D.1 High Integrity Magnesium Automotive Castings (HI-MAC)

STATEMENT OF WORK

Objective
Vehicle weight reduction is a key enabler to meet future stringent CAFE requirements, and this can best be achieved by the use of more light weight materials such as magnesium. This project objective is to develop existing and new metal casting process technologies and tools required to manufacture cost effective high integrity cast magnesium automotive chassis components. The goal is to increase the use of magnesium for structural automotive components that require properties beyond that can be obtained by current high pressure die casting (HPDC) processes. High Integrity castings are defined as sound castings with low porosity (meeting ASTM E-155 grade B or better) that meet high ductility and strength requirements. This project will develop casting processes for magnesium from existing processes for aluminum that include low pressure permanent mold and squeeze casting. Processing costs as well as technical and manufacturing issues for each process will be developed and validated; limited parts will be produced, investigated for material properties, analyzed by NDE and tested both by static / vehicle methods.

Executive Summary
The High Integrity Magnesium Automotive Castings (HI-MAC) is a United States Automotive Materials Partnership (USAMP) sponsored project to develop and optimize casting processes for automotive magnesium components. Converting steel and aluminum automotive components to lighter magnesium components will help reduce vehicle weight and in return, improve vehicle performance.

The United States Automotive Materials Partnership (USAMP) sponsored project, Structural Cast Magnesium Development (SCMD), successfully demonstrated that the re-design and conversion of an aluminum cradle to magnesium provided a weight reduction of approximately 35%. A similar reduction in weight can be achieved by converting suspension and chassis components to magnesium. To produce affordable, high strength magnesium castings, however, it is essential to further develop and optimize magnesium casting technologies (both existing and new). Specifically, the SCMD project identified three key technology barriers that
needs to be overcome before conversion to magnesium components is feasible. These key technology barriers are:

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

Eliminating these technical barriers for the conversion of automotive components to magnesium will help better the position the automotive industry to fulfill future automotive needs. The HI-MAC project addresses the near and mid term development required to overcome these technical barriers and will address the following issues:

- **Development of Casting Tools:** Develop technologies and tools that are required for sustainable long-term procurement of cast magnesium automotive components. Address the science and technological barriers that currently inhibit production and affect the affordability of cast magnesium components.

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

- **Infrastructure Development:** Development of equipment uniquely suitable for the production of magnesium components. Development of a broader scientific understanding of magnesium.

The 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. Additionally, HI-MAC will 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 by low-pressure cast, squeeze cast and a new emerging casting process. Control arms will be delivered for static and/or vehicle testing.
**Strategy**

The HI-MAC project is divided into eight tasks to help address key technology barriers for conversion of suspension and chassis components to magnesium.

**Task 1:** Squeeze Casting Process Development

**Task 2:** Low Pressure Casting Technology

**Task 3:** Thermal Treatment

**Task 4:** Microstructural Control

**Task 5:** Computer Modeling and Properties

**Task 6:** Controlled Molten Metal Transfer and Filling

**Task 7:** Emerging Casting Technologies

**Task 8:** Technology/Commercial Transfer Throughout the Automotive Value Chain

**TASK 1: SQUEEZE CASTING PROCESS DEVELOPMENT**

Squeeze casting is considered a “high integrity” casting process because it imparts qualities to a metal that are difficult to achieve with conventional casting techniques such as high pressure die casting. 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 and pressure tightness. Preliminary squeeze cast research has demonstrated feasibility of casting magnesium alloys. Continued process development 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**

The American Foundry Society Magnesium Division has identified low pressure permanent casting process and variant related technologies (VRC/PRC, PCPC etc) 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 and technical feasibility and began magnesium low pressure process development. MLPD successes included: 1) increased understanding of the effect of pressure application on magnesium fluidity and feeding, 2) improved understanding of microstructure and grain refining techniques, 3) validation of alternative protective cover gas technology, and 4) development of a mold coating for magnesium permanent mold casting. HI-MAC will build on MLPD knowledge
base and demonstrate the production potential for automotive suspension components through process validation and limited production of LPPM cast control arms. HIMAC research will also validate and commercialize a magnesium permanent mold coating.

Technical Challenges
a) Lack of suitable mold coatings for permanent mold casting of magnesium
b) Introducing sand cores in the metal mold
c) Unknown mold temperature requirements
d) Lack of thermal control for the mold
e) Limited knowledge on the fluidity of magnesium

TASK 3: THERMAL TREATMENT
Magnesium alloys typically require long solution and aging cycles to achieve the desired mechanical properties. These long cycles add to the cost of manufacturing magnesium components. The American Foundry Society Magnesium Research Committee has completed preliminary research into alternative magnesium heat treatment cycles and new heat treating technologies such as the fluidized bed process. By reducing the heat treating time, it is envisioned that the heat treating costs can be reduced by over 70%. Furthermore, previous research has shown that mechanical properties of wrought magnesium alloys can be significantly increased through a multi-step heat treating process. Multi-step heat treating may also yield similar results for magnesium casting alloys.

Technical Challenges
a) Higher costs than aluminum heat treatments due to lengthy cycle times
b) Distortion of thin wall components
c) Low level of development resulting in non-optimized heat treat procedures

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 reasonable techniques for the grain refining of Aluminum containing magnesium alloys. However, the current method used to grain refine the high temperature magnesium 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
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 structure-property relationships 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 prediction of 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) Lack of thermo-physical data for magnesium alloys required for modeling
b) Limited understanding of how to model hot tearing in magnesium alloys
c) No correlation between existing magnesium models and casting results for 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 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 an open furnace vessel can be 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) Precision filling of molds and dies with magnesium using electromagnetic pumps
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

**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 in under 120 seconds after completion of pour, preventing contraction of the cast structure and mold from thermal stress interaction. Technical feasibility has been demonstrated for aluminum castings. Preliminary experiments in magnesium have demonstrated concept feasibility. Continued investigation will 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. In addition, 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.