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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

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Project Timeline

- Start: 10/01/2010
- Finish: 6/30/2014

Budget

- Total project funding
  - DOE – $1220K
- FY11 Funding - $375K
- FY12 Funding - $365K
- FY13 Funding - $280K
- FY14 Funding - $200K

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

- 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
- This project will develop a unique forming process that produces desirable strength and residual ductility from a highly corrosion resistant 6000-series containing low levels of Cu and Mg alloying elements

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

Milestones – FY2013

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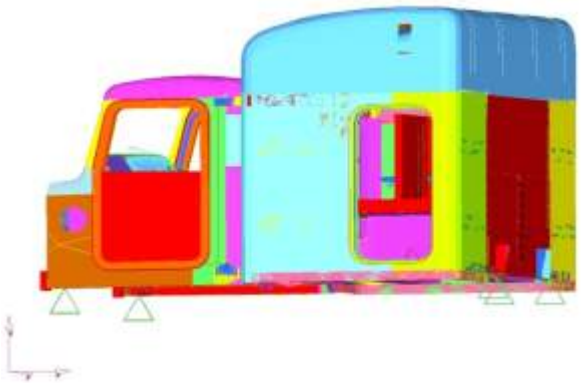
Complete forming of 25 left- and right-hand aerodynamic truck prototype components and deliver to PACCAR Technical Center (June, 2013)

Project Background

- Focused on Class 8 Truck cab components that provide weight savings and contribute to aerodynamic optimization
- Aluminum can provide >40% weight savings compared to SMC and steel
- Aluminum is not used in potential stamped component applications because it:
  - Lacks formability required for aerodynamic panels
  - Must be compatible with established manufacturing and finishing processes



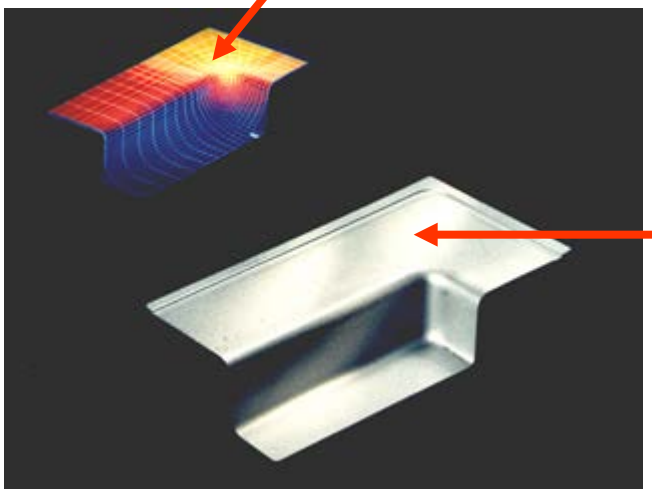
Material Characterization and Process Validation – Task Plan

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

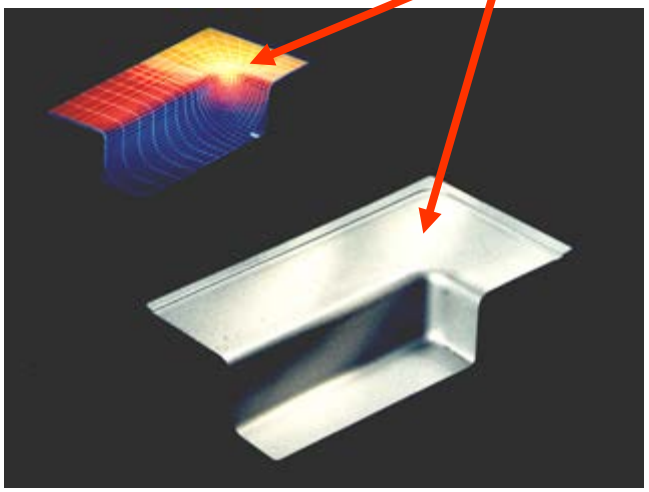
RT

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



X608-T4 Sheet

Preform Sheet Blank @ Room Temp.

Hot Gas Finish Form Single Sheet

450 – 540 C

Tool Removal / Cooling Fixture

Air Cool / Forced Air Cool

Solution Heat Treat/Water Quench

450-550 C – 10 min.

E-Coat / Paint Bake Heat Treatment

180 C / 20 min.

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 tensile specimens. Results for Novelis 6XXX-2 sheet

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 candidate forming method:
  - 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

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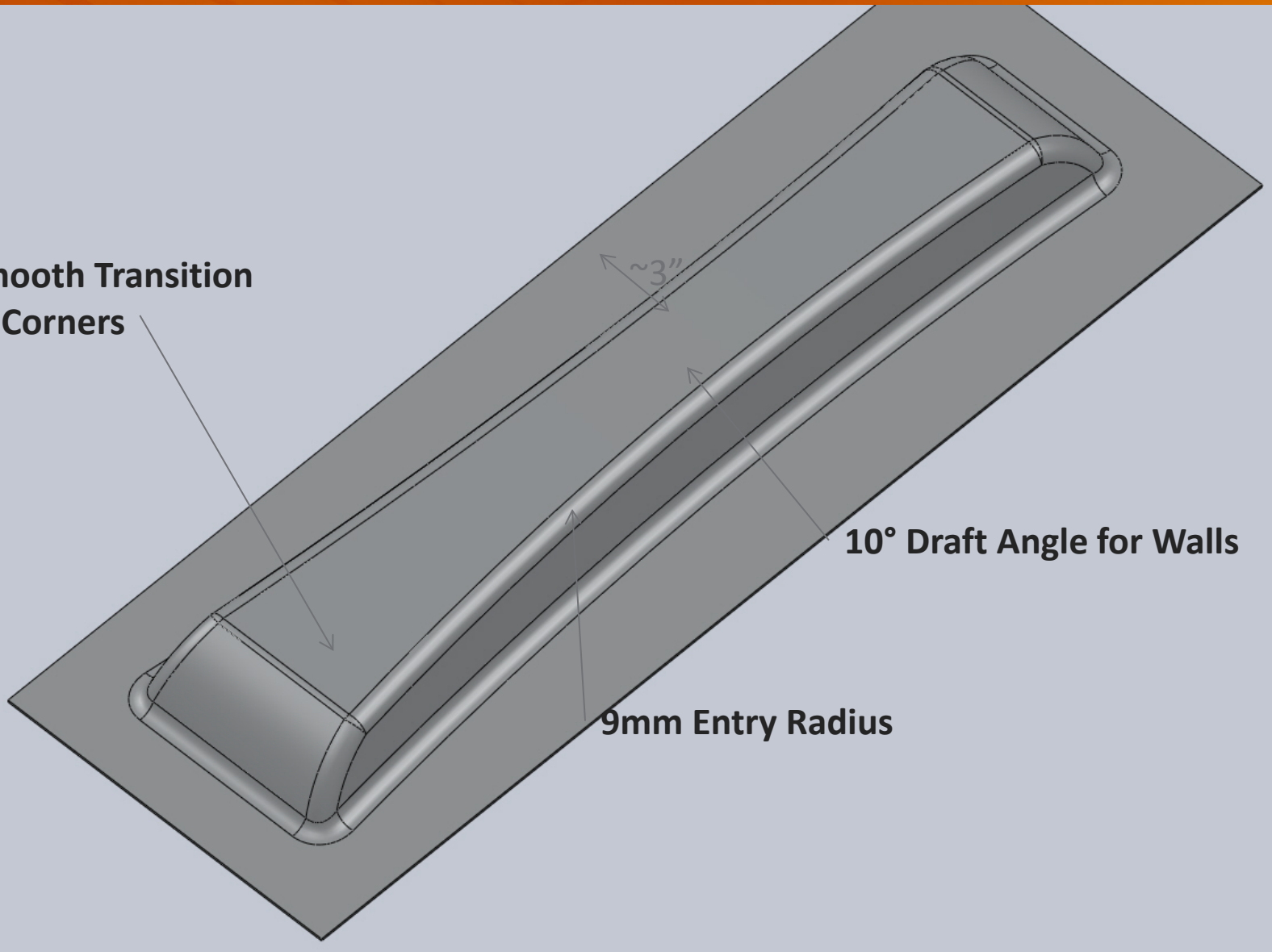


Aluminum Tray Forming Results – Phase I

- 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

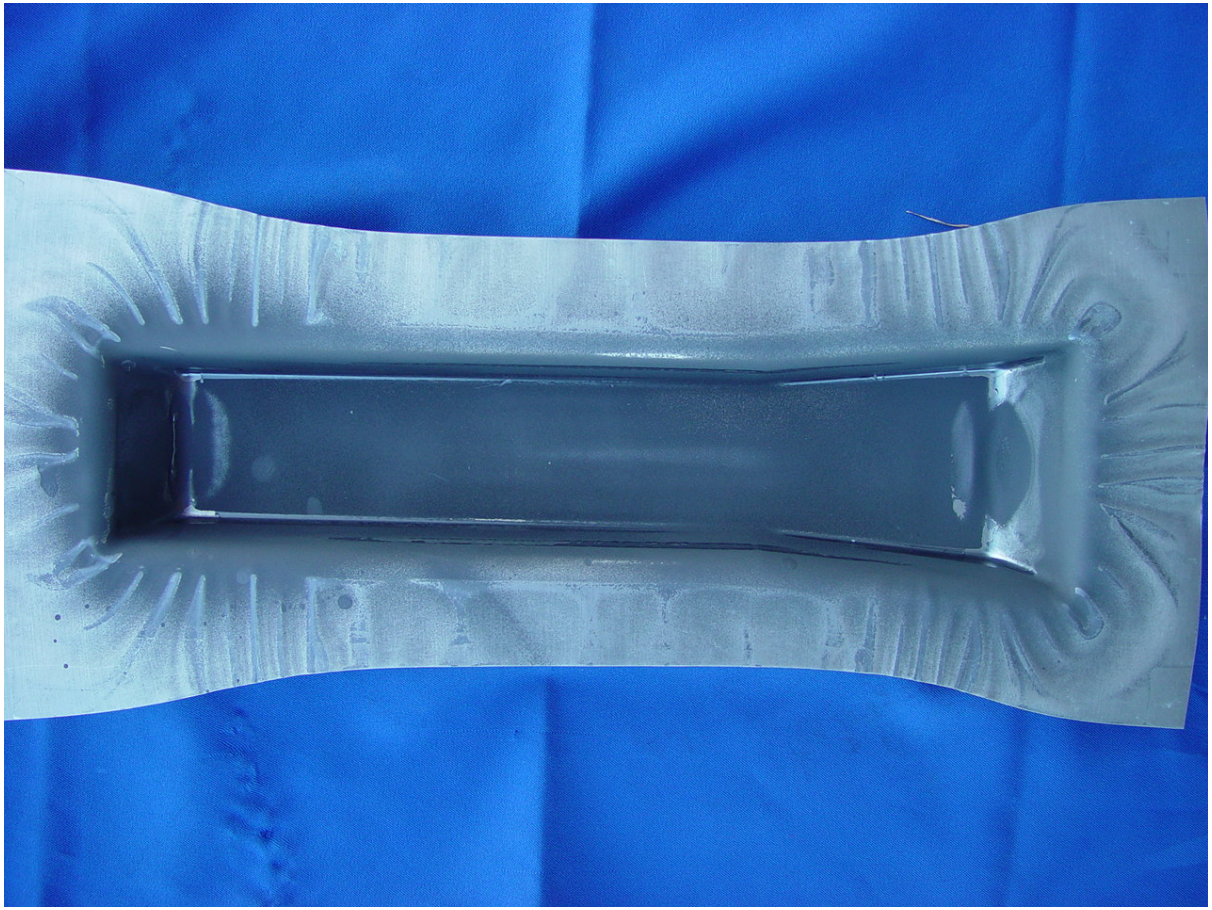
Hot Preformed Tray Prior to Room Temperature Final Forming

Picture of bottom of hot preformed X608 aluminum tray showing draw-in of sheet

Room Temperature Final Formed Tray

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 (ksi)	Ultimate Tensile Strength MPa (ksi)	Elongation (%)
HF 500 C/AC + CF + PB	119.7 (17.4)	210.3 (30.5)	22.9
HF 500 C/WQ + CF + PB	121.4 (17.6)	211.2 (30.6)	22.8
HF 540 C/AC + CF + PB	140.8 (20.4)	241.8 (35.0)	22.9
HF 540 C/WQ + CF + PB	144.8 (21.0)	245.0 (35.5)	22.8

HF = Hot Form; CF = Cold Form; AC = Air Cool; WQ = Water Quench; PB = Paint Bake (180 C for 20 min.)

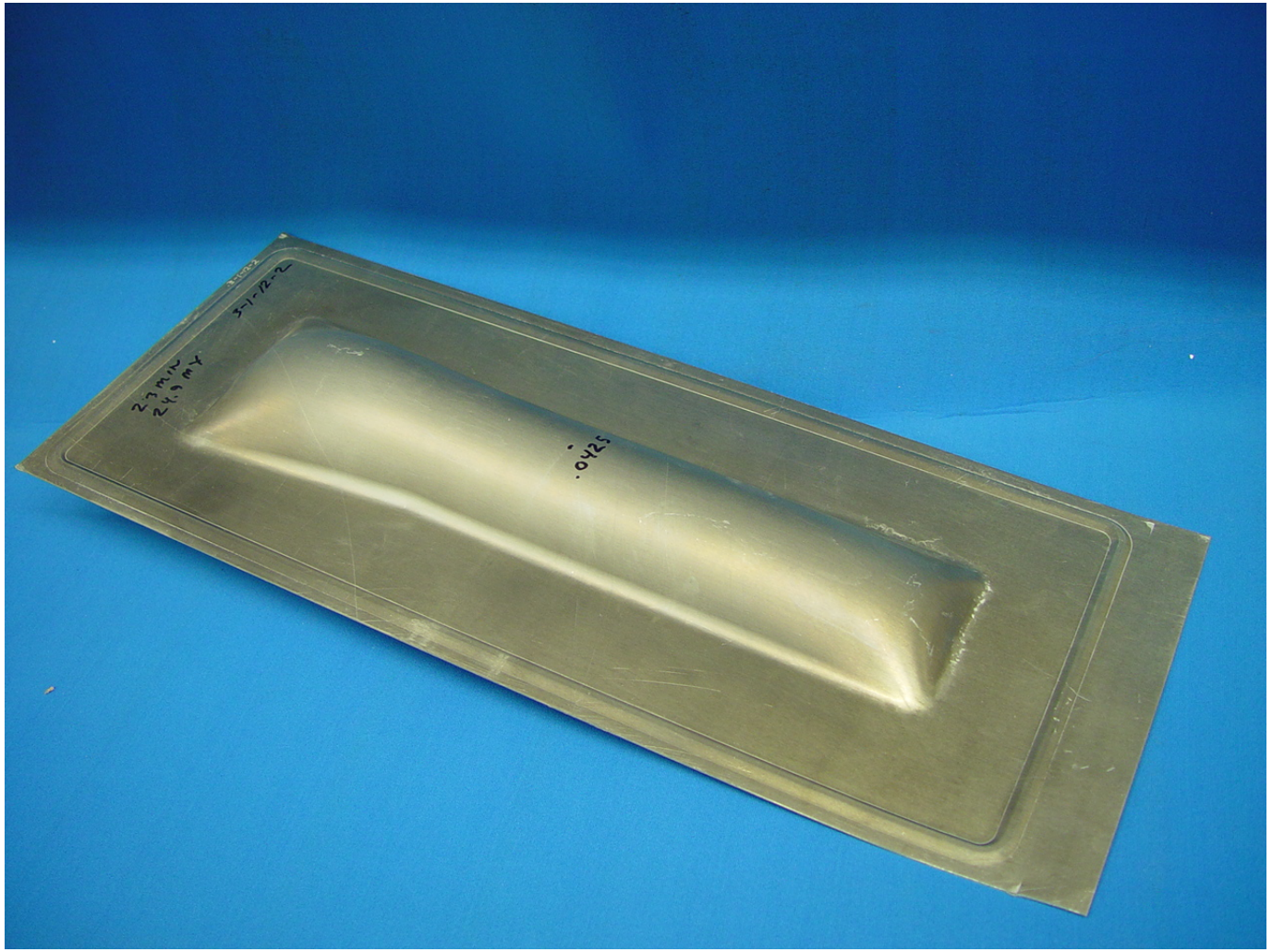
Aluminum Tray Forming Results – Technical Accomplishments and Progress

- 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

Aluminum Tray Forming Results – Phase 2 Tray Forming Experiments

- Utilize batch No. 2 X608 sheet (kept in freezer)
- Hot preform using constrained edge bead and gas pressure in SPF forming press (approximately 20% hot strain)
- Room temperature final form with approximately 5% cold strain
- Simulate paint bake and tensile test
- Provide baseline sheet and samples from hot/cold formed tray to PACCAR Technical Center for E-coat and paint adhesion tests

Hot Gas Pressure Formed Tray with Edge Constraint



Room Temperature Final Formed Tray Showing End Tearing Resulting from Non-Optimized Preform Geometry

Room Temperature Tensile Test Results for Hot Gas/RT Formed Trays

Forming Conditions	0.2% Yield Strength MPa (ksi)	Ultimate Tensile Strength MPa (ksi)	Elongation (%)
Batch No. 2 As-Received/ 5% strain + PB	230.2 (33.4)	274.4 (39.8)	27.1
HF 500 C/AC + CF + PB	150.6 (21.8)	216.6 (31.4)	17.6
HF 500 C/WQ + CF + PB	146.7 (21.3)	228.4 (33.1)	21.5
HF 540 C/AC + CF + PB	176.1 (25.5)	235.2 (34.1)	16.7
HF 540 C/WQ + CF + PB	163.7 (23.7)	236.4 (34.3)	20.0

HF = Hot Form; CF = Cold Form; AC = Air Cool; WQ = Water Quench; PB = Paint Bake (180 C for 20 min.)

Adhesion Testing of Production E-Coat – Hot Formed Materials Passed Adhesion Tests

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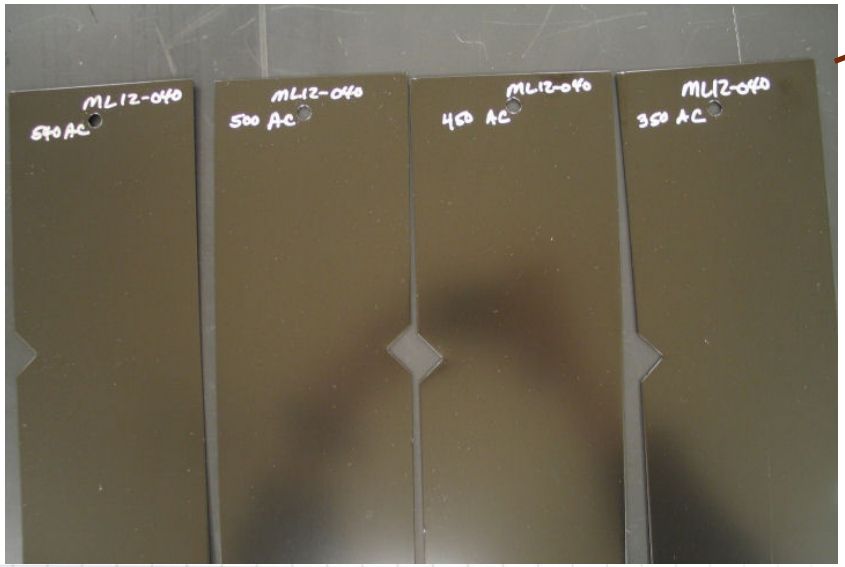
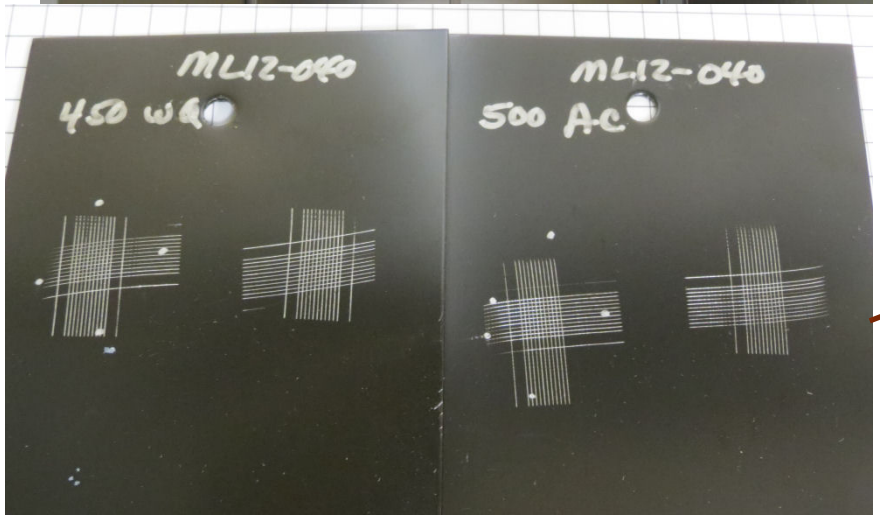


Sample Panels after E-Coat

ML12-040 Warm Forming CREDA (PNNL)				
VERIFICATION				
Requirements from PACCAR Corporate Standard CMT0030				
Prime Paint for Aluminum and Ferrous Substrates				
	RESULTS			
TEST	AC 350, 450, 500, 540	WQ 350, 450, 500, 540	REQUIREMENT	PASS/FAIL
Dry Film Thickness				
-E-Coats	Ave. = 0.75 mils	Ave. = 0.75mils	0.6 to 1.0 mils	Pass
Dry Adhesion	5B, 5B, 5B, 5B	5B, 5B, 5B, 5B	4B Minimum	All Pass
Wet Adhesion	5B, 5B, 5B, 5B	5B, 5B, 5B,5B	4B Minimum	All Pass



After Wet (with dots) and Dry Adhesion Testing

Results From Phase 2 Tray Forming Experiments

- Phase 2 preforms have 15-20% hot strain prior to RT final forming
- During RT forming trays split on the ends but still had sufficient material for tensile specimens
- RT forming produced an average of approximately 4-5% cold strain
- Yield strength properties for the Phase 2 trays are significantly higher than previous Phase 1 trays
- Residual ductility remains very good (>15%)
- The material used for the Phase 2 forming is from batch No.2 of Novelis X608, which was kept in a freezer, but is beyond shelf life
- Hot/RT formed materials passed PACCAR E-coat and paint adhesion tests with excellent results

Prototype Development and Testing Phase

- Prototype component currently made in glass-reinforced plastic (SMC) to be formed in aluminum using X608 alloy
- Magna – Stronach Centre For Innovation (SCFI) engaged to utilize their "HotBox" preforming technology for preforming step + RT final forming
- Requesting 25-30 each of left hand and right hand cab components
- Cab components will be used for:
  - Demonstrating compatibility with cab assembly and finishing process
  - On-cab component testing (cab shake or on the road)
  - Formed components for property testing and characterization

PACCAR Prototype Component

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PACCAR Prototype Component – Peterbilt 579

PACCAR Prototype Component – Kenworth T680

Aluminum Tray Forming Results – Technical Accomplishments and Progress (FY2012)

- Phase 2 tray forming was completed with results showing increased tensile yield and ultimate strengths while retaining good ductility
- PACCAR and Magna SCFI have selected a truck cab components for demonstration of forming process
- A cost-shared contract with Magna SCFI has been placed to produce 25 each of a left and right cab aerodynamic component that will demonstrate assembly and finishing compatibility and cab structural performance

Collaboration

- PACCAR Technical Center
  - Principal industry partner – contributing component design, design requirements, material specifications, assembly and testing
- Magna SCFI – Research and development arm for major 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 and tray forming experiments
- Tensile properties of the Phase 2 forming demonstrations are improved and formed material retains excellent ductility (required for self-piercing rivets and hemming)
- Magna SCFI is engaged for prototype development of cab aerodynamic component
- PACCAR will assemble components on production truck cabs to demonstrate compatibility with assembly, E-coat and paint bake steps, and perform cab structural testing