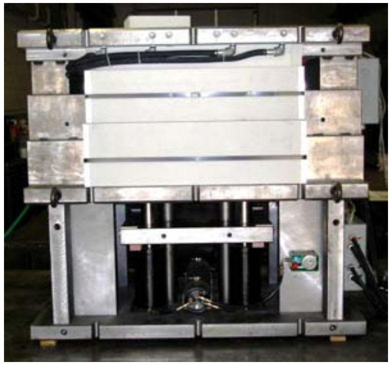
Development of High-Volume Warm Forming of Low-Cost Magnesium Sheet

Project ID "LM10"

AMD 602

2010 DOE Merit Review Presentation

Prepared by: Peter Friedman, Ford Motor Company



Acknowledgement

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Overview

Timeline

- Start: Nov. 1, 2006
- End: Sept. 30, 2009

Budget

- Total project funding
  - DOE share: $675k
  - USAMP share: $675k
- Funding in FY09: $245 K
- Funding plan for FY 10: $0 (project ended FY09)

Barriers/targets

- Development of a high volume manufacturing technique for forming magnesium sheet.
- Determination of process parameters for warm forming of magnesium sheet.
- Development of a supply base for low-cost magnesium sheet.

Partners

- OEMs: Chrysler, Ford, GM
- Supplier list (next slide)

AMD 602 Project Team

- OEM's
  - **Chrysler, Ford , GM**
- Contracts
  - **Troy Tooling Technologies**
  - **Materials Suppliers**
    - Magnesium Elektron
    - POSCO
    - Thyssen
    - CSIRO
    - Luoyang CU
  - **U. of Virginia**
  - **CANMET**
  - **PNNL**
  - **Fuchs Lubricants**
  - **Jay and Kay Manufacturing**
  - **Ricardo Meda**

Overall Objectives

Develop the technology and material supply base for cost-effective lightweight body panels fabricated from sheet magnesium. A warm forming system will be designed and built to develop a suitable process for forming magnesium sheet as well as a test bed to evaluate potential low cost magnesium sheet from various global producers. Specific deliverables from this project will include the following:

- Design and build a warm forming die and demonstrate a deep draw capability on conventional direct chill (DC) material.
- Evaluate materials and compare the formability of continuous cast (CC) and direct chill (DC) materials.
- Demonstrate high volume cycle times with CC material on an integrated forming cell.

FY2009 Targets

- Establish forming window for both DC and Low-Cost (Con-Cast) Mg sheets with respect to various process parameters.
- Develop simulation methods of the warm forming process.
- Demonstrate a warm forming cell capable of run-at-rate conditions for both aluminum and magnesium sheet.

FY2009 Milestones

- Completed full-scale forming trials and determined forming windows for all Mg sheets with respect to temperature, binder pressure, lubricant and blank size.
- Developed finite element prediction methods 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 sheet.

APPROACH

The major barrier to the application of magnesium sheet components in vehicle structures is a combination of two factors: the limited formability of magnesium sheet and the cost of producing the sheet itself.

Continuous casting (CC) is a key technology for enabling the development of low cost Mg sheet. This project will drive material development in the supply base by giving them a mechanism for evaluating materials. The project will receive material from major global magnesium suppliers and be characterized via lab-scale investigation at the University of Virginia and CANMET and through stamping trials at Troy Tooling Technologies.

Novel die systems will be designed and constructed that enable the use of warm forming in a conventional single-action presses. The die will be used to determine critical forming parameters for magnesium sheet including preheat temperature, die temperature, forming speed, etc. The forming windows for the different materials will be determined to see the effect of processing via different methods (e.g. continuous casting vs. ingot (DC) casting).

Full automation including loading of pre-heated sheet and part extraction will be developed to achieve acceptable cycle times (5-10 jpm) demonstrating the high volume feasibility of warm forming.

APPROACH

TASK 1: Acquire Low-Cost Magnesium Sheet

TASK 2: Design and Build Warm Forming Tool

TASK 3: Material Characterization

TASK 4: Lubrication

TASK 5: Die Tryout and First Phase Trials

TASK 6: Automated Cell

TASK 7: Cost Model

TASK 8: Forming Trials on Integrated System

TASK 9: Report Results

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FreedomCAR & Fuel Partnership

Project Timing

Key Gates

1 Demonstrate with DC
2 Material Evaluation
3 Demonstrate High Volume

Specific Deliverables

1 Low-Cost Magnesium Sheet
Acquire magnesium sheet from suppliers to be included in forming trials…

2 Design and Build Warm Forming Tool
Apply lessons learned from previous warm forming project (AMD307)…

3 Material Characterization
Perform tensile testing at elevated temperatures to characterize…

4 Lubrication
Leverage work on previous warm forming project (AMD307)…

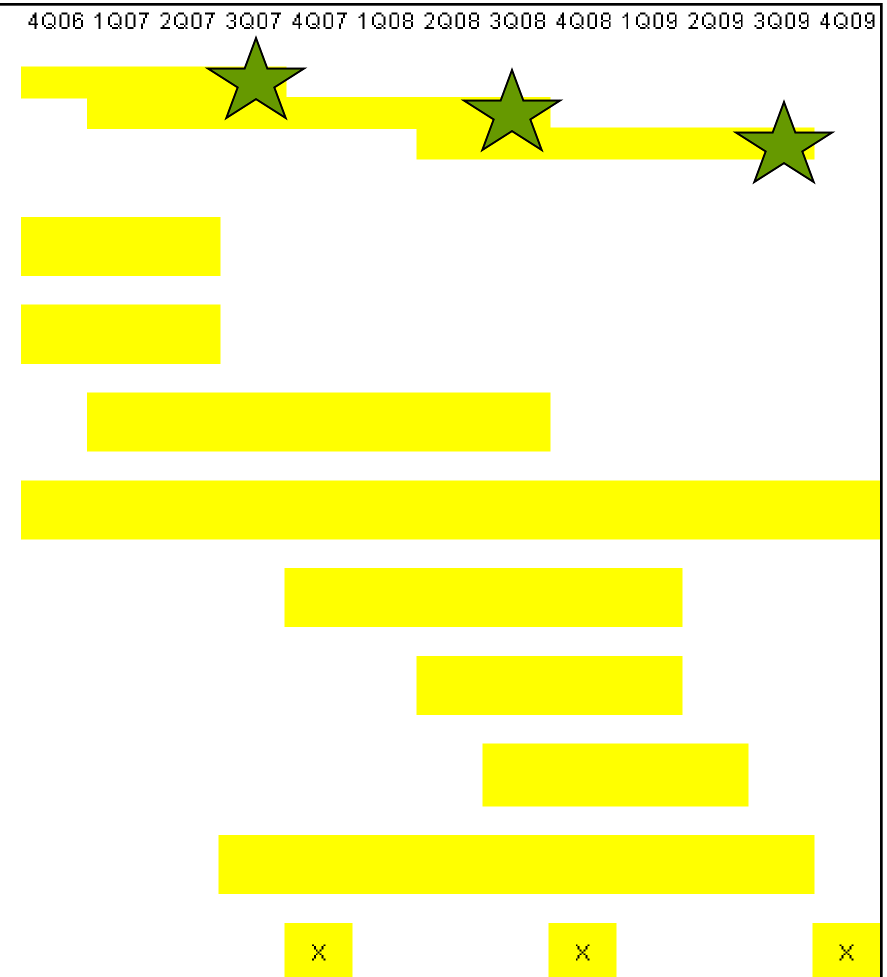
5 Die Tryout and First Phase Trials
Conduct first phase forming trials on various materials…

6 Automated Cell
Design and build pre-heater, automated blank loader and integrate system…

7 Cost Model
Update existing Warm Forming cost model for warm forming of magnesium sheet…

8 Forming Trials on Integrated System
Establish optimal warm forming process of magnesium sheet…

9 Report Results
Report out project deliverables…



Indicates task completed

FY2009 Accomplishments

- Established forming maps for all five materials and correlated those maps to the lab-scale characterization work. Both DC and CC material displayed large forming windows at 300°C.
- Designed, developed a new pre-heating system based on a retrofitted conveyor furnace capable of supporting a production rate of 5 to 10 parts per minute.
- Integrated pre-heater, press and newly acquired robot (loaned from Ford) to automatically load pre-heated sheets into the press. Connected PLCs from the press and robot with various limit switches to enable a fully-automated forming cycle.
- Demonstrated run-at-rate capability of warm forming panels from both DC and lower-cost con-cast Mg sheet.

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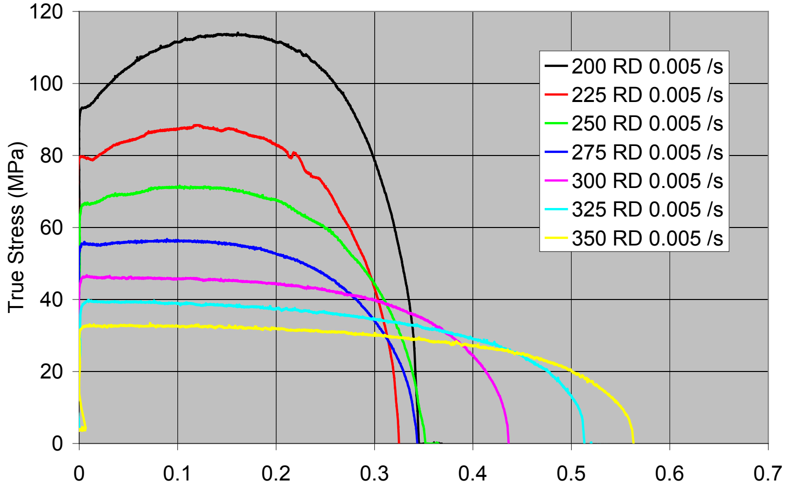
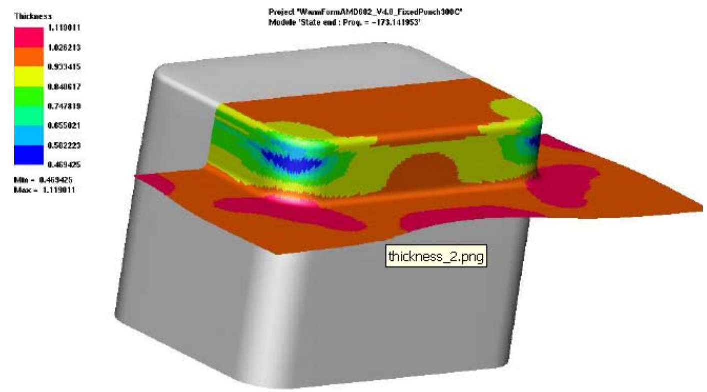
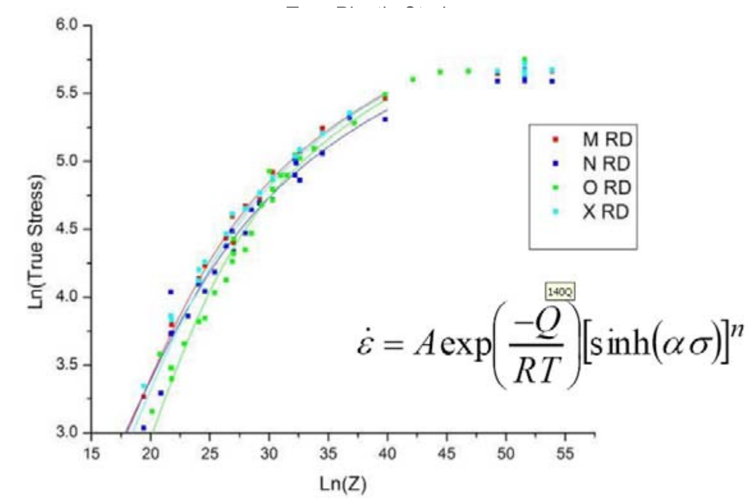
FY2009 Accomplishments

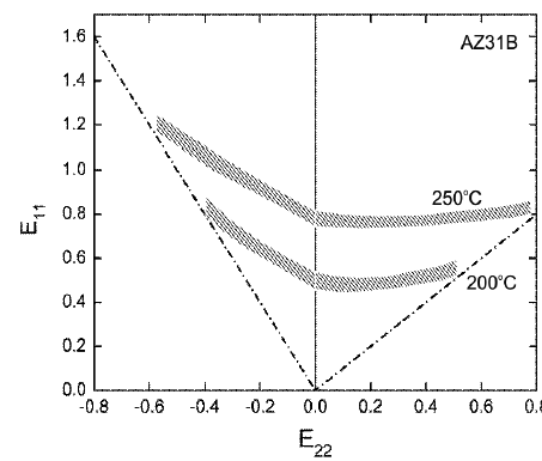
Material Characterization and FEA Simulation







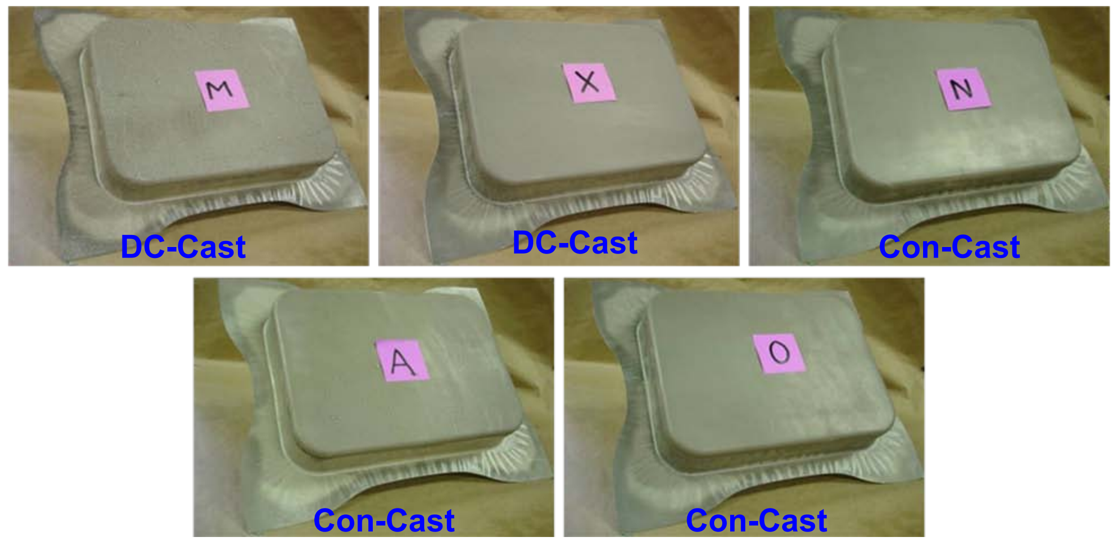
$$\dot{\varepsilon} = A\exp\left(\frac{-Q}{RT}\right)\left[\sinh(\alpha\sigma)\right]^n$$



Laboratory work performed at PNNL, UVA and CANMET.

FY2009 Accomplishments

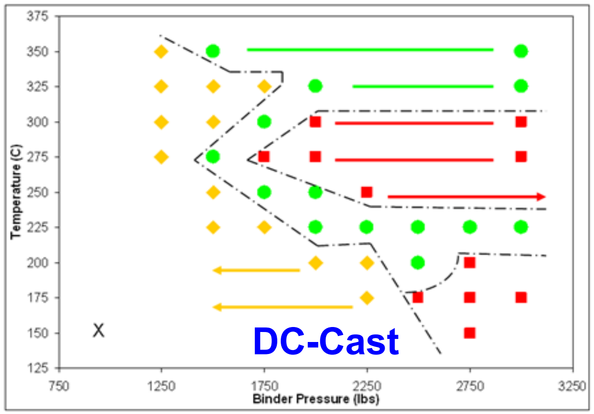
Forming of both DC and CC Materials

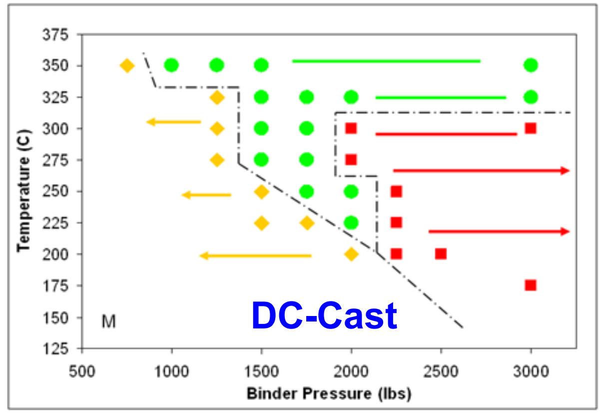


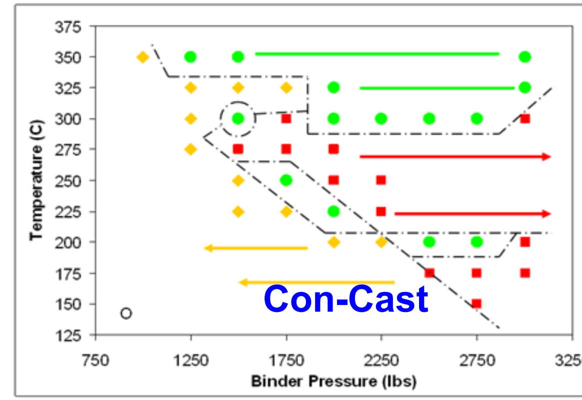
Pans warm formed at 300°C from all five materials.

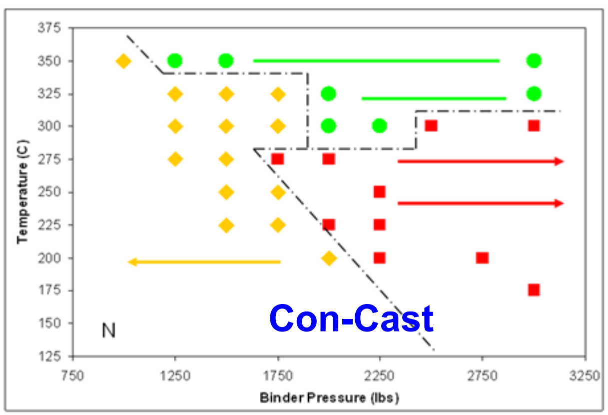
FY2009 Accomplishments

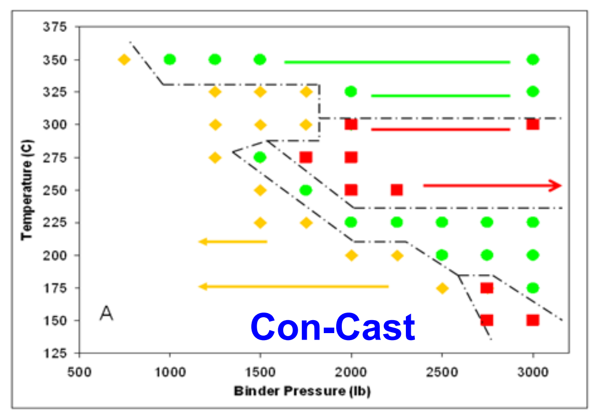
Forming Maps for both DC and CC Materials







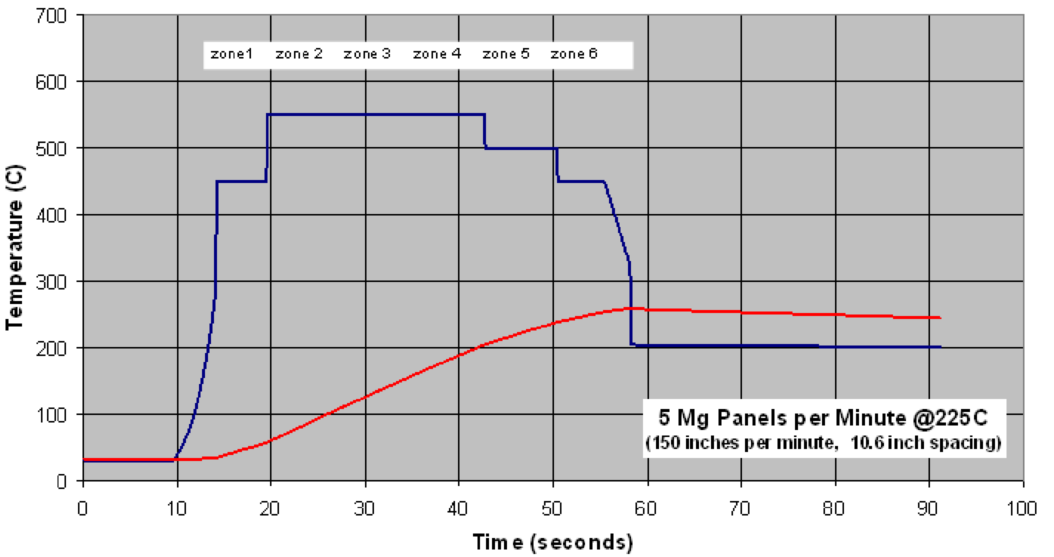




All five materials exhibited a robust forming window above 300ºC. At lower temperatures, significant differences in behavior were observed.

FY2009 Accomplishments

Pre-Heater Design and Implementation



Retrofitted conveyor oven used to heat blanks to target temperature. Selection of a production system would be based on part size, production rate and required thermal profile.

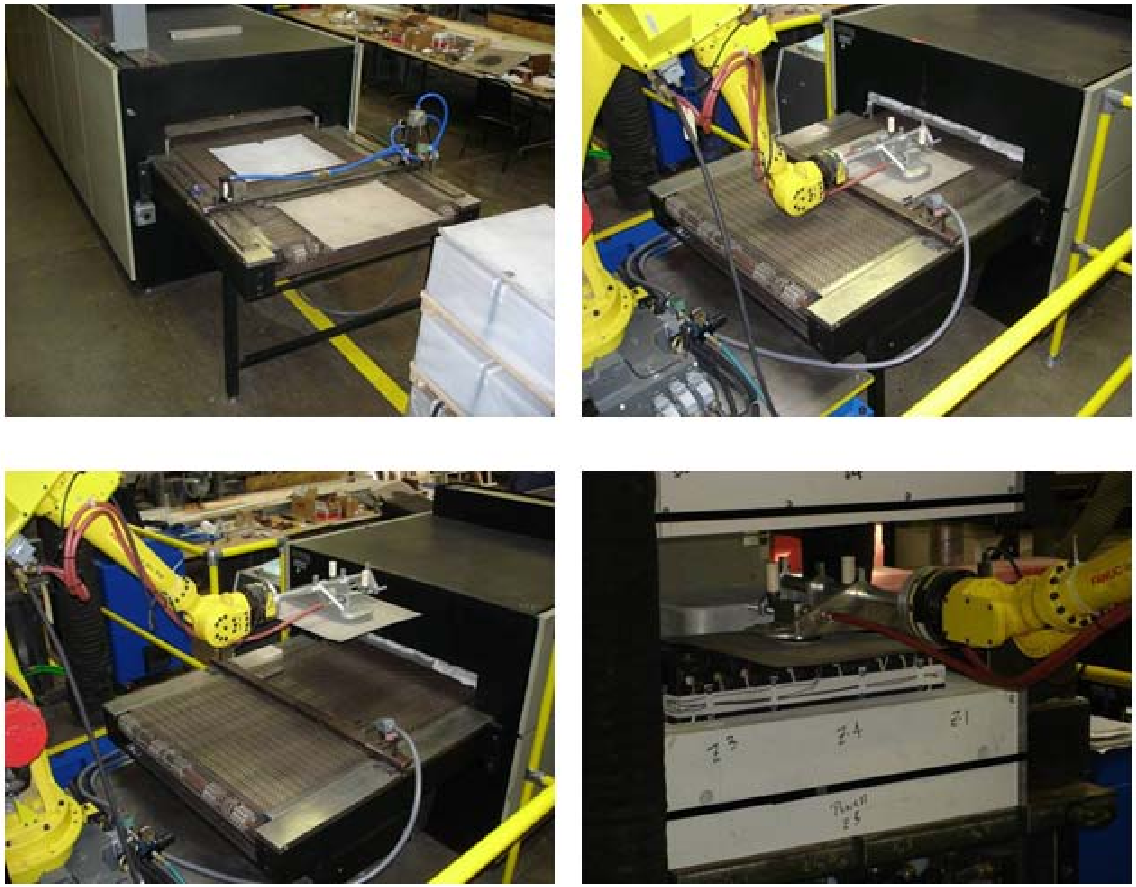
FY2009 Accomplishments

Integrated Forming Cell

Warm forming cell capable of running at 5 to 10 parts per minute. This cell represents the first known warm forming prototype cell enabling controlled experiments that can be performed without variations in temperature due to the inconsistency of loading.

FY2009 Accomplishments

Integrated Forming Cell



Click for Movie

Photographs of the forming cell showing the blank entering the pre-heater, the blank triggering the proximity switch, the robot transferring the blank from the pre-heater to the forming die and the end effector placing the blank on the die while simultaneously pushing a formed part off the blankholder.

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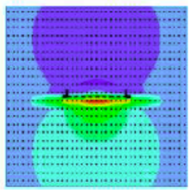
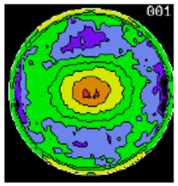
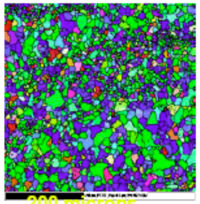
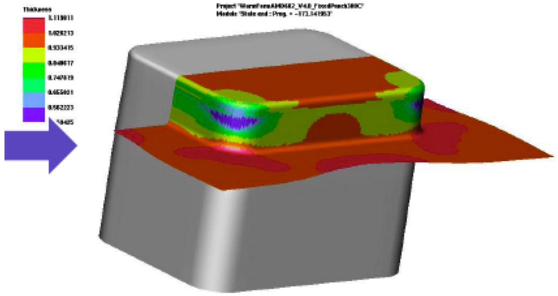
FY2009 Accomplishments

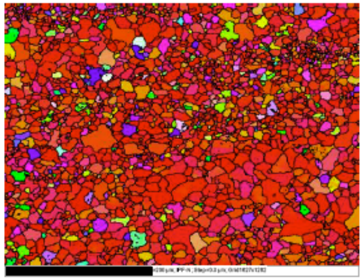


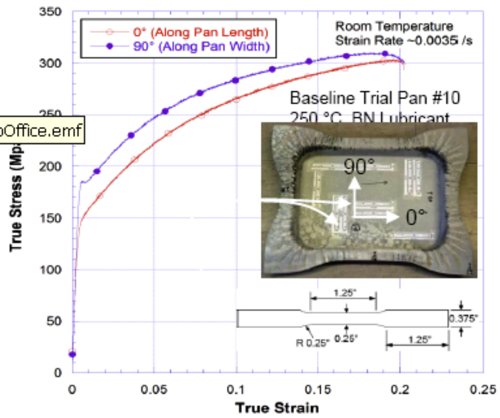


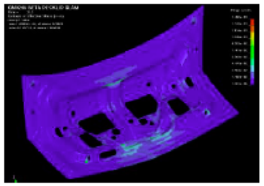


$$\dot{\varepsilon} = A\exp\left(\frac{-Q}{RT}\right)\left[\sinh(\alpha\sigma)\right]^{n}$$









Project produced significant data for the ICME effort in AMD 702/703.

Summary

- AMD602 completed all project deliverables
- All AZ31 materials were characterized in both the laboratory and within the prototype forming cell.
- A simulation capability for warm forming of Mg sheet was developed and correlated with experimental formings.
- Fully-automated forming cycle was demonstrated with both DC and lower-cost con-cast sheet materials with the capability to run a minimum of 5 parts per minute.
- Patents were filed on both die and process technology.