Magnesium-Intensive Front End Sub-Structure Development

USAMP AMP800

2014 DOE Merit Review Presentation

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Project ID "LM077"

Acknowledgement

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AMP800 (DE-EE0005660)

Magnesium-Intensive Front End Sub-Structure Development

Timeline

- Start: June 1, 2012
- End: May 31, 2015
- ~60% complete

Budget

- Total project funding
  - DOE: $3,000,000
  - Contractor share: $3,000,000
- Funding received in FY13 $452,870
- Funding for FY14
  - DOE: $1,680,946
  - Contractor share: $1,680,946

Barriers and Targets

- Manufacturability, joining & assembly of Mg in multi-material systems:
  - *Demonstration of a Mg-intensive “demo” structure in automotive body application*
- Predictive modeling & performance:
  - *Performance validation of “demo” structure in corrosion, fatigue, and durability*

Partners

- OEMs: Chrysler, Ford, GM
- U.S. suppliers and universities
- International partners from China and Canada

Relevance - Objectives

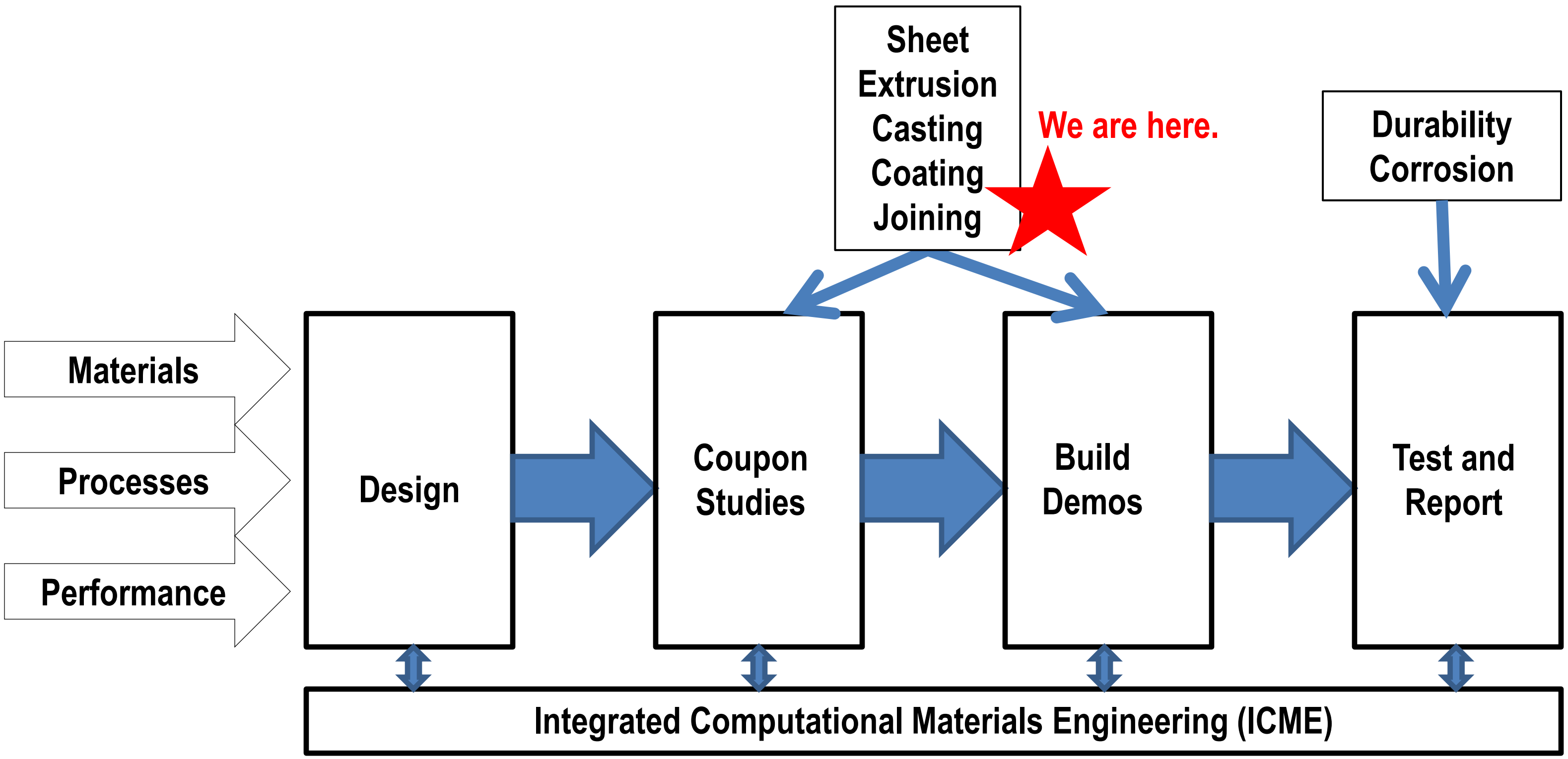
- Mass reduction of Mg-intensive body structures: up to 45% less than steel comparator; 20% less than aluminum comparator structure
- Design, build and test a Mg-intensive, automotive front-end “demo” structure – leading to lightweight multi-material applications
- Develop enabling technologies in new Mg alloys, joining (including dissimilar metals), corrosion, and materials performance and predictive capability (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

Approach

- Collaborate with international and domestic researchers and suppliers to leverage research and to strengthen the supply base in magnesium automotive applications
- Use a “demo” structure to validate key enabling technologies, knowledge base and ICME tools

Approach - Milestones

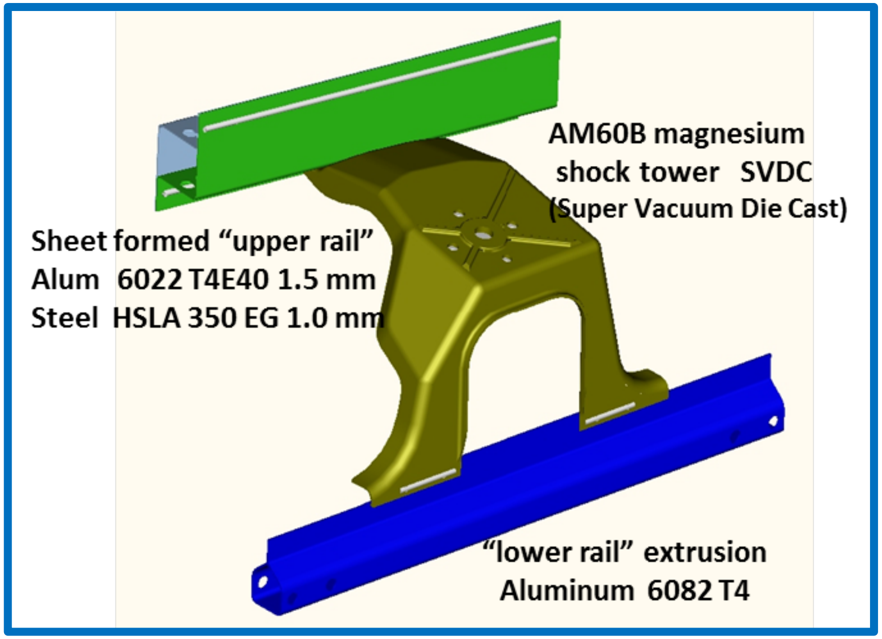
- ❑ Project "kick-off" with DOE at USCAR (Southfield, MI) on Sept. 26, 2012
- ❑ Design, analyses, part and demo build, test and reports on a "demo" structure



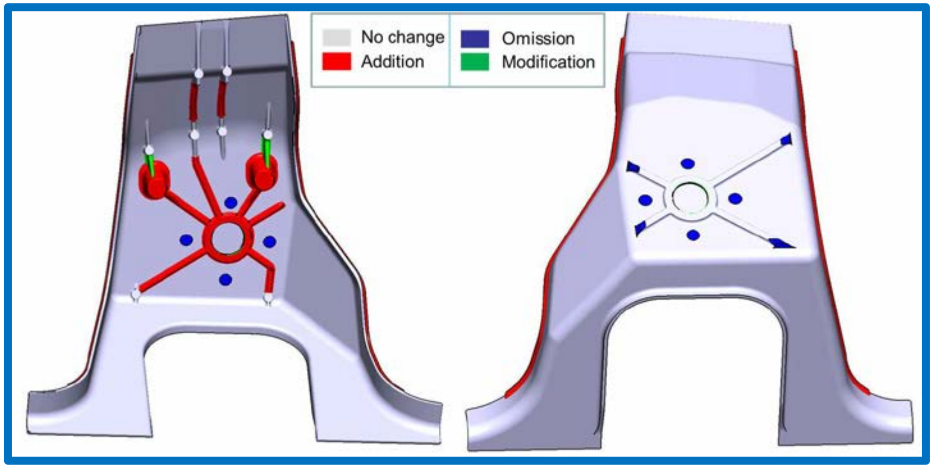
Year 1 Design & Analyses	Year 2 Demo Build	Year 3 Test and Report

FY2013 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 T4) (parts delivered)
  - Steel (HSLA350 + EG) and Al alloy (AA6022 T4E40) sheet rail (parts delivered)
- Developed CAE Models for "demo" structure with initial joining assumptions.
- Produced fixture blocks as tooling aides.
- Made improvements to Mg shock tower (SVDC) casting design



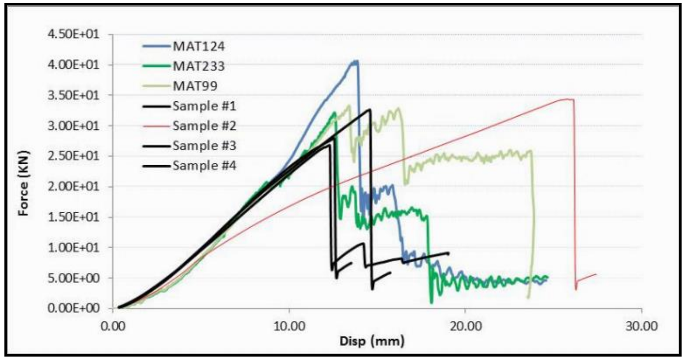
Phase III Shock Tower Design Changes from previous Phase II



FY2013 Accomplishments - Task 3 Crashworthiness & NVH

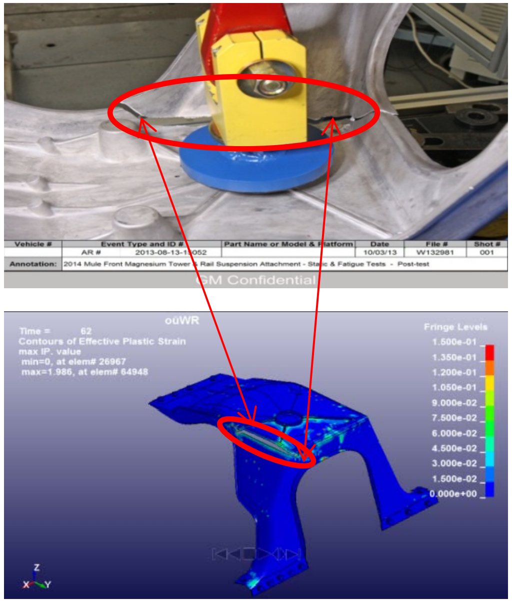
- Improved LS-DYNA MAT 233 Mg for shells and created MAT 233 Mg for solid to simulate super-vacuum die casting (SVDC) AM60B alloy
- Conducted quasi static loading test and CAE predictions on AM60B cast shock tower using three LS-DYNA material models
- LS-DYNA MAT 233 Mg predicted peak load and failure location with good match to test results
- Initiated tension and compression tests under different strain rates for ZE20
- Created shear test coupons for AM60B

Test and CAE prediction Force vs. deflection

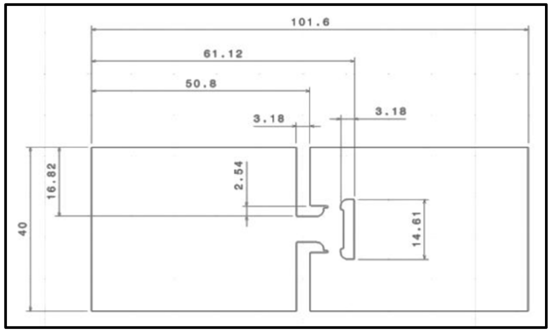


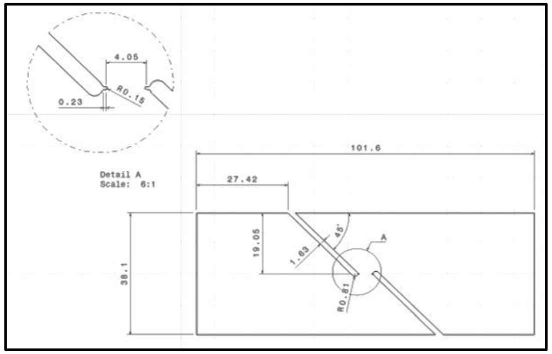
MAT Model Type	Test	MAT124	MAT233	MAT099
Max Load (KN)	30.50	40.66	32.21	33.32
% Diff		33.3%	5.6%	9.2%

Test vs. CAE prediction failure location



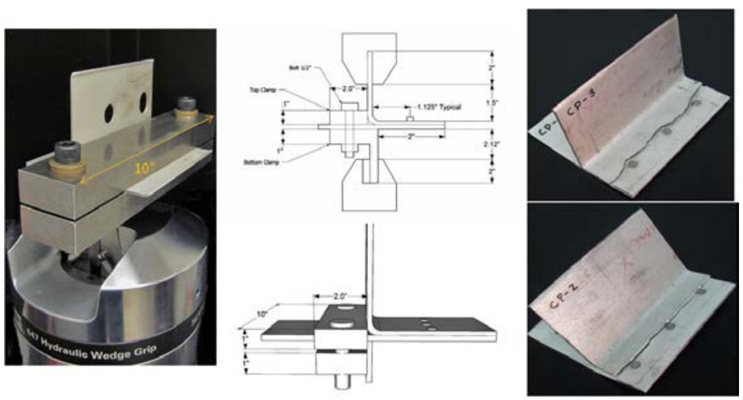
Shear samples for AM60B casting



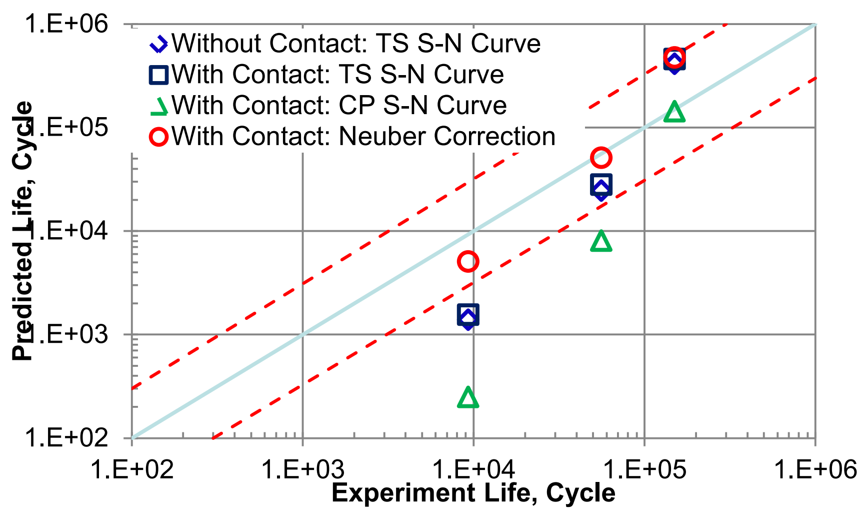


FY2013 Accomplishments - Task 4 Fatigue and Durability

- Improved CAE models correlate well with the fatigue Laboratory tests completed in MFERD Phase II.
- Performed fatigue tests on specimens involving more than one joint. Verified the Mg-Mg Joint CAE models using the above fatigue test data
- Completed CAE durability analysis of the new demo structures with mixed metal joints.
- Applied lessons learned from the above CAE analysis to improve the design and durability test plan for the new demo structures.



Specimen with multiple joints used in fatigue tests



Life prediction of multiple joints fatigue tests with different CAE models

FY2013 Accomplishments - Task 5 Corrosion and Surface Treatment

- Used surface spectroscopy to evaluate effects of surface contamination and pretreatment interactions (Ohio State).
- Applied a unique electro-ceramic pretreatment process to Phase II magnesium-intensive structures, applied topcoats and initiated cyclic corrosion testing by OEMs.
- Evaluated localized galvanic corrosion adjacent to Zn-Sn coated self-piercing rivets in all-magnesium assemblies (Missouri S & T) and devised measurement protocols for assessment of same (North Dakota State).
- Established an experimental array of mixed metal joint configurations to evaluate rivet coatings, joint designs, pretreatments, topcoats and corrosion environment exposures.

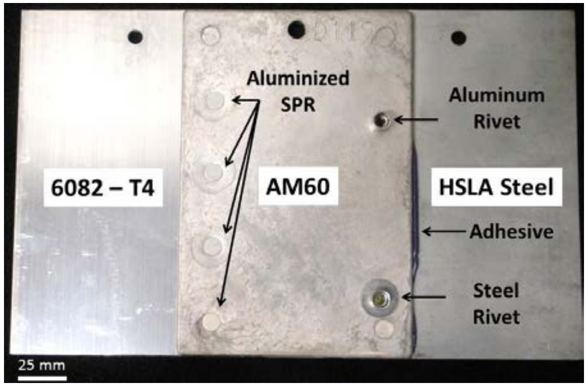
Construction
AM60/6082 SPR(Zn/Sn)
AM60/6082 SPR (IVD Al)
AM60/6082 SPR (IVD Al) + Adhesive*
HSLA Steel/ AM60/6082 BreakStem + Adhesive/ SPR (IVD AL)*
AM60/6022 FSW
AM60/6022 FSW + adhesive

Pretreatment
Alodine® 5200™
ZircoBond
Tectalis
Interlox® 5705

Topcoat
Powder epoxy
Electrocoat

Test Method
ASTM B-117
SAE J2334

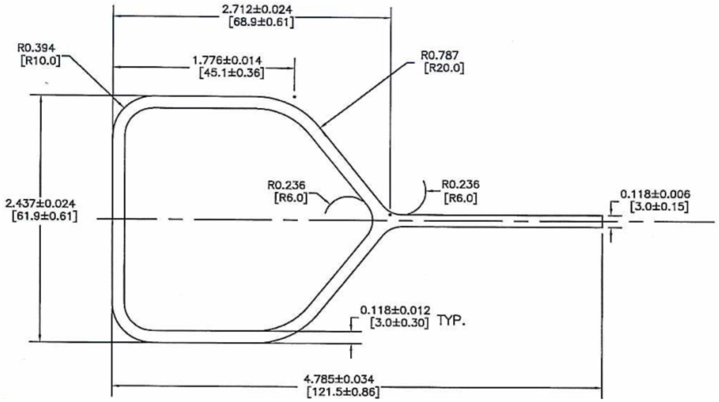
Control: No coating



3-metal test assembly (uncoated)

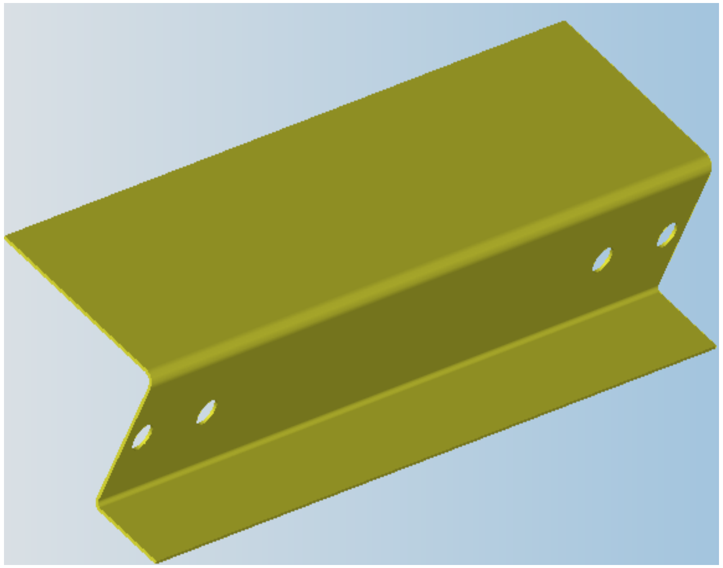
FY2013 Accomplishments - Task 6 Extrusion

- Mag Specialties delivered 97 ZE20 extruded rails to the team
- ZE20 rails distributed to ICME Task team and Crashworthiness team for testing and evaluation
- Lehigh University on board to develop ZE20 material card for DEFORM™ and Ohio State University commissioned to perform Gleeble™ testing on AM30 and ZE20. All billet materials received by universities
- Exploring options for small scale extrusion manufacturing at PNNL for validation of material cards
- Kaiser completed AA6082 aluminum extruded rail production and parts sent to Metro Technology for scalloping and machining



FY2013 Accomplishments - Task 7 Low-Cost Sheet and Forming

- ❑ Provided steel and aluminum test coupons for joining and corrosion studies.
- ❑ Provided press-brake-formed upper-rail half sections in steel and aluminum for use in magnesium-intensive demo structures.
- ❑ Provided supplier and material information to the Canadian and US teams.
- ❑ Maintained awareness of the Canadian Team’s work on ZEK100 sheet, including: texture, anisotropy, formability and post-forming properties



Brake formed upper-rail half section.

- 1.0mm HSLA 350 70g/70g electro-galvanized steel sheet.
- 1.5mm AA6022-T4E40 aluminum sheet.

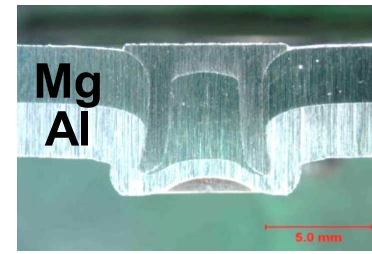
FY2013 Accomplishments – Task 8 High Integrity Casting

- Top Hat castings have been produced by CANMET and shipped to USA. A few have been distributed to US Task Teams.
- Two casting trials for Shock Towers have been completed by CANMET. Cracks were found in both trials but at different locations.
- Die design and process modifications have been implemented at CANMET to enable them to provide crack free castings to the US Team by the end of April, 2014.

FY 2013 Accomplishments – Task 9 Joining

Joining Technologies Selected for Demo Structures

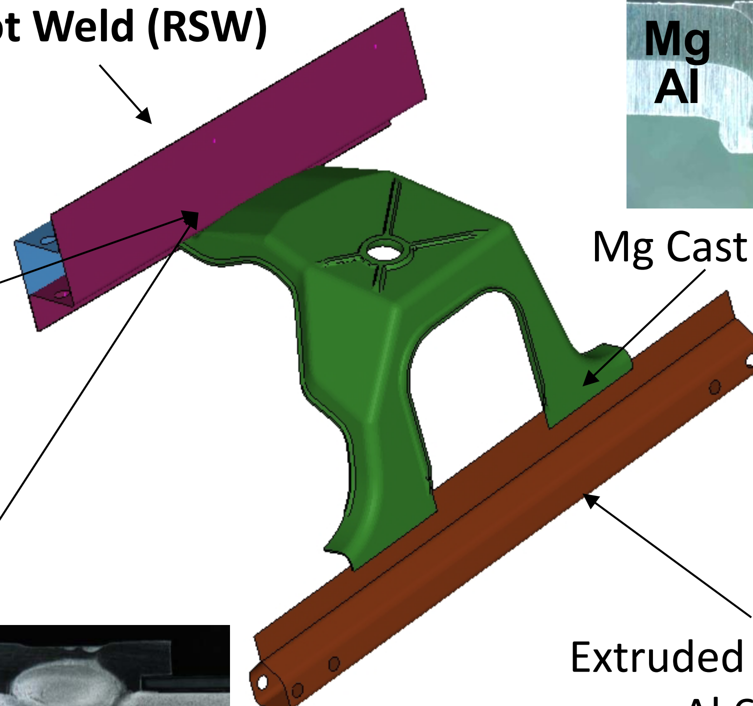
Self Piercing Rivets (SPR)



Mg Cast – Al Extrusion

Rail to Rail - **Resistance Spot Weld (RSW)**

Sheet formed "upper rail"
Al 6022 T4E40 1.5 mm
or
Steel HSLA 350EG 1.0 mm

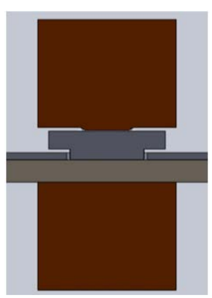


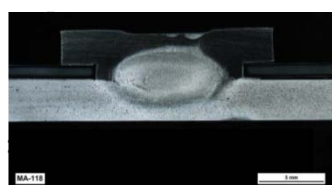
Extruded "lower rail"
Al 6082 T4

Friction Stir Linear Weld (FSLW)

Al Sheet – Mg Cast

Adaptable Insert





Steel Sheet – Mg Cast

FY 2013 Accomplishments – Task 9 Joining

Friction Stir Welding (FSW)

- With Hitachi, established feasibility of friction stir welding (linear and spot) to obtain strong joints of Mg to Al
- Optimized process for 3.1-mm AM60B to 1.5-mm AA6022-T4, fabricated and tested ~200 samples; selected FSLW with Al on Top; lap-shear load = 3.3 kN

Adaptable Insert Welding (AIW)

- With AET Integration, identified AIW as best potential process for joining Die Cast AM60B Mg shock towers to steel upper rails
- Optimized the process for joining bare Mg castings to bare steel using AZ31 Mg inserts (after evaluating steel inserts and AM60 inserts)

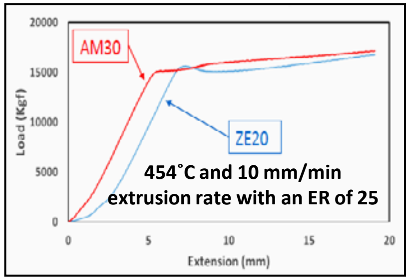
Self Piercing Rivets (SPR)

- Henrob identified rivet/die combination and completed all coupon assemblies for AM60/6082 T4 Stack-ups for corrosion and durability testing
- SPR coatings examined: standard Zn/Sn coating, IVAD Al coating (Titanium Finishing), Alumiplate Al coating (non-aqueous electrolytic process) – electropotential testing only (NDSU), EC^2 coating (Henkel) – electropotential testing only (NDSU)

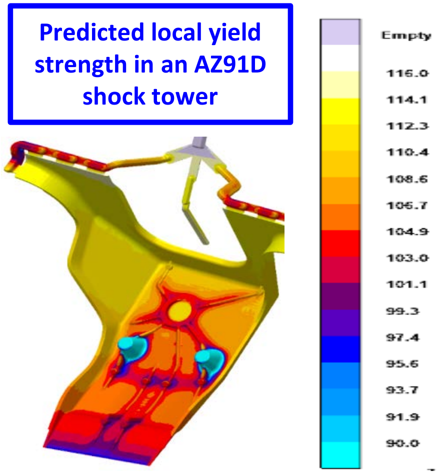
FY2013 Accomplishments – Task 10 ICME

- ❑ Refined yield strength model was integrated into casting process model
- ❑ Incorporated heterogeneous material state, porosity, pore size into FEA model to predict the monotonic and cyclic loads to failure
- ❑ Developing processing-structure-property relationships for ZE 20 extrusion accounting for the texture evolution during extrusion process
- ❑ Developing microstructural evolution understanding of ZE20 to incorporate into models for yield strength and fatigue strength

Comparable Load vs. Extension curve between ZE 20 and AM30

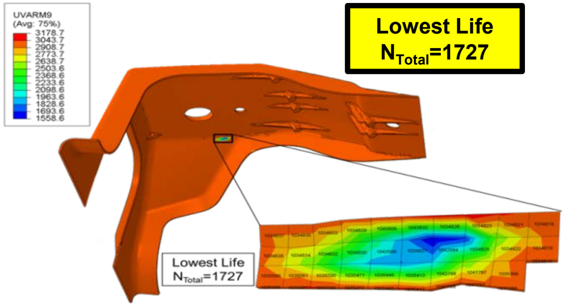


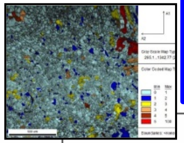
Predicted local yield strength in an AZ91D shock tower



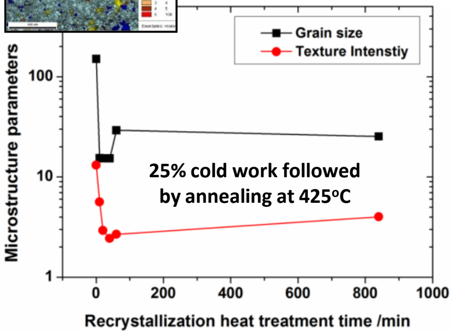
Heterogeneous material state, porosity, pore size at the crack initiation site

Lowest Life N_{Total}=1727





Static recrystallization of ZE20 - significant decrease in average grain size & texture intensity in 10 min



Collaboration and Coordination

- Broad participation of domestic OEMs, suppliers and universities (over 25 in total)
- Project executed at task level (9 task teams) and coordinated by a USAMP core team
- The first-of-its-kind US-Canada-China collaboration, leveraging significant international resources on coordinated pre-competitive research

U.S. Partner Organizations

USAMP Core Team

Chrysler	Ford			GM
Sukhbir Bilkhu Steve Logan Dajun Zhou	Xiaoming Chen Joy Forsmark	Bita Ghaffari Mei Li Xuming Su	David Wagner Jake Zindel	Jon Carter Alan Luo ** Jim Quinn

Bob McCune, Technical Project Administrator

** Formerly GM – Employed by Ohio State University since mid-2013

Collaboration and Coordination

U.S. Partner Organizations

Industry Partners (20)

ACT Test Panels
AET Integration
Almond Products
Atotech
Cana-Datum
Duggan Mfg.
Element Technologies
Exova
Forming Simulation Technologies
Henkel Corp.
Henrob Corp.
Hitachi America
Kaiser Engineering
Luke Engineering
Mag Specialties
Metro Technologies
PPG Industries
Universal -LINC
U.S. Magnesium
Vehma Engineering

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

China Partners (10)

China Magnesium Center
Chongqing University
Institute of Metals Research (Shenyang)
Ministry of Science and Technology
Northeastern University
Shanghai Jiao Tong University
Shenyang University of Technology
Tsinghua University (Beijing)
Xi'an University of Technology
Zheijang University

Canada Partners (9)

Auto 21 Network
Canmet
Auto 21 Network
Magna
Meridian Light Metals
University of Waterloo
University of Western Ontario
University of Windsor
Ryerson University

Remaining Challenges and Barriers

- Evaluation of improved Mg crashworthiness codes for predicting performance of die cast AM60 alloys with solid elements and for predicting performance of anisotropic wrought alloys with shell elements. Much of this challenge is expected to be resolved by the conclusion of this project.
- Validation of durability performance of dissimilar metal joints on complex assemblies. On previous phases of the MFERD project, fatigue modeling and correlation, especially of the 3-dimensional assemblies was problematic. Much work has been done in this project to improve the fatigue prediction of dissimilar metal joints, however, the success of these efforts cannot be fully evaluated until the structures have been built and tested.
- Validation of corrosion performance of dissimilar metal joints on complex assemblies. Although much work has been done to identify new and improved coating and joining processes to minimize the risk of galvanic corrosion, and the project plan calls for evaluating this performance on test specimens and demo structures, successful corrosion performance especially is expected to continue to be a significant challenge.

Future Work

- Continue joining, corrosion protection and durability (fatigue) validation of selected dissimilar material couples.
- Continue evaluation, development, and validation of improved crashworthiness simulation capabilities for AM60 die cast and ZE20 Mg extrusion alloys.
- Continue dissimilar metal joining evaluation and development.
- Finalize production of “demo” structure component parts (upper rails and shock towers) from selected materials, and assemble “demo” structures.
- Conduct validation testing on “demo” structures, especially durability and corrosion evaluation.
- Continue development of more deformable grades of magnesium extrusion (ZE20) including acquisition of billet stock and trial runs with Mag Specialties.
- Complete ICME “fatigue” studies of MFERD Phase II “demo” structures and investigate the ICME of ZE20 magnesium.

Summary

- Relevance
  - The project is clearly relevant to DOE goals of reducing vehicle weight through increased integration of magnesium into multi-material vehicle structures.
- Approach
  - The approach of a leveraging a large international collaboration effort to conduct research and enabling technology development followed by the build of multi-material "demo" structures to validate processes and technologies should help to achieve DOE goals
- Technical Accomplishments
  - Validated improved LS-DYNA MAT 233 Mg for shells and created MAT 233 Mg for solid to simulate super-vacuum die casting (SVDC) AM60B alloy
  - Verified predicted joint fatigue performance on test specimens involving more than one joint and applied lessons learned o improve design and durability test for new "demo" structures.
  - Developed and verified FSW process for joining Mg to Al and developed Adaptable Insert Welding process for joining of Mg to Stl as well as validating room temperature SPR process for joining of Mg to Al.
- Collaborations
  - The international collaboration includes three U.S. automotive OEMs, over 20 U.S. industrial partners and universities, and over 20 Canadian and Chinese organizations.
- Future Work
  - Primary focus on building "demo" structures with processes developed over past two years, and validating performance of said "demo" structures.

Technical Back-Up Slides

Project Structure and Timing (MFERD Phase I, II and III)

FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15

MFEDD Phase I. Front End Design and Feasibility

USAMP PROJECT (AMD603) : Magnesium Front End Design & Development (MFEDD)

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

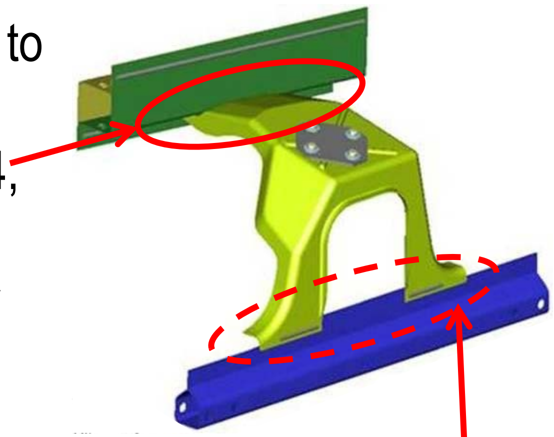
Phase I. Enabling Technology Development (AMD604)
- Crashworthiness research
- NVH research
- Fatigue and durability research
- Corrosion and coatings
- Low-cost extrusion & forming
- Low-cost sheet and forming
- High-integrity body casting
- Welding and joining
- Integrated computational materials engineering

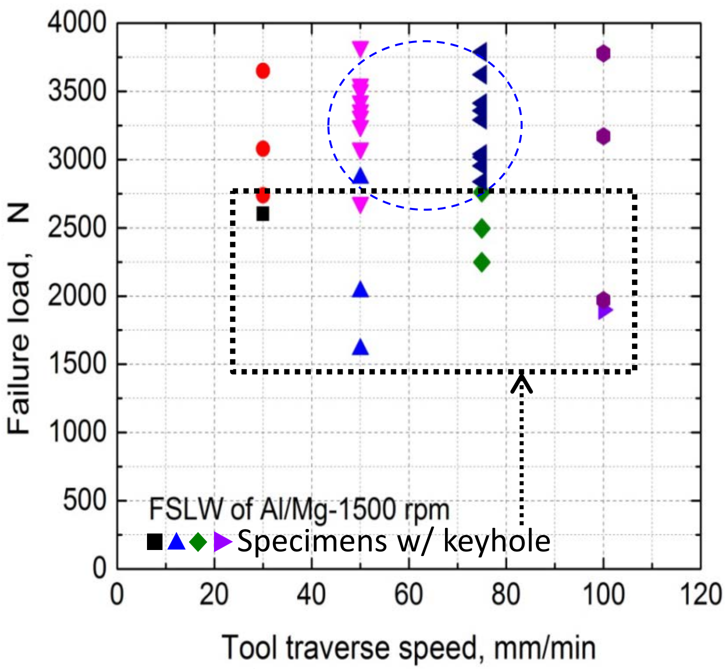
Phase II. Demo Structure (AMD904)
Magnesium only

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

FY 2013 Accomplishment – Task 9 Friction Stir Welding of Mg to Al

- Established feasibility of friction stir welding (linear and spot) to obtain strong joints of Mg to Al
- Optimized process for 3.1-mm AM60B to 1.5-mm AA6022-T4, fabricating and testing ~200 samples
- Chose process for demo structure upper-rail joint: friction stir linear welding (Al on top); lap-shear load = 3.3 kN

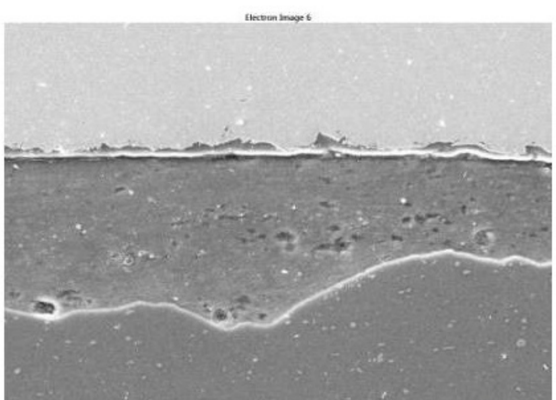


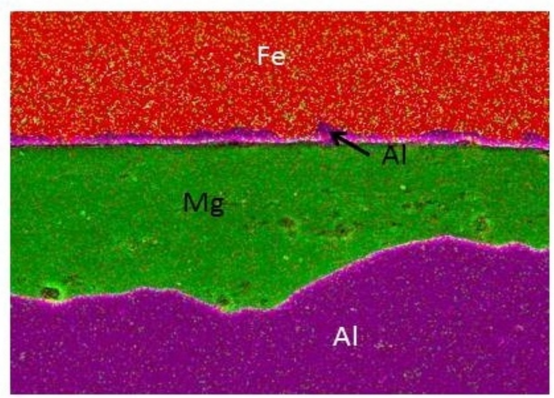


- Delivered 90 2-plate friction stir samples (for the corrosion team) and 45 2-plate samples (for the durability team)
- Will produce more samples for full characterization of joint performance
- Will determine feasibility of friction stir welding of 3-mm AM60B castings to 3-mm AA6082 extrusions

FY 2013 Accomplishment – Task 9 SPR Development

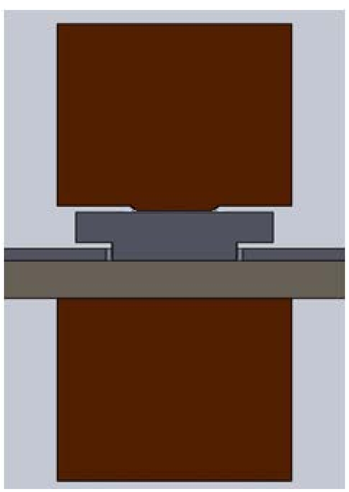
- Completed all coupon assemblies for AM60/6082 T4 Stack-ups for Corrosion and Durability Teams
- SPR coatings examined:
  - Zn/Sn standard coating
  - IVAD Al coating (Titanium Finishing)
  - Alumiplate Al coating (non-aqueous electrolytic process) – electropotential testing only (NDSU)
  - EC[2] coating (Henkel) – electropotential testing only (NDSU)
- SEM/EDS examination of Henrob SPRs indicate spalling of Mg on inserted SPR surface (both Zn/Sn and IVAD Al surface coatings) – unknown if this will impact performance

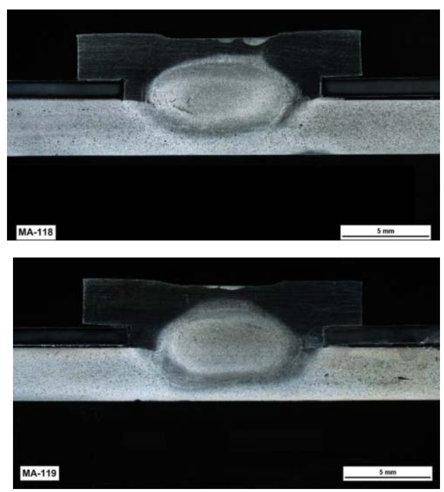


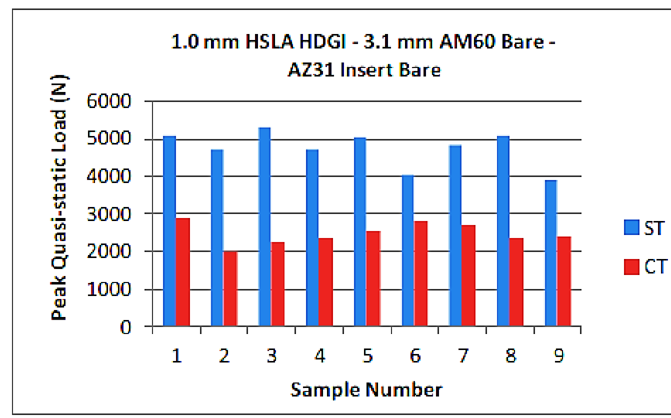


2013 Accomplishment – Task 9 Adaptable Insert Welding

- Identified Adaptive Insert Welding process as best potential process for joining Die Cast AM60B Mg shock towers to steel upper rails
- Optimized the process for joining bare Mg castings to bare steel using AZ31 Mg inserts (after evaluating steel inserts and AM60 inserts)
- Evaluating / developing process for joining coated coupons, joining with die-castable AM60 or AZ91 alloy inserts, and using non-copper electrodes for improved corrosion performance
- Additional work required to develop the process for assembling demo structure Mg die cast shock towers to stamped steel upper rails.







ST = Shear Tension, CT = Cross Tension