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Preface to special section on composite materials

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This special section contains peer-reviewed papers presented at a symposium on Composite Materials, held in Detroit, MI, USA, between September 16–20, 2007, as a part of the Materials Science & Technology (MST'07) conference. The conference was held under the sponsorship of The Minerals, Materials and Metals Society (TMS), ASM International, American Ceramic Society, and the Association for Iron and Steel Technology. The symposium brought together researchers working on a variety of composite systems, including polymer, metal, and ceramic matrix composites. Work on fibers and nanotube reinforcement was also presented. Traditionally, these topics are presented and reviewed at separate conferences. In this symposium we tried to bring together researchers working on a variety of composite systems to allow fruitful discussion in all areas of composites. This cross-fertilization was appreciated by all the participants and promoted an appreciation of the commonality of phenomena between various composite systems.

Here we provide a summary of the topics covered in the collection of papers in this special section. Specialty fibers represent a small but high-worth market. Making continuous carbon fibers form carbon nanotubes is a very important part of the research effort in this field. Zhang et al. [1] describe their results on making continuous carbon nanotube (CNT) fibers and yarns. They dry-draw directly from water-assisted chemical vapor deposition (CVD) grown forests about 1 mm in height. Water-assisted CVD is a novel technique that allows a size-selective growth of highly pure, very long, and vertically aligned CNT forests. The authors grew CNT forests about 1 mm in length by water-assisted CVD, followed by drawing in the dry state. As drawn carbon multiwall nanotube fibers have the structure of an aerogel, which can be changed into more compact and long fibers via twisting or densification with a volatile organic liquid. The as-drawn fibers were twisted and subsequently densified to lock-in the effects from twisting. Long fibers are more efficient in load transfer when they are used in a matrix to form a composite. Besides microstructural characterization of CNT fibers, they report on the mechanical properties and electrical conductivity of the post-treated carbon nanotube fibers. Guo et al. [2] fabricated pPolyacrylonitrile (PAN)/vapor grown carbon nanofiber (VGCNF) composite films from N,N-dimethylformamide (DMF), with various weight fractions of nanofibers, ranging from 5 to 90 wt%. Tensile, dynamic mechanical, electrical, structural, and morphological properties of these composite films were studied. An enhancement in tensile strength was observed in composites with nanofiber loadings of up to 40 wt%. The electrical conductivity of composite films also increased with increasing nanofiber content. Energy dissipation in carbon nanotube composites was the focus of the paper by Suhr and Koratkar [3]. They examined the energy

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dissipation that takes place by activating interfacial slip between nanoscale fillers (single-walled and multi-walled) as well as fullerenes in a matrix material such as polycarbonate, PEO, PEG, and epoxy. These composites are fabricated by a solution mixing technique with tetra-hydrofuran as the solvent. Interfacial friction damping was analyzed via uniaxial dynamic load experiments and measurement of the storage and loss moduli of the composite. Effects of variables such as nanotube weight fraction, nanotube surface treatment (oxidation, epoxidation, etc.), test frequency, strain amplitude, operating temperature, as well as effect of pre-strain or biased strain were investigated. The effect of geometry (i.e., aspect ratio) of the nanotubes was also considered by comparing the damping response of fullerene composites with that of nanotube composites. Among the interesting findings of this work are that frictional sliding at the carbon nanotube/polymer interfaces can result in an order of magnitude (>1000%) increase in loss modulus of the bulk polycarbonate system with only 2% weight fraction of oxidized SWNT fillers. Large increases in damping were observed at large strain amplitudes, when the tube-polymer adhesion is not strong enough to prevent interfacial slip. High temperature helped the activation of tube-polymer sliding because of enhanced mobility of the polymer chains closer to the glass transition temperature. A comparison of the damping behavior of nanoparticles *via à vis* that of nanotube additives showed that low aspect ratio nano particle additives were ineffective in improving the damping behavior.

Layered composites have an excellent combination of strength and toughness. Metal/ceramic laminates with individual laminae of nanometer-sized thickness can have impressive properties, such as high strength, superb abrasion resistance, and often time biocompatibility. Chawla et al. [4] describe the nanoindentation characteristics of metal/ceramic nanolaminates consisting of alternating layers of aluminum and silicon carbide (Al/SiC). These nanoscale composites were fabricated by physical vapor deposition of the layers on a Si substrate. These multilayers at the nanoscale exhibited extraordinary flexibility during nanoindentation. Extensive pileup was observed in these laminates which involved bending of hard SiC laminae and plasticity of Al layers. Damage occurred by localized cracking of SiC and plasticity, void nucleation, and growth in aluminum layers. The voids were confined to the Al layers, indicating a strong interface between Al-SiC. The damage pattern observed was qualitatively supported by numerical simulations. On a more macroscopic level Kulkarni et al. [5] examine laminates of long fiber thermoplastic (LFT)/metal composites (LML). The LFT/Al laminates (LMLs) were processed by compression molding and were characterized for their Young's modulus, mechanical strength, and low velocity impact properties. Failure mechanisms included delamination between LFT composite and Al, fiber fracture and pullout in LFT composite, and shear fracture of aluminum and LFT composite layers. Rule-of-mixtures, predictions of laminate properties in tension compared well with the experimental values. Specific perforation energy of the laminates determined by low velocity impact (LVI) was significantly greater than that of the LFT composite alone. Overall, the LML showed significant improvement in the properties compared to the LFT composite. Deka et al. [6] examined the behavior of laminated thermoplastic composites under high velocity impact. They impacted laminates of plain-weave E-glass/polypropylene of different thicknesses by right-cylinder-shaped projectiles in a gas gun. An explicit three-dimensional finite element code LS-DYNA was used to model the impact behavior. Good agreement between the numerical and experimental results was attained in terms of predicting ballistic limit, delamination, and energy absorption of E-glass/PP laminate.

Composite materials must be able to withstand extreme and aggressive environments. Silicon carbide fiber reinforced titanium alloy composites have an impressive array of characteristics, especially creep resistance. The effect of molybdenum (Mo) on the microstructure and creep behavior of Ti-24Al-17Nb (at.%) alloys and SiC-fiber composites thereof (fiber volume fraction approximately 0.35) was the focus of the paper by Quast and Boehlert [7]. The addition of about 2% Mo resulted in significantly greater creep resistance in both the unreinforced alloy and the composite. The secondary creep rates of SiC/Ti alloy composites MMC were predicted from the monolithic matrix secondary creep rates of the unreinforced alloy. For identical creep temperatures and applied stresses, the MMCs with fibers at 90° to the tensile axis exhibited greater creep rates than their monolithic matrix alloy counterparts. This was attributed to the low interfacial bond strength between the matrix and the fiber, which was measured using a cruciform test methodology. Microstructural observations showed that the carbon layer at the fiber/matrix interface was responsible for preferential debonding. Ultraviolet rays can have very deleterious effects on materials, especially polymeric materials (natural or synthetic). Goel et al. [8] explored the effect of UV exposure on the microstructure and dynamic Young's modulus of polypropylene (PP)/21 vol. % E-glass long fiber thermoplastic (LFT) composites. Microscopic observations revealed that the damage due to UV was confined to the surface region only. This damage was in the form of surface cracking and exposure of fibers to the surface in the case of LFT and surface cracking in the case of neat PP. Fourier Transform Infrared (FTIR) spectroscopy showed that the crystallinity of PP in the damaged layer increased, both in neat PP as well as in LFT, with exposure time. This phenomenon, called chemicrystallization, involves rearrangement of broken polymer chains into crystalline form. Crystalline PP is expected to have a higher modulus than the amorphous PP. However, it is virtually impossible to make tensile specimens out of the cracked surface layer to measure the modulus. The technique of nanoindentation is apt for such measurements. Results of nanoindentation showed that the Young's modulus of the PP in the damaged layer increased, with UV exposure time. Although the local Young's modulus of the degraded layer increased because of chemicrystallization, the dynamic Young's modulus of the overall composite showed a decrease with UV exposure time. This is because the damaged PP matrix at the surface, because of chemicrystallization, undergoes a reduction in volume compared to the most of underlying, undamaged PP matrix, which results in tensile stresses in the damaged layer and a compressive stresses in the undamaged PP. The tensile stresses lead to the formation of transverse cracks in the damaged layer. This surface cracking is responsible for the observed decrease of dynamic Young's modulus of the overall LFT.

In the realm of tissue engineering, scaffolds are the extracellular materials that play a very important role. There is an urgent need to be able to design these scaffolds with the necessary mechanical characteristics and consequently the requisite microstructure that helps growth of new tissue. An aspect of this is bone tissue engineering which involves bioceramic materials such as hydroxyapatite, bioactive glass (e.g., Bioglass®), alumina, titania, and calcium phosphates. These are brittle materials. The scaffolds also need to be highly porous to provide a means of integration for the bone material. Yunos et al. [9] explored a variety of approaches involving polymer/ceramic composites, e.g., polymer coating or polymer/ceramic microstructures that resemble the structure of the bone. Toughening can be achieved by using the approach of an interpenetrating network microstructure in scaffolds. The addition of a polymer phase can also provide other functions, e.g., a biodegradable polymer can act as carrier for biomolecules, growth factors, and antibiotics. Addition of nanoparticles or carbon nanotubes to the polymer coating results in nanotopographical surface features that can enhance cell attachment and cellular characteristics in contact with the scaffold.

This collection of manuscripts represents a small slice of the current activities in the field of composites. We hope that this summary has whet the reader's appetite for the full-length manuscripts that follow.

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