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Development and thermal properties of carbon nanotube-polymer composites

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The favorable conductive properties of carbon nanotubes (CNTs) offer opportunities for constructing CNT-based nanocomposites with improved thermal conduction for a range of potential applications. Such lightweight composite materials are expected to have thermal properties that depend on their CNT volume fraction and operating temperature. The lack of available CNT processing methods that are compatible with multi-laminated composite structures is one of the largest challenges facing the construction of CNT-based nanocomposites.

The aim of the work is to develop enhanced thermal properties in carbon nanotube-polymer composites that can replace traditional aerospace metallic materials to reduce the weight in space structures. Dispersing the carbon nanotube onto prepreg composite structure, increases the thermal storage, increases the thermal transport and supports scientific instrumentation. The investigated composites were processed and characterized using Raman spectroscopy, thermogravimetric analysis, thermal diffusivity and differential scanning calorimetry.

Through varying the concentration of single-walled carbon nanotubes (SWCNTs) up to 30 wt% to the IM7 prepreg composite, its heat capacity increased as much as 30% greater than the tested temperature range and its through-thickness thermal diffusivity increased by 30% compared to the virgin composite material. The addition of randomly oriented SWCNTs yielded an increase in the in-plane thermal conductivity ranging from 120 to 150 percent greater than the temperature range of 120–470 K and 30% in the through thickness. This may be due to interfacial resistance between the SWCNTs, the 8552 epoxy and the IM7 composite. The developed methods provide the opportunity for enhancing the thermal properties of a composite through the use of CNTs as additives. These improvements would be particularly beneficial applications such as solar arrays, fairings and thermal radiators.

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1. Introduction

Favorable strengths, stiffness, thermal conductivities, and lightweight characteristics are critical property requirements for materials used for aerospace structure and vehicles. Currently, many of these systems, use lightweight aluminum alloys such as 2219, 2090, and 2195. These three alloys were used in vehicles such as those in the Space Shuttle and Ares 1-X spacecraft programs, but only have limited uses in NASA's Space Launch Systems heavy launch vehicle. Some of the problems with these alloys (and/or most metals) are they exhibit reduced thermal conductivities at higher temperatures and have high densities in comparison to polymers, which could serve as structural replacements. Lighter-weight alternative materials that could also provide superior thermal properties would provide immediate benefits in the design and operation of future vehicles.

Carbon nanotubes exhibit a remarkable set of electrical, mechanical, and thermal properties that offer opportunities for materials design for aerospace and other applications [1,2]. The CNT densities are less-than half that of aluminum alloys. Despite there

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has been extensive research on the properties of CNTs [1–16], they have not reached their full potential as additives within composites [2]. To access the favorable thermal properties provided by CNTs in practical aerospace structures or components, the CNTs will need to be assembled into mechanically robust elements that could comprise functional macroscopic structures. An approach would be to incorporate the CNTs within prepreg composite structural elements at sufficient quantities to provide significantly improved properties.

Highly efficient components are required for heat dissipation and heat exchange within the thermal transfer and control systems of many industrial processing and maintenance architectures. Similarly, materials with high thermal conductivities and directional heat dissipating paths are an important part of successful interstellar space vehicles. The effective development of nanomaterials and technologies with improved thermal conduction and transfer characteristics will impact many figures of merit in assembled units, such as performance, capacity, reliability, and safety. The potential impacts of CNT-based composites and nanomaterials on the aerospace industry are summarized in Table 1.

The ability to develop future high-performance composites for thermal management applications will rely on the ability to incorporate the exceptional thermal properties of CNTs into existing materials. Systems that could benefit from these capabilities are heat dissipating components and heat exchangers. Due to their weight reduction, using CNTs to advance the manufacturing technologies of high-performance composites would offer particular benefits for future space vehicles.

There are three major challenges exist in this research which includes: (1) the ability to disperse CNTs in a solvent for casting, (2) uniformly coating of a composite with CNTs, and (3) measuring the thermal properties of the developed nanocomposites. Carbon nanotubes have a tendency to form agglomerates and bundles due to the van der Waals attraction between each set of tubes. Functionalization, high-shear mixing, ultra-sonication, and surfactant wrapping are some of the methods employed in the literature to assist in uniformly dispersing nanotubes in a solvent. When the thermal properties of the composite are under consideration, functionalization and surfactant wrapping disrupt the sidewall sp^2 hybridization and reduce the thermal conductivity of the nanotubes. Therefore, there is a trade-off between avoiding functionalization of the CNTs and achieving good dispersions. Since nanotubes conduct along their length, their alignment is additionally important for achieving optimal thermal properties. A good dispersion of single-walled carbon nanotubes (SWCNTs) in solution along with modest alignment on the prepreg composite are critical requirements to enable this research.

As new applications for CNTs emerge, it is necessary to characterize the thermal behavior of these nano-scaled materials. This project seeks to develop carbon nanotube-polymer composites with enhanced thermal properties to replace traditional aerospace

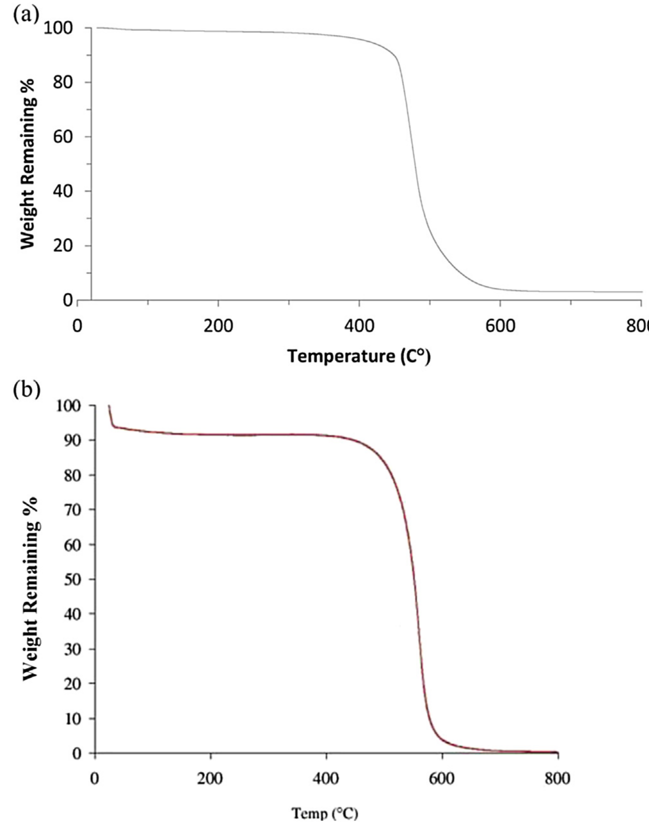

Fig. 1. (a) TGA of US Research Nanomaterials, Inc., SWCNTs. (b) TGA reported by Chiang et al. of SWCNTs prepared using a high pressure carbon monoxide disproportionation (HiPco) process. SWCNTs were heated in air to 800 °C at 5 °C/min [18].

metallic materials. Aerospace design and manufacturers will be able to capitalize on reduced weight for thermal processing equipment within space structures.

2. Experimental setup, results and discussions

Single-walled carbon nanotubes were obtained and used as received from US Research Nanomaterials, Inc., located in Houston, TX. The SWCNT were characterized by thermogravimetric analysis (TGA), Raman spectroscopy, and differential scanning calorimetry (DSC) to confirm their integrity before use in composites.

TGA is an analytical technique used to determine a material's thermal stability and its volatile content by monitoring the weight change that occurs as a specimen is heated. TGA can be used to test the purity of SWCNTs. As shown in Fig. 1, the SWCNTs obtained from US Research Nanomaterials, Inc., exhibited a TGA profile

Table 1
Potential impacts of CNT-based composites on the aerospace industry.

Advance technology	Expand capacity
• Enable fast heat dissipation in critical structural or functional components	• Enable multifunctionalities, such as extreme load bearing and electrical conductivity.
• Improve the performance of thermal control system	• Allow structures directly tailored to vehicle and systems needs
• Encourage performance-based standards for aerospace composites	• Satisfy future growth in demand
Increase vehicle flexibility	**Enhance safety**
• Reduce the weight of space and airship vehicles	• Minimize the impact of temperature, friction and other conditions
• Increase the flexibility and efficiency gains of current space vehicles and management systems	• Successful implementation of the properties would Improve safety of air transportation systems
• Lower the launch cost	