Project # 3: Nanostructured Composite Materials

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Project Summary:

Laminated composite materials consist of a stiff and strong micron-size reinforcement phase and a matrix phase, usually a polymer. Composite materials can have very high mechanical properties at a very low weight penalty, and thus constitute most of the structural components in high performance applications for the aerospace and defense industries among others. However, these materials can experience a delamination failure when cracks propagate along the intra-laminate planes and cannot be arrested due to the lack of fibers in the transverse direction to the composite laminate. Composite materials also have a very low resistance to impact loading and poor transport in the transverse direction to the laminate. In order to mitigate these drawbacks, a new generation of composite materials with reinforcements spanning several scales needs to be developed. Polymeric nanocomposites have become relevant in recent years since they exhibit synergistic properties derived from their two components: the polymeric matrix and the reinforcing nanoparticles. Nanocomposites could also constitute the matrix of laminated composites to form nanostructured composites that may yield record high matrix-dominated mechanical, thermal and electrical properties.

The goal of this project is to understand the basic physical phenomena that govern the response of nanostructured composite materials under mechanical and thermal loads, and thus lead to the development of composite materials with superior mechanical, thermal and electrical properties. In this project the teachers will fabricate composite panels, prepare and instrument composite specimens, conduct tests, analyze the collected data, and prepare a report with the most relevant results with the assistance of Dr. Abot and his team. This project will be intertwined with an ongoing project to test the hypothesis that carbon nanotube (CNT) arrays and carbon nanotube yarns, properly functionalized and intermingled in polymeric laminated composite materials, can modify the intra-layer interphase morphology and render high interlaminar composite properties (see Figure 1). The RET teachers will investigate the effect of several parameters including CNT structure and architecture, functionalization schemes, and processing parameters. The prepared composite specimens will be tested under quasi-static mechanical and thermal loading in a tensile stage to measure forces, displacements and strains (see Figure 2). Nanostructured composite materials with superior interlaminar mechanical properties have already been produced and further development and eventually new discoveries are expected during the first year. In the second and third years, emphasis will be placed on tailoring the electrical response of the CNT structures to provide sensing capabilities for the composite materials. This will require design of novel experimental setups to measure electrical conductivity and the coupled mechanical-electrical properties.

Ideas for Classroom Implementation:

A science classroom module will be designed for the students to manufacture a set of polymeric composite panels through a resin infusion technique. Specimens will be prepared from the panels and their mechanical and electrical responses will be determined with a portable characterization system that will be taken into the classroom. A student competition will be conducted by allowing the students to vary the reinforcement architectures and composite material phases to achieve a set of prescribed properties.

Figure 1. (a) Optical image of a carbon nanostructured composite ply showing CNT array bonded to the carbon fabric; (b) Scanning Electron Microscope (SEM) image of aligned CNT array

Figure 2. Graduate student conducting a characterization experiment on a carbon/epoxy composite specimen in a Dynamic Mechanical Analyzer to determine its response under dynamic loading