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RESEARCH AND DEVELOPMENT PRIORITIES IN ORDER TO MAKE METAL MATRIX COMPOSITES

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Abstract: Because composites can be tailored in so many ways to the various requirements of a particular engineering component, the key to optimizing cost and performance is a fully integrated design process capable of balancing all of the relevant design and manufacturing variables (matrix and fiber properties, fabrication processes, analysis of the properties and behavior of the resulting structure). In spite of the fact that ceramic, polymer and metal matrix composites are at different stages of technological maturity, the challenges for all categories are remarkably similar. In order to make metal matrix composites more commercially attractive, and to develop better materials, several research and development priorities should receive attention in advanced industrial sectors. The four most important research and development priorities are presented in this paper.
Keywords: structural composites, metal matrix composites,

1. INTRODUCTORY NOTES

During the past decades, unprecedented progress has been made in the development of new structural materials. These materials, which include advanced ceramics, polymers, metals, and hybrid materials derived from these, called composites, open up new engineering possibilities. Their superior properties, such as the high temperature strength of ceramics or the high stiffness and light weight of composites, offer the opportunity for more compact designs, greater fuel efficiency, and longer service life in a wide variety of products, from sports equipment to high performance aircraft and automotive. In addition, these materials can lead to entirely new industrial and commercial applications that would not be feasible with conventional materials. Moreover, in the next decades, new structural materials like composites will provide a powerful leverage point for the manufacturing sectors, delivering superior performance and value of the larger systems in which they are incorporated. Given this multiplier effect, it is likely that the application of advanced structural materials will have a high impact on employment in the advanced industries, including the automotive sector. All of the manufacturing sectors have recognized these opportunities and are competing actively for shares of the large industrial and commercial applications.

Monolithic materials often find limitations on increasing performance requirements in various environments. Hence there has been need to find new materials with tailor made properties, which can offer performance advantages over such traditional materials. With the development of new materials such as structural composites, engineers now have many more options available for de signing products. These new materials can offer performance advantages over such traditional materials. The materials likely to have the greatest impact on several industries are the composites. Therefore, the importance of substitution by alternative materials is likely to be significantly greater in the next decades.

Structural composites are recent material systems usually associated with the manufacturing industries, in which the components are first produced individually and then combined in a controlled way to attain the desired structure, properties, and part geometry. These synthetic materials are the composites usually thought of in the context of engineered products. Composites are classified according to their matrix phase. Thus, there are:

- Metal Matrix Composites (MMCs) include mixtures of ceramics and metals, such as cemented carbides, as well as aluminum or magnesium reinforced by strong, high stiffness fibers.
- Ceramic Matrix Composites (CMCs) are the least common category. Aluminum oxide and silicon carbide are materials that can be imbedded with fibers for improved properties, especially in high temperature applications.

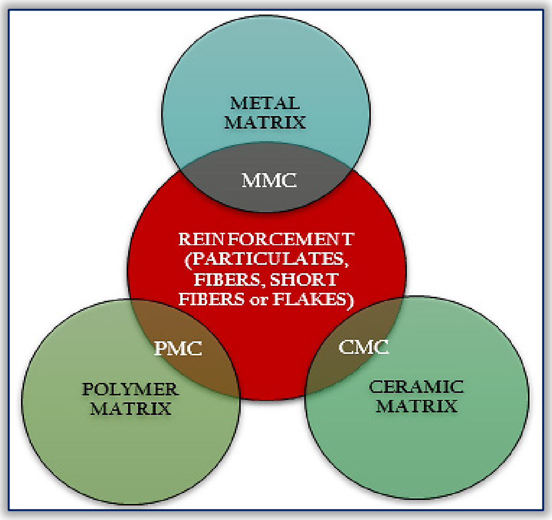

Figure 1. Structural composites

- Polymer Matrix Composites (PMCs) include mixtures of polymers with fiber or powder reinforcements. Thermosetting resins are the most widely used polymers, epoxy and polyester being commonly mixed with fiber reinforcement, and phenolic being mixed with powders. Thermoplastic molding compounds are often reinforced, usually with powders.

New structural materials can be classified as ceramics, polymers, or metals. Two or more of these materials can be combined together to form a composite that has properties superior to those of its constituents. Materials within these categories are often called "advanced" if they exhibit properties, such as high temperature strength or high stiffness per unit weight, that are significantly better than those of more conventional structural materials, such as steel and aluminum.

A composite material is a material arrangement combined of two or more physically discrete phases whose combination gives aggregate properties that are special from those of its constituents. In certain respects, composites are the mainly exciting of the engineering materials because their structure is more intricate than the other three types. The technological and commercial attention in composite materials derives from the fact that their properties are not just different from their components but are a lot far superior.

Advanced materials have offered the materials designer a wide range of options in the specification and selection of materials for various applications. Material properties are continually being improved to meet safety and operational standards in line with prevailing technological developments. Modern technological requirements, together with the consumers' demands for systems and machines that are more energy efficient, stronger, light-weight, cost-effective, etc., dictate that the search for new and advanced materials will remain a subject of interest all the time.

2. RESEARCH AND DEVELOPMENT PRIORITIES

Automakers are being subjected to increasingly strict fuel economy requirements, while consumers are demanding improved interior comforts and advanced electronic systems for safety, navigation, and entertainment, all of which add otherwise unnecessary weight. To meet these challenges, automotive manufacturers are turning to lightweight metals as a solution. Metal matrix composites offer to the automotive industry an opportunity to reduce vehicle weight and improve the general performance. The auto industry can customize lightweight metal matrix composites with a wide variety of properties for use in specific applications to make significant weight reductions and improve fuel efficiency.

Aluminum engine blocks, suspension components, body panels, and frame members are increasingly common, in addition to the use of magnesium in components such as instrument panels, valve covers, transmission housings, and steering column components. Combining or replacing these efforts with the use of advanced metal matrix micro- and nano-composites not only reduce mass, but can also improve reliability and efficiency.

Metal-matrix composites are metals or alloys that incorporate particles, whiskers or fibers, made of a different material, and offer unique opportunities to tailor materials to specific design needs. These materials can be tailored to be lightweight and with various other properties including:

- high specific strength and specific stiffness;
- high hardness and wear resistance;
- low coefficients of friction and thermal expansion;
- high thermal conductivity;
- high energy absorption and a damping capacity.

In addition to these properties, new metal matrix composites have self-healing, self-cleaning, and self-lubricating properties, which can be used to enhance energy efficiency and reliability of automotive systems and components.

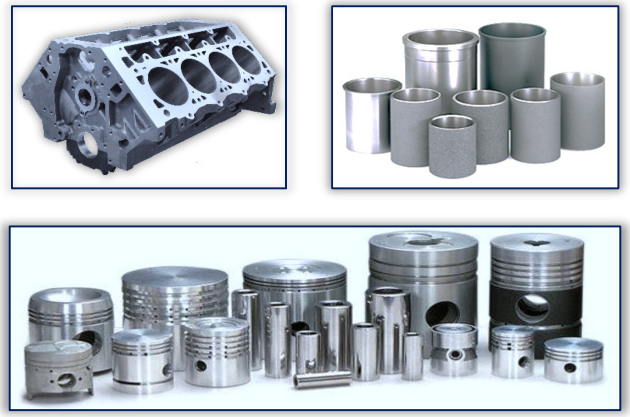

Figure 2. New metal matrix composites

Aluminum engine blocks typically require cast iron cylinder liners due to poor wear characteristics of aluminum. Some automakers uses metal matrix composites for cylinder liners by integrating a porous silicon preform into the cast aluminum block, and an others uses a similar method incorporating alumina and carbon fibers in the bores of die cast aluminum. These practices improve wear characteristics and cooling efficiency over cast iron liners. Also, aluminum alloy pistons and cylinder liners containing dispersed graphite particles that provide solid lubrication. Aluminum-based composite liners can be cast in place using conventional casting techniques, including sand, permanent mold, die casting, and centrifugal casting. Application of this material for cylinder liners in lightweight aluminum-engine blocks enable engines to reach operating temperatures more quickly while providing superior wear resistance, improved cold start emissions, and reduced weight.

Because composites can be tailored in so many ways to the various requirements of a particular engineering component, the key to optimizing cost and performance is a fully integrated design process capable of balancing all of the relevant design and manufacturing variables (matrix and fiber properties, fabrication processes, analysis of the properties and behavior of the resulting structure). In spite of the fact that ceramic, polymer and metal matrix composites are at different stages of technological maturity, the challenges for all categories are remarkably similar. The four most important research and development priorities are given below:

- Research and development on the processing methods, as a key to understanding how processing variables such as temperature, pressure, and composition influence the desired final properties. The two principal goals of processing science should be to support development of new, low-cost manufacturing methods, and to help bring about better control over reproducibility so that large numbers of components can be manufactured within specification limits.
- Research and development on the structure-property relationships, having in view that the tailorable properties of composites offer new opportunities for the designer. However, because composites are more complex than metals, the relationships among the internal structure, mechanical properties, and failure mechanisms are less well understood. A better understanding of the effects of an accumulation of dispersed damages on the failure mechanisms of composites is especially desirable.
- Research and development on the behavior in severe environments, having in view that many applications may require new materials to withstand high-temperature, corrosive, or erosive environments. These environments may leading to failure. Progress in this area would facilitate reliable design and life prediction.
- Research and development on the matrix and reinforcement interface in composites, knowing that the poorly understood interracial region has a critical influence on composite behavior. Particularly important would be the development of ideal interface in composites that would permit the use of a single type of reinforcement with a variety of matrices.

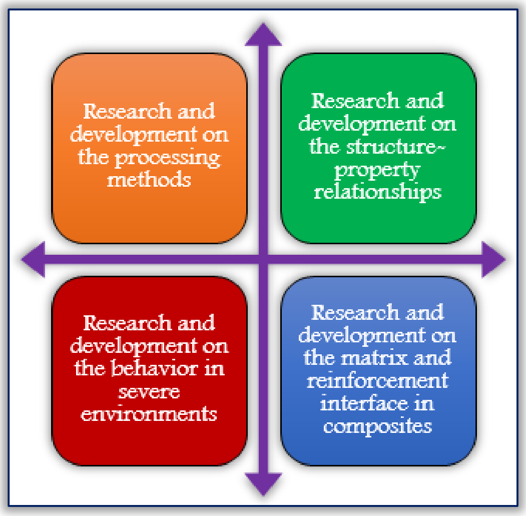

Figure 3. Research and development priorities

In order to make metal matrix composites more commercially attractive, and to develop better materials, several research and development priorities should receive attention in advanced industrial sectors. The priorities relative to the metal matrix composites are grouped in the above-mentioned broad categories of descending priority, which reflect the special needs to be done in order to promote the development of these materials in advanced sectors, including the automotive industry. First of all, the research in the area of development of lower cost manufacturing technologies have a major attention, first in importance being the need for low-cost and the highly-reliable manufacturing processes. In this sense, the actions are oriented to develop high efficient manufacturing processes, research should concentrate on optimizing and evaluating processes such as powder metallurgy processes, modified casting techniques, liquid metal infiltration and diffusion bonding. For particulate-reinforced metal matrix composites, powder metallurgy and liquid infiltration techniques are considered most promising, while for production of fiber reinforced metal matrix composites the diffusion bonding and liquid metal infiltration are preferred. Also, several industries are oriented to the modified casting processes. The important cost factors in considering advanced composites usage are life-cycle costs and production costs. But, the major improvement in future costs should come from improved fabrication methods.

3. CONCLUSIONS

As automakers strive to meet imposed fuel economy and emissions regulations while producing vehicles with the quality and consumers expect, the industry needs to rely on advancements made in the field of metal matrix composites. By using advanced materials, the auto industry can customize high-strength, wear-resistant, and self-lubricating lightweight metal matrix composites for specific applications to make significant weight reductions and improve fuel efficiency.

Aluminum alloys possess a number of mechanical and physical properties that make them attractive for automotive applications, but they exhibit extremely poor resistance to seizure and galling. Reinforcement of aluminum alloys with solid lubricants, hard ceramic particles, short fibers and whiskers results in advanced metal-matrix composites (MMC) with precise balances of mechanical, physical and tribological characteristics. Advanced manufacturing technologies such as squeeze infiltration of molten alloys into fiber performs can be employed to produce near net-shape components. Brake rotors, pistons, connecting rods and integrally cast MMC engine blocks are some of the successful applications of Al metal matrix composites in automotive industry.

Aluminum based particulate composites, mainly made up of SiC/Al and Al/Al2O3, have been successfully used in pistons, engine blocks, disc rotor brakes, drums, calipers, connecting rods, drive shafts, snow tire studs and other automobile parts. The usage of aluminum based composite is increasing day by day in the entire manufacturing sectors due to their unique properties such as high strength to weight ratio, good mechanical properties and better durability. Subsequently a lot of research has taken place in aluminum composite material with addition of carbides based particulate reinforcement. These reinforcements provide better microstructure and mechanical properties when combined with the metal matrix materials. When compared to monolithic aluminum, Al-based metal matrix composites shows the significant improvement in mechanical properties in terms of enhanced strength and stiffness, good fatigue and wear resistance, less weight and high-temperature stability. Thus, aluminum based particulate composites exhibit superior wear resistance compared with aluminum alloys and cast iron under sliding wear conditions. This enables the implementation of aluminum based particulate composites in automotive applications such as brake discs, drum brakes, calipers and cylinder liners and weight reduction due to the substitution of iron base materials.

Metal-matrix composites offer considerable promise to help automotive engineers meet the challenges of current and future demands for recyclable, fuel-efficient, safe, and low-emission vehicles. These materials can be engineered to match the design requirements of automotive power-train or chassis components. Technological and infrastructural barriers tend to limit the implementation of these materials, but it is believed these barriers can be overcome and that metal-matrix composites can be applied in high-volume vehicle production. Reducing these barriers will require much effort by engineers and scientists, managers and planners at automotive manufacturers, and their suppliers. The result will be the gradual introduction of metal-matrix composites in high-volume vehicle production to satisfy customer desires while meeting regulatory requirements and competitive pressures.

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