G. Structural Cast Magnesium Development

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Contractor: U.S. Automotive Materials Partnership
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Objective

Overcome technical and manufacturing issues (high-integrity castings, corrosion & joining) that limit the light weighting application of structural cast magnesium automotive components. Then demonstrate the successful application of a magnesium engine cradle in a volume production type vehicle.

Approach

- Improve our scientific understanding of magnesium alloys.
- Develop a cost model that compares cast magnesium chassis component costs to other materials and processing techniques.
- Provide comprehensive database and design guidelines.
- Develop improved casting processes.
- Identify and/or develop methods to improve corrosion resistance.
- Improve joining technologies.
- Transfer knowledge and lessons learned to industry.
- Complete all of the scientific project tasks relevant to microstructure-property modeling, corrosion mitigation, joining behavior and nondestructive evaluation (NDE) methods.
- Convert an existing aluminum cradle to magnesium and have the parts ready for testing and approved for Corvette's Job #1 for 2006. Both industry and the scientific development part of this project worked simultaneously to solve all aspects of the project (see Figure 1) to meet the time schedule.

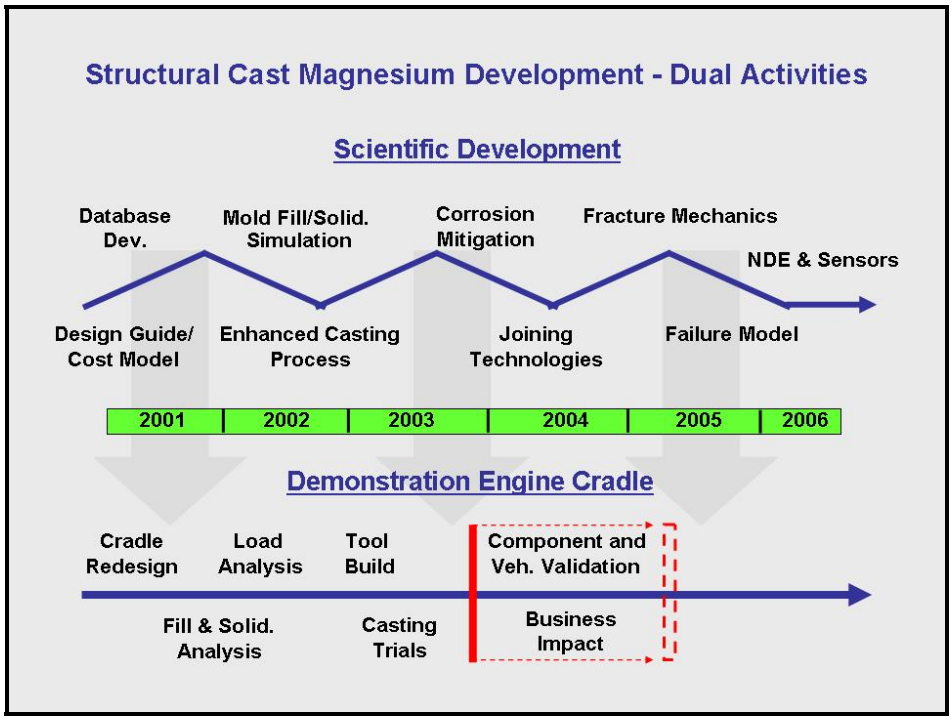

Figure 1. Dual-project path for science and magnesium demonstration casting validation activities.

Accomplishments

- Completed magnesium to aluminum cradle re-design and FEA analysis.
- Full vehicle and subsystem validation testing has been completed for 150 prototype cradle castings with no issues reported to date.
- The magnesium cradle (see Figure 2) achieved a 5.5 kg reduction in weight (35%) with respect to the current aluminum cradle now used in production applications.
- Completed mechanical property and microstructural characterization of numerous magnesium alloy production components.
- A new, high-temperature, creep-resistant alloy, AE44, was developed by participating team member Hydro Magnesium, which successfully completed at-bench and on-vehicle testing.
- CANMET's corrosion studies showed the need for dissimilar metal isolation requirements.
- Bolt Load Retention (BLR) CANMET analysis demonstrated that the cradle attachments would meet vehicle performance requirements.
- SCMD team developed and implemented successful galvanic corrosion mitigation strategy which proved successful in at-bench and on-vehicle validation testing. SCMD Database material testing was completed and provides CAE properties.
- Mississippi State University and Sandia National Lab completed material testing quantitative microstructure characteristics and they are beginning to exercise the Damage model.
- Lawrence Livermore National Lab completed fabrication of several ASTM E505 Radiographic Inspection Standards (RIS) which will improve casting evaluation sensitivity.
- Project demonstration cradle passed all validation requirements with no issues and is now in volume production on the 2006 Z06 Corvette.

- SCMD and MPCC (see report 2.H) project teams developed and published a Magnesium 2020 document which outlines a North American Strategic Vision (from 2005 through the year 2020) for Automotive Weight Reduction using magnesium components.
- SCMD database has been improved with a new navigation system and additional property inputs.
- SCMD Principal Investigators and core team members published and presented 46 papers in 2005.

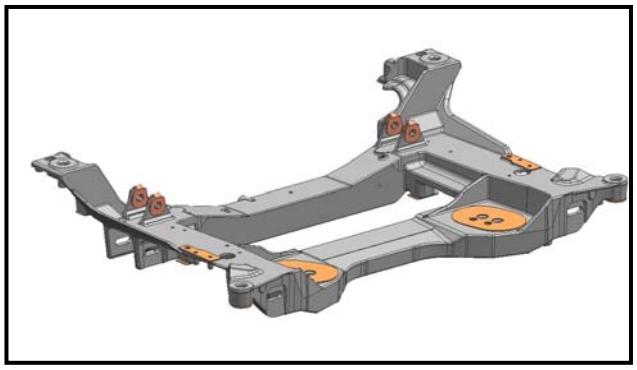

Figure 2. Machined Magnesium Cradle

Future Direction

- SCMD project has made significant scientific and application progress, but this project alone is insufficient for Mg to realize its full vehicle weight-saving potential without a dedicated, long-term vision to focus future research and development efforts. Therefore, the scope of the SCMD project was increased on 3/9/05 to develop an industry vision that will outline the potential to increase the use of magnesium (North American Automotive) from 10 #/typical vehicle in 2005 to 250 #/typical vehicle in 2020. The document was completed and reviewed by the SCMD participating companies, the AMD USAMP Board and a representative from the DOE on 10/11/05 and it will soon be distributed by a representative from USCAR.
- The SCMD Core Team continues to work and develop the Structural Cast Magnesium Development (SCMD) Project's Statement of Work (SOW) Tasks to complete both the scientific and manufacturing aspects of the project.
- The SCMD Core Team continues the investigation of the LPPM casting process to cast a duplicate magnesium cradle by this alternative casting process. Progress reports are reviewed at all SCMD meetings.

Introduction

The SCMD project has focused on resolving critical issues that limit the large-scale application of magnesium castings in automotive components. The project activities combine the science and manufacturing technology necessary to implement front and rear structural cradles. Such components offer all of the difficult manufacturing issues, including casting process (high-pressure die, semi-solid, low-pressure, squeeze, etc) and joining, along with harsh service environment challenges such as corrosion, fatigue, and stress relaxation associated with fasteners.

The project team includes personnel from:

- The "Big Three" automotive companies
- 34 companies from the casting supply base
- Academic personnel
- Independent testing and research labs
- American Foundry Society (AFS)
- Technical Associations
- Oak Ridge National Laboratory (ORNL)
- Sandia National Laboratory (SNL)
- Lawrence Livermore National Laboratory (LLNL)
- Natural Resources Canada (CANMET)

Industry Participants

An existing aluminum engine cradle (that is currently in production use) was redesigned for two different magnesium casting processes: High-Pressure Die-Casting (HPDC) and Low-Pressure Permanent Mold (LPPM). Utilization of computer simulations (prior to tooling design) indicated good correlation of casting fill operation (and their effects) to actual production experiences (see Figure 3).

Tooling and castings have been made for both processes. Several hundred HPDC production prototype castings were distributed to SCMD project participants and to GM Corvette Team for the vigorous testing procedures that were required for the HPDC cradle (See Figure 4). Based on the results of the ongoing tests, the Corvette Team decided to start a parallel production program for the implementation of using a magnesium cradle for the 2006 Z06 Corvette.

The Low Pressure Permanent Mold (LPPM) process (see Figure 4-A) has had another project extension to complete the results of this process investigation.

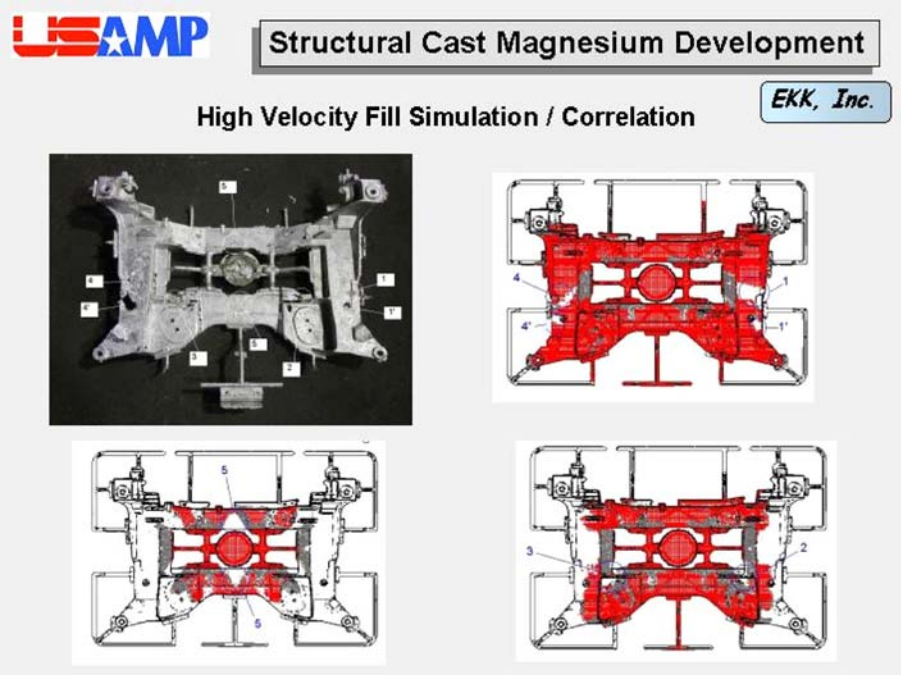

Figure 3. EKK, Inc. cavity fill simulations show excellent correlation with short fill HPDC castings.

Figure 4. Initial machined HPDC cradle castings

Figure 4-A. Initial LPPM magnesium cradle

Importance/Significance: Utilization of up-front computer modeling (used for both HPDC and LPPM processes) resulted in significant savings (time and costs) and eliminating casting defects in the initial castings. Based on the prototype castings produced by both processes, there is an estimated 35% weight savings in the magnesium cradle versus the current aluminum production part. The investigation of producing the same casting by the two different processes (HPDC and LPPM) has a great potential for the utilization of existing aluminum casting companies to expand their operations into magnesium, without huge capital and facility expenditures.

Project progress/status vs. targets

The most recent project targets were to complete the outstanding Statements of Work for the final project report to meet Job #1 2006 objective for Corvette (completed), and to complete the Magnesium 2020 document (completed).

Remaining Technical Challenges and Plans

The SCMD project will complete the outstanding Statements of Work for the final project report. In addition, the project team was recently assigned an additional task of completing the LPPM casting process that was heretofore stopped due to insufficient funds. This task will be completed before the final report is published in June of 2006.

Milestones

Cooperative Agreement

Magnesium front cradles (HPDC process) have passed all at-bench and on-vehicle testing; actual testing results have coincided with predicted computer modeling techniques; all tasks were completed on time to meet Corvette's evaluation of installing a similar Mg cradle for Job #1-2006 production vehicle.

A new, high-temperature, creep-resistant alloy, AE44, was developed by a participating project team member who successfully completed bench and vehicle testing.

Detailed quantitative microstructural characterization continues for other production components cast with AZ91D, AM 50, and AM 60 magnesium alloys. CANMET's corrosion studies showed (see Figure 6) the need for dissimilar metal isolation. CANMET's Bolt Load Retention (BLR) analysis (see Figure 6) demonstrated that the Mg cradle attachments would meet vehicle performance requirements.

Cooperative Research and Development Agreement (CRADA)

ORNL—ORNL continues the investigation of modeling software from four of the supply teams. The results of the investigation will be applied to the ORNL models using current commercial software; ORNL continues investigating the effects of using die lube for HPDC and LPPM operations (see Figure 5).

Importance/Significance: These investigations (real-time and software-proven) have already indicated that gas can be generated from the lube when molten metal (higher temperature) is introduced into the mold cavity. The gas then disperses throughout the casting, causing various types of porosity defects.

SNL/MSU—SNL is coordinating and collecting project data from all the SCMD project testing sites and then using the data to expand the mathematical "failure model" (see Figure 7).

Importance/Significance: Designers can use the multiscale fatigue model to develop castings, with the accurate knowledge of providing known failure points**.**

LLNL—LLNL has completed the fabrication of several ASTM E505 Reference Quality Indicators that will improve casting evaluation sensitivity (see Figure 8); performing radiographic analysis of production parts and test samples to determine discontinuity types and grades at predicted high-stress locations; investigating the possibility of using fiber-optic, in-mold; thermal monitoring system for HPDC continues in a high-volume production facility; working with suppliers to provide a system to detect impurities in the metal that is charged into the furnace.

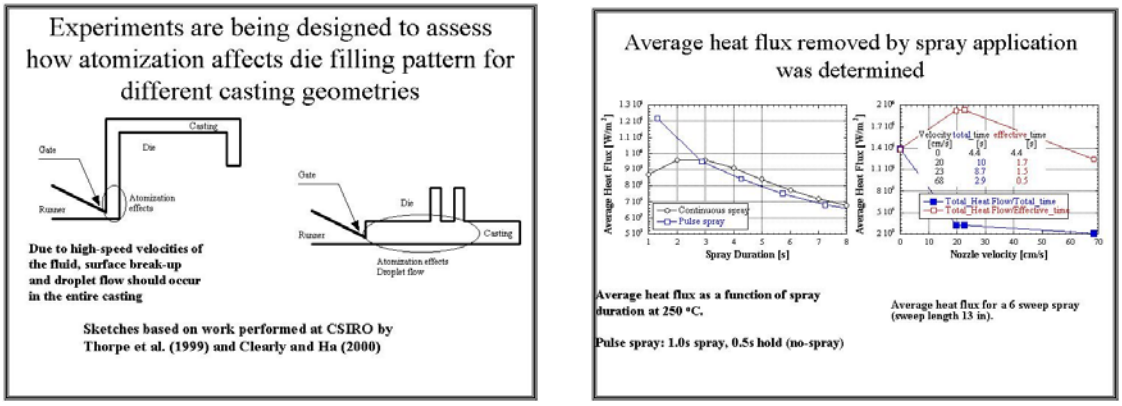

Figure 5. ORNL Die-Lube Investigation Work

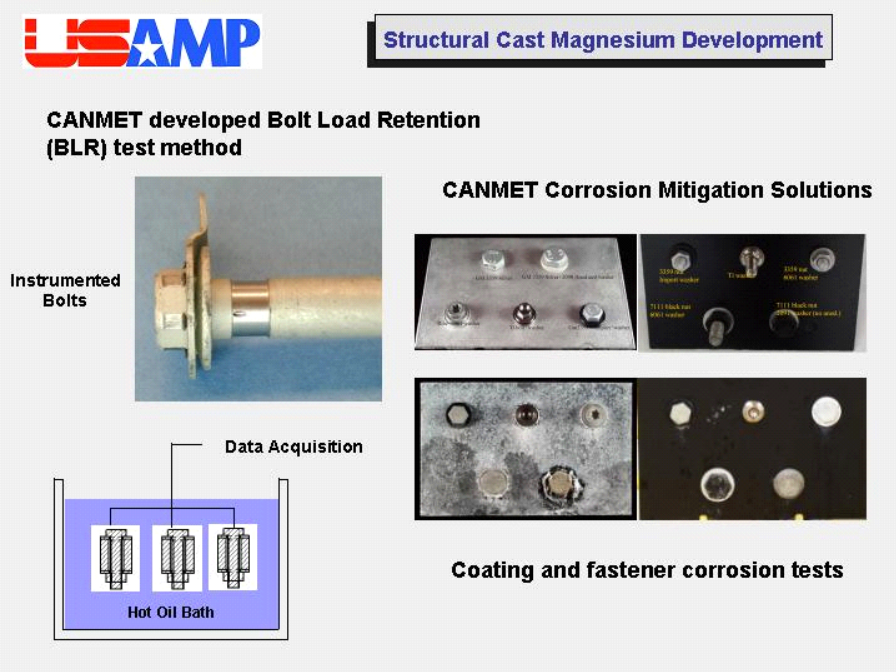

Figure 6. CANMET bolt load retention testing and corrosion studies developed knowledge required for product implementation.

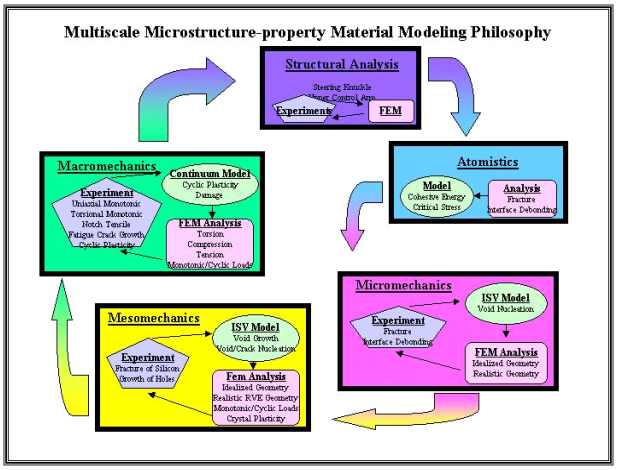

Figure 7. SNL damage model for simulating component material properties.

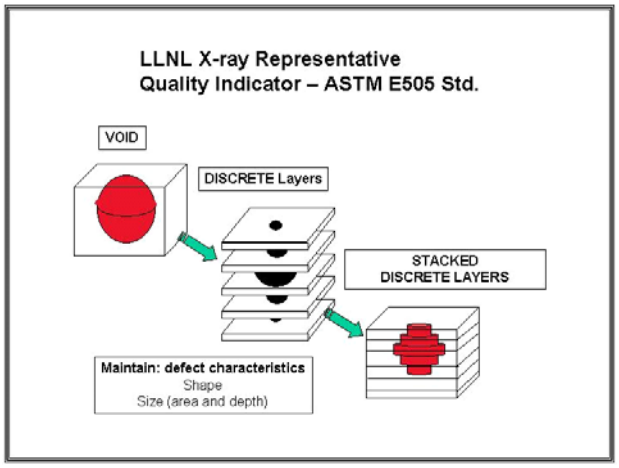

Figure 8. LLNL development activities.

Importance/Significance: All of the above procedures and investigations will provide more consistent and measurable standards that are required for improved quality control and to improve the safety-critical components that are cast in magnesium.

Academia participants: Academia participation in the SCMD project is involved with: the investigation of and characterization of crack nucleation and growth; the investigation into the cause of casting defects and the ability to separate gas and shrinkage effects that are generated (in the casting) by the various processes. (See Figure 9).

Importance/Significance: The importance of understanding the crack nucleation and the results of gas generated in magnesium castings will help to provide tools to manufacturing (or change process parameters) to eliminate casting defects. Both of these investigations by academia are working with the information supplied by ORNL and sample parts provided by the manufacturing team. The understanding of the gas effects in castings, generated by die lube could be a major breakthrough in understanding defects in magnesium castings.

Project Benefit

Expected DOE and U.S. industry benefits derived from successful completion of this project will include vehicle mass savings for ground and air transportation, leading to reduction in fuel consumption, emissions, and less dependence on foreign oil.

The North American auto industry currently uses approximately 70,000 MT/year of magnesium, which is equivalent to some 3.5 kg per vehicle. The ability to significantly increase magnesium usage will help the auto industry meet future Federal CAFE targets and reduce exposure to CAFE penalties. Cast magnesium structures have the potential to reduce 100 Kg of vehicle mass, which could reduce emissions by 5% and reduce fuel consumption by approximately 1.0 mpg (ignoring secondary mass savings).

Light metal alloys have greater recycling value with reduced energy consumption versus plastics (including melting, machining, handling, and transportation energy requirements).

The Big Three's competitive global postures will increase as a result of designing and manufacturing vehicles that offer greater consumer value. This can improve the U.S. trade balance with countries that market higher-fuel-efficiency vehicles than those produced in North America.

Health and environmental issues for workers are reduced during light-metal casting operations when compared to ferrous foundries and polymer molding operations.

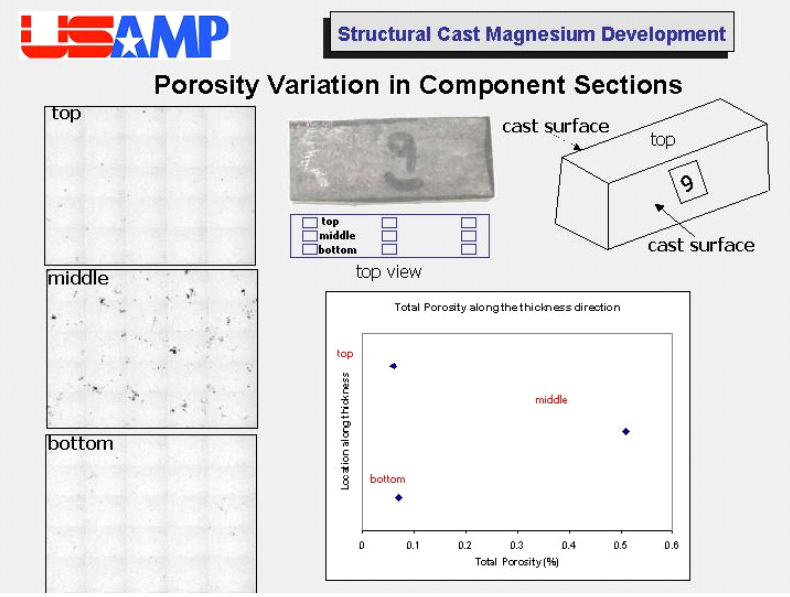

Figure 9. Georgia Institute of Technology characterization of AE44 alloy HPDC cradle section.

National laboratories are provided with valuable manufacturing development and product application experience.

Another benefit is the dual-purpose role of providing the national laboratories (and academia) an opportunity to develop math-based simulation models and NDE technologies that benefit both the auto industry and Federal ongoing technology programs.

The successful casting of a magnesium cradle (by low-pressure die-casting) will indicate to the existing aluminum casting industry that the transfer of casting technology (aluminum to magnesium casting) can be achieved at a low facility cost.

Conclusion

USAMP prototype and GM production cradles have passed all validation criteria except for galvanic corrosion. Process and production simulation, galvanic corrosion, joining and enhanced casting process development continue to be top cost issues for structural castings.

The SCMD project has been extended through 12/06 to complete additional testing and investigation of the LPPM process, and to develop a plan for the increase use of automotive magnesium through the year 2020.

Most important, the project success to date has proven that the technical and manufacturing issues (high integrity castings, corrosion & joining) that has heretofore limited the light weighting application of structural cast magnesium automotive cradles has been successfully solved.

In conclusion, the SCMD project has proven the successful casting (and recent production use) of a magnesium engine cradle is a major accomplishment for the North American magnesium casting industry.

Presentations

Numerous SCMD Core team presentations to attendees at 2005 SAE World Congress.

SCMD Core team presentations to attendees at 2020 Magnesium Document Review Meeting 10/11/05 at USCAR Office.

S. G. Lee, A. M. Gokhale, and G. R. Patel, “Macro-Segregation in High-Pressure Die-Cast AM60B Alloy” Magnesium Technology 2005 Symposium, TMS Annual Meeting, San Francisco, CA, February 14-17, 2005.

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