K. Magnesium Front End (AMD 603[i] and AMD 604[i])

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Objective

The Magnesium Front End (MFE) effort consists of the two related projects:

- **Magnesium Front End Design and Development (AMD 603)**: The goal of this USAMP project is to develop and validate lightweight magnesium (Mg) front end designs for unibody and body-on-frame architectures with 50-60% mass reduction and equivalent performance compared to the steel baseline.
- **Magnesium Front End Research and Development (AMD604)**: The goal of this Canada-China-US collaborative project is to develop key enabling technologies (e.g., high-integrity body castings, extrusions, sheet forming, joining) and the accompanying knowledge base (crashworthiness, NVH, durability and corrosion resistance) to permit design, and eventual implementation of lightweight Mg automotive body structures with equivalent performance and affordable cost.

Two attributes of this effort are particularly significant:

- The focus on an entire "front end" structures as the development object as opposed to individual components, thereby offering critical vehicle-level benefits in terms of mass distribution and performance, while challenging the technical community to devise materials and manufacturing approaches to permit mass production of such structures.
- The establishment of a truly international effort (AMD 604) bringing together scientific and engineering expertise in the field of Mg technology from Canada, China and the United States, in what may be a first-of-its-kind collaboration.

Approach

- Project Organization and Administration. Because of the magnitude of the overall effort involving both fundamentally new and challenging technologies, and also a high level of international collaboration and participation, particular attention has been paid to the establishment of an organizational and management structure that facilitates both the flow of information and the coordination of activities.

- Partitioning of Projects. The extent of this effort also demands careful partitioning of the technical tasks, firstly, at the international level by degree of alignment and capabilities directed toward the overall goals, and, secondly, on a technical level which separates the design and analysis function from the enabling technologies required to achieve the intended outcomes.
- Design and Analysis. The design and analysis functions relating to the envisioned Mg front-end structures are partitioned under a separate USAMP project (AMD 603 Magnesium Front End Design and Development – MFEDD) for purposes of retaining OEM-critical design aspects within the confines of the USCAR collaboration agreement between Ford, GM and DaimlerChrysler. "Donor" design target vehicle structures have been provided by GM (rear-wheel-drive (RWD) unibody design) and Ford (light truck body-on-frame (BOF)). These structural "envelopes" will serve as the starting point for consideration of material replacement with Mg alloys. Actual designs employable in computer-aided engineering (CAE) and subsequent analysis are expected to be conducted by an independent design house.
- Enabling Technologies. The ability to actually fabricate a Mg-intensive front-end structure for use in mass-produced automobiles critically depends on existence and implementation of robust technologies for manufacturing and, furthermore, material properties that provide acceptable, if not superior, performance to their present comparators (in this case principally steel stampings joined by resistance welding, arc welding or adhesive bonding). It is the area of "enabling technologies" that is expected to achieve the greatest benefit from international collaboration with experts in metal production, forming, joining, finishing and durability. This aspect is the basis for the Magnesium Front End Research and Development (MFERD) project, AMD 604.
- Integrated Computational Materials Engineering (ICME). This is the third, related USAMP project, which is critical to the automotive applications of Mg alloys and other materials. ICME is intended to provide a unifying organization structure to a palette of computational tools integrating materials engineering and manufacturing disciplines.
- Technical Gateways. As in most product development formalisms, technical gateways provide the means for assessing engineering progress against intended metrics at sub-levels of the project, with the aim of assuring overall targets are ultimately achieved, or, alternatively, that further work is discontinued if required metrics cannot be achieved. In this effort, gateways exist for both the design stage and also for the enabling technologies, such that efforts for actual prototype build (Phase 2) only occur at successful accomplishment of Phase 1. Overall timing and conceptual flow is illustrated in Figure 1.

Accomplishments

- Official launch of AMD 603 and AMD 604 occurred with the OEM "kickoff" meeting on November 1, 2006 at USCAR Headquarters, followed by an OEM-Supplier kickoff on November 28. Following the November, 2006 kickoff meetings, the individual project task teams in AMD 603 and AMD 604 have begun organizational meetings, participant selection and refinement of the various technical agendas. These activities are expected to continue into 2007 as both the USAMP and international technical formats evolve.
- Leading up to launch of the MFERD project by the respective organizations in the Canada, China and U.S., was an over three-year effort in the organization and management structure tasks by representatives of DOE, USAMP, CANMET, the Chinese Ministry of Science and Technology (MOST), the China Nonferrous Metals Industry Technical Development and Exchange Center, and individual researchers, primarily the following events:
    1. Informal discussion of the concept of a three-way international collaboration by Dr. Joseph Carpenter (U.S. DOE), Dr. Jennifer Jackman (CANMET) and Professors Shoumei Xiong and Baicheng Liu of Tsinghua University (Beijing) at the Light Metals Technology Conference in Brisbane, Queensland, Australia in September, 2003.
    2. More extensive discussion involving Drs. Carpenter and Jackman and Chinese Ministry of Science and Technology (MOST) officials (Mr. Bing Liu, Mr. Jing Xu) and Dr. Wenfang Shi (China Nonferrous Metals Industry Technical Development and Exchange Center) at the International Magnesium Conference (Beijing, September 2004). Subsequent discussions at this meeting also included Dr. Alan Luo of General Motors Corporation.

3. A technical organizing meeting held at the campus of the University of Michigan – Dearborn in October of 2005, at which time the conceptual target of the vehicle front end structure was introduced by Dr. Luo as a "focal point" for collaborative work between the three nations.
4. Meetings of the ad hoc Project Steering Committee (PSC) and Project Technical Committee (PTC) at Kauai, Hawaii in April, 2006 and Beijing in June of 2006, further defining the management structure and operating principles.

- By the end of calendar 2006, all three participating countries had conducted project kick-off events for MFERD, and the technical teams had begun organization and refinement of the technical agenda set forth in the project statement of work (SOW) which had been agreed to during 2006.

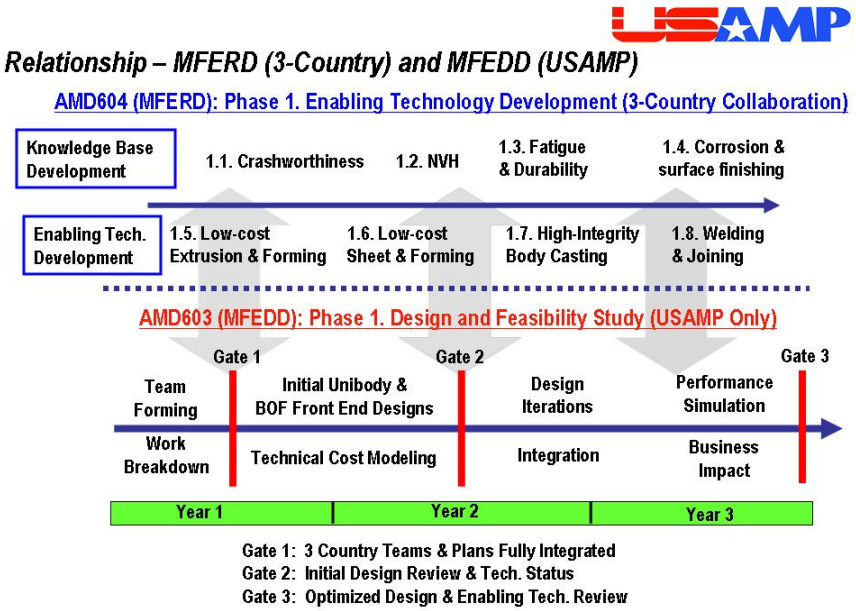

Figure 1. Structure and timing of Magnesium Front End effort.

Future Direction

- The AMD 603 design and analysis task will start in the first quarter, and the technical cost modeling task will begin in the fourth quarter in 2007.
- The next official event for AMD 604 will be meetings of the Project Steering Committee (PSC), Project Technical Committee (PTC) and individual task areas on March 1 and 2, 2007, following the TMS Annual Meeting in Orlando, FL, that week. A collaborative R&D work plan is expected to be prepared and agreed by all country task leaders, for each task, at this event. Ongoing events for the visiting Chinese participants are planned for the Detroit area the following week.
- It is expected that the ICME project will be approved by USAMP and funded by DOE in 2007. Using the Mg front-end body application as a test bed, this project aims to establish an ICME infrastructure for alloy development, microstructural engineering, and process and product optimization.

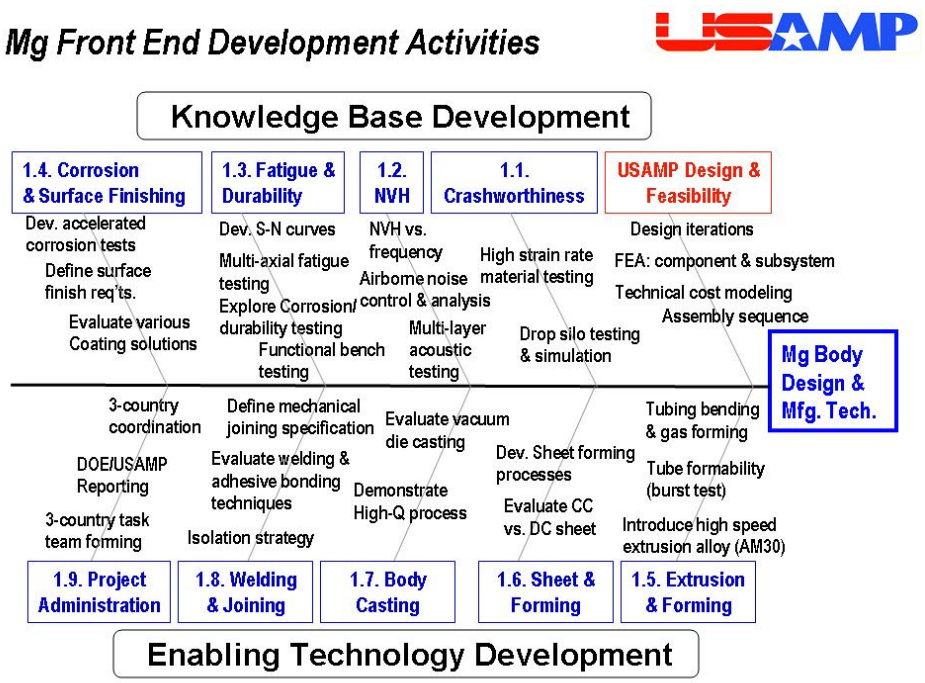

Figure 2. Magnesium Front End Research and Development project structure fishbone diagram.

Introduction

Despite both advances in Mg manufacturing technologies and favorable material costs leading to generally increasing levels of use in automotive structures, widespread and expansive use of Mg alloys as a major automotive structural material in the same class as steel and aluminum (Al) is yet to be realized. This is, in part, due to fundamental physical properties of Mg castings, which are the predominant form of usage, particularly with regard to deformation and fracture behaviors. Furthermore, technologies which permit the manufacture of extended structures by joining of individually formed components are not well-developed for this material. Nevertheless, as a structural material, with high strength-to-weight values approaching or exceeding that of Al, Mg offers an attractive approach for achieving the FreedomCAR materials goals of up to 50% weight reduction in comparison to steel alternatives, with cost, reliability and recyclability attributes that are comparable or better than other structural materials of consideration for these tasks.

Project AMD 604 (Magnesium Front End Research and Development – MFERD) brings together a unique team of international scope – i.e., Canada, China and the United States – to explore certain "enabling" technologies which could, if successful, permit the integration of Mg-based subsystems into optimized assemblies for vehicle body structure applications using the "front end" structures as a test bed, thereby permitting exceptional levels of overall vehicle weight reduction and handling attributes supporting the FreedomCAR initiative.

The organizational aspects of the project have been treated in the earlier section of the report and will not be elaborated upon here. The formation of an international effort is aimed at bringing together the unique attributes from each nation, e.g., United States – product development, design and manufacturing, Canada – extractive metallurgy and manufacturing, and China – low-cost extraction, forming and manufacturing, into a homologous project with the common technical focus of a useful and critical aspect of lightweight vehicle architecture.

The following sections describe key technical attributes of the project and accomplishments occurring during FY 2006.

Project Technical Structure and Achievements

Figure 2 illustrates in "fishbone" format, how the various organizational aspects of the project contribute to the overall objective of a durable, affordable and manufacturable magnesium front-end structure. The program is divided into two major elements:

(1) Knowledge-base development incorporating features of: corrosion resistance and surface treatment (Task 1.4), fatigue and durability (Task 1.3), NVH (Task 1.2) and crashworthiness (Task 1.1), and

(2) Enabling technologies development including: extrusion and forming (Task 1.5), sheet manufacture and forming (Task 1.6), body castings (Task 1.7), and joining (Task 1.8). Additionally, Task 1.9 provides for a project administrator to assist in matters of project organization, three-country coordination, reporting and financial analysis.

The "fishbone" diagram also illustrates the relationship to a separate but closely related project (AMD 603 - MFEDD) which concentrates on design aspects using contributed design data from the USCAR participant companies (i.e., Ford, DaimlerChrysler and GM), and is organizationally isolated from the three-country collaboration for proprietary reasons.

During 2006, the two "donor" structural platforms, namely, a "unibody" structure for use with an RWD GM vehicle (steel baseline design in Figure 3) and a BOF structure intended for use in a Ford light truck structure (schematized in Figure 4) were identified and formed the basis for future designs and analyses.

In addition to formulating the overall project SOW in FY 2006, project task teams in the U.S. conducted individual organizational meetings for the purpose of identifying potential suppliers and university researchers, as well as refinement of the specific task objectives as will integrate into the overall structure of the effort.

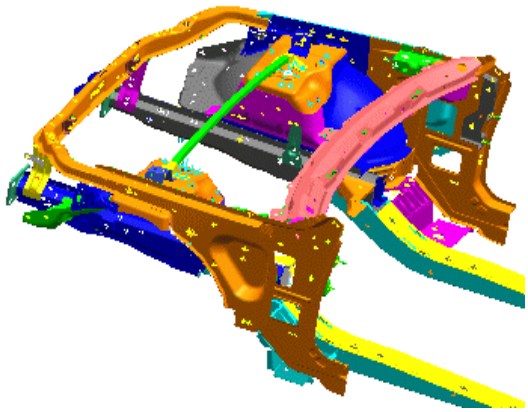

Figure 3. Steel baseline front-end design for unibody architecture.

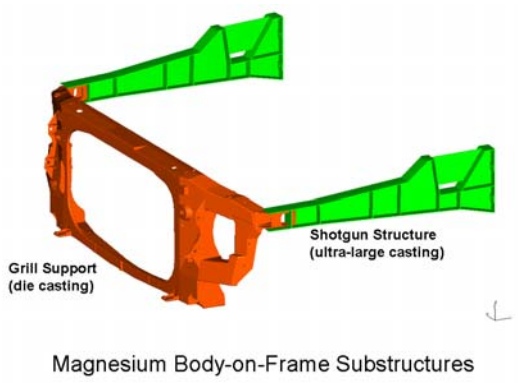

Figure 4. Anticipated elements of magnesium-intensive Body-on-Frame structure.

Conclusions

The Magnesium Front End effort, consisting of the USAMP Magnesium Front End Design and Development (AMD 603) and the first-of-its-kind Canada-China-US collaborative project Magnesium Front End Research and Development (AMD 604), has been formalized and launched in 2006. This project seeks to both explore emerging technologies and conduct basic research in the design, manufacture and performance of structures predicated on forming, joining and finishing of commercial Mg alloys.

Presentations/Publications

- J. Carpenter, J. Jackman, N. Li, R. Osborne, B. Powell, and P. Sklad, "Automotive Magnesium Research and Development in North America," International Magnesium Association 63rd Annual World Magnesium Conference, Beijing, China, May 21-24, 2006. Plenary

presentation at 2nd International Conference on Magnesium, Beijing, China, June 26-28, 2006.

- A.A. Luo, "Research and Development Challenges for Magnesium Applications in Automotive Structures", Plenary presentation at 2nd International Conference on Magnesium, Beijing, China, June 26-28, 2006.

- J. Jackman and J. Carpenter, "Automotive Magnesium Research and Development in North America," Plenary presentation by E. Nyberg at the Intl. Conference on Mg Alloys and their Applications, Dresden, Germany, November 6, 2006.

Acknowledgments

The success of this project is due to the dedicated efforts of a large number of team members at Ford, DaimlerChrysler, and General Motors, as well as international counterparts in Canada and China. The continuing support of our respective organizations and the US Department of Energy is gratefully acknowledged.

[i] Denotes projects 603 and 604 of the Automotive Metals Division (AMD) of the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the "Big Three" traditionally USA-based automakers to conduct joint pre-competitive research and development.