Magnesium-Intensive Front End Sub-Structure Development

Project ID “LM077”
USAMP AMP800

2013 DOE Merit Review Presentation

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Magnesium-Intensive Front End Sub-Structure Development

AMP800 (DE-EE0006662)
Magnesium-Intensive Front End Sub-Structure Development

Timeline
- Start: June 1, 2012
- End: May 31, 2015
- 20% complete

Budget
- Total project funding
  - DOE: $3,000,000
  - Contractor share: $3,000,000
- Funding received in FY12
  - $38,619
- Funding for FY13
  - DOE: $983,650
  - Contractor share: $983,650

Barriers/targets
- Manufacturability and joining & assembly:
  Demonstration of a Mg-intensive multi-material “demo” structure in automotive body applications
- Predictive modeling & performance:
  Performance validation of “demo” structure in crashworthiness, corrosion, 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

**Industry (15)**

- ACT Test Panels
- AET Integration
- Almond Products
- Atotech
- Cosma Engineering
- Forming Simulation Technologies
- Henkel
- Henrob
- Hitachi
- Kaiser Aluminum
- Luke Engineering
- Mag Specialties
- North American Die Cast Assn.
- PPG Industries
- Troy Tooling Technologies

**Universities (7)**

- Lehigh University
- Mississippi State University
- Missouri Science and Technology
- North Dakota State University
- The Ohio State University
- The University of Alabama
- The University of Michigan
## International Partner Organizations

<table>
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<th>Canada</th>
<th>China</th>
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<tr>
<td>CANMET</td>
<td>China Magnesium Center</td>
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<td>(Natural Resources Canada)</td>
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<td>Auto 21 Network</td>
<td>Tsinghua University (Beijing)</td>
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<td>NRC – Aerospace Divn.</td>
<td>Northeastern University</td>
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<td>MAGNA</td>
<td>Inst. of Metals Research – Shenyang</td>
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<td>Meridian Lightweight - Canada</td>
<td>Shanxi Yingguang Magnesium</td>
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Overall Objectives: Relevance

- Design, build and test a Mg-intensive, automotive front-end “demo” structure – leading to lightweight multi-material applications
- Develop enabling technologies in new Mg alloys, joining (including dissimilar metals), corrosion and materials performance (including fatigue and high strain rate deformation) for lightweight automotive structures
- Contribute to integrated computational materials engineering (ICME) efforts specifically focused on magnesium alloy metallurgy and processing
- Collaborate with international and domestic researchers and suppliers to leverage research and to strengthen the supply base in magnesium automotive applications

Approach

- Mass reduction of Mg-intensive body structures: up to 45% less than steel comparator; 20% less than aluminum comparator structure
- Use a “demo” structure to validate key enabling technologies, knowledge base and ICME tools
Project Structure and Timing (MFERD Phase I, II and III)

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<th>FY07</th>
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<td>MFEDD Phase I. Front End Design and Feasibility</td>
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USAMP PROJECT (AMD603) : Magnesium Front End Design & Development (MFEDD)

CANADA-CHINA-USA COLLABORATIVE PROJECT:
Magnesium Front End Research & Development (MFERD)

Phase I. Enabling Technology Development (AMD604)
Crashworthiness research
NVH research
Fatigue and durability research
Corrosion and coatings
Low-cost extrusion & forming
Low-cost sheet and forming
High-integrity body casting
Welding and joining
Integrated computational materials engineering

Phase II. Demo Structure (AMD904)

Phase III. Mg-Intensive Front End (AMP800)
Demo design, build and testing
Crashworthiness research
Fatigue and durability research
Corrosion and coatings
Extrusion
Sheet and forming
High-integrity body casting
Welding and joining
Integrated computational materials engineering

This presentation does not contain any proprietary, confidential or otherwise protected information
Milestones

- Project “kick-off” with DOE at USCAR (Southfield, MI) on Sept. 26, 2012
- Design, analyses, part and demo build, test and reports on a “demo” structure

Processes
- Design & Analyses
- Coupon Studies
- Build Demos
- Test and Report

Materials
- Sheet Extrusion
- Casting
- Coating
- Joining

Integrated Computational Materials Engineering (ICME)

Performance
- Durability
- Corrosion

We are here.
FY2012 Accomplishments - Task 2 Demo Design, Analysis, Build & Testing

- Completed the Mg-intensive multi-material “demo” structure design
  - Mg shock tower (SVDC) with major improvements in casting design
  - High-ductility Al extrusion rail (AA6082)
  - Steel (HSLA350 + EG) and Al alloy (AA6022) sheet rail

**Multi-material “demo” structure design**
FY2012 Accomplishments - Task 3 Crashworthiness & NVH

- Expanding “shell elements” to “solid elements” material models in LS-DYNA for super-vacuum die casting (SVDC) AM60 alloy: improving crash simulations
- Leveraged NVH testing and simulation results of Mg vs. steel dash panels in China and Canada

FEA models for material model evaluation

Simulation of transmission loss in Mg vs. steel dash panels (Zhejiang University, China)

Free-free modal testing of the Viper Mg dash panel (Zhejiang University, China)
FY2012 Accomplishments - Task 4 Fatigue and Durability

- Evaluated the discrepancies between the durability simulation and test results in MFERD Phase II and set out plans to improve the predictive models for joint fatigue failure with new measurements
- Prepared samples to determine the effect of friction-weld pinhole on fatigue

Coach peel style test specimen to validate joint fatigue model

FEA simulation of proposed tests
FY2012 Accomplishments - Task 5 Corrosion and Surface Treatment

- Compiled the ‘best practices’ on corrosion measurements for Mg structures in automotive applications
- Finalized the plans for galvanic corrosion evaluation of riveted Mg and the influences of Mg surface impurity on corrosion and isolation methods
- Initiated preliminary study on aluminized rivet performance under cyclic corrosion test conditions (Ford cyclic corrosion protocol for test coupons)
- Finalizing details for testing 5 coating strategies for Al-Mg and 3 coating strategies for Al-Mg-Steel coupon assemblies

Multi-material joint for fatigue & corrosion testing

Mg/Al joint with aluminized SPR rivet (from Henrob)
FY2012 Accomplishments - Task 6 Extrusion

- “Secured” the supply of a new high-ductility Mg alloy billets: ZE20 (Mg-2%Zn-0.2%Ce)
- Ordered AA6082 aluminum extrusion plate samples for coupon testing and rails for “demo” build

Lower rail for “demo” structure (all dimensions in inch [mm])

Cut length: 34” [864 mm]
FY2012 Accomplishments - Task 7 Low-Cost Sheet and Forming

- Identified the sources of steel and aluminum sheets for “demo” build
- Developed the work plan to form steel and aluminum upper rail structures
- Modified designs of materials and tooling to accommodate the thinner steel sheet (1 mm) and aluminum sheet (1.5 mm) compared to Mg sheet (2 mm)
- Conducted tryout door inner panels with Canadian team using a new Mg sheet alloy: ZEK100 (Mg-1%Zn-0.1%RE-0.1%Zr)

Upper rail for “demo” structure

ZEK100 door inner (1.2 mm thickness)
FY2012 Accomplishments – Task 8 High Integrity Casting

- Modified the shock tower tool for improved die fill, joining interfaces and durability testing
- Provided AM60B ingots and casting simulations to SVDC casting trials at CANMET

SVDC shock tower simulation

SVDC shock tower castings
FY2012 Accomplishments - Task 9 Welding and Joining

- Developed multi-joint coupon configurations for multi-material joining trials and testing
- Down-selected joining techniques for “demo” build and initiated coupon trials such as self-pierce rivet (SPR) joints of Mg (AM60B) casting to Al (6082-T6) extrusion

FSLW test coupon configuration

Initial self-pierce rivet joint of Mg-to-Al
FY2012 Accomplishments – Task 10 ICME

- A hybrid phase-field / transmission electron microscopy (TEM) approach has been developed to quantify the evolution of Mg$_{17}$Al$_{12}$ precipitates in AZ91 Mg alloys.
- Both experimental and first-principles data were successfully incorporated.
- Local porosity was mapped to FEA model to predict the monotonic load to failure
- Microstructural and preliminary yield strength model were integrated into casting process model

Comparison of calculated and measured length distributions for beta phase precipitates in an AZ91D shock to micrograph

Load displacement curves from numerical and experimental testing of the shock tower with the porosity from casting process simulations
Collaboration and Coordination

- Broad participation of domestic OEMs, suppliers and universities (25 in total)
- Project executed at task level (10 teams) and coordinated by a USAMP core team
- Centered and coordinated around a “demo” structure as a focal point
- The first-of-its-kind US-Canada-China collaboration, leveraging significant international resources on coordinated pre-competitive research
Summary

- Successfully kicked-off project with all tasks running.
- Expanded the scope to a multi-material “demo” structure to include magnesium, aluminum and steel components to address the critical challenges of multi-material design, manufacturing and performance.
- Completed the multi-material “demo” design and started groundwork in all nine task areas.

Future Work

- Joining, corrosion protection and durability (fatigue) validation of selected dissimilar material couples.
- Production of “demo” structure component parts: upper rails, shock tower and lower rail from selected materials.
- Development of an assembly framework for production of “demo” assemblies and trials where appropriate.
- Continued development of more deformable grades of magnesium extrusion (ZE20) include acquisition of billet stock and trial runs with Mag Specialties.
- Completion of ICME “fatigue” studies of MFERD Phase II “demo” and initial investigation of the ICME of extruded 6082 aluminum and ZE20 magnesium.