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Carbon Nanotube/nanodiamond Reinforced Carbon Fiber Epoxy Matrix Composites – Processing and Characterization

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Abstract

Composite face sheets were prepared in order to attach with the Nomex® core honeycomb structure for the manufacturing of composite sandwich panels for aero space applications. Nano reinforcements including carbon nano tubes (CNTs) and nano diamonds (NDs) were reinforced in the epoxy matrix along with carbon fibers to fabricate composite face sheets. The micro-nano composites were characterized mechanically and micro structurally by tensile testing and scanning electron microscopy (SEM). Uniform dispersion of both the nano-fillers was ensured by microscopic techniques. It was found that a uniform dispersion and distribution of nano reinforcement led to an increase in the mechanical performance of the composites.

Keywords: Sandwich structure, Nomex honeycomb, Carbon nano tubes, Dispersion, Scanning Electron Microscopy

Introduction

The polymer matrix composites filled with nanoparticles have been actively studied and researched since the emergence of nano reinforcements. In particular, the use of carbon based nano fillers in polymeric matrices has been actively explored during the last decade due to an increased interest in the applications of multi functional composites with tailored mechanical properties. Several studies have focused on the use of single wall and multi wall carbon nano tubes (MWCNTs) as well as carbon black [1,2], as a replacement of or in combination with traditional fillers like carbon fibers. Chin et al. [3] uses carbon fibers to reinforce poly lactic acid matrices to form CF/PLA composites for improved mechanical properties. Guzman et al. [4] used vertically aligned carbon nano tubes between all plies of carbon fiber to reinforce the interlaminar region. Significant improvement in Mode I and II interlaminar toughness have been observed. Tehrani et al [5] deposited CNTs on the surface of carbon fibers and studied the mechanical properties. They observed that despite the minimal degradation in the storage modulus, the loss tangent (damping) for the hybrid composites improved by 56% compared to the reference samples (based on raw carbon fibers with no surface grown carbon nano tubes) over the frequency range 1–60 Hz.

Sandwich composites offer high stiffness-to-weight and strength-to-weight ratios. A sand wich panel is composed of composite skins bonded to the light weight honeycomb core using an adhesive film. Higher thickness of the honeycomb or the foam cores provides higher stiffness and strength of the panel at the cost of minimal addition to weight. Sandwich structures in several applications have shown to have high fatigue strength, acoustical insulation and better thermal insulation [6]. The honeycomb cores have various advantages over the foam based or wood based sandwich structures due to their high crush strength and stiffness, better fatigue resistance and less moisture absorbance [7]. The sandwich panels have variety of applications in aerospace, automobile, railway and marine structures. In aerospace industry the parts of the aircrafts like ailerons, flaps and rudders have been manufactured from honeycomb sandwich panels.

In this study carbon fiberepoxy matrix composites filled with MWCNTs and nano diamond (ND) were prepared to achieve better mechanical properties. The main objective of the inclusion of ND in the presence of non functionalized MWCNTs was to achieve better mechanical properties due to load transfer from matrix to these two nano-reinforcements [8]. The use of ND particles is also beneficial for improved dispersion of MWCNTs in the epoxy first followed by in the carbon fabric. Uniformity and minimum thickness of such hybrid nano composites is another highlight of the presented work which has been achieved after through control over synthesis parameters.

Experimental

Materials:

ND powder was produced through detonation synthesis and supplied by Heyuan Zhonglian Nano technology Company, China. The mean size of NDs is ~5 nm, and particle size distribution is from 4 to 10 nm as can be seen from the TEM image in Fig. 1a. Before incorporating into the epoxy matrix, NDs were air oxidized (2 h at 440 ^{o}C) to remove the impurities and also subjected to UV/O_3 cleaner (Jelight 144AX-220) emitting radiation of 28μW/cm^2 by lowpressure mercury vapor grid lamp [9]. MWCNTs were purchased from Chengdu Organic Chemicals Company China. The outerdiameter of the MWCNTs was~100nm, length was ~10-20 µm and purity>95%. The SEM image of as grown MWCNTs is shown in Fig. 1b.

The carbon fabric had 3K plain weave with 200g/m^2 mass density. The epoxy 5052 along with its curing agent (hardener) was used as resin.

Fabrication of Nanocomposites:

For the preparation of carbon fibere poxy matrix composites reinforced with nanoparticles, the MWCNTs and NDs were separately dispersed ultrasonically in 5052 epoxy.After 2 h of sonication, the mixture was degassed for 10 min to remove entrapped air bubbles. Afterwards the curing agent 5052 was mixed through mechanical mixing. The resultant MWCNTs and NDs filled resin was used to reinforce with carbon fiber by VacuumAssisted Resin transfer Molding (VARTM) Process. Standard curing cycle for epon 5052 was adopted starting from 24 hours curing at room temperature followed by 4 hours at 100 °C. The fiber volume fraction is 55 % and 4 number of plies of carbon cloth were used with 0 degree stacking sequence for the laminate fabrication. By this process, composite face sheets of 1mm thickness were manufactured for microscopic and mechanical characterization.

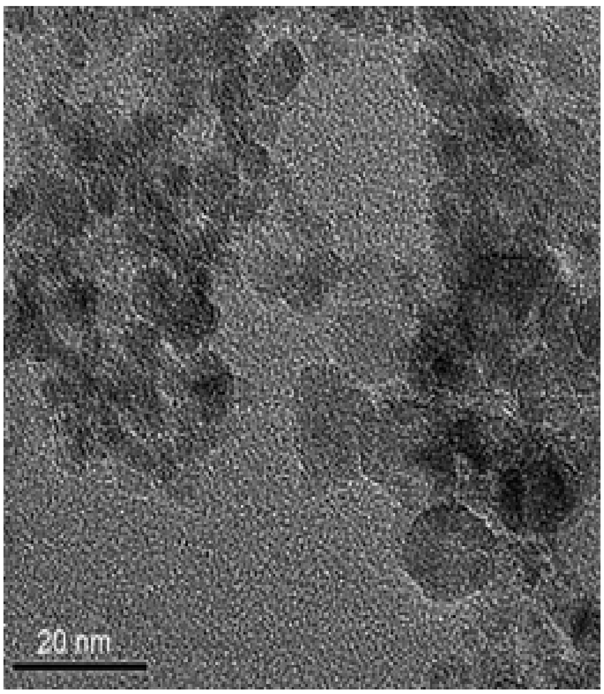

Fig.1a:TEM image of nanodiamond powder

Carbon fiber epoxy matrix composite face sheets without nanofillers were also fabricated to prepare reference specimens.Tensile tests of the samples were carriedout using UTM Model WDW-30according to the ASTM standard D3039. The SEM images were acquired using JSM 6490 A. Analytical Scanning Electron Microscope, JEOL Japan.

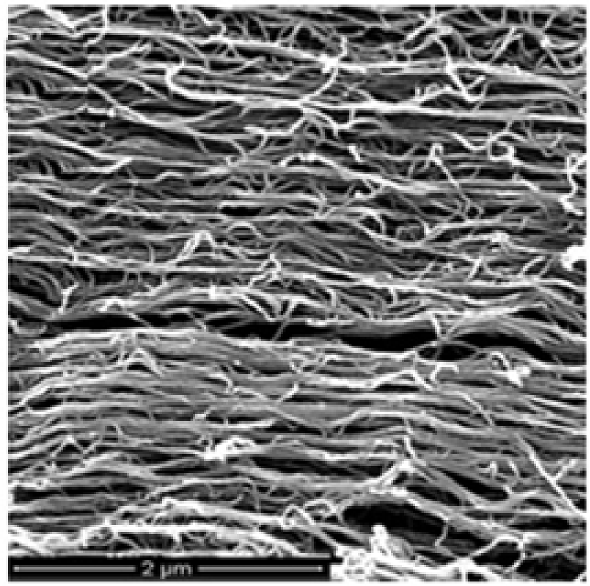

Fig.1b:SEM image of MWCNTs

Results and Discussion

Fig.2 shows SEM image of carbon fiber epoxy matrix composite without nanoreinforcement. Image was acquired from the fractured surface of the specimen.

Fig.3 shows SEM image of carbon fiber epoxy composite reinforced with 0.1 wt% CNTs and 0.1 wt% NDs at a higher magnification. Uniform dispersion of nanofillers is evident.

Fig.4 shows SEM image of carbon fiber epoxy composite reinforced with 0.4wt% CNTs and 0.1 wt% NDs. An increased content of nanoreinforcement is evident without imparing the quality of dispersion.

Typical stress-strain curves of carbon fiber epoxy matrix composites with and without nanoreinforcements are shown in Fig.5. The strength values of CF-epoxy composite, 0.1 wt% ND, 0.1wt%MWCNTsand 0.1 wt% ND, 0.4wt% MWCNTs are 895, 1053 and 1187MPa respectively. The fraction of the MWCNTs was varied from 0.1 wt% to 0.4 wt% while the loading of NDs was kept constant at 0.1 wt%. An increase in the tensile strength was found by the addition of only 0.1 wt% MWCNTs. The face sheet containing 0.1 wt % of NDs and 0.4 wt % of CNTs showed the highest tensile strength as compared to composite face sheet containing 0.1 wt% NDs and 0.1 wt% CNTs.

The increase in mechanical properties are also observed in literature but only with CNTs. The experiments on bi filler i.e. on reinforcement effects of CNTs and NDs has been observed in epoxy systems only not in carbon fibers. Guzman et al. [4] placed Vertically aligned carbon nanotubes (VACNTs) between the plies of carbon fiber reinforced plastic laminate to reinforce the interlaminar region in the z-direction. Improvement of 10% was observed in open-hole compression ultimate strength. Tehrani et al. [5] grew CNTs on the surface of carbon fibers.. The dynamic mechanical analysis (DMA) results indicated that the loss tangent for the hybrid composites utilizing improved by 56% compared to the reference samples (based on raw carbon fibers with no surface treatment or surface grown carbon nanotubes) over the frequency range 1–60 Hz.

Fig.2: SEM image of carbon fiber epoxy composite

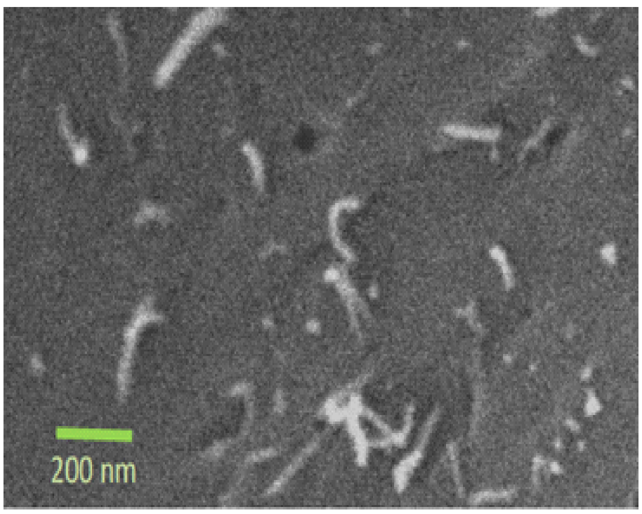

Fig.3: SEM image of carbon fiber epoxy matrix composite containing 0.1 wt% NDs and 0.1 wt% CNTs

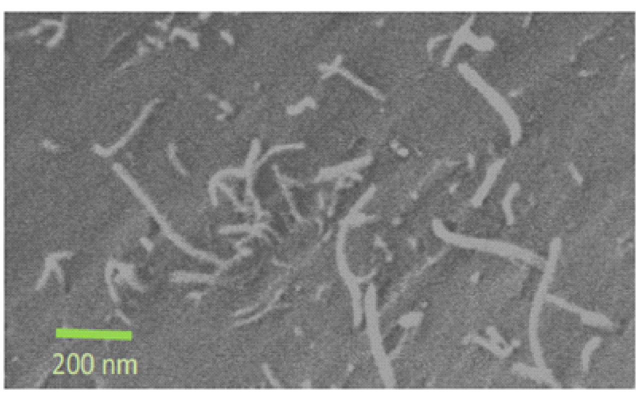

Fig.4: SEM image of Carbon fiber epoxy matrix composite containing 0.1 wt% NDs and 0.4 wt% CNTs.

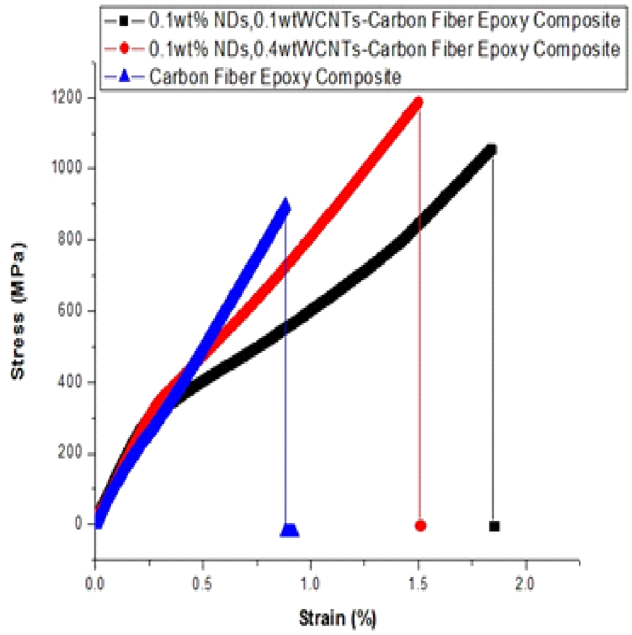

Fig.5: Stress-Strain curve of carbon fiber epoxy matrix composites

Conclusions

Tensile tests of carbon fiber epoxy matrix composite face sheets have shown greater mechanical strength by the addition of nano fillers. Which shows that the load applied to the composites was effectively transferred from the polymeric matrix to strong nanoreinforcement. Uniform dispersion of the nanofillers led to the fabrication of high quality composites showing better mechanical properties.

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