Thermal Characterization of Plain and Carbon Nanotube reinforced Syntactic Foams

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ABSTRACT

Composite materials fabricated using hollow microspheres are called syntactic foams. Particulate filler composites such as syntactic foams, consisting of glass microballoons and epoxy resin, are desirable for applications that require high compressive and impact strengths and low thermal conductivities. However, for heat dissipation applications, filler additions are required to increase the thermal conduction capacity of syntactic foams. Carbon nanotubes are structures that have exhibited a unique combination of mechanical, electrical and thermal properties making them excellent candidates for replacing conventional fillers such as carbon black, silicas, clays, aluminum and copper [1]. In this research, the effect of nanotube addition on the thermal properties of syntactic foam is studied. Addition of nanotubes to the syntactic foam composite is performed in two ways. In the first method, the nanotubes are separately mixed with resin and further with microballoons. In the second, nanotubes are grown over the surface of microballoons. These nanotube grown microballoons are mixed with resin to fabricate syntactic foam.

Multi-walled carbon nanotubes (MWCNTs) are used in the first method of fabricating syntactic foams. These nanotubes are commercially obtained and added to the epoxy resin using ultrasonication and three-roll milling. Further, the microballoons are added to the mixture of resin and nanotubes. Nanotube reinforced syntactic foams are fabricated with 10, 20 and 50% volume fraction of S22 type glass microballoons. The nanotube volume fraction in the syntactic foam is varied from 0.1 to 0.5%. In order to compare the enhancement of thermal conductivity with an addition of nanotubes, plain syntactic foams of the corresponding volume fractions of microballoons are also fabricated. Composite foams are tested for thermal conductivity, thermal diffusivity and specific heat experimentally using a Flashline 5000 thermal analyzer. Theoretical values of conductivity in syntactic foams are calculated using the rule of mixtures. Theoretical values matched to those of plain syntactic foam, but not for the nanotube reinforced syntactic foams. Even though the inclusion of CNTs forms a percolated network in the matrix of the syntactic foams, the improvement is only modest (Fig. 1). This is mainly due to thermal resistance at the interface of nanotubes and matrix [2,3], along with nanotube agglomeration in resin (Fig. 2). Transmission electron microscopy (TEM) images are obtained to observe the dispersion of the CNTs in the epoxy resin using mixing processes such as ultrasonication and three-roll milling. The influence of filler contents of carbon nanotubes and glass microballoons is discussed.

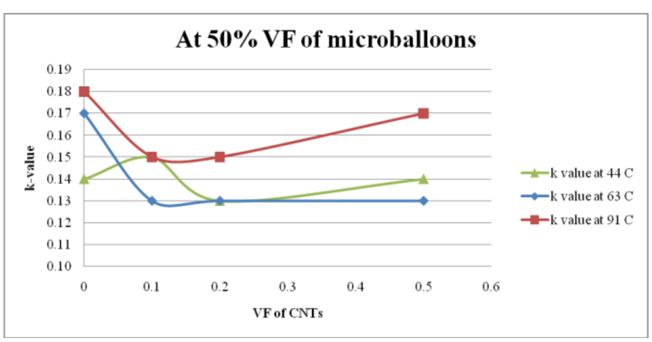

Fig 1. Effect of nanotube addition to thermal conductivity of syntactic foam at 50% volume fraction of glass microballoons.

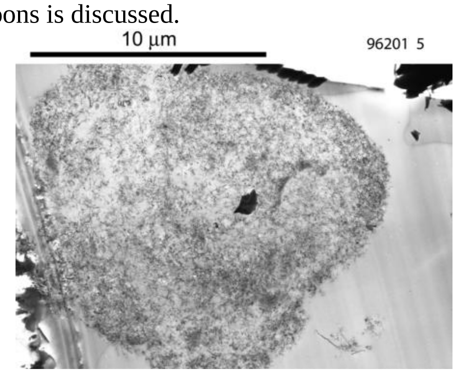

Fig 2. Agglomeration of carbon nanotubes in epoxy resin

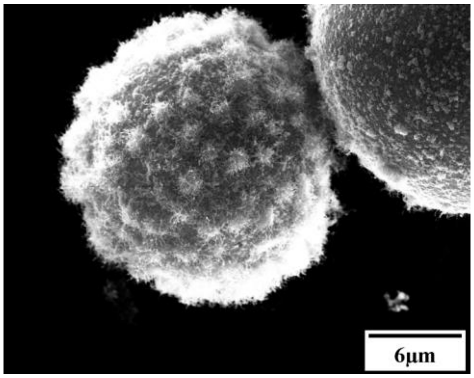

Fig 3. Growth of carbon nanotubes on the surface of S22 glass microballoons.

The second method was devised with an objective to overcome the problems mentioned above. This method attempts to obtain a structured formation of the nanotubes in syntactic foam by growing the nanotubes on the surface of the glass microballoons. The growth of nanotubes on the spherical surfaces would provide a highly controlled inclusion of nanotubes within the resin, along with yielding a densely connected network of nanotubes at high volume fractions of microballoons. The method would result in obtaining a light-weight, thermally and electrically conductive composite material with improved mechanical properties.

Several studies have been performed to synthesize carbon nanotubes using methods such as laser vaporization, arc discharge, pyrolysis and chemical vapor deposition (CVD). Of these, CVD was found to be the most advantageous due to the high purity, high yield, uniform growth and vertical alignment of nanotubes achieved in the process [4]. In this part of the research, a low temperature growth of carbon nanotubes (CNTs) is achieved on S22 type glass microballoons at 550 °C using a thermal chemical vapor deposition of acetylene gas (Fig. 3). Since the glass microballoons have a transition temperature of about 600°C and acetylene decomposes efficiently above temperatures of 800 °C, a two-stage CVD setup is constructed for the nanotube growth on the glass substrate [5]. Acetylene gas is heated in the first zone of the reactor at 850 °C and then brought into the second zone maintained at 550 °C, where the substrate is placed. Carbon nanotubes are grown uniformly around the entire spherical surface. The glass microballoons did not exhibit any thermal deformation or material degradation throughout the process.

Carbon nanotube growth by the CVD process requires metallic catalyst nanoparticles over non-metallic surfaces for the bulk diffusion of carbon on these substrates [6]. Hence, the surface of the glass microballoons is initially cleaned and then coated with a thin film of nickel using an electroless plating process (Figs. 4, 5) [7]. The nickel film is deposited uniformly around the spherical surface of the microballoons. The physical dimensions of the nanotubes

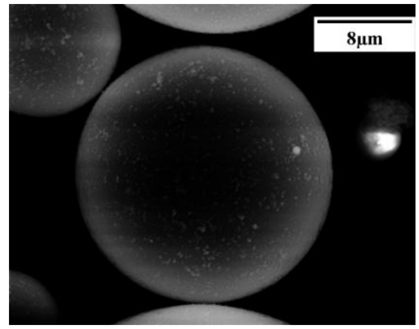

Fig. 4. Glass microballoon after surface cleaning.

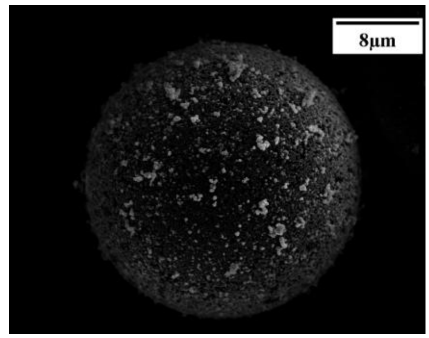

Fig 5. Nickel coating on microballoon by electroless plating process.

are dependent on the thickness of the nickel coating. Scanning Electron Microscope (SEM) images are obtained to observe the nickel deposition and the growth of nanotubes on the microballoons.

Future work would be to combine this new structure, viz. carbon nanotubes on glass microballoons with epoxy resin to form a nano-reinforced syntactic foam material whose thermal properties are to be compared with the nanotube inclusion process mentioned in the first method.

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