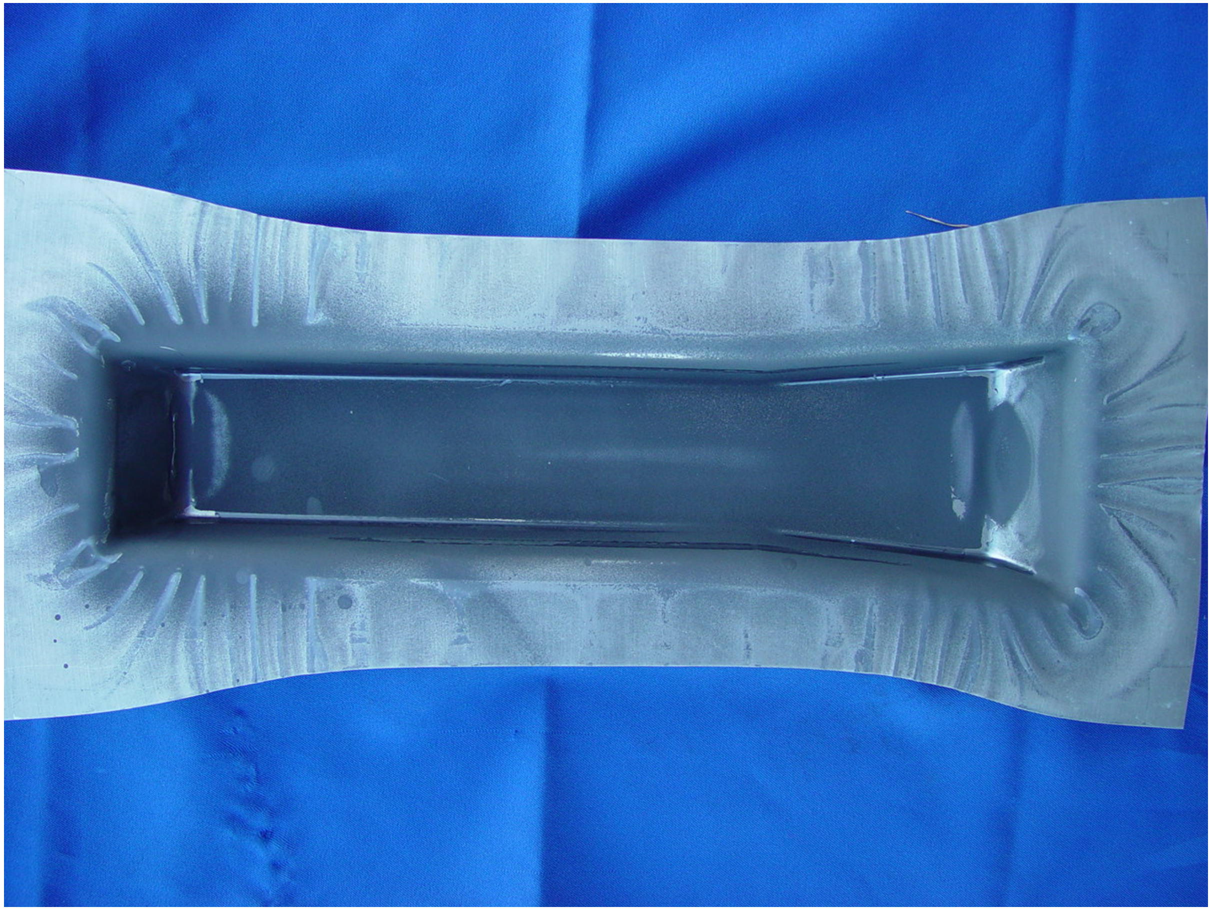
Picture of bottom of room temperature final formed X608 aluminum tray showing additional material draw-in of the sheet

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

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

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)

Aluminum Tray Forming Results – Technical Accomplishments and Progress

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- 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

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- 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

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- 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