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Foreword

A composite material in the traditional sense is defined as a materials system composed of two or more physically distinct phases whose combination produces desirable overall properties that are different from those of its constituents. Present day researchers have pushed the envelope on this way of thinking beyond its traditional definition by creating tailor-made 'engineered composites' and 'smart materials'. The uses for such materials are continuously growing and soon they will play a major role in many arenas of our lives. For example, smart coatings, nano-particulate materials for tailored high-temperature applications, electronic-ceramic materials, piezo-ceramics in structures, fiber-optics smart materials etc., are the way of the future. A clear understanding of these engineered composites requires an interdisciplinary thought process grounded in a sound fundamental knowledge of traditional composite materials.

This special issue on the "*Interdisciplinary Approach to Smart Composite Structures and Materials*" aims to identify

- Key basic science issues underlying these materials.
- Challenges and opportunities for new applications of these materials.
- Mechanisms for collaborative interdisciplinary research involving the basic and applied sciences that will promote new developments in, and a clearer understanding of, Smart and Advanced Materials and Structures.

With these goals in mind, the articles in this issue have been selected to reflect a diversity of research interests and achievements. These include applications of electronic composites and smart composites, nanophase composites and coatings, and the science issues such as composition, microstructure, properties, failure behavior, mechanics and modeling.

One of the key requirements in developing composites and other advanced materials is generation of a good understanding of the relationships between composition and structure on the one hand, and properties and behavior on the other. Another key requirement is application of this understanding to develop a material with the desired properties. A third key requirement is to understand the new material's failure mechanisms. All of these are encompassed in the term "characterization", which is the subject of the first paper. Pasto et al. describe the various fundamental science studies that are being conducted for the development of these materials at the High Temperature Materials Laboratory (HTML), a US Department of Energy (DOE)-designated National User Facility.

Following the same theme, the second paper by Weimer and Bordia investigates nanophase reinforced ceramics which have been shown to exhibit attractive mechanical properties (high toughness, strength and creep resistance). Silicon nitride matrix composites are particularly desirable for many structural applications. In the paper status of nanophase reinforced ceramic matrix composites is reviewed with particular emphasis on slicon nitride matrix composites. Currently, the biggest obstacle to widespread usage of these composites is the need for expensive and specialized synthesis and processing techniques.

The need for research on this aspect is highlighted and it is emphasized that multi-disciplinary teams will be required to handle this research challenge. Results from ongoing research on the synthesis of nanophase reinforced composite powders, their processing and mechanical properties are presented. It is shown that the carbothermal nitridation technique is suitable for producing nanophase composite powders that can be processed into high density composites, with attractive mechanical properties, using versatile and inexpensive processing techniques (pressureless sintering). Areas of further research are highlighted.

The next five papers provide an insight into how laser processing can help provide tailored film properties, thus creating engineered composites for a wide range of applications. Especially, Pulsed Laser Deposition (PLD) method is rapidly proving to be an effective method of producing thin films of a variety of materials such as Diamond Like Carbon (DLC), high temperature superconductors, ferroelectrics, nitride and metal compounds. This provides high energy to ablate the target. Material vaporization forms a plume that directly deposits the target material on the substrate.

Rawdanowicz et al. provide a procedure on how the strength and toughness of hard coatings may be optimized by combining the attractive properties of differing multiple material layers in a single protective coating. The result can be composite coating systems with reduced thin film thickness (decreased processing time) and improved performance (increased hardness, elastic modulus and toughness). In addition, adjusting the material composition and microstructure can optimize the strength and toughness in hard coatings for specific applications. Covalent materials like AIN are difficult to realize as single layer coatings because of the lack of adherence to metallic substrates. However, no problems with adherence occur at the interfaces with other covalent hard materials such as TiN. As a

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consequence, the authors show how covalent hard materials can be bonded into wear-resistant multilayer with improved properties.

Lee et al. discuss a novel method to fabricate adherent interfaces in high thermal-expansion-coefficient mismatched systems, thereby creating a surface engineered composite. During heating or cooling these systems induce very high stresses in the coatings that frequently lead to debonding, cracking, or delamination of the coating from the substrate material. The authors investigate a novel process for the formation of laser induced micro-rough surfaces (interfaces) on cemented carbide substrates with compositionally gradient diamond coating with improved characteristics.

Wei et al. show a novel target design adopted to incorporate foreign atoms into the DLC films during film deposition. Optical microscopy of the pure DLC of a certain thickness shows severe buckling and the authors show qualitatively through scratch tests that pure DLC films have quite poor adhesion due to the large compressive stress, while doped DLC films exhibit much improved adhesion. Copper, titanium and slicon are chosen as the dopants and the effect of dopants on the Raman spectrum is analyzed. Wear tests show improved wear resistance in the doped DLC coatings. The doped DLC films have slightly lower hardness and Young's modulus as compared with pure DLC films. All these were understood by analyzing the internal stress reduction as derived from Raman G-peak shift to lower wavenumbers. A preliminary model of the stress reduction mechanism is discussed.

Ebihara et al. study the effect of DLC film deposition on PZT ferroelectrics and YBCO superconducting films. The ferroelectric $PbZr_{0.52}Ti_{0.48}O_3$ (PZT) and superconducting $YBa_2Cu_3O_{7-x}$ (YBCO) are two of the promising film materials for future electronic devices. Long term reliability is an important issue related to these films and the authors give a very timely discussion on how the degradation of this composite is protected by coating the surface with the diamond-like film formed by ablating graphitic carbon with an excimer laser.

The last paper in this group, by Aoqui et al., provides a deeper understanding related to the laser ablation process characteristics for Carbon Nitride (CN) and DLC films preparation, an important issue related to the development of smart composites. These films are metastable amorphous materials which have been studied intensively, especially for electronic applications due to the diamond-like properties such as hardness, highly optical transparency, chemical inertness, and high resistivity. The authors present some key results related to the dynamics of the plasma plume during the preparation of DLC and CN thin films by the PLD method.

The next set of six papers deals with smart materials and composites. The field of smart and adaptive structures has progressed over the past decade from simple cantilever beam experiments to complex real-world aircraft structures. Piezoelectric materials belong to a group of materials used to construct smart or adaptive structures. At present, these materials have been used extensively as discrete or distributed sensors and actuators in smart structures to control/suppress vibration. The development of piezoelectric sensors and actuators is essential for the design of future light-weight and high-performance structures with intelligent adaptive capabilities. By the same token, research must progress towards the development of other innovative smart materials and structures.

Denda and Lua summarize the analytical foundation for the formulation of the boundary element method for plane piezoelectric solids. To achieve a rationally based design, a computer-aided optimization approach which involves a through and accurate analysis of all the factors affecting the performance of the structure has to be implemented. The duality relations between the force/charge and the displacement/electric potential solutions, embedded in the Stroh formalism, are exploited in the paper as the foundations for the analytic and the numerical approaches to the piezoelectric boundary value problems in two-dimensions. The analytical and numerical foundations established in this paper enable us to solve important problems of piezoelectricity with arbitrary geometry and composition.

While most of the existing micro-mechanics models for smart composites are based on random microstructure, Yu focuses on periodic microstructure, which is observed in practical piezoelectric composites. The model provides closed-form solutions to the overall properties of a broad class of piezoelectric composites and involves many microstructural parameters. This understanding can serve as an effective and efficient tool for the conceptual design of smart transducer materials.

Schulz et al. present techniques for detecting damage and reducing the vibration of composite structures. Vibration transmittance functions are used to identify delamination in composites, and nonlinear saturation control, hybrid laser sensing, and active constrained layer damping techniques are used to suppress vibration of flexible structures. The paper provides strategies for using smart materials to counter the susceptibility of composites to vibration and damage, and is pertinent to expanding the use of composites for flight and other applications.

Agnes and Mall give an overview of the structural integrity issues during piezoelectric vibration suppression of composite structures. This timely issue highlights the current status of the modeling and application of piezoelectric vibration suppression technology. A rationale for increased understanding towards electro-thermo-mechanical fatigue of adaptive structural systems (as opposed to components or only materials studies) for future real world application is clearly outlined.

Oh et al. present a study related to the fundamentals of controlling structural vibration of plates treated with a new class of Passive Magnetic Composites (PMC). Using both finite element modeling and experimentation the authors convey effectively the potential of this new materials system for controlling structural vibrations.

Kalamkarov et al. discuss the use of the pultrusion process for the manufacturing of fiber reinforced polymer (FRP) composites with embedded Bragg grating and Fabry–Perot fiber optic sensors. These sensors should provide insight into the process induced strains within the composite. The paper provides a lucid discussion of a test methodology to validate this technique and provides a framework for further development of these advanced materials.

Finally, Hung presents a novel optical measurement technique called shearography for both present day and future testing of composite structures. It is a laser-based technique for full-field and non-contact measurement of surface deformation. Despite being relatively young, the technique has already received considerable industrial acceptance for nondestructive testing, in particular for NDT of composite structures. In this application, shearography detects defects by looking for defect-induced deformation anomalies. Being full-field, its inspection speed is about 1000 times faster than ultrasound, as the ultrasonic inspection requires point-by-point scanning. Other applications include strain measurement, material characterization, residual stress evaluation, vibration studies, 3D shape measurement, as well as leak detection.

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