Ceramic-Carbon Nanotube Composites and Their Potential Applications

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

Carbon nanotubes (CNTs) have been the subject of intensive research for nearly two decades, and this is due to their exceptional lightness, large aspect ratio, extraordinary mechanical, electrical, thermal properties and additional multi-functional characteristics. Ceramics have high stiffness and good thermal stability with a relatively low density, and they are an important constituent in the fabrication of advanced composites where high thermal and chemical stability are important. However, brittleness has limited their application in many structural applications. The combination of ceramic (alumina in particular) and CNTs, endeavouring to develop functional composites, offers a very attractive system for research and development. The fabrication of such alumina-CNT composites at bulk scale is therefore highly desirable for industrial applications. However, the synthesis of such composites possesses many technical challenges which need to be addressed. Poor synergy between the matrix and CNTs, potential damage to CNTs, obtaining a uniform and agglomeration-free distribution of CNTs within the matrix, and high cost of CNTs and processes involved in their composite fabrication have proved to be the significant challenges.

In this thesis, the focuses are laid on addressing these issues and on the fabrication of specially engineered composites for particular applications such as filter and composites with improved mechanical properties. In this regard, it has been tried to directly fabricate CNTs in different ceramic matrices based on the application requirements. After that, the critical issues and challenges in the fabrication of these functional materials have been clearly investigated and by introducing novel methods and approaches, it has been tried to solve these problems.

Also, a new polymer-ceramic-CNT composite has been fabricated by using two different thermoset (epoxy resin) and thermoplastic (polyamide 12) matrices. In this regard, good interfacial bonding between the composite elements along with good wettability of ceramic and CNTs with polymer had to be addressed as critical issues and challenges in the fabrication process. If the adherence at the interface is not strong enough, the material will tear and fail easier. In contrary, a tailored functionalization of CNTs can lead to an improved wettability and as the results, strong interfacial adhesion and bonding between the composite elements. These dominating factors will improve the degree of filling which results in existence of fewer voids inside the composite. These voids will act later as stress points and reduce the composite strength. At the end, the mechanical properties of the fabricated samples have been assessed.

The CNT filters have been tested in the removal of bioorganic (yeast cells) and inorganic (heavy metal ions) contaminants from water, and of particulates from air, and they all showed very promising results. More than 99.6% of the air particles (size ranges from 0.3 to 10 μm) were filtered using 300 mm long CNT filter. A complete removal of heavy metal ions from water was reported particularly for single ion. 98% of the yeast cells were filtered. Different factors involved in the filtration efficiency such as ceramic pore size, length of filters, CNT loading and injection rates have also been discussed.

Furthermore, the mechanical properties (compression test, hardness and impact test) of the composite materials (including ceramic-CNT, epoxy resin-ceramic-CNT and polyamide-ceramic-CNT composites) have been assessed. During impact test, the epoxy resin-ceramic-CNT composite absorbed 117.2% and 32.7% more energy compared to the pure epoxy resin and epoxy resin-ceramic composite, respectively. The epoxy resin-ceramic-CNT composite sustained 40% more elastic deformation before breakage compared to the epoxy resin-ceramic composite as a result of the CNT reinforcement. The addition of CNTs to the polyamide12-ceramic composite increased its yield stress by 41%.

All of these results represent a big leap towards practical applications for the composite reported in the thesis, which may open up new opportunities for CNT engineering at industrial scales, due to the easy fabrication methods introduced and the promising performance they have exhibited.

Presentations and Publications

- Parham, H., Bates, S., Xia, Y. & Zhu, Y. A highly efficient and versatile carbon nanotube/ceramic composite filter. Carbon 54, 215-223, (2013).

- Parham H, Kennedy A, Zhu Y. Preparation of porous alumina–carbon nanotube composites via direct growth of carbon nanotubes. Composites Science and Technology. 2011;71(15):1739-45.

- Parham H, Bates S, Xia Y, Zhu Y. Carbon nanotube composite filter. 3rd International Conference on Nanotechnology: Fundamentals and Applications. Montreal, Quebec, Canada, 7-9 August 2012.

- Carbon nanotube-reinforced porous Al2O3 nanocomposites filters. Tenth international conference on materials chemistry (MC10). Manchester, UK. 4-7 July 2012.

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