1. Introduction

As a component of the U.S. Department of Energy's (DOE's) Vehicle Technologies Program (VTP), the Lightweight Materials (LM) activity focuses on the development and validation of advanced materials and manufacturing technologies to significantly reduce light and heavy duty vehicle weight without compromising other attributes such as safety, performance, recyclability, and cost. Because it takes less energy to accelerate a lighter object, replacing cast iron and traditional steel components with LM such as high-strength steel, magnesium, aluminum, and polymer composites can directly reduce a vehicle's fuel consumption. For example, a 10% reduction in vehicle weight can result in a 6%–8% fuel economy improvement. Reducing vehicle weight has other benefits such as allowing cars to carry advanced emissions control equipment, safety devices, and integrated electronic systems without becoming heavier. LM are especially important for improving the efficiency and range of hybrid electric, plug-in hybrid electric, and electric vehicles because they offset the weight of power systems such as batteries and electric motors.

The LM activity focuses on the research and development (R&D) required to support reduced vehicle fuel consumption. The primary LM activity goal is to validate a cost-effective weight reduction of 50% in total vehicle weight by 2015 while maintaining safety, performance, and reliability as compared to a 2002 baseline vehicle weighing 3450 lbs.

In the short term, vehicle weight reduction can be achieved by replacing heavy steel components with materials such as high-strength steel, aluminum, or glass fiber-reinforced polymer composites. The properties and manufacturing of these materials are well established, but better and cost effective technologies and processes are needed for joining, modeling, and recycling them. In the longer term, even greater weight savings are possible (50%–75% weight reduction for some components) through use of advanced materials such as magnesium and carbon fiber reinforced composites. However, more extensive R&D is needed to better understand the properties of these materials and reduce their costs.

Research and development work conducted within the LM activity is broken down into three categories: Properties and Manufacturing, Modeling and Computational Materials Science (CMS), and Multi-material Enabling. Work within Properties and Manufacturing aims to improve properties (such as strength, stiffness, or ductility) and manufacturability (such as material cost, production rate, or yield) of a variety of metal and polymer composite materials. The focus of the Modeling and CMS and Multi-material Enabling work is to provide supporting technologies necessary for full system implementation such as joining methods, corrosion prevention techniques, predictive models, and other computational tools. This introduction summarizes the highlights of the program in all of these areas during the 2009 fiscal year. The following sections outline objectives, progress, and highlights for each of the key materials in the program. The remainder of the report provides details and specific technical accomplishments of each project.

Carbon Fiber Reinforced Polymer Composites

The focus for this area continued the investigation of lowering the cost of carbon fiber through different low cost starting materials including textile grade polyacrylonitrile, lignin, and polyolefins; and advanced processing techniques for stabilization and oxidation as well as carbonization/graphitization that promise to improve the rate and cost of conversion to carbon fiber. The process improvements are enabling validation of successfully converting larger volumes (tows) of precursor to carbon fiber. This section includes detailed reports on progress made under each aspect of cost reduction to realized carbon fiber at $5 per pound.

In the area of lowering the cost of processing, the predictive modeling capability has developed tools for prediction of fiber length and orientation of long fiber injection molded thermoplastic composites. From this information, the mechanical properties can be predicted. The focus has shifted from model development to validation of prediction of stiffness and strength in progressively complex shaped parts. The detailed report for predictive engineering documents the advances made in developing and understanding this aspect so that industry may use this robust capability to accelerate product development of injection molded composites and lower the technical risk by optimizing tool design and injection molding conditions to optimized properties.

Magnesium Alloys

Magnesium (Mg) alloys, with the lowest density of all structural metals, have the potential to reduce component weight by greater than 60%. However, significant technical barriers limit the use of Mg to approximately 1% of the average vehicle by weight. These barriers include high raw material cost and price volatility, relatively low specific stiffness, difficulty in forming sheet at low temperatures, low ductility of finished components (such as in Figure 1), and a limited alloy set, among others. In addition, using Mg in multi-material systems introduces joining, corrosion, repair, and recycling issues that must be addressed.

Figure 1. Mg Extrusion Exhibiting Low Ductility Failure

As described in Chapters 2, 3, and 6 of this report, Mg R&D conducted through the LM activity has addressed metallurgical, manufacturing, and design challenges in both cast and wrought Mg. Fundamental research, such as the work discussed in report 6E, has helped develop a better understanding of the deformation mechanisms in Mg. Manufacturing research, such as report 2B, has helped advance Mg towards more practical manufacturing. Significant work in design and applications, such as discussed in reports 6B and 6C, are creating opportunities for Mg use in near term automotive designs.

Highlights from the 2009 fiscal year include demonstrating a prototype Mg warm forming manufacturing cell capable of 4 jobs-per-minute (report 2B) and design of a Mg intensive vehicle front end that is 45% lighter than the standard design. With enormous potential for weight reduction, Mg will continue to be a key material within the LM portfolio.

Aluminum Alloys

Aluminum (AL) alloys represent a middle-ground in the structural light metals spectrum. Years of development within the aerospace, construction, and automotive industries have led to a well developed and reasonably well understood alloy and processing set. Applications of Al within automotive design include hoods and panels, power train components, and even entire vehicle body-in-white (BIW) structures. There are several barriers to the increased use of Al in vehicle weight reduction applications such as material cost, room temperature formability, and limitations within the existing manufacturing infrastructure. As with Mg, the addition of significant amounts of AL to the automotive manufacturing stream presents added multi-material challenges in joining, corrosion, paint and coatings, repair, and recycling.

LM funded work in AL includes exploration of increased formability processing techniques (reports 2C and 2D), improved post-form properties of superplastically formed panels (report 2G), and demonstration of high strength cast AL components (report 3A).

Advanced High Strength Steel (AHSS)

Conventional iron and steel alloys are prominent in existing vehicle architectures, making up over 70% of the weight of a vehicle. Despite the relatively high density of iron based materials, the exceptional strength and ductility of advanced steel offer the potential for efficient structural designs and reduced weight. Application of a new generation of AHSS has the potential to reduce component weight by up to 25%, particularly in strength limited designs. Steel components are also generally compatible with existing manufacturing infrastructure and vehicle materials, making them a likely candidate for near-term weight reduction. Steel development and research in the LM activity is focused on introducing the so-called "3rd generation". As shown in Figure 2, 3rd generation AHSS are targeted to properties in between 1st and 2nd generation AHSS with high strength, improved ductility, and low cost.

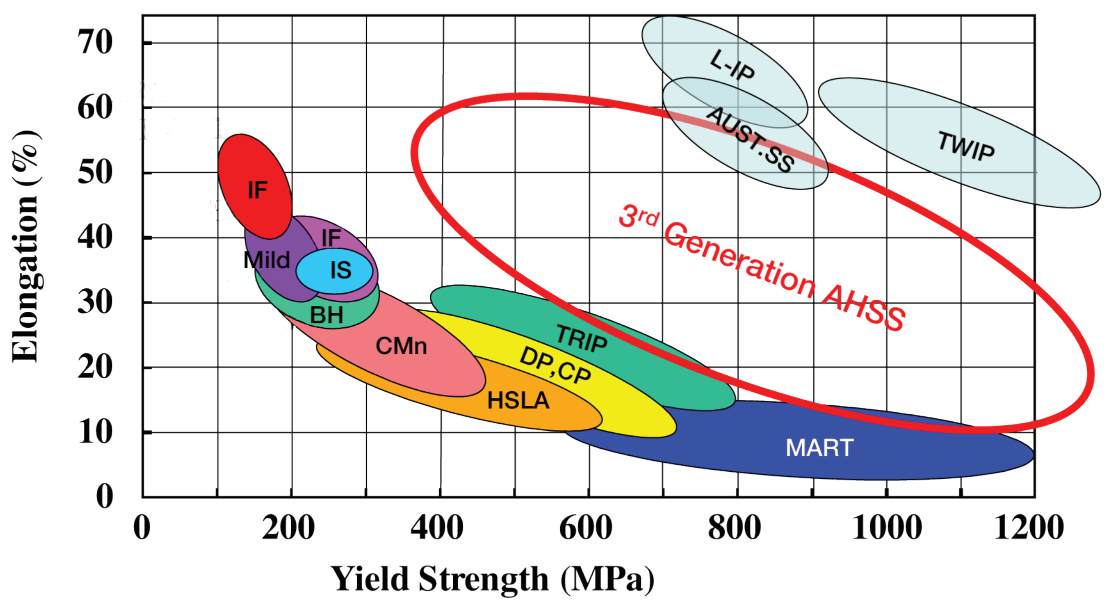

Figure 2. Yield Strength versus Uniform Elongation for a variety of steel types

As outlined in Chapter 5 of this report, steel development in the LM activity is occurring at all levels of the technology spectrum, from fundamental university research (reports 5M – 5U and others) to industry collaboration (reports 5A – 5H and others). The National Labs have also played a significant role in understanding and improving the properties and manufacturability of advanced steels.

Highlights from fiscal year 2009 include demonstrating a cost- and stiffness-neutral AHSS rear chassis design that is 28% lighter than the standard version (report 5H), and developing an improved understanding of the mechanisms and process requirements for quench & partition (Q&P) steels (report 5P). Continued demonstration of improved properties, combined with a better understanding of metallurgical strengthening and ductility mechanisms are targeted as the LM activity continues to support AHSS research.

Multi-material Enabling

Improving the properties and manufacturability of LM such as carbon fiber reinforced polymer composites, Mg, and AL will allow for increasing use in automotive applications. The increased use of mixed materials in vehicle systems is accompanied by technological hurdles in areas such as joining, corrosion, non-destructive evaluation, and recycling.

In the area of joining, significant work has been dedicated to evaluating new solid-state joining techniques such as friction stir welding (FSW) and ultrasonic welding (USW). Fusion welding of joints between materials with significant melting temperature differences can lead to a variety of metallurgical challenges. Solid state joining methods circumvent these issues by relying on different joining mechanisms. Advances in these techniques can be found along with other joining work in Chapter 9.

Corrosion issues in multi-material systems can limit durability and add cost during vehicle construction. Several research groups are investigating corrosion mechanisms and prevention techniques in the LM activity. Developing a better understanding of how LM corrode in hostile automotive environments (such as in reports 2H and 3G) will enable better predictions and designs for durability.

Several other system enabling issues are also addressed in this report. From advanced non-destructive evaluation techniques for LM (Chapter 10) to improvements in recycling technology (Chapter 11), the LM activitycontinues to identify and address multi-material technology gaps.

Modeling and Computational Materials Science

Developing new, lightweight vehicle structures will require advances in areas such as structural design, processing, and alloy chemistry. Classical approaches to these advancements such as experimental, analytical, or Edisonian techniques can often yield the desired results but with limited efficiency. Numerical and computational approaches to materials engineering offer the potential to "short-circuit" the development cycle through predictive engineering and simulated experimentation. Advanced modeling techniques can also be used to optimize designs in well established materials, further reducing components weight such as in Figure 3. By reducing the time and resources necessary to advance LM towards vehicle applications it is possible to introduce relatively immature materials such as Mgwithout the decades (or centuries) of development applied towards conventional steel and AL.

The LM activity focus on modeling and computational materials science (CMS) is manifest in a variety of projects. Examples of these techniques applied to the development of Mg (such as in reports 6F and 6G) and polymer composites (report 8K) demonstrate the potential of CMS. Process models to improve performance or predictability (such as in report 9B) are also in development to help support the enabling multi-material processes that will be necessary. Most projects conducted in the LM activity contain at least a small element of modeling or CMS.

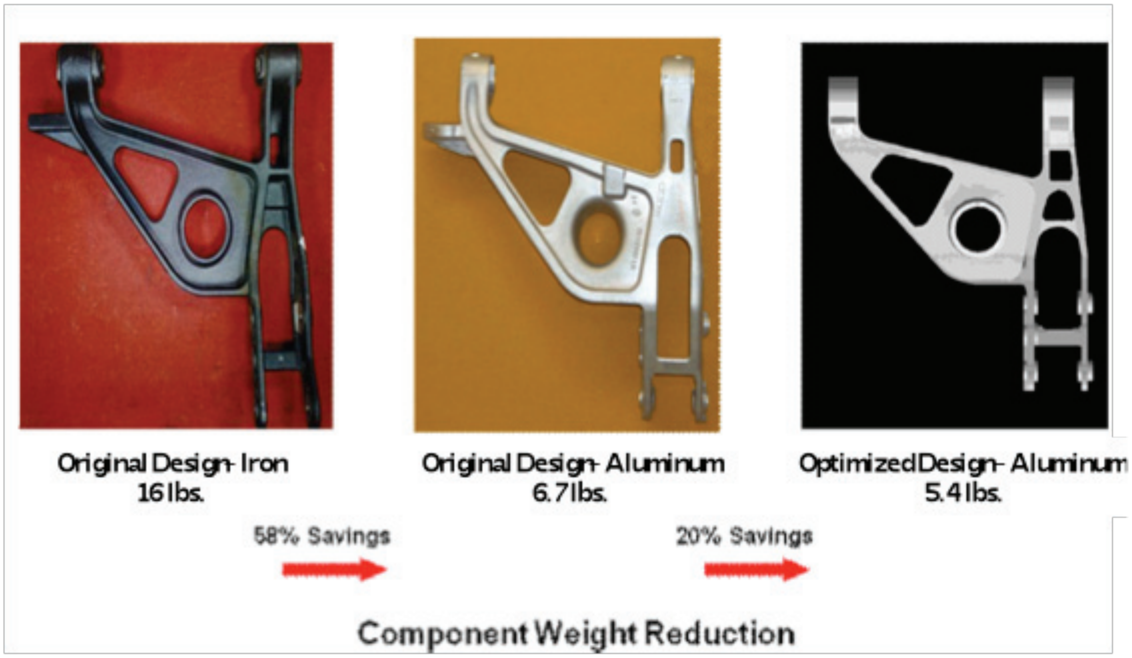

Figure 3. Example of Using Computational Materials Science to Optimize a Lightweight Design

Looking Forward

The following reports provide a detailed description of the activities and technical accomplishments of the LM activity during the 2009 fiscal year. The work shown here has produced technologies that make today's vehicles more efficient, safe, and affordable. In collaboration with industry, universities, and national laboratories, VTP continues to develop the next generation of lightweight components. These efforts are building the foundation of technologies—and technology manufacturers—that tomorrow's vehicles need to achieve ultra-high efficiency and resulting reductions in petroleum use and greenhouse gas emissions.