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Metal- and Polymer-Matrix Composites: Functional Lightweight Materials for High-Performance Structures

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The special topic "Metal- and Polymer-Matrix Composites" is intended to capture the state of the art in the research and practice of functional composites. The current set of articles related to metal-matrix composites includes reviews on functionalities such as self-healing, self-lubricating, and self-cleaning capabilities; research results on a variety of aluminum-matrix composites; and investigations on advanced composites manufacturing methods. In addition, the processing and properties of carbon nanotube-reinforced polymer-matrix composites and adhesive bonding of laminated composites are discussed. The literature on functional metal-matrix composites is relatively scarce compared to functional polymer-matrix composites. The demand for lightweight composites in the transportation sector is fueling the rapid development in this field, which is captured in the current set of articles. The possibility of simultaneously tailoring several desired properties is attractive but very challenging, and it requires significant advancements in the science and technology of composite materials. The progress captured in the current set of articles shows promise for developing materials that seem capable of moving this field from laboratory-scale prototypes to actual industrial applications.

COMPOSITE MATERIALS

Increasing interest in lightweight and high-performance materials is leading to significant research activity in the area of composite materials. One recent focus area is to develop multifunctional composites that have more than one property tailored as per the design requirements in addition to achieving low density. Automotive, aeronautics, and wind-energy sectors have been the major users of composite materials. The transportation sector is especially interested in such materials for structural applications due to steadily rising energy costs and a desire to reduce emissions. This interest in metal- and polymer-matrix composites for structural applications inspired the Metal and Polymer-matrix Composites symposium that was organized as a part of Materials Science and Technology 2013 (MS&T'13) conference in Montréal, Canada. The topic of this issue is a follow-up to the symposium and is expanded beyond the articles presented in Montréal to develop a more comprehensive overview of the field.

A brief snapshot of functional composites is presented in Fig. 1. The upper half of the figure lists properties that can be used to generate various functionalities in the material, whereas the lower half presents examples of functionalities. More properties and functionalities can be added to this diagram to develop a comprehensive picture of the field. Damage-sensing and self-healing capabilities are of great interest to the aerospace structures. The self-cleaning and self-lubricating surfaces are relevant to the engine applications. The development of functioning capabilities in the base material can reduce the requirements for additional systems on the application platform and can help in reducing the weight.

Carbon-fiber-reinforced polymer-matrix composites have seen strong growth in recent years in automobile bodies and wind turbine blades. However, the use of

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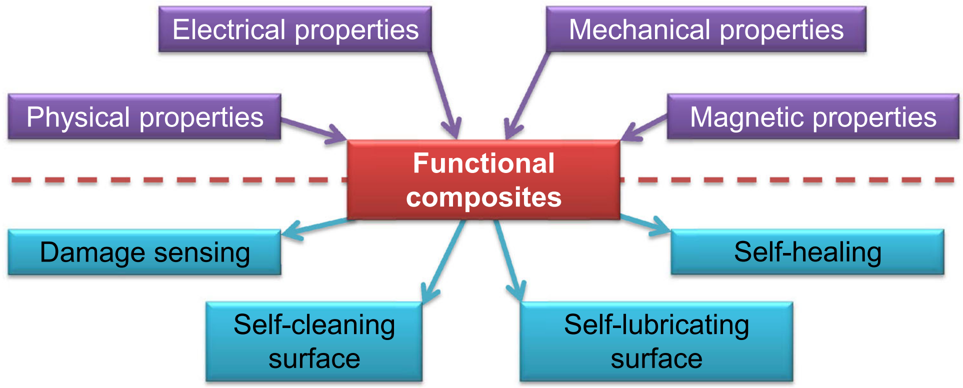

Fig. 1. A snapshot of the properties and functionalities of functional composites.

polymer-matrix composites in engine components is limited due to high temperatures. Metallic materials are suitable for such applications. The development of lightweight metal-matrix composites with functional properties and high performance is very challenging, and studies ongoing in this area are captured under this topic. Thirteen papers are included under this topic in this issue. A summary of these articles is presented in the following discussion.

MULTIFUNCTIONAL MATERIALS

The designers of automotive components usually have a long wish list for properties that are required in a given part. As an example, an engine block is required to have high dimensional stability at different temperatures, wear resistance, modulus, and fatigue life in addition to low weight. Such complex requirements inspire the development of multifunctional materials, which is an important focus area of research. In this issue, four articles focus on discussing multifunctionality in composite materials. The article by Ferguson et al.[1] titled "Self-Healing Metals and Metal Matrix Composites" discusses the current state of the art in the area of self-healing metallic materials. Self-healing in polymer-matrix composites has been demonstrated by several different approaches in the past two decades. However, achieving similar capabilities in metallic materials is much more complex. The article by Dorri et al.[2] titled "Functional Metal Matrix Composites: Self-Lubricating, Self-Healing, and Nanocomposites—An Outlook" discusses the current status and future perspective in multifunctional metallic materials. Self-lubrication through either solid- or liquid-phase lubricant that is released from the material microstructure can be useful. Self-healing can be achieved through approaches such as the release of a healing agent or the use of shape-memory materials. The manuscript also discusses hollow-particle-filled composites called syntactic foams, which are especially suitable for development with such functional capabilities. Syntactic foams are synthesized by filling hollow particles in polymer or metal-matrix. Syntactic foams are further discussed by Orbulov and Majlinger[3] in their article, "Compressive Properties of Metal Matrix Syntactic Foams in Free and Constrained Compression." They found that radial confinement of the specimens causes a remarkable difference in the compressive properties of syntactic foams. Such results can be useful in automotive applications in which foam-filled channels are used for energy absorption in crushing zones. The availability of tailored high-quality hollow particles is very important in developing high-performance syntactic foams. The article by Shunmugasamy et al.[4] titled "Compressive Characterization of Single Porous SiC Hollow Particles" examines the recently developed high-quality particles through single-particle compression testing. Reliable information on the properties of hollow particles can help in using theoretical models to accurately predict the properties of syntactic foams. The hollow SiC particles characterized in this study have porous walls, which made it difficult to conduct direct measurement of wall thickness and true particle density. Syntactic foams with very low thermal expansion coefficient can be developed by using hollow SiC particles.

ALUMINUM-MATRIX COMPOSITES

Lightweight aluminum-matrix composites form an important research area. A series of articles are focused on aluminum-matrix composites. The article by Jiang et al.[5] titled "The Microstructural Design of Trimodal Aluminum Composites" discusses ultrahigh-strength trimodal composites developed by their group. The matrix contains ultrafine nanocrystalline grains as well as coarser grains, in addition to ceramic reinforcing particles, which helps in obtaining ultrahigh strength. The role of interface and grain boundaries on the properties of the composite is discussed. The study by Altinkök[6] titled "Optimization of Mechanical Properties of Hybrid Al_2O_3/SiC_p Reinforced Composites Produced by Pressure-Assisted Aluminum Infiltration" used Al_2O_3/SiC_p preforms to synthesize composite materials. The effect of infiltration pressure and temperature was studied on the tensile properties of the composite. Wear properties of the composites were also characterized. The reinforcing mechanisms in such hybrid composites can be complex. Another effective reinforcement for aluminum-matrix composites is diamond, which is investigated by Caccia et al.[7] in their article "Diamond Surface Modification to Enhance Interfacial Thermal Conductivity in Al/Diamond Composites." The decreasing price of synthetic industrial diamonds is making them viable reinforcement for commercial composite materials. The article is focused on studying the possibility of modifying the surface of reinforcing diamond particles to obtain sp^2 hybridization, which has a better compatibility with aluminum than sp^3 hybridized diamond surface. Corchado et al.[8] studied the effect of in situ-precipitated AlB_2 particles in aluminum-alloy matrix composites in their article "Effects of AlB_2 Particles and Zinc on the Absorbed Impact Energy of Gravity Cast Aluminum Matrix Composites." They also studied the effect of zinc concentration on the impact and hardness of this material system. There is a trade-off in the hardness and impact resistance with respect to the increasing AlB_2 concentration, and appropriate compositions need to be determined as per the primary requirements of the application.

COMPOSITE SYNTHESIS METHODS

Methods of composite synthesis are the primary focus in two articles. Borkar et al.[9] studied the laser-engineered net shaping (LENS process for Ni-Ti-C alloy in the article "Laser-Deposited *In Situ* TiC-Reinforced Nickel Matrix Composites: 3D Microstructure and Tribological Properties." The Ni-10Ti-10C composite exhibits primary cuboidal TiC precipitates as well as eutectic carbide precipitates, whereas the Ni-3Ti-20C composite exhibits an additional graphitic phase in the microstructure. A three-dimensional microstructural analysis reveals the distribution and morphology of phases. Webb and Charit[10] studied the spark-plasma sintering (SPS) process in their article "Fabrication of Cermets via Spark-Plasma Sintering for Nuclear Applications" for $W\text{-}UO_2$ cermets. The SPS process yielded dense $W\text{-}CeO_2$ specimens with a finer microstructure than other sintering techniques.

The infiltration of Cu-Si alloy in porous preforms of carbon is modeled by Iqbal et al.[11] in the article "Numerical Studies of Infiltration Dynamics of Liquid–Copper and Silicon/Solid–Carbon System." Wetting of reinforcement by the melt is an important consideration in infiltration processes. The effect of various parameters such as preform pore size and infiltration rate on the wetting angle is included in the model.

POLYMER-MATRIX COMPOSITES

The article by Paramsothy[12] discusses the processing and properties of carbon nanotube (CNT)-reinforced composite materials in his article "Dispersion, Interface, and Alignment of Carbon Nanotubes in Thermomechanically Stretched Polystyrene Matrix." Obtaining uniform dispersion of CNTs in the microstructure and a strong CNT-matrix interface is critical for obtaining improvement in mechanical properties of nanocomposites. Preferential orientation of CNTs can provide directional properties in the composites.

Poveromo and Earthman[13] discuss joining of composites in their article "Analysis of 'Kiss' Bonds between Composite Laminates." They show that 'kiss' bonds can be formed using room temperature curable epoxy paste adhesives by creating an amine blush on the epoxy surface or by applying a release agent on the bonding surfaces. Bond line integrity is an important issue for any component containing adhesive joints.

SUMMARY

The rapid growth in the demand for lightweight and high-performance materials in all modes of transportation has been a driving force behind numerous recent innovations in the area of metal- and polymer-matrix composites. The new focus on multifunctional material has resulted in the development of self-healing, self-lubricating, and self-cleaning materials. New reinforcement materials, including microscale and nanoscale materials, are being developed for various matrices. The advancements related to synthesis methods have helped in developing new compositions and reducing the cost of final products. Thirteen articles included under the Metal- and Polymer-Matrix Composites topic discuss various aspects of the processing, microstructure, and properties of composite materials. Many studies are focused on aluminum-matrix composites because of interest in lightweight composites to replace heavier steel parts. Hollow-particle-filled syntactic foams were discussed for compressive properties and for the possibility of filling the hollow particles with liquids for generating self-healing and self-lubricating composites.

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