Advanced Multifunctional Composites Featuring Carbon Nanotube Additives

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ABSTRACT

Due to its unique blends of mechanical, thermal and electrical properties, carbon nanotubes are envisioned as the ideal reinforcement fillers for polymer composites in order to improve its overall properties. Carbon nanotube based polymer nanocomposites have been studied extensively for their strength, stiffness, damping and their electrical properties. However, some of the most important mechanical properties for structural material such as its fatigue behavior, creep and buckling stability have not been investigated previously. In this work, we investigated the mechanical creep, buckling stability, fatigue crack propagation and self structural health monitoring capability of the carbon nanotube filled polymer nanocomposites in a systematic manner.

Epoxy is a highly cross-linked thermoset polymer that has versatile applications in many technological fields including composites, tooling, molding, electronic packaging and constructions etc. However, its brittle and notch-sensitive characteristics might hinder their application in some areas such as high performance aerospace and automotive composites due to catastrophic failure from long term fatigue loading. Here we demonstrate the use of carbon nanotubes (MWNT and SWNT ropes) to dramatically reduce the fatigue crack propagation rate of epoxy resins. Over one order of magnitude reduction (>1000%) in fatigue crack growth rate is achieved with incorporation of only 0.5 wt% of untreated carbon nanotubes. The reduction in fatigue crack propagation rate is primarily attributed to fiber bridging and carbon nanotube fiber pull-out processes. A theoretical model based on linear elastic fracture mechanics is built to predict the effects of weight fraction; fiber geometry and interfacial strength on the fatigue crack

propagation rate of the composite. The fatigue behavior is further improved by optimizing the fiber aspect ratio and nano-engineering of polymer/CNT interface.

One of the other major limitations of the polymeric materials for long-term structural applications is its excessive creep deformation under tensile load. And the creep performance usually degrades as the structure operates at elevated temperature. In this study, carbon nanotube filled epoxy composite is fabricated using improved processing methods for better dispersion. We demonstrate here that carbon nanotube additives in low weight fractions (0.1-0.25%) are effective in limiting the load-induced relaxation and re-orientation of epoxy chains, resulting in a significant reduction of the creep deformation. Also, the creep responses of nanocomposites with different filler (MWNT, SWNT & C60 Buckyball) are compared. Carbon nanotube additives could therefore be the key enabler for long-term higher temperature application of polymeric structures which would otherwise fail by excessive creep deformation.

To study the buckling stability of the carbon nanotube composites, an experimental study on single-walled carbon nanotube (SWNT) filled polycarbonate nanocomposite column structures is presented. Significant increase (29-51%) in critical buckling load is observed with the addition of relatively small weight fraction (1-2%) of chemically oxidized SWNTs into the polycarbonate matrix. Based on the increase in elastic modulus of the nanocomposite compared to the pristine polycarbonate, the critical buckling load is expected to increase by 5-17% for 1-2% weight fraction of nanotube fillers. The observed 29-51% increase in buckling load suggests a significant enhancement in load transfer effectiveness between the polymer and the nanotube bundles when subjected to a high compressive load as compared to tensile load. Such nano-composite systems with high buckling stability show potential as lightweight and buckling resistant structural elements in aeronautical and space applications.

In-situ structural health monitoring of high performance carbon fiber composite and polymer composite can be performed by measuring the electrical response of the material after the addition of carbon nanotube fillers. This simple technique is shown to correlate the structural defects and material degradations with its electrical properties very effectively. With proper processing, CNTs exfoliates and disperse well throughout the material and provide three dimensional networks for electrical conduction. For a structure under fatigue cyclic loading, the reduction in material stiffness will result in increase in electrical resistance. Thus, by measuring the electrical resistance, the health of the structure can be inferred. Also, the crack length and internal flaws resulting from service loading can also be quantitatively determined based on the measured electrical response. This simple structural health diagnosis can help reduce the possibilities of catastrophic failure of the structure and able to extend the service life of structural components by maintenances after such a diagnosis. This non-intrusive technique will also reduce the cost and minimize the complexity of the high performance structure by eliminating some of the expensive integrated sensors onboard.