INTRODUCTION

The symposium Processing, Properties and Performance of Composite Materials was organized as a part of the Materials Science and Technology 2008 conference in Pittsburgh, Pennsylvania, October 5–9, 2008. The symposium was organized by Nikhil Gupta of New York University, Nikhilesh Chawla of Arizona State University, Darrell Herling of Pacific Northwest Research Laboratory, and Pravash Chandra Maji of Punjab Technical University, India. The Composite Materials Committee of TMS and ASM-International sponsored the symposium.

Increasing applications in modern structures have resulted in over 6% growth rate of the composite materials market, leading to immense interest in this area. The symposium was a timely effort to review the progress made in this area, discuss the cutting-edge research efforts, and determine future directions. The main focus of the symposium was on metal- and polymer-matrix composites. However, a few papers on ceramic-matrix composites were included. The symposium consisted of 44 presentations divided into eight sessions over four days. These contributions came from fourteen countries around the world. Several other papers from the symposium were presented in the poster sessions. This summary includes only those papers that were part of the oral presentation sessions. Availability of the full text paper in the conference proceedings is indicated by an asterisk (*) by the presenter’s name.

MODELING OF COMPOSITE MATERIALS

The first session had three presentations, two of which were invited. Jonath than Spowart of the U.S. Air Force talked about the computationally efficient multi-scale analysis of area fractions (MSAAF) technique and its application to discontinuously reinforced composites. He focused on epoxy-matrix composites containing aluminum and nickel reinforcements. The study parameters included area fraction, aspect ratio, and orientation of second phase particles in two-phase microstructures. The MSAAF technique is found to be effective in quantitative characterization of orthotropic microstructures at low computational expense. Nikhilesh Chawla continued the discussion on modeling techniques and presented his work on microstructure-based finite element modeling techniques for particle-reinforced metal-matrix composites (MMCs). In this technique, successive polishing and microscopy generate a series of images through the specimen thickness. These images are combined to obtain a three-dimensional model of the microstructure, which is discretized and used for finite element analysis. Such techniques are expected to be more efficient and accurate than the traditional approaches because the size, shape, orientation, and distribution of particles, and grain size, shape, and orientation of the matrix alloy can be captured and included in the analysis.

An invited paper presented by Pavel Simacek* of the University of Delaware was focused on simulation of resin flow in a mold containing reinforcing fabrics to fabricate polymer-matrix composites (PMCs). Inadequate control over the resin flow can cause entrainment of air bubbles in the composites, which is undesirable. Insufficiently impregnated fiber tows can retain micro-size porosity, which can be acceptable in some applications but not in aerospace structures. Recent increase in the use of composite materials in commercial and military aircraft has brought focus to these issues and has demanded substantial advancements over the present industrial practices and quality standards.

METAL-MATRIX COMPOSITES–LAMINATES

The invited speaker Krishan Chawla, University of Alabama–Birmingham, talked about the recent advances in the area of metallic nanolaminates. He described the fabrication processes for nanolaminates composed of 25–50 nm thick layers of aluminum and silicon carbide. Nanoindentation techniques were used to test these laminates and obtain load-displacement curves. Bending and localized cracking of SiC layers was observed as a failure mechanism. The second invited speaker, Amit Misra of Los Alamos National Laboratory, also talked about 1–60 nm thick multilayer laminates. The strength of such nanolaminates was found to be significantly higher than the microscale laminates of the same materials. At higher temperatures the strength decreased and ductility increased, which is related to the enhanced cross slip and climb of dislocations across interlayer boundaries. Shoichi Nambu* of the University of Tokyo, Japan, presented two papers on metallic laminates composed of high-strength steel. In one study focused on microstructural evolution at the interface they found that the fragments of surface oxide of each layer were alternately distributed on the interface. The other study characterized the interfacial bond strength with respect to the heat treatment temperature and the layer thickness. Baoshuai Du from the University of Tennessee pre-
presented recent work on laser processing of wear-resistant TiB$_2$-TiC coatings on steel. The coatings had different morphologies of TiB$_2$ and TiC particles due to a difference in the crystal structures and the formation mechanisms of these phases. Lichun Chen of Technical Materials Inc. presented work on developing processing methods for metallic laminates.

**ALUMINUM-MATRIX COMPOSITES**

In this session two papers on nanostructured composites synthesized by cryomilling were presented by the group of Enrique Lavernia at University of California–Davis. Rustin Vogt talked about processing and properties of ultrafine-grained aluminum-boron carbide plates and Troy Topping discussed the thermal stability of cryomilled aluminum alloys. The processing of composites includes hot or cold isostatic pressing of cryomilled powder, followed by extrusion or forging. The effect of processing parameters on the properties of bulk nanostructured materials was discussed in both presentations. Matthias Merzkirch* from the University Karlsruhe, Germany, described an approach to use an extrusion process to produce AA 6060 matrix wires reinforced with composite fibers of aluminum-Nextel alumina fibers. Boron nitride used for lubrication of the die was found at the matrix-composite fiber interface and resulted in poor interfacial bonding. Composite wires produced without this lubricant showed good interfacial bonding and improved tensile properties. Ultrasonic consolidation of pure aluminum and Al-Ni composite powder was discussed by David Colanto* of Northeastern University. He showed that the use of ultrasonication led to significantly lower porosity in the specimens. Higher temperature and pressure also provided lower porosity content in the specimens. Al-Ni composites produced by this method failed at the interface due to a lack of strong bonding.

Lilia Olaya-Luengas* of the University of Puerto Rico showed results of a study on centrifugal casting of aluminum alloys containing boron and magnesium. The process resulted in the formation of AlB$_2$ and AlB$_{12}$ particles, which were radially distributed in the specimen to provide a functionally graded structure. The effect of the presence of copper, vanadium, and zirconium on the composite hardness was also characterized. Microscopy, x-ray diffraction, and hardness studies confirmed the presence of functionally graded structure and provided insight into the role of each alloying element on the chemical composition and properties of the resulting composite material. Joseph Antony* of the National Institute of Technology–Calicut, India, talked about experiences related to developing a processing method for carbon-fiber-reinforced aluminum-matrix composites. Their experiments resulted in brittle Al$_4$C$_3$ phase at the fiber-matrix interface. The tensile properties of these composites were characterized and compared with published work on similar composites. Synthesis methods and characterization results on hollow ceramic microsphere filled Al 6082 alloy composites were presented by Yuyuan Zhao* of the University of Liverpool, United Kingdom. These hollow particle-filled composites, known as syntactic foams, were fabricated by liquid phase sintering of particles and aluminum powder. The resulting composites had densities in the range of 1,500–1,900 kg/m$^3$ and showed over 40% failure strain. The presentation was followed by a long discussion about the potential applications of these materials and suggestions from the audience included possibilities from blast resistant armors to non-load-bearing decorative items. The last paper of this session was presented by Sylvain Dubois of Laboratoire PHYMAT, France, on Al-Al-Cu-Fe composites produced by hot isostatic pressing. The reinforcement particles had a different crystal structure, either icosahedral or tetragonal, depending on the processing temperature. Results showed that the yield stress strongly depended on the phase of the reinforcement particles.

**METAL-MATRIX COMPOSITES–NANOCOMPOSITES**

This session had four presentations including two invited talks. Nikhil Gupta presented an invited lecture on metal-matrix nanocomposites (MMNCs). Use of composite materials has reached a level of about 50% by weight in recent civilian and military aircraft. Gupta attributed this increase mainly to polymer-matrix composites due to substantially increased automation in fiber placement and composite fabrication. While traditional MMCs are still not at the desired level of applications, higher-performance MMNCs can accelerate the growth rate of this market. This talk covered recent advances in processing of MMNCs and compared their properties and performance to the traditional MMCs. The second invited talk of this session was presented by Mirle Surappa of the Indian Institute of Science–Bangalore, India. He presented recent results from his group on aluminum-matrix micro- and nano-composites reinforced with carbon, silicon carbide, alumina, and fly ash. The development of a stir-casting method for aluminum-alumina nanocomposites was presented by Benjamin Schultz of the University of Wisconsin–Milwaukee. The studies have been aimed at obtaining a uniform dispersion of alumina nanoparticles in aluminum melt. The last paper of this session was presented by Shahraram Amini of Drexel University on TiAlC/nanocrystalline magnesium matrix composites. The magnesium grain size was less than 50 nm. These composites were found to have very high damping capacity. The study investigated microstructural evolution and structure-property relations in these composites.

**PROPERTIES OF COMPOSITE MATERIALS**

Six presentations were included in this session, which covered thermal transport, machinability, fatigue, wear, damping, and tensile properties of a variety of composites. An invited talk by Ajit Roy of the Air Force Research Laboratory, Dayton, Ohio, discussed thermal applications of composite materials relevant to the aerospace sector. Thermal properties of functionalized exfoliated graphite-filled epoxy-matrix composites and of other nanocomposites were discussed. Such highly conducting composites are desired in electronic packaging for heat dissipation. Sri Harsha Panguntani* of Northern Illinois University discussed the laser-
assisted machining of silicon nitride with emphasis on the structure of the heat affected zone. Tensile and fatigue properties of silver-cored composite multi-strand cables were presented by John Lewandowski of Case Western Reserve University. Interactions between the constituent wires and strands of the cable do not play a significant role in the fracture of the cable under uniaxial tensile loading. Fatigue properties of cable were found to be strongly dependent on the cable architecture. Mirle Surappa presented damping and wear characteristics of fly ash filled A356 matrix composites. Detailed discussion on the effect of fly ash particle size, size distribution, and volume fraction on the wear properties was presented. Yanwen Wang of the Missouri University of Science and Technology presented results on tensile properties of SiC particle reinforced Al-Y-Ni-Co alloy composites prepared by powder metallurgy. The tensile properties in the longitudinal and transverse to the compaction direction are found to be different. Tensile, fatigue, creep, and thermal properties of TiB/Ti-6Al-4V composites were presented by Hiroshi Izui of Nihon University, Japan.

**METAL-MATRIX COMPOSITES–PROCESSING**

The first three talks of this session were related to aluminum-matrix composites. Srinath Viswanathan of the University of Alabama discussed the benefits of in-situ processing methods, including bubbling of reactive gases in the melt. The use of AlB₃ single-crystal flakes in reinforcing aluminum alloys to obtain over 100% improvement in modulus was presented by Jacob Meyer of University of Illinois–Urbana Champaign. Yuyuan Zhao* presented his second paper in this session where he continued discussion on various types of syntactic foams. The presentation was focused on fabrication processes and structure-property correlations. Mark Lubrick* of the University of Windsor, Canada, presented results on measurement of porosity in a composite using acoustic wave velocity. Powder-metallurgy-based processing methods and hardness measurements of tungsten-reinforced Ni-W composites were presented by Andrew Zeagler of Virginia Tech. Evaldo Kubaski* of the University of Sao Paolo, Brazil, discussed the use of milling to prepare different compositions of NiCrAl-Al₂O₃ composite powders. The results reported the presence of a mechanically induced self-propagating reaction in the milling process, which resulted in a sudden rise in temperature. Nui Nai* of the National University of Singapore presented results on Sn-0.7Cu and Sn-3.5Ag lead-free solders reinforced with different volume percentages of nano-size alumina and tin oxide particles. These composites are used in electronics packaging. In general, hardness and strength of composites were higher and ductility was lower than the matrix alloys.

**POLYMER-MATRIX COMPOSITES I AND II**

Two sessions focused on various aspects of polymer-matrix composites. An invited lecture by Volkan Otugen of Southern Methodist University introduced the concept of whispering gallery mode micro-optical sensors. These sensors are made by optical coupling of a micro-particle with an optical fiber. These sensors are considered suitable for structural health monitoring applications in composites because of their structure, small size, and high sensitivity. Nikhil Gupta presented a detailed analysis on these sensors embedded in a polymeric matrix. The sensitivity of encapsulated sensors is modeled using finite element analysis. In another presentation Nikhil Gupta presented a review of the properties of a variety of polymer and metal-matrix syntactic foams. The effect of wall thickness and volume fraction of hollow particles on the properties of syntactic foams was discussed. Gajendra Pandey (substituting for Jeevan Kumar*) of Oklahoma State University presented the effect of fiber orientation on the moisture absorption and degradation characteristics of carbon-fiber-reinforced epoxies. An increase in the moisture exposure time resulted in a decrease in the flexural strength and modulus of composites. Two applications-oriented talks, by Judy Schneider of Mississippi State University and Yong-Shin So of Hyundai Heavy Industries, Korea, focused on the development of composite-wrapped storage vessels for cryogenic fuel storage and on stern-tube bearing of ships, respectively. These talks stimulated discussion on load-bearing structural applications of composites. Asaad Mazen* of El-Menia University, Egypt, and Savita Murthy* of S.J.C. College of Engineering, India, presented results on laminated composites containing glass fibers in epoxy and vinyl ester resins and tested under flexural loading. An invited presentation in this session, by Eyassu Woldesenbet* of Louisiana State University, was focused on self-healing composites. Various healing mechanisms based on filled particles and fibers and their effectiveness were discussed. Sarah Lewis of Starfire Systems Inc. discussed a process of formulating new polymers for specific applications and presented results on a high-performance polymeric group of polymers.

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