Developing a Technical Roadmap for Automotive Lightweight Metals Recycling

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The U.S. Department of Energy (DOE), together with the Vehicle Recycling Partnership LLC (VRP) of the United States Council for Automotive Research LLC (USCAR) and Argonne National Laboratory, sponsored a one-day workshop on automotive recycling technology issues on September 24, 2008 at the USCAR offices in Southfield, MI. The purpose of the meeting was to identify R&D technology needs for the optimum recovery, reuse, and recycling of lightweight automotive materials.

Workshop Objective

The primary objective of the meeting was to facilitate a technology interaction and exchange between automotive companies, metals suppliers and recyclers, and the national laboratories and academia that would ultimately result in the development of a technical roadmap with a time frame of 25 years to guide future R&D investment. The scope of the meeting was to cover lightweight automotive materials such as aluminum, magnesium, titanium, and metal-matrix composites in decreasing order of priority.

Secondary objectives of the meeting were to evaluate and identify expected significant losses in the life cycle of these lightweight metals, primarily in the automotive sector, and then identify technology and R&D needs and priorities that can cost effectively minimize these losses to ensure optimum materials utilization and recycling.

Participants

A group of about 35 subject matter experts included participants from the original equipment manufacturers (OEMs) of Chrysler LLC, Ford Motor Company, and General Motors Corporation; representatives from Argonne National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory (PNL); representatives from the Canadian Centre for Mineral and Energy Technology (CANMET) and the Canadian AUTO21 project; representatives from the Center of Automotive Research (CAR); members of the Institute of Scrap Recycling Industries (ISRI) and other recycling and scrap shredding companies; as well as the Automotive and Light Truck Committee of The Aluminum Association; and industry participants from Novelis, Inc. and Aleris, Inc. The workshop consisted of a mix of informal presentations and vigorous facilitated discussions from the participants to identify the challenges to the effective recycling of lightweight materials and the priorities for action.

Background

Over the past decade the quantity of light metals used by vehicles has continued to increase and is projected to grow further in the future. For example, surveys by the Ducker Company show that the amount of aluminum in the average North American vehicle has grown from about 80 lbs in 1974 to 327 lbs in 2007 and is projected to reach 374 lbs by 2015. Historically, the aim of lightweight metals has been to reduce vehicle weight, increase fuel efficiency, improve vehicle performance, and enhance safety.

Recent growth in the use of lightweight metals for automotive construction has been in response to rising fuel costs as U.S. automakers look to provide consumers greater fuel efficiency and to meet more stringent Corporate Average Fuel Efficiency (CAFE) regulations passed recently by Congress. With the development of alternative propulsion systems such as plug-in hybrids and electric drive vehicles, the trend to lightweight vehicles is expected to continue. In preparation for the influx of lightweight materials, the workshop was timely as the world strives to attain more sustainable mobility.

General Presentations

The participants were welcomed by Dr. Claudia Duranceau, Ford senior research recycling engineer and member of the VRP Engineering Project Oversight Committee and Dean Paxton of PNL (on behalf of Joe Carpenter of the DOE Office of Vehicle Technologies). Duranceau opened to say that the VRP wanted to achieve a roadmap that would aid understanding of state-of-the-art lightweighting metals—especially aluminum and magnesium—but the discussions also explored the possibilities of the use of titanium and metal matrix composites (MMCs) in the future.

The workshop aimed to uncover key technology gaps and suggest needs and high priorities for future R&D. Paxton indicated that from the DOE perspective, the 2010 goals of the FreedomCAR and Fuel Partnership are to achieve a 50% reduction in the weight of vehicle structure and subsystems, increased affordability and an increased use of recyclable materials. With regard to the latter, cost is the major challenge that must be overcome. It was noted that recycling might provide a significant beneficial impact on the cost of lightweight metals.

Recyling for Recovery While Preserving Material Value: Jay Baron, president of the Center of Automotive Research (CAR), provided an overview of future automotive trends. He cited the increasing pressures for the OEMs due to fuel prices, higher light metals costs, and the need to retool facilities for the production of smaller vehicles. He noted the trend toward lower volumes per vehicle nameplate and that more niche vehicles are being built on global platforms to extend program life and utilize production capacity. Trends in material use show that the use of high-strength steel, aluminum, and plastics is increasing primarily at the expense of mild steel. Baron also said that the bulk of these materials is recycled—present estimates for recycling in the U.S. are 97% for steel and 90-95% for aluminum—but that recycling is complex and driven primarily by market demand in North America.

A key issue, according to Baron, in recycling is not just recovering the materials, but doing so in a way that preserves material value. The complexity of vehicle propulsion systems will increase greatly in the future with a gradual phase-out of gasoline engines and the growth of hybrid, clean diesel, and flex-fuel propulsion systems. Since all the producers have finite limits of financial and technical resources, he advocated increased collaboration between the OEMs in USCAR and the transplant auto producers such as Nissan, Honda, and Toyota as a means to mitigate the technical and financial risk.

Boyd Davis, president of Kingston Process Metallurgy Inc., echoed the benefits of collaboration in describing the activities of AUTO21, the Canadian R&D collaboration (Figure 1). The program enables a wide collaboration between industry and academia, allowing for an effective and more relevant concentration of R&D for

Figure 1. Boyd Davis, a Theme D Leader at Auto21, discusses the future of recycling lightweight metals at the September workshop at USCAR in Southfield, MI. Photo courtesy of USCAR.

the auto industry among the Canadian universities. Davis mentioned that the AUTO21 program had recently been reauthorized for the next seven years. He also mentioned that about 500 students were involved in all facets of the program, which augers well for the auto industry in the future.

Importance of Separating Al and Mg Recycling Streams: Adam Gesing, president of Gesing Consultants, provided an overview of light metals in current post-consumer metal recycling systems. He stressed that market needs drive much of what actually is sorted and sold back to the industry. He noted that currently, much of the nation's post-shredder scrap is exported to China for hand sorting. Thus, the scrap and its energy content is also lost. With regard to scrap sorting and the growing use of magnesium, he indicated that a key need is to separate the aluminum and magnesium recycle streams. This would have the benefit of growing a stronger secondary magnesium industry; at present only a fledgling secondary industry exists. If the Al and Mg streams are not separated, magnesium has to be removed subsequently by fluxing which results in losses of both aluminum and magnesium. Accordingly, a separation of both streams will optimize the recovery of both metals. Gesing emphasized that one needs a complete system for recycling—it is not feasible to "cherry pick" a particular metal or alloy out of the system—without a plan to treat the bulk of the waste. He also noted that more than 40% of magnesium is used as an alloying addition to aluminum alloys and about 10% is used for steel desulphurization.

Metal Specific Presentations

Specific presentations were made for aluminum by Doug Richman of Kaiser Aluminum, for magnesium by Bob Powell of General Motors, and for titanium by Curt Lavender, PNL and for MMCs to discuss the trends in automotive applications in each case and highlight any technology gaps and R&D needs. These were followed by presentations focused on recycling and melting process developments for aluminum (Ray Peterson, Aleris International, Inc.) and for magnesium (Boyd Davis, Kingston Process Metallurgy Inc.), respectively. The formal presentations were then followed by a wide-ranging discussion which attempted to prioritize the technology gaps and R&D needs.

Identification of Areas for Improvement in Al Recycling: In the case of aluminum, Richman mentioned that the driver for recycling is that 95% of both the energy and emissions are saved as compared to deriving the metal from the ore. Accordingly, metal suppliers will attempt to use as much recycled material as possible. The important issue is to recycle the metal with a minimum loss of value. Unfortunately, the value of shredded auto hulks is reduced by some 30% as compared to pure ingot. A major technology gap in the recycling of aluminum alloys is the build up of iron impurities that arise from the wear of processing equipment. This iron content compromises mechanical and corrosion properties of the recycled material. A process to remove iron dissolved in molten aluminum would be a huge benefit to the quality of the recycle stream. Likewise, it is important to minimize the use of dissimilar metal fasteners, design more monolithic components, and reduce the use of paint coatings and adhesives as much as possible. Finally, Richman noted that alloying additions of lithium from certain aerospace alloys and various particulates from MMCs are most detrimental to the quality of recycled aluminum.

Complexities of Mg Recycling: Concerning magnesium, Powell noted that there are many similarities with aluminum but that the total usage in auto applications is at least 20 times smaller than for aluminum. Recent comparative numbers for the General Motors vehicle fleet were cited as 325 lbs for Al and 14.8 lbs for Mg for the average vehicle. Magnesium is mostly used as die castings with little wrought material being used. Galvanic corrosion can be a problem with magnesium and designers have to be aware of this issue. Corrosion can be controlled by reducing the impurity contents of the metal, specifically the Fe, Cu, and Ni values (and needs to be reduced significantly to <0.04 weight percent) so that the quality of the oxide film is not compromised for corrosion resistance. This is an order of magnitude more than for the case of Fe impurities in aluminum, where most Fe specifications in Al alloys call for <0.4 weight percent.

The recycling of magnesium will be made more complex by the inclusion of creep-resistant alloys in power train applications. These alloys derive their higher temperature creep resistance through the alloying of calcium, strontium, and rare earth elements, which will be detrimental to general recycled metal quality. Almost certainly, these alloys would need to be separated from the general magnesium recycled stream.

Ti Auto Applications Still Limited: Concerning titanium, Lavender noted that the overall market is again smaller than magnesium, and much smaller than aluminum. Titanium is prepared by the Kroll process, which consumes magnesium in the reduction of titanium tetrachloride, and so cost is a major issue. Cost has limited its automotive applications to components like springs, valve trains, and fasteners in some niche vehicles. This situation is not expected to change until a new lower cost preparation process emerges. Several processes are being explored but none has yet showed sufficient promise for commercial development. Lavender indicated that titanium is extensively recycled in the aerospace industry, e.g. by e-beam melting. Care is required to control the interstitial content of carbon, oxygen, and hydrogen as these elements can influence mechanical and corrosion properties.

MMCs Not Viable for Recycling Now: With regard to metal-matrix composites, Lavender noted that these materials are more specialty materials, and not in any sense commodity metals. Further, the complexity of the field is enormous as both the matrix and the reinforcing phase can be varied. Also, the reinforcements can be particulate, fibrous, or even woven fabric with variable size and orientation. An aluminum alloy matrix reinforced with silicon carbide particles at the 20% level (6061/SiC/20p – T6 in the terminology that has developed) has been used in niche automotive applications. Pistons and connecting rods have been developed and the Prowler vehicle had brake rotors fabricated from these materials, but there have not been any applications in large volume. It was noted that the reinforcing phase would probably end up in dross; it would be a risk to metal quality in aluminum recycling, and no aluminum recycler is likely to accept the MMC material.

Peterson and Davis discussed the processing issues with the recycling of aluminum and magnesium, respectively. As for aluminum, Peterson noted that 30% of the domestic aluminum supply is recycled material, but that in the case of Aleris International, Inc., this number is as high as 70%. Processes are well established and the key is to be able to blend scrap sources of "known" composition. Attempts to minimize oxidation during melting enhance metal recovery. He suggested that the automotive industry should evolve towards using fewer and more compatible alloys as an aid to subsequent recycling. Also, as an R&D need, he mentioned that a cost effective alternative process to chlorine fluxing for magnesium removal would be most beneficial.

With regard to magnesium, Davis indicated the molten metal is highly reactive and sulfur hexafluoride, SF6, is employed as a cover gas to reduce oxidation and "runaway" vaporization. This gas is a potent greenhouse gas and so there's a critical need to identify a substitute. Sulfur dioxide and blends of inert gases have been tried but are not as effective as SF6. The control of Fe, Ni, and Cu impurities to extremely low levels is critical to achieve good corrosion performance for magnesium alloys. In the case of Fe, this is accomplished by the formation of dense inter-metallic compounds that fall to the bottom of the melter. At present, there is no separation of the rare earth or "misch metal" elements that are used to confer higher temperature creep resistance on magnesium alloys. Hence, these alloys should be recycled as a separate stream and not be mingled with other magnesium or aluminum streams.

Discussion Session: Designing for Recycling, Life Cycle Analysis Critical, Improving Shredder/Sorter Technology

Following the formal presentations, there was a facilitated discussion to define technology gaps, R&D needs, and priorities for action. The participants discussed the suggestion from the aluminum industry to evolve to a design approach where fewer, more compatible alloys are used in vehicle assembly. This discussion grew into a more extensive debate about the importance of "designing for recycling" and included topics such as joining processes, avoiding dissimilar rivets that reduce the efficiency of sorting processes, and the use of adhesives.

The use of life cycle analysis was discussed as an aid to determining the low-energy option for recycling. This was not intended as a rigorous computation but more as a methodology to assess recycling options and to ensure that processes used in recycling do not compromise the conclusions from previously determined life cycle analyses.

Another topic that was debated extensively was the issue of dismantling prior to shredding of the auto hulk. It was suggested that since much of the aluminum is concentrated in the propulsion system, it might be possible to remove this material in larger components when the vehicle is being "de-polluted." After much discussion, the prevailing view was that because of the advances in shredder and sorting technology, it was more efficient to allow the complete hulk to be shredded and sorted.

Editor's Note: A more detailed technical Roadmap report of the Lightweight Metals Recycling Workshop is being prepared under the support of Argonne National Laboratory. The report is expected to be published in early 2009. For more information about the Roadmap, please contact John N. Hryn, principle engineer of Process Development Energy Systems at Argonne Nat'l Laboratory, by email: jhryn@anl.gov.