Magnesium Front End
Research and Development (MFERD)
Project ID “LM008”
AMD 603, 604 and 904

2011 DOE Merit Review Presentation

Alan A. Luo
General Motors Global Research and Development
Acknowledgement

This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number No. DE-FC26-02OR22910.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Such support does not constitute an endorsement by the Department of Energy of the work or the views expressed herein.
# AMD603: Magnesium Front End Design and Development

## Timeline
- Start: Oct. 1, 2006
- End: Sept. 30, 2009
- 100% complete

## Budget
- **Total project funding**
  - DOE: $1.1 M
  - USAMP: $1.5 M
- **Funding received in FY08:** $282.1 K
- **Funding for FY09:** $760.9 K
- **Funding for FY10:** $0 (Project ended FY09)

## Barriers/targets
- Mg application in primary load-path body structures for mass saving with equivalent performance
- Design and engineering simulation of Mg body structures
- Technical cost modeling of lightweighting with Mg applications

## Partners
- **OEMs:** Chrysler, Ford, GM
- **Design:** Cosma Engineering
- **Technical Cost Modeling:** Camanoe Associates

This presentation does not contain any proprietary, confidential or otherwise protected information.
Timeline
- Start: Oct. 1, 2006
- End: March 31, 2010
- 100% complete

Budget
- Total project funding
  - DOE: $1.5 M
  - USAMP: $2.7 M
    - Canada: $3M (U.S. Equiv.)
    - China: $3M (U.S. Equiv.)
- Funding received in FY09: $645 K
- Funding for FY10: $225 K (project ended in FY10)

Barriers/targets
- Improved high-volume manufacturing techniques for Mg casting, extrusion, and sheet forming
- Improved high-volume manufacturing techniques for joining and corrosion protection of Mg structures
- Improved knowledge base in Mg crashworthiness, NVH (noise, vibration and harshness), fatigue and durability

Partners
- OEMs: Chrysler, Ford, GM
- U.S. Supplier list (slide 5)
- International Partners from China and Canada (slide 6)
AMD904: Magnesium Front End Research and Development (MFERD) – Phase II

Timeline
- Start: April 1, 2010
- End: Sept. 30, 2011
- 30% complete

Budget
- Total project funding
  - DOE: $1.214 M (through 9/30/11)
  - USAMP: $1.214 M
    - currently booked $347 K
    - Canada: $1.2M (U.S. Equiv.)
    - China: $1.2M (U.S. Equiv.)
- Funding received in FY10: $114 K
- Funding for FY11: $1.1 M

Barriers/targets
- Demonstration of Mg casting, extrusion, sheet and joining techniques in automotive body structures
- Performance Validation of Mg crashworthiness, NVH (noise, vibration and harshness), fatigue and durability

Partners
- OEMs: Chrysler, Ford, GM
- U.S. Supplier list (slide 5)
- International Partners from China and Canada (slide 6)
U.S. Partner Organizations (MFERD Phase I & II)

- Cosma Engineering
- University of Dayton – Research Institute
- IAC Corporation
- Westmoreland Testing
- Henkel U.S.
- PPG Industries
- Chemetall Oakite
- MetoKote
- Atotech
- MacDermid
- Luke Engineering
- University of Michigan – Dearborn
- Ohio State University
- Eastern Michigan University
- Contech U.S., LLC
- Scientific Forming Technologies Corp.
- Lehigh University
- North Dakota State University
- Mississippi State University
- Magni Industries
- Keronite
- International Hardcoat Corp.
- Dow Automotive
- Visteon Inc.
- MNP Corp.
- ATF Inc.
- Kamax LP
- REMINC
- Hitachi America
- North American Die Casting Assn.
- Gibbs Die Casting
- EKK Inc.
- Timminco Corp.
- U.S. Magnesium Corp.
### International Partner Organizations (MFERD Phase I & II)

#### Canada
- CANMET
  - (Natural Resources Canada)
- Auto 21 Network
- University of Waterloo
- University of Western Ontario
- Ryerson University
- University of Sherbrooke
- University of Windsor
- Centerline Corp.
- University of Toronto
- NRC – Aerospace Divn.
- MAGNA
- Meridian Lightweight - Canada

#### China
- China Magnesium Center
  - (Ministry of Science and Technology)
- Tsinghua University (Beijing)
- Chinalco - Louyang Copper
- Zhejiang University
- Shanghai Jiao Tong University
- Shenyang University of Technology
- Xi’an University of Technology
- Chongqing University
- Northeastern University
- Inst. of Metals Research – Shenyang
- Dalian University of Technology
- Shanxi Yingguang Magnesium
Overall Objectives

- Develop key enabling technology for lightweight Mg applications in automotive body structures
- Design, build and test a "demo" structure for technology validation and demonstration
- Establish OEM-supplier-academia and US-China-Canada international collaborations in Mg automotive applications

General Targets

- Mass reduction up to 60% less than steel comparator; 35% less than aluminum comparator structure
- Neutral or slight cost penalty compared to steel baseline
- Vehicle performance attributes comparable to baseline structures

FY2010 Targets

- Design and select “demo” concept for final analyses, build and testing
- Select Mg alloys and manufacturing processes for “demo” build and testing
- Plan and coordinate test matrix for “demo” testing and validation
- Host international review meetings in Michigan, October 2010
FY2010 Milestones

- Completed “Magnesium Front End Research and Development Phase I Summary Report: A Canada-China-USA Collaborative Research and Development Project”, and passed final technical review with international Project Steering Committee (including DOE representatives) in March 2010.
- Generated six concepts and selected one final design for “demo” build and testing in October 2010.
- Hosted in the 4th International Review Meeting in Ann Arbor, Michigan on October 25-27, 2010, and contributed to 3rd progress “Proceedings” (529 pages) of the international project released at the Canada meeting.
Unibody (BFI) Front End Design Summary
(AMD603: Magnesium Front End Design and Development)

Baseline: 2008 Cadillac CTS

Steel baseline design
110 Parts & 99.6 kg

Mg-intensive design
47 Parts & 55.3 kg

44.3 kg mass reduction (44.5%)
63 part reduction (57.3%)
Body-on-Frame Front End Design Summary
(AMD603: Magnesium Front End Design and Development)

Baseline: 2009 Ford F150

Steel baseline design
20 Parts & 57.1 kg

Magnesium design
18 Parts & 42.9 kg

14.2 kg mass reduction (24.9%)
2 part reduction (10%)
FY2010 Accomplishments - Task 2.0 Demo Design, Construction and Analysis

- Generated six concepts and selected one final design for “demo” simulation, build and testing

“Demo” design

Proposed test loading
FY2010 Accomplishments - Task 2.1 Crashworthiness

- Exercise and validate “best” material model in LS-DYNA for super-vacuum die casting (SVDC) AM60 alloy

Crash testing and simulation of Mg castings
FY2010 Accomplishments - Task 2.2 Noise, Vibration and Harshness (NVH)

- Provided Viper dash panel parts (Mg die casting) to China and Canada for NVH analysis
- Verified acoustic performance (noise reduction) of Dodge Viper dash (bare and with current sound package)

Automotive noise sources

Structure-borne Noise Sources
~ 0- 500 Hz

Airborn Noise Sources
~ 315 Hz - > 10kHz

Dash + Sound Package 1

- Steel Dash
- Aluminium Dash
- Magnesium Dash
- Magnesium-Sandwich Dash

This presentation does not contain any proprietary, confidential or otherwise protected information.
FY2010 Accomplishments - Task 2.3 Fatigue and Durability

- Completed Round-Robin fatigue testing Mg AZ31 friction stir spot welds of 4 different labs in US, Canada and China

**Fatigue and monotonic failure analysis**

**Monotonic Fracture**

**Cyclic 3 kN**

**Cyclic 1 kN**

**Round-Robin fatigue testing results of Mg AZ31 friction stir spot welds**

This presentation does not contain any proprietary, confidential or otherwise protected information
FY2010 Accomplishments - Task 2.4 Corrosion and Surface Finishing

- Established the model corrosion protection system for "demo" build and testing
- Completed OEM assessment and developed joint recommendation for cyclic corrosion testing of structural features

Model Corrosion Protection System for Magnesium

Options: powder epoxy (viz. F-150), e-coat:
- off line
- in vehicle paint shop

Polymer Topcoat
Polymeric adhesive also relies on pretreatment

Variety of 'pretreatment' processes: conversion coats, anodizing, others (EC)^

- Metal cleaning and 'activation'
- Inhomogeneities
- Contaminants

Base Mg Metal

Corrosion test results of various fastener coatings

GM Measurements

<table>
<thead>
<tr>
<th></th>
<th>Wt. Loss (gms)</th>
<th>Pit Depth (mm/10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>F</td>
<td>0.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>G</td>
<td>0.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>K</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>P</td>
<td>0.1</td>
<td>-0.2</td>
</tr>
<tr>
<td>R</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>T</td>
<td>0.3</td>
<td>-0.2</td>
</tr>
<tr>
<td>Y</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>
FY2010 Accomplishments - Task 2.5 Low-Cost Extrusion and Forming

- Identified a new high-ductility alloy: ZE20 (Mg-2%Zn-0.2%Ce) developed by GM

**Improved ductility (125% improvement) in ZE20 alloy**

**Randomization of texture and the low peak intensity in ZE20 alloy**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Tensile Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM30</td>
<td>170</td>
</tr>
<tr>
<td>Mg-0.2Ce</td>
<td>69</td>
</tr>
<tr>
<td>ZE20 (Mg-2Zn-0.2Ce)</td>
<td>135</td>
</tr>
</tbody>
</table>

![Tensile properties comparison](image)

![Randomization of texture](image)
FY2010 Accomplishments - Task 2.6 Low-Cost Sheet and Forming

- Evaluated the formability of various Mg sheet materials produced by direct-chill (DC) cast and CC processes for “demo” build
FY2010 Accomplishments - Task 1.7 High Integrity Body Casting

- Identified a high strength heat treatable magnesium alloy: NZ30 (Mg-2.5%Nd-0.5%Zn) developed in China

<table>
<thead>
<tr>
<th>Temper</th>
<th>UTS/MPa</th>
<th>YS/MPa</th>
<th>Elongation/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>NZ30 (As-cast)</td>
<td>211.4</td>
<td>153.5</td>
<td>6.8</td>
</tr>
<tr>
<td>NZ30-T5</td>
<td>223.9</td>
<td>168.4</td>
<td>6.4</td>
</tr>
<tr>
<td>NZ30-T6</td>
<td>278.3</td>
<td>187.8</td>
<td>11.3</td>
</tr>
<tr>
<td>Al: (Aural2-T6)</td>
<td>230</td>
<td>180</td>
<td>10</td>
</tr>
</tbody>
</table>
FY2010 Accomplishments - Task 1.8 Welding and Joining

- Selected the joining techniques (friction-stir welding, self-pierce riveting with and without adhesive) for “demo” build and testing
- Completed the static testing of typical Mg joints

Lap shear test results of Mg joints
Future Work: Magnesium Front End Research & Development Phase II (AMD904)

- “Demo” final design, analyses and tested has been awarded to a general contractor
- “Demo” component manufacturing – 2Q2011
- “Demo” assembly and testing – 3Q2011
- Project completion and reporting – 3Q2011
This presentation does not contain any proprietary, confidential or otherwise protected information.
Conclusions

- The Magnesium Front End Design and Development (AMD603) suggested that a Mg-intensive front end design can achieve nearly 50% mass reduction with equivalent performance (based on simulations) relative to a highly efficient state of the art steel baseline for the unibody architecture based upon known manufacturing technologies and presumptions regarding joining and surface finishing technologies.

- The Magnesium Front End Research and Development Phase I project (AMD604) has developed key enabling technologies and knowledge base for Mg applications, which will be validated and demonstrated in Phase II project (AMD904) using a “demo” structure.

- As first-of-its-kind US-Canada-China collaboration, the Magnesium Front End Research and Development Project has clearly demonstrated the capability for an international cooperative research effort with multiple and complex technical disciplines and targets, resulting in the development of significant enabling technologies and knowledge based for magnesium automotive applications.