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AUTOMOTIVE MAGNESIUM: IMPACTS AND OPPORTUNITIES

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Extended Abstract

Structural magnesium alloys are simultaneously among the most promising and most challenging options as materials for next-generation, lightweight vehicles. Compared to conventional automotive materials, magnesium alloys can reduce the weight of structural components and systems by more than 50%. Vehicle fuel economy improves by 6-8% for every 10% reduction in weight [1], thus the significant potential for weight savings makes magnesium alloys an attractive technology to support improved efficiency in our cars and trucks. However, magnesium alloys for use in commercial and passenger vehicles face a variety of technical challenges [2] [3]. The maturity of magnesium alloys will be discussed in three main categories: (1) properties and manufacturability of alloys that meet automotive performance and cost requirements on a part-by-part basis, (2) joining and multi-material enabling technologies that support integration of magnesium components into structural systems, and (3) modeling and simulation of magnesium alloys and processes that allow rapid development and compatibility with existing, computationally-intensive vehicle design techniques.

Exceeding the properties and manufacturability requirements for automotive components is critical for implementation of magnesium alloys. Broadly speaking, the high cost of producing magnesium components with adequate properties limits applications of Mg to less than 0.5% of the weight of an average vehicle [4]; however, the scientific and manufacturing drivers for high cost vary by alloy and manufacturing process. In general, cast magnesium components are the most mature among automotive systems though significant improvement in strength and heat treatability, ductility and uniformity, and material cost would enable wider use. Magnesium sheet products have seen wide consideration in the automotive industry owing to general compatibility with the sheet-based architecture of most vehicles; while some successful automotive sheet demonstrations exist, broad application of magnesium sheet is limited by high material cost, infrastructure limitations for high temperature forming, and mechanical properties of the final product. Magnesium extrusions present excellent weight savings opportunities for rail-type geometries in the vehicle structure as well as window/sun-roof frames and similar components. Low extrusion speed, and thus high cost, contributes along with challenges in anisotropy of mechanical properties to preventing the use of magnesium extrusions in vehicles. Properties and manufacturability of magnesium alloys represents an enormous technical space, thus the highest priority needs and promising technology pathways will be addressed.

Perhaps the steepest barriers to the increased use of magnesium in vehicles lie in the areas of joining and multi-material enabling technologies. Resistance spot welds of Mg-Mg joints are possible but prone to severe heat affected zones, cracking, and void formation; resistance spot welds of Mg-Al and Mg-steel joints are similarly difficult with the compounding effects of intermetallic formation, thermal mismatch, and formation of galvanic couples. A variety of other techniques such as friction stir welding and ultrasonic welding of magnesium have been demonstrated with varying degrees of success in quickly producing strong, durable joints. Magnesium and its alloys are highly anodic to essentially all other automotive structural materials; the resulting galvanic couples between magnesium and aluminum or steel make design of strong, stable multi-material systems quite difficult. A wide array of alloying, joining, and coating strategies exist – particular needs and the most encouraging opportunities will be discussed.

Finally, design of vehicles (and, increasingly, design of materials) is a computationally intensive process where accurate simulation results are critical to enabling rapid testing, analysis, and iteration. Simulating the mechanical behavior of magnesium alloys is complicated by severe anisotropy in the deformation mechanisms. Further, while a vast scientific knowledge base has developed around steel and aluminum alloys owing to their broad range of applications, structural magnesium has historically lacked sustained demand by the automotive, aerospace, or defense industries and the basic science input required for accurate modeling and integrated computational materials engineering (ICME) often does not exist. Computational materials science and ICME for magnesium alloys will be described, with a particular emphasis on integrated development of new alloys and processes with development of new automotive structures.

Bibliography

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