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HIGH INTEGRITY AUTOMOTIVE CASTINGS

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Abstract

The High Integrity Magnesium Automotive Casting (HI-MAC) is a $6 million (US) program funded through the US Department of Energy to develop technologies to enable the widespread use of magnesium in structural castings. This program will utilize low-pressure permanent mold, squeeze casting and electromagnetic pumping of magnesium into dies as casting methods. HI-MAC is also investigating grain refining technologies, new heat treat methods, improved fluid flow and solidification modeling as well as emerging technologies to produce affordable, high volume automotive components. This paper describes the program and the progress of the first year of research.

The HI-MAC Program

The use of magnesium automotive components in new vehicle applications can be utilized to reduce vehicle weight and improve performance. Magnesium sheet and wrought technologies hold potential for vehicle application, but application is long term. Perhaps the quickest near term path to increased magnesium content in automobiles is via castings.

Wider vehicle application of cast magnesium components has the potential of weight reduction of 100 Kg per vehicle. The US Department Of Energy Structural Cast Magnesium Development (SCMD) project has successfully demonstrated the conversion of an aluminum cradle to magnesium, providing a weight reduction of approximately 35%. Similar applications of magnesium castings for suspension and chassis components can be achieved. To produce affordable, high strength magnesium castings, it will be necessary to develop and optimize magnesium casting procedures (existing and new) and develop tools that support the casting process and reduce the cost of magnesium components.

The United States Automotive Materials Partnership (USAMP) Mag 2020 document provides a vision that identifies the cost and quality of magnesium components, the need for engineering and manufacturing process development, and the lack of enabling infrastructure as key inhibitors to magnesium applications on vehicles. Specifically, the document identifies three key technology barriers that must be overcome to increase the application of magnesium cast components in vehicles by 2020.

- Lower manufacturing costs
- Improved casting quality requiring lower porosity and new casting methods
- Infrastructure development

HI-MAC addresses the near and mid term metalcasting development needs identified in the Mag 2020 document. Eliminating those technical barriers that currently inhibit magnesium casting production will move the automotive industry into a better position to realize emerging automotive magnesium component needs, build needed magnesium industry infrastructure and develop tools that will be needed to reduce the cost of magnesium components and enable sustainable production requirements. HI-MAC will address these three key issues:

- ***Development of Casting Tools:*** Develop technologies and tools that will be required for sustainable long-term procurement of cast magnesium automotive components.

- ***Casting Process Development:*** Develop casting processes to facilitate production of cast magnesium automotive chassis components that cannot be manufactured using current process limits.

ñ ***Infrastructure Development:*** Development of casting processes and tools will include industry participation by automotive suppliers currently producing aluminum components, the development of equipment uniquely suitable for the production of magnesium components and development of a broader research and science base.

HI-MAC research will broaden the range for potential cast magnesium component applications by developing and optimizing manufacturing technologies that can produce a greater range of geometries and properties than are available today and encourage potential supplier base infrastructure through project partnerships; investigate and evaluate new and emerging technologies and develop tools that address critical technology barriers currently inhibiting magnesium application and component affordability. Casting process and tool development will be demonstrated by production of a magnesium control arm (see Figure 1) by low-pressure cast, squeeze cast and a new emerging casting process. Control arms will be delivered for static and/or vehicle testing.

The project is divided into eight tasks to address key technology barriers that limit cast magnesium automobile suspension and chassis applications and affect the manufacturing costs of these components.

Figure 1: Lower control arm

TASK 1: SQUEEZE CASTING PROCESS DEVELOPMENT

Squeeze casting is considered a "high integrity" casting process because it imparts qualities to a casting that are difficult to achieve with conventional magnesium casting techniques such as high pressure die casting. Squeeze casting can provide higher tensile properties and improved ductility due to reduced or absence of porosity in the metal, and the ability to heat treat the cast component. In recent years, the squeeze casting process has been widely used with various aluminum alloys to manufacture near-net shape automotive components requiring high strength, ductility or pressure tightness. Preliminary squeeze cast research has demonstrated potential for magnesium. This program will focus on applying this preliminary research for the production of an automotive component

Technical Challenges

a) Lack of suitable lubricants
b) Unknown properties from actual shape castings
c) Oxide reduction and metal handling problems
d) Microstructure segregation

TASK 2: LOW PRESSURE CASTING TECHNOLOGY

Through research and concept feasibility studies, the American Foundry Society Magnesium Committee has identified low pressure permanent casting process and variant technologies as the shortest route to procurement of magnesium structural automotive components. The Magnesium Low Pressure Development (MLPD) project (funded as part of the USAMP SCMD project) demonstrated concept feasibility and began magnesium low pressure process development. [1] MLPD successes included increased understanding of the effect of pressure application on magnesium fluidity and feeding, improved understanding of microstructure and grain refining techniques, validation of alternative protective cover gas technology, and development of a mold coating for magnesium permanent mold casting. HI-MAC will build on the MLPD knowledge base and demonstrate the production potential for automotive suspension components through process validation and limited production of a low pressure permanent mold cast control arm.

Technical Challenges

a) Cast aluminum applications in automobiles utilize several casting platforms (such as high pressure die casting, low pressure permanent molding, tilt pour permanent molding, precision sand etc.) but only high pressure die casting is currently used for magnesium automotive components.

b) Die-cast methods alone cannot be expected to meet future magnesium component demands

c) Large gap exists between aluminum and magnesium casting permanent mold casting technologies for high volume production.
   - Ø No existing mold coating exist for magnesium permanent molding
   - Ø There is little information on use of sand cores in metal molds when casting magnesium
   - Ø No defined permanent mold high temperature magnesium alloys
   - Ø Molten magnesium creates mold thermal control issues
   - Ø There is limited knowledge of fill profile and pressure requirements for magnesium low pressure casting

TASK 3: THERMAL TREATMENT

Some work has been done on alternative magnesium heat treatment cycles that can lead to significantly lower costs of magnesium cast components including preliminary investigations into fluidized bed heat treatment of magnesium alloys. Magnesium alloys typically require long solution and aging cycles to achieve the desired mechanical properties, and this can add increased costs to heat treated magnesium castings. By heat treating in a shorter time frame, the heat treat costs for magnesium components can be one-third their current costs and less than the costs of conventionally heat treated aluminum castings. There is evidence in the literature on wrought magnesium alloys that a multi-step solution and aging treatment can add significantly to the mechanical properties of magnesium components, yet little work has been done to investigate the potential effect of a multiple step heat treatment process for magnesium castings.

Technical Challenges

a) Current costs are higher than for aluminum heat treatments

b) Properties developed for heat treated magnesium components are low when compared to aluminum castings

TASK 4: MICROSTRUCTURE CONTROL

Casting microstructure is a key factor in component mechanical and fatigue properties. Development of microstructure through grain refining in aluminum alloys is well established. There are some low cost techniques for the grain refining of aluminum containing magnesium alloys. However, the current method used to grain refine the high temperature alloys includes using zirconium additions, which are costly and difficult to control in the production volumes required for potential automotive applications. Recent research has improved our understanding of magnesium metallurgical issues, defect formation and microstructure. But additional work will be required to produce new methods and materials for grain refining and microstructure assessment.

Technical Challenges

a) Lack of low cost grain refining options for high temperature alloys
b) Current grain refining techniques result in significant sludge and metal waste
c) Lack of shop floor techniques to assess proper grain refining
d) Few established relationships between grain refining and mechanical properties
e) Few established relationships between grain refining and castability
f) Insufficient metallurgical standards
g) Lack of up to date reference microstructures
h) Limited property-structure correlation at both the macro and micro level

TASK 5: COMPUTER MODELING AND PROPERTIES

Casting simulation suppliers and researchers have improved the state of simulation software, as new models have been developed and are being utilized by multiple foundries. Recent examples include models and new software modules for porosity in steel and aluminum alloys, hot tears and re-oxidation inclusion formation in steel castings, and thermo-physical properties for a variety of iron- and nickel-based alloys. While some preliminary work has been done on the solidification and fluid flow modeling on a few of the magnesium alloys, none of these advanced features are available for magnesium alloy casting.

Technical Challenges

a) No thermo-physical data exists for many magnesium alloys to be used for structural applications
b) No fundamental understanding of hot tearing in magnesium alloys, how it differs from other alloy systems and how to model it in available software
c) No correlation between existing magnesium models and casting results in casting processes such as low pressure, permanent mold and squeeze casting

TASK 6: CONTROLLED MOLTEN METAL TRANSFER AND FILLING

Low pressure casting has been identified as having the highest short term potential for production of cast magnesium components for automotive power train and suspension components. Development of a molten magnesium pump is critical to low pressure casting development, since the use of an open furnace vessel is used, enabling better access for grain refining and metal handling than the typical sealed low pressure vessel. The materials and technology used in current molten metal pumps are not suitable for use in molten magnesium. While materials may exist that will provide the long-term resistance to molten magnesium corrosion, testing and development work is needed to develop the right combination of materials and technologies for maximum magnesium pump longevity. Current aluminum pump technology will need to be improved to control the fill profiles with the precision required for low pressure magnesium casting.

Technical Challenges

a) No experience in precision electromagnetic pumping of magnesium into molds/dies
b) Unknown reaction of pumping chamber clogging due to magnesium oxides
c) No established methodology for melt protection/cleaning/grain refining using electromagnetic pumping systems
d) Unknown material issues with pump function and longevity for precision electromagnetic pumping of magnesium

TASK 7: EMERGING CASTING TECHNOLOGIES

A new casting process (Ablation) using an aggregate mold will be evaluated to cast magnesium based alloys for automotive components. The casting process allows metal to fill the mold quiescently followed by rapid solidification rates equaling or exceeding die-cast cooling rates and enabling sound cast structures to be created. The mold is removed during the solidification process, preventing residual stresses caused by casting/mold interaction. Technical feasibility has been demonstrated for aluminum castings. Preliminary experiments in magnesium have demonstrated concept feasibility. This continued investigation would determine technical feasibility, define potential mechanical properties and explore the potential for casting magnesium components.

Technical Challenges

a) Can ablation process be used in magnesium?
b) Is the process more suited for thin-walled body sheet or structural components?
c) Lack of developed procedures for use of this technology for magnesium.

TASK 8: TECHNOLOGY/COMMERCIAL TRANSFER THROUGHOUT THE AUTOMOTIVE VALUE CHAIN

Unlike aluminum, plastics and steel, there are no major R&D/technical institutions fostering the necessary infrastructure to support the large-scale application of automotive magnesium components. It is for this reason, that if the auto industry wishes to take advantage of magnesium's potential weight-reduction opportunities, it will have to nurture it through programs sponsored and directed by USCAR. This program will only have a significant impact on North America's ability to use more magnesium if the Tier One and Tier Two suppliers participate in this project. The International Magnesium Association (IMA), North American Die Casting Association (NADCA) and American Foundry Association (AFS) will participate in the project to make this task successful.

8.1 The project team will request the professional support of societies to publish notices of meetings, and project information as released by the project team.

8.2 The Big 3 will provide their respective purchasing departments with project developments.

8.3 Big 3 purchasing support of project team by providing information regarding Tier 1 and Tier 2 companies involved in casting light metal chassis and suspension components.

8.4 Distribution of findings and data to automotive sub-tier companies.

8.5 Issuance of progress reports at all major technical society meetings.

8.6 Issuance of a final report to all project participants.

Recent Progress

A substantial amount of progress has been made on many of the listed tasks. The squeeze casting cell for HI-MAC has been developed and sample castings produced. Control arm tooling is in development. (See Figure 2)

Figure 2 : Tooling for squeeze casting

The low pressure cell has been developed and sample castings will be produced during the summer of 2007. (See Figure 3)

Figure 3 : Low pressure cell for magnesium

Many lessons were learned in the MLPD program. Difficulties in thermal control of the mold and the tendency of many magnesium alloys to hot tear were considered in the development of the tooling for the low pressure cell. Hot oil will be used to control the mold temperature and pullbacks will be used so that the casting can contract without the development of high stresses that could cause hot tearing. (See Figures 4 and 5) Hot tearing work done during the MLPD program demonstrated that maintaining an adequate mold temperature was critical to eliminating hot tearing during magnesium permanent mold casting.

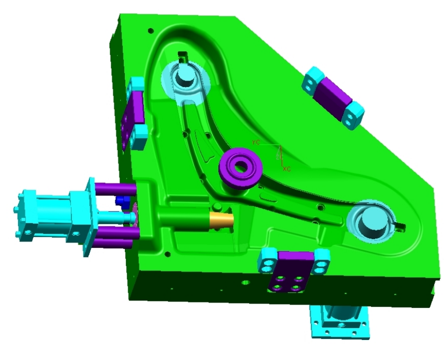

Figure 4 : Upper mold half showing retractable cores. The two cored holes shown in blue retract as well

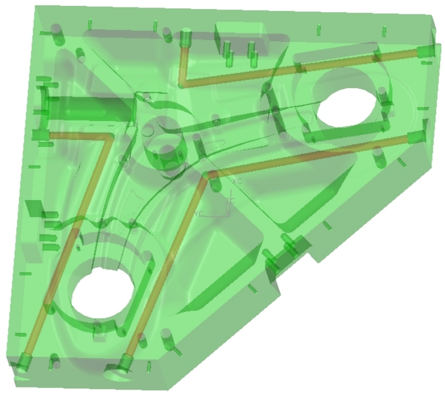

Figure 5 : Mold half showing oil heating and cooling lines

While the initial work with the control arm will not use expendable cores, the problems of trapped core gas during the MLPD program demonstrated a lack of understanding of the gas released from cores during magnesium casting. It was demonstrated experimentally that the amount of gas released during casting was different than in aluminum casting but no controlled studies were done at that time. The University of Alabama-Birmingham devised a procedure to measure both quantity and the chemical composition of the gases released during magnesium casting using various binder levels and coatings. The first part of the study has been completed and it shows differences in the amount of core gases released depending on whether the cores are exposed to aluminum or magnesium alloys.

Table 1 Gas evolution for standard binder system

	Magnesium	Aluminum
0.9% PUCB	6.0	4.9
0.9% PUNB	5.2	3.5
SO2	6.6	7.6

Table 1 shows gas evolution in relative units for three standard binder systems. In two of the three, gas evolution is higher in magnesium than in aluminum.

Table 2 Gas evolution for different core mixes

	Magnesium	Aluminum
0.9% PUCB	6.0	4.9
0.9%PUCB 1% KBF4	4.5	5.2
0.9% PUCB Water Wash	11.2	13.6

Table 2 shows gas evolution in relative units for cores prepared differently. The use of a KFB inhibitor in the core mix reduces the amount of gas produced when used with magnesium alloys but increases the gas produced when used with aluminum alloys. The use of a water based wash increases gas evolution using both aluminum and magnesium. A complete technical report on the core gas work should be available in 2008.

Alloys for Permanent Molds

Most magnesium alloys were developed to be used in either sand casting or die casting. Little work has been done in documenting properties or understanding castability of these alloys in permanent mold or squeeze casting. The only alloy where work has been done across processes has been AZ91. This program ran a range of sand cast and die cast alloys in a low pressure system at CANMET, Ottawa, Canada. All of the alloys will be tested both as cast as well as in an optimized heat treat condition. Table 3 shows results of the alloys tested to date in the F or as cast condition.

Table 3 Mechanical properties of low pressure permanent mold cast Mg alloys

Alloy Type	UTS MPa	Yield Strength MPa	%Elongation
AE44F	122	74	3.75
AM60F	149	68	4.2
MRI-206F	168	77	11.1
AZ91E-F	154	88	2.3

References

[1] Magnesium Casting Process Development: Designing An Engine Cradle For Magnesium Semi-Permanent Mold Casting, Transactions of the American Foundry Society V 113 Paper 05-217(06) P 911 - 924 (14 p)