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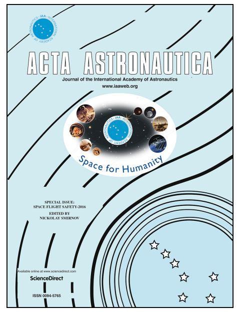

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Behnam Ashrafi, Michael B. Jakubinek, Yadienka Martinez-Rubi, Meysam Rahmat, Drazen Djokic, Kurtis Laqua, Daesun Park, Keun-Su Kim, Benoit Simard, Ali Yousefpour

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Multifunctional Fiber Reinforced Polymer Composites Using Carbon and Boron Nitride Nanotubes

Behnam. Ashrafi[a]*, Michael B. Jakubinek[b], Yadienka Martinez-Rubi[b], Meysam Rahmat[c], Drazen Djokic[c], Kurtis Laqua[a], Daesun Park[a], Keun-Su Kim[b], Benoit Simard[b], and Ali Yousefpour[a]

[a] *Aerospace, National Research Council Canada, 5145 Decelles Ave., Montreal, Quebec, H3T 2B2, Canada;*
[b] *Emerging Technologies, National Research Council Canada,100 Sussex Dr., Ottawa, Ontario, K1A 0R6, Canada;*
[c] *Aerospace, National Research Council Canada, 1200 Montreal Rd., Ottawa, Ontario, K1A 0R6, Canada;*
* Corresponding Author (behnam.ashrafi@nrc-cnrc.gc.ca)

Abstract

Recent progress in nanotechnology has made several nano-based materials available with the potential to address limitations of conventional fiber reinforced polymer composites, particularly in reference to multifunctional structures. Carbon nanotubes (CNTs) are the most prevalent case and offer amazing properties at the individual nanotube level. There are already a few high-profile examples of the use of CNTs in space structures to provide added electrical conductivity for static dissipation and electromagnetic shielding. Boron nitride nanotubes (BNNTs), which are structurally analogous to CNTs, also present a range of attractive properties. Like the more widely explored CNTs, individual BNNTs display remarkable mechanical properties and high thermal conductivity but with contrasting functional attributes including substantially higher thermal stability, high electrical insulation, polarizability, high neutron absorption and transparency to visible light. This presents the potential of employing either or both BNNTs and CNTs to achieve a range of lightweight, functional composites for space structures. Here we present the case for application of BNNTs, in addition to CNTs, in space structures and describe recent advances in BNNT production at the National Research Council Canada (NRC) that have, for the first time, provided sufficiently large quantities to enable commercialization of high-quality BNNTs and accelerate development of chemistry, composites and applications based on BNNTs. Early demonstrations showing the fabrication and limited structural testing of polymer matrix composites, including glass fiber-reinforced composite panels containing BNNTs will be discussed.

Keywords: Nanotechnology, nanocomposites, carbon nanotubes, boron nitride nanotubes, buckypaper, glass fiber reinforced polymer composites

1. Introduction

Carbon nanotubes (CNTs) and boron nitride nanotubes (BNNTs) have excellent mechanical properties, high thermal conductivity, low density, and a unique geometry (a small diameter of a few nanometers and high aspect ratios of typically >1000). These characteristics make them attractive for the fabrication of mechanically and thermally enhanced lightweight composites for a wide range of applications. BNNTs and CNTs, however, offer different multifunctional characteristics; CNTs are electrically conductive while BNNTs possess superb resistance to oxidation, a wide energy band gap, and high neutron absorption capability. In space-related applications, multifunctional CNT-based composites can provide mechanical and electrical properties (*e.g.*, electromagnetic shielding on the Juno spacecraft [1]). BNNTs can provide complimentary multifunctional properties, most notably for electrically insulating, high temperature and neutron radiation shielding applications. The fabrication of BNNT-polymer composites via dispersion/mixing of BNNTs into bulk polymers has been reported including poly (methyl methacrylate) [2], polycarbonate [3], epoxy resins [4], among other matrices [5] and these composites have shown improvement in thermal and mechanical properties versus the unmodified polymer matrix. More recently the first cases of composites based on free-standing BNNT buckypaper sheets [6, 7], which has been an effective approach in the CNT field, and of multiscale composites employing BNNTs and a traditional fiber fabric [8], were reported. The latter case demonstrated improved thermal conductivity isotropy of a glass fiber reinforced polymer [8]; however, the potential to improve structural properties (*e.g.*, impact resistance) of fiber-reinforced polymer composites remains unexplored and, in all cases, the number of studies of BNNT composites is vastly smaller than for carbon nanotube (CNT) composites [9,10].

The discrepancy in the development of BNNTs *vs*. CNTs is directly attributable to nanotube production scale. Worldwide production of highly-crystalline few-walled BNNTs until as late as 2012 could be estimated as only a few 10's of grams per year. Recent advances [11], including the development of a pilot-scale production process at the National Research Council Canada (NRC) with a demonstrated capacity of ~200 g/day [12] and other approaches [13,14], have provided significant advances in worldwide BNNT production capacity, which we now estimate as ~10 kg/year. While this is still a limited supply, it enables development and demonstration of composite structures and the scalability of the new processes means that BNNT production is moving towards being demand-limited and will