Magnesium Front End Research and Development – Phase I

Project ID "LM008"

AMD 604

2010 DOE Merit Review Presentation

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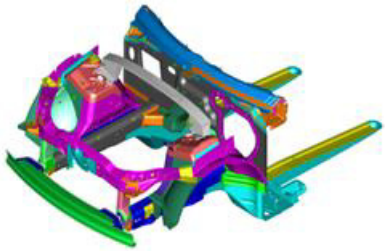


Unibody Body Front End – Steel Baseline

Acknowledgement

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

Overview

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 magnesium structures.
- Improved knowledge base in Mg crashworthiness, NVH (noise, vibration and harshness), fatigue and durability

Partners

- OEMs: Chrysler, Ford, GM
- U.S. Supplier list (next slide)
- International Partners from China and Canada. (slide 4)

U.S. Partner Organizations

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

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

Organize and deploy an international research and development project aimed at the advancement of magnesium technology by a dedicated collective of researchers toward the goal of having sufficient engineering and manufacturing capabilities to exploit the full weight-reduction potential of magnesium alloys as engineering materials for entire automotive sub-structures, thereby leading to concomitant fuel economy realizations at affordable cost, excellent vehicle performance and with due consideration for the environment.

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

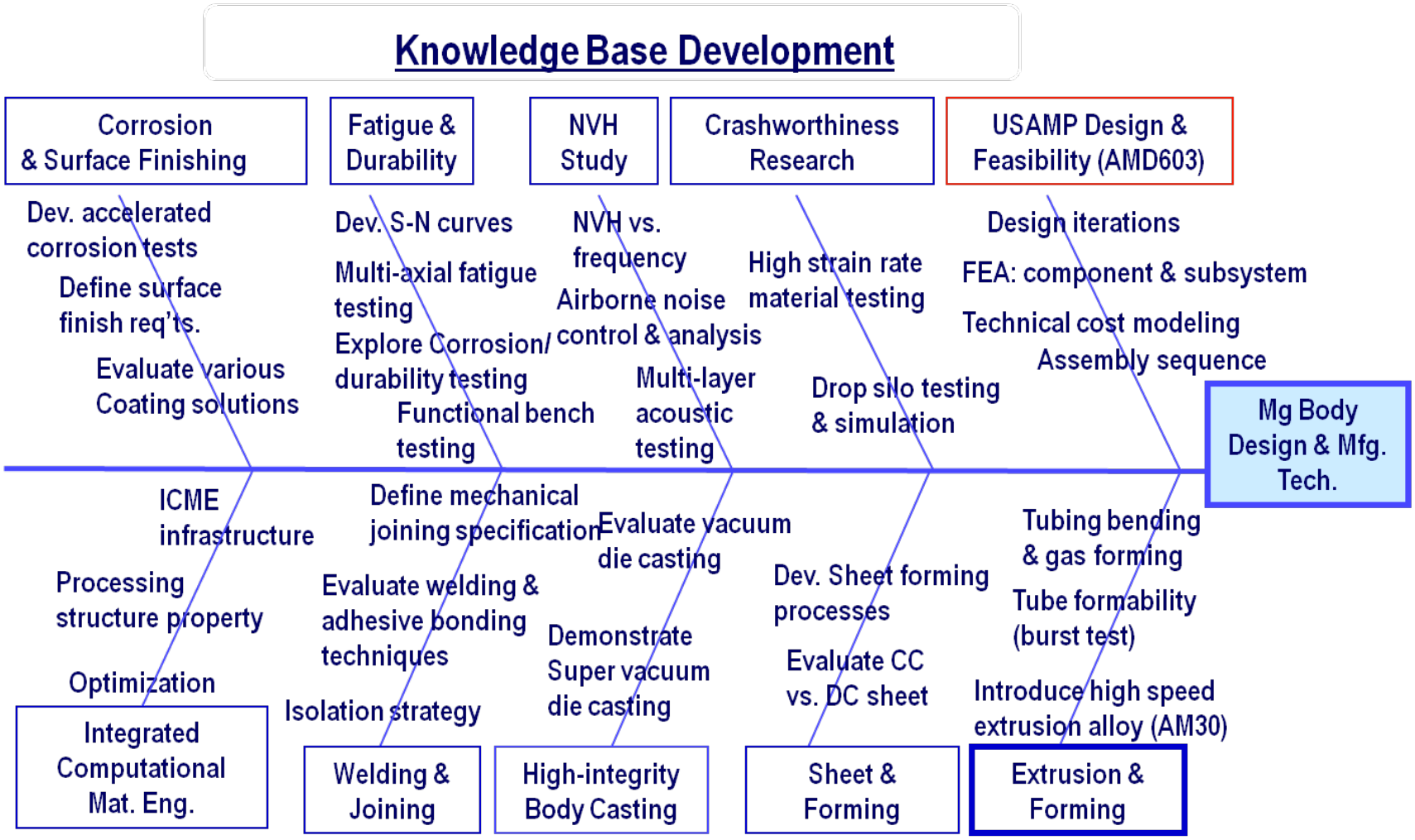
FY2009 Targets

- ❑ Develop pertinent technologies to meet U.S. task goals
- ❑ Support conduct of international review meeting in Canada, May 2009
- ❑ Demonstrate technology readiness required to pass project “Gate 3” (final) review
- ❑ Propose MFERD Phase II project to demonstrate the technologies developed in Phase I

FY2009 Milestones

- Participated in the 3rd International Review Meeting in Canada on May 11-13, 2009, and contributed to 2nd progress "Proceedings" (570 pages) of the international project released at the Canada meeting.
- Passed final "Gate 3" technical reviews with international Project Steering Committee (including DOE representatives) in May and USAMP AMD Board of Directors in September, 2009.
- Conducted the USAMP annual review and technology rollout on November 19, 2009.
- Completed "Magnesium Front End Research and Development – Phase II" project proposal and obtained approvals from USAMP and DOE in 2009/2010.

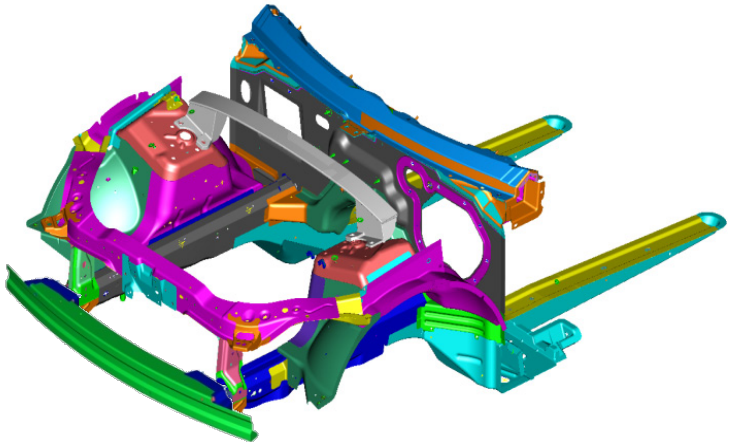
APPROACH



Unibody (BFI) Front End Design Summary

(Accompanying USAMP AMD603: Magnesium Front End Design and Development)

Baseline: 2008 Cadillac CTS



Steel baseline design
110 Parts & 99.6 kg

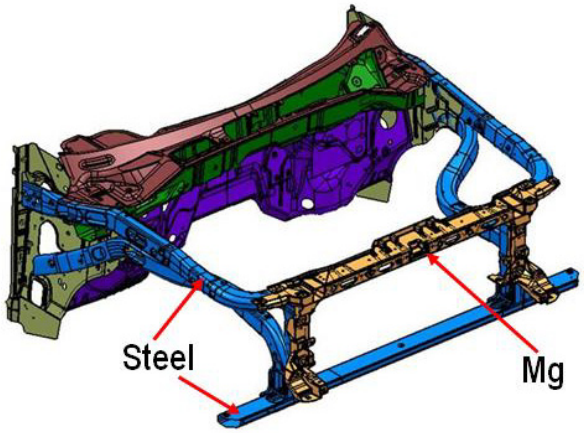
Mg-intensive design
47 Parts & 55.3 kg

44.3 kg mass reduction (44.5%)
63 part reduction (57.3%)

Body-on-Frame Front End Design Summary

(Accompanying USAMP 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%)

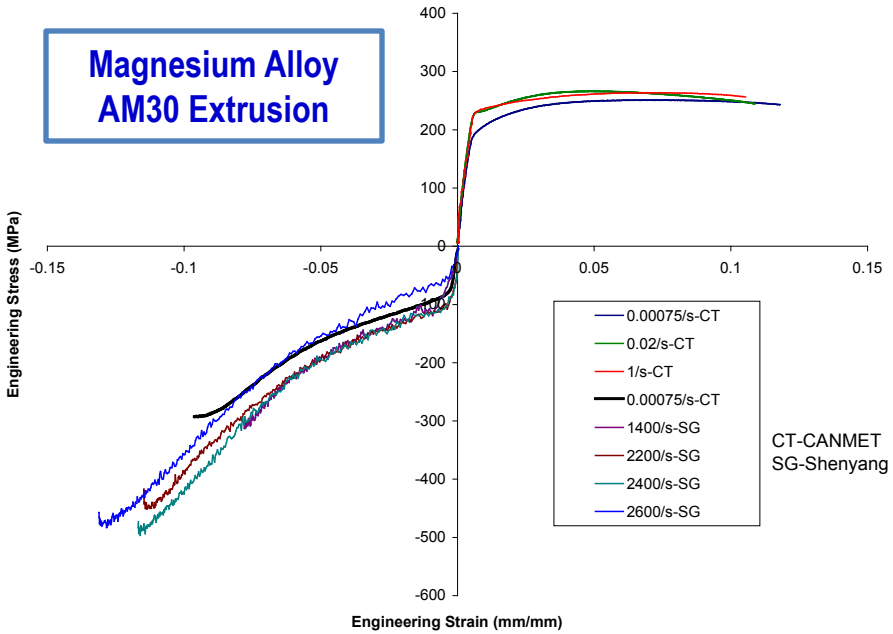
FY2009 Accomplishments - Task 1.1 Crashworthiness

- Generated significant tension & compression data at various strain rates for AM30 extrusion, AZ31 sheet and AM60B die castings and initial material models for simulation
- Despite the initial buckling deformation, all three Mg alloys showed pervasive fracture in crash loading, which is less desirable for automotive applications compared to Al or steel

Magnesium Alloy AM30 Extrusion

Aluminum Alloy 5754 Extrusion

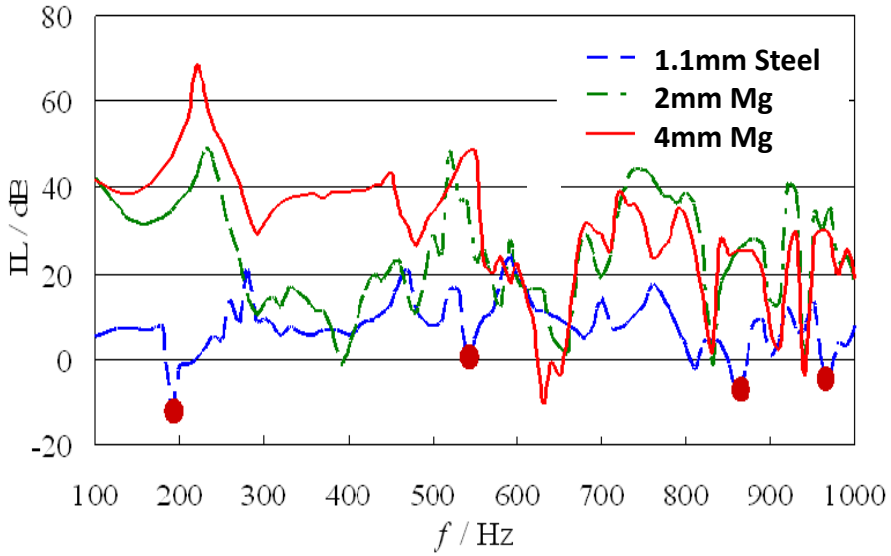
Magnesium Alloy AM30 Extrusion



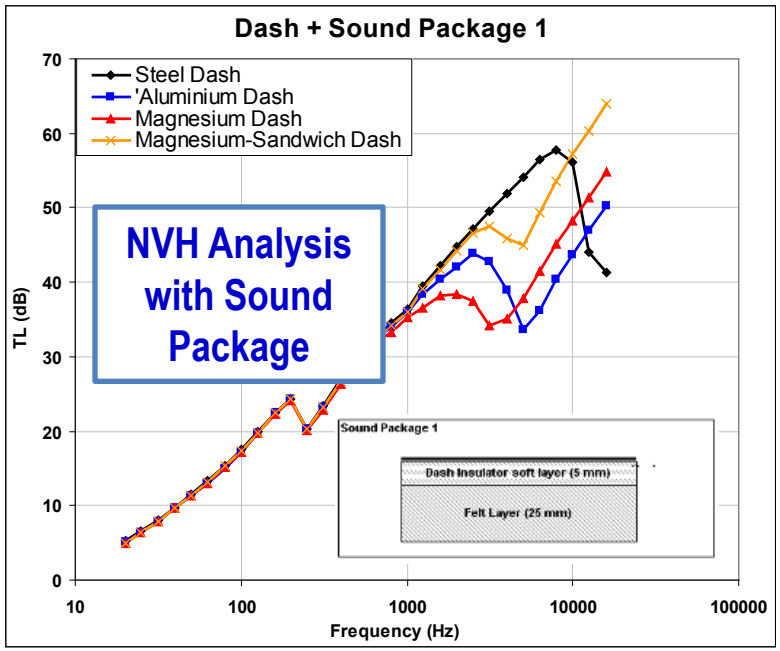
FY2009 Accomplishments - Task 1.2 Noise, Vibration and Harshness (NVH)

- Mg has high damping capability, which can be translated into better NHV performance in low- to mid-frequency up to 1000 Hz
- For high-frequency (>1000 Hz) airborne noise, a lightweight Mg panel would transmit significantly more noise into the occupant compartment unless the acoustic frequencies could be broken up and damped
- Simulation and testing suggest that proper sound package can compensate the NVH performance of a low-mass Mg panel

NVH simulation in low- to mid-frequency range



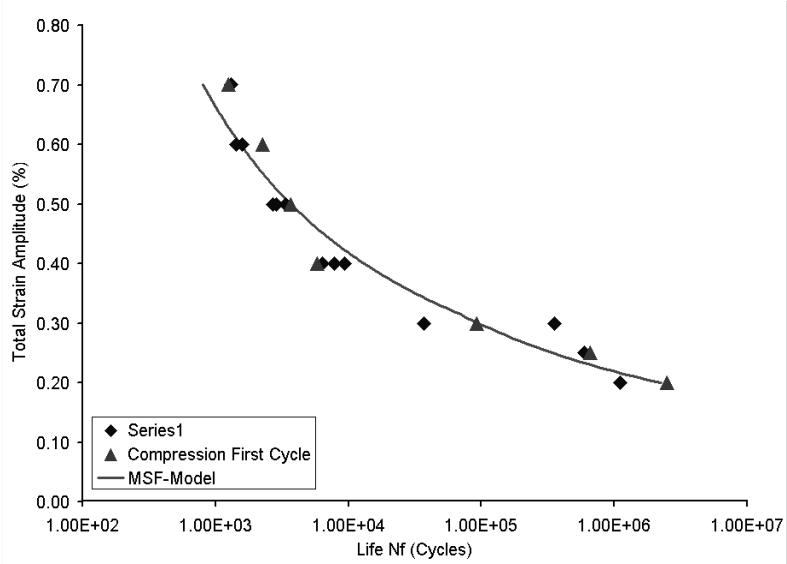
NVH simulation with sound packages



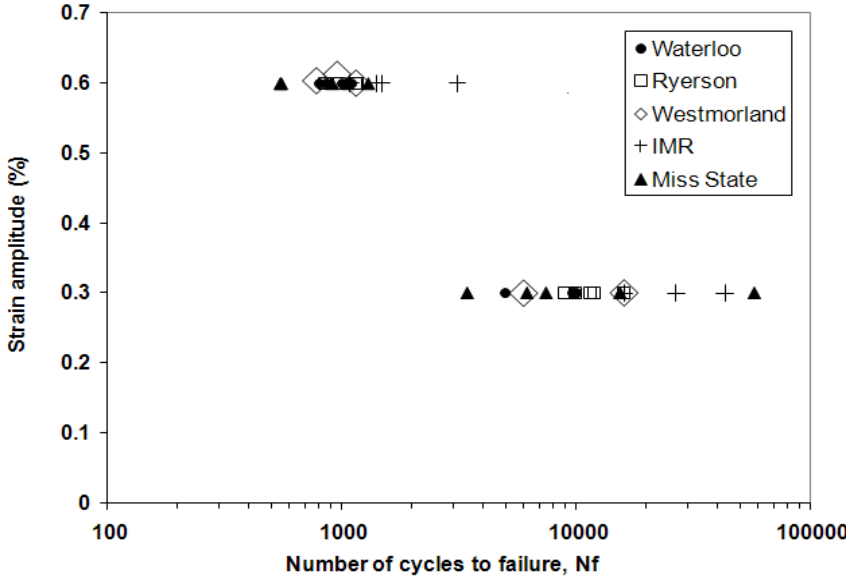
FY2009 Accomplishments - Task 1.3 Fatigue and Durability

- Completed a Round-Robin testing of 5 labs in 3 countries showing a reasonably good agreement in test results
- Completed strain-life fatigue testing of extrusion alloys (AM30 & AZ31), sheet alloy (AZ31) sheet, and casting alloys (AZ91D and AM60B) - similar fatigue results to some Al alloys
- Initiated fatigue testing of Mg joints (resistance spot-welded and friction stir welded) and multi-stage fatigue modeling work - promising results

Multi-Stage Fatigue (MSF) model correlation with experimental Strain-Life data AZ31 alloy

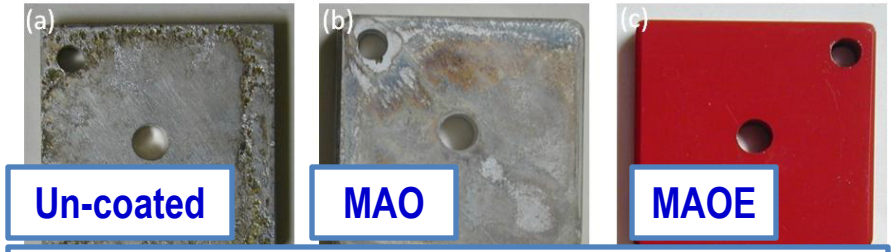


Round-Robin test results on AM30 extrusion

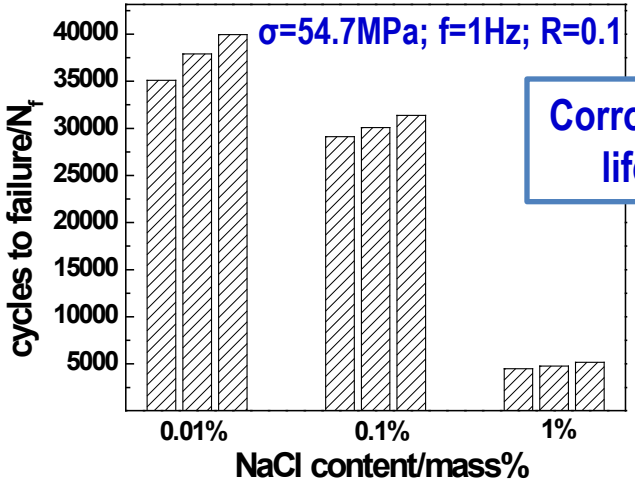


FY2009 Accomplishments - Task 1.4 Corrosion and Surface Finishing

- Completed evaluation of 14 pre-treatment processes for adhesive bonding and corrosion resistance
- Developed micro arc oxidation (MAO) and a combined micro arc oxidation plus electrophoresis (MAOE) process for corrosion protection
- Initiated corrosion fatigue study of Mg alloys

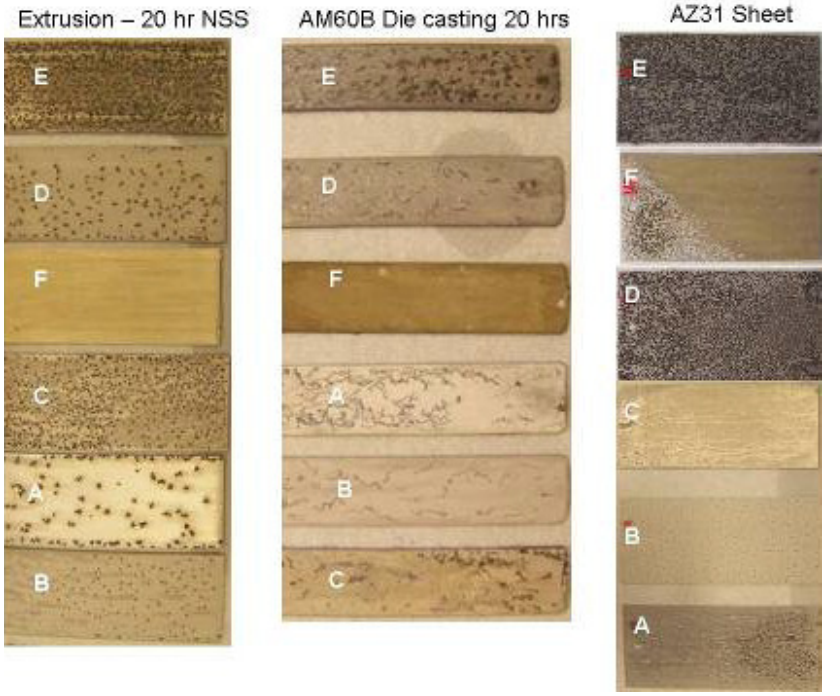


Corrosion test results of MAO and MAOE coated samples



Corrosion fatigue life of AZ31

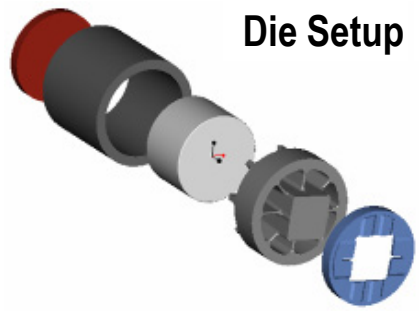
ASTM B117 test (20 h) of various pre-treatments

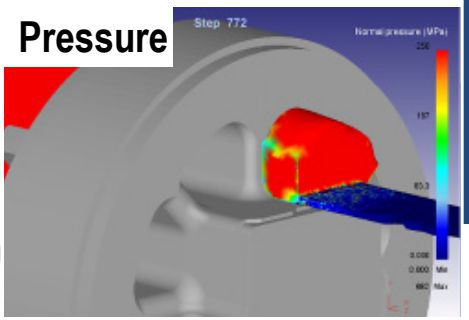


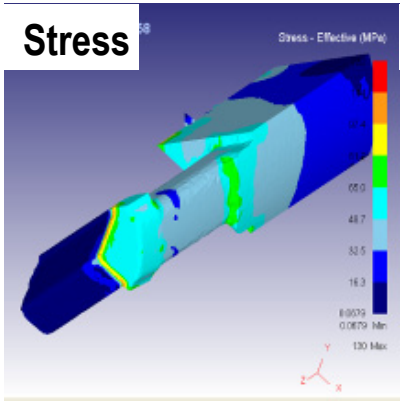
FY2009 Accomplishments - Task 1.5 Low-Cost Extrusion and Forming

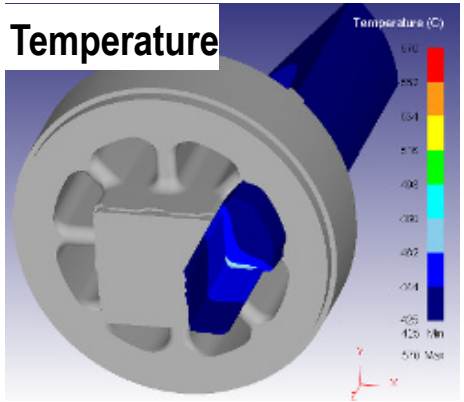
- Developed a flow stress model and adapted DEFORM 3D for Mg extrusion simulation using porthole dies (seam-weld) and conducted extrusion simulation
- Evaluated various Mg tubes for bending and warm gas-forming processes
- Explored microalloying (Ce, Nd & Y, etc.) to improve the mechanical properties of AZ31, AM20, ZM21 and AZ61 alloys)

Mg extrusion simulation using DEFORM 3D



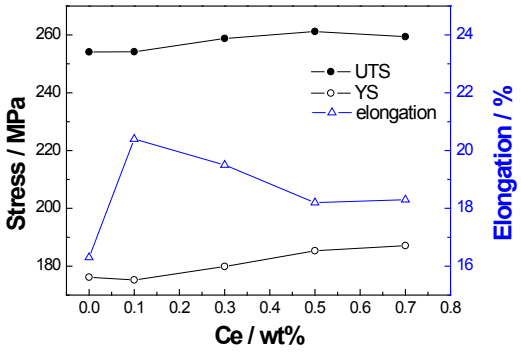


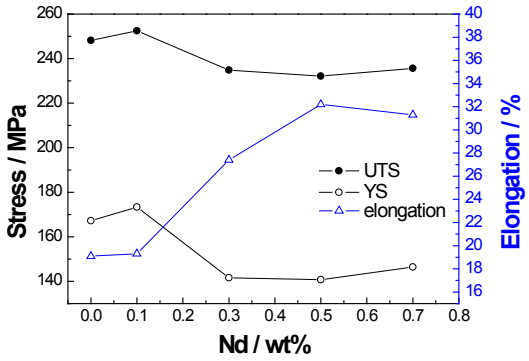




Bending & gas-forming

Ce & Nd effect on ZM21



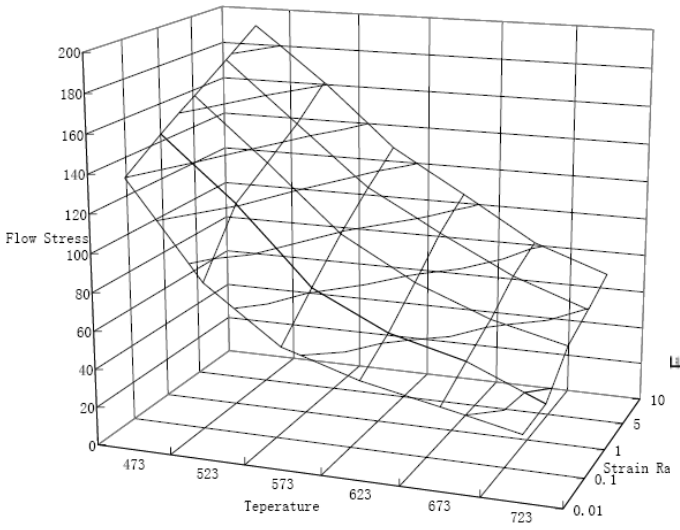


FY2009 Accomplishments - Task 1.6 Low-Cost Sheet and Forming (US contribution from USAMP AMD602)

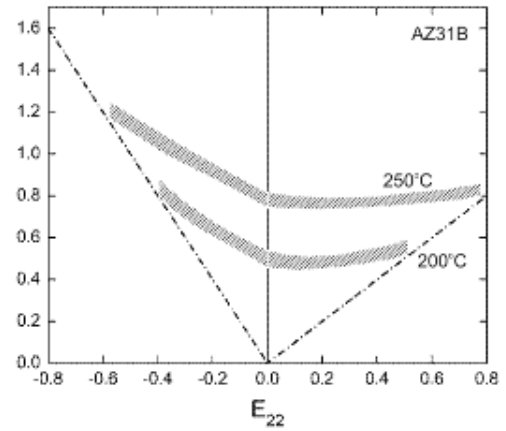
- Developed a low-cost continuous casting (CC) process in China to produce Mg sheet as thin as 1 mm
- Evaluated the formability of various Mg sheet materials produced by direct-chill (DC) cast and CC processes
- Developed material models (stress-temperature-strain rate relationship) for ICME

Direct-chill (DC) cast and continuous cast (CC) sheet

Material model development



Formability evaluation



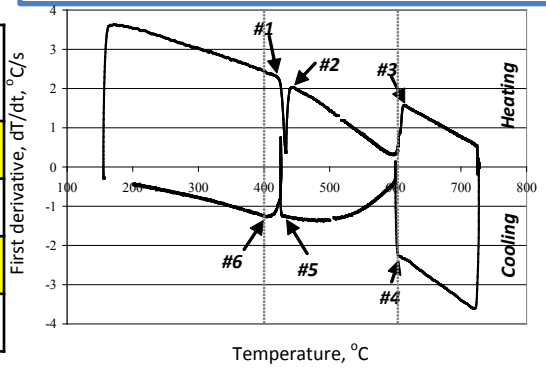
FY2009 Accomplishments - Task 1.7 High Integrity Body Casting

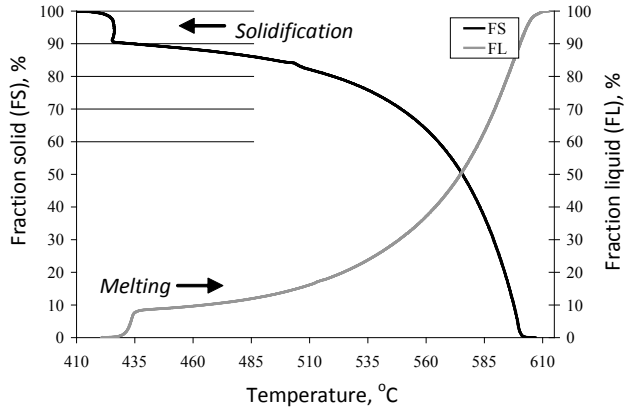
- Developed super-vacuum die castings (SVDC) with significantly improved mechanical properties (50-60% improvement in ductility) and heat-treatability
- Studied the solidification process using simulation and thermal analysis
- Investigated the heat treatment process for SVDC castings

Super-vacuum die casting: 50-60% improvement in ductility

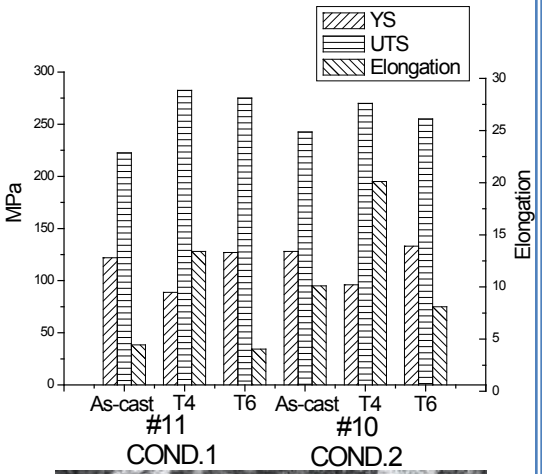
Alloy	UTS, MPa	YS, MPa	Elongation, %
AZ91D-SVDC	230	160	4
AZ91D-HPDC	200	150	2.5
AM60B-SVDC	230	125	9
AM60B-HPDC	210	120	6

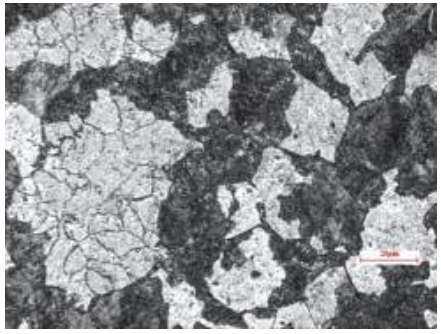
Solidification study using thermal analysis





Heat treatment study





FY2009 Accomplishments - Task 1.8 Welding and Joining

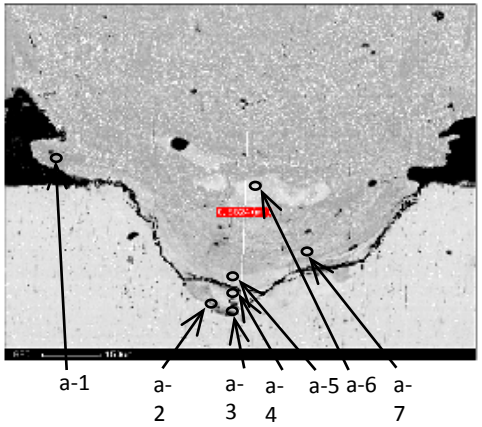
- Developed the process parameters for Mg welding: MIG, laser, resistance spot and friction stir spot welding
- Made significant progress in adhesive bonding and self-pierce riveting
- Explored Mg-to-Al joining processes: laser weld bonding and friction stir welding

MIG welding of AZ31 sheet

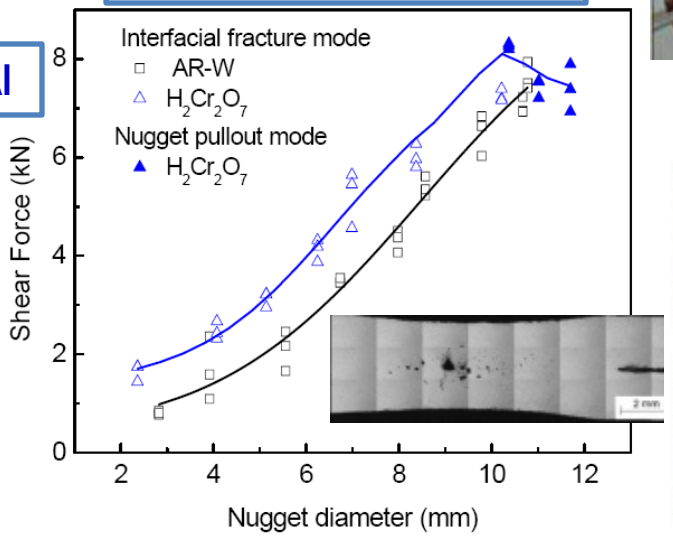
Laser welding

Self-pierce riveting

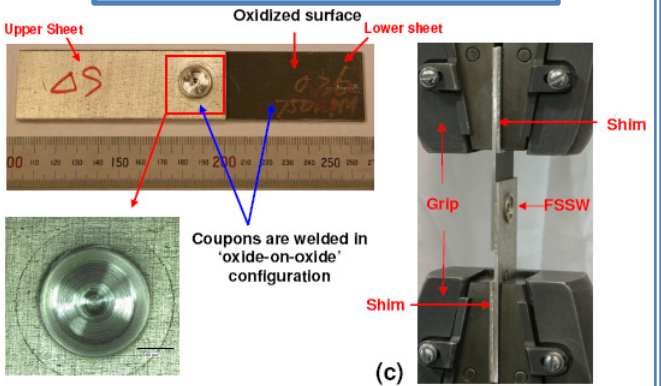
Laser weld bonding of Mg to Al



Resistance spot welding

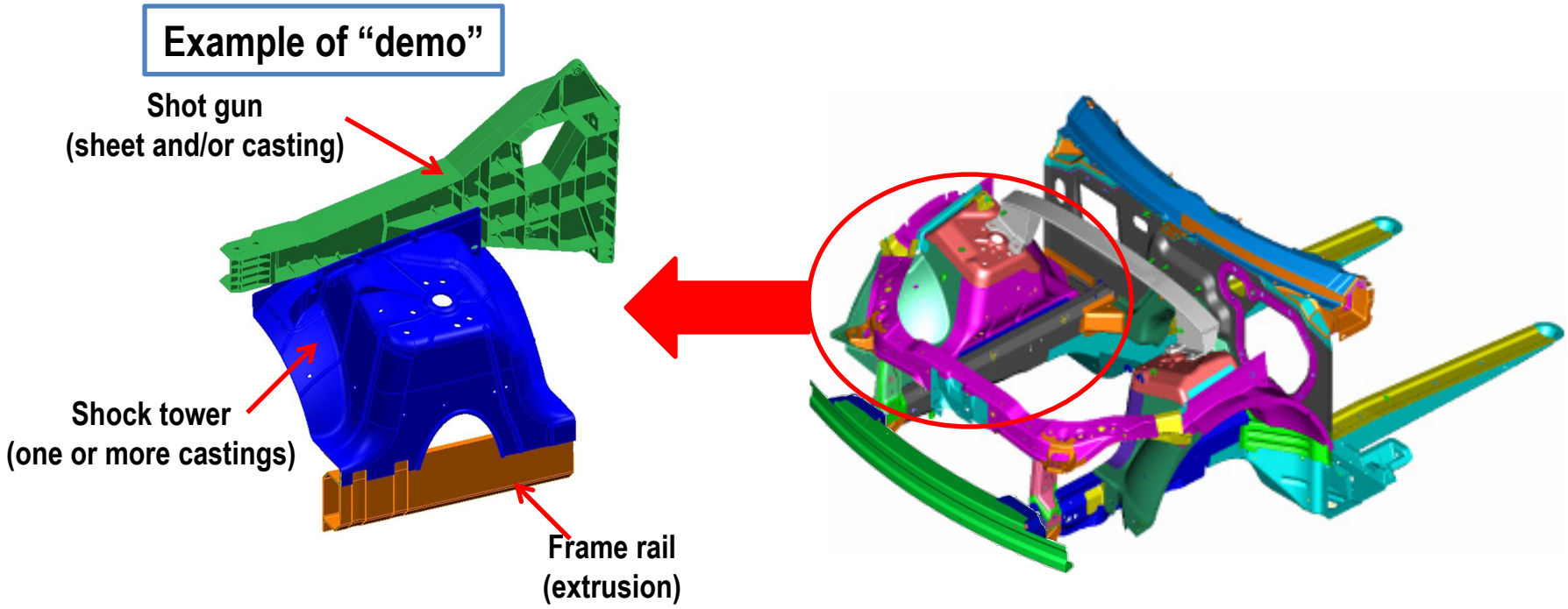


Friction stir spot welding



Future Work: Magnesium Front End Research & Development Phase II (AMD904)

- ❑ Design and build demo structure which embodies attributes of a major body structure
- ❑ Main tasks in corrosion, fatigue and joining centered around a demo structure
- ❑ Continue extrusion, sheet and casting tasks to
  - Make parts for the demo structure and fully integrate with ICME task
  - Potentially evaluate additional alloys: age-hardening alloys and reduced anisotropy
- ❑ Redefine the crashworthiness and NVH tasks



Summary

- As first-of-its-kind US-Canada-China collaboration, the Magnesium Front End Research and Development Phase I Project (AMD604) has been successfully completed and 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.

- Results from the companion design project (AMD603) suggest 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 (e.g. die casting, sheet forming and extrusion), and presumptions regarding joining and surface finishing technologies.

- The Magnesium Front End Research and Development Phase II Project (AMD904) has been approved and successfully launched in April, 2010, to demonstrate key enabling technologies developed in Phase I using a reduced “demo” structure.