CARBON NANOMATERIAL INCORPORATED CARBON EPOXY THREE PHASE COMPOSITES

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Dedicated

To

My Grandfather and Parents

CERTIFICATE

This is to certify that the thesis entitled **"Carbon Nanomaterial Incorporated Carbon Epoxy Three Phase Composites"** being submitted by **Mr. Sohel Rana** to the Indian Institute of Technology, Delhi, for the award of degree of **Doctor of Philosophy**, in Textile Technology, is a record of bonafide research work carried out by him. Mr. Sohel Rana has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard.

The results contained in this thesis are original and have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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Abstract

Vapor-grown carbon nanofibres (VCNFs) and carbon nanotubes (CNTs) have attracted the attention of scientists worldwide due to their outstanding mechanical, thermal and electrical properties. Many attempts were made to utilize these nanostructures in composites in order to develop high performance materials for various applications. In the present research, VCNFs and single-walled CNTs (SWCNTs) were dispersed in the matrix of carbon fabric reinforced epoxy composites in order to develop novel three phase (carbon fabric/epoxy/carbon nanomaterial) composites with superior mechanical, thermal and electrical properties.

However, due to their strong agglomeration tendency, the nanomaterial dispersion in the matrix is the major issue for developing such composites. The dispersion problem was solved in this study by dispersing carbon nanomaterials at very low concentrations (CNF up to 1.0 wt.% and SWCNT up to 0.1 wt.%) using suitable dispersion techniques. The dispersion route was selected based on the effect of various dispersion routes (such as ultrasonication, high speed mechanical stirring at 2000 rpm, use of surfactant, solvent and higher temperature) on the dispersion behaviour of CNF and CNT in the epoxy resin as well as on the mechanical properties of carbon nanomaterial/epoxy two phase composites.

The effect of dispersion techniques on CNF dispersion was found to be the most crucial factor in determining the mechanical properties of CNF/epoxy two phase composites. Surfactant assisted ultrasonication proved to be a very effective route for low nanofibre concentrations. Dispersion of only 0.1 wt.% CNF using this route improved the Young's modulus and tensile strength of rubbery epoxy matrix by 98% and 30% respectively. Similarly, dispersion of 0.1 wt.% nanofibre using surfactant assisted ultrasonication led to 57% and 17% improvement in Young's modulus and tensile strength of glassy epoxy matrix

respectively. However, among the all dispersion routes, the combination of ultrasonication with high speed mechanical stirring at 2000 rpm proved to be the best route as nanofibres dispersed by this route led to highest improvement in tensile strength, work of rupture and fracture toughness of epoxy as well as a fairly good improvement in modulus. Improvements of 60% in tensile strength, 145% in work of rupture and 43% in fracture toughness of glassy epoxy were achieved by dispersing only 0.1 wt.% CNF using a combination of 2 hours ultrasonication with 1 hour mechanical stirring. Moreover, this route was found very effective in dispersing higher nanofibre concentrations (0.5 wt.%). However, the selection of proper treatment duration for both ultrasonication and mechanical stirring to disperse a particular CNF concentration was found to be very essential in ensuring homogeneous dispersion with minimum nanofibre breakage.

In contrast to CNFs, a longer dispersion route was found suitable for SWCNTs. Moreover, the improvement in mechanical properties of epoxy was less with CNT than with equal concentration of CNF probably due to the poor stability of nanotube/epoxy dispersion resulting in considerable nanotube re-agglomeration with time. Incorporation of 0.1 wt.% CNT improved the tensile and flexural strength of epoxy by 15% and 39% respectively. However, modulus improvement of epoxy was not observed on dispersing nanotubes up to 0.1 wt.%. The major improvement in the properties of epoxy by adding SWCNTs was observed in the bulk electrical conductivity which shifted to the percolation transition range from dielectric range after addition of 0.1 wt.% CNT.

Mechanical, thermal and electrical properties of carbon fabric/epoxy composites improved significantly by uniformly dispersing both CNF and CNT in the matrix. The improvement in properties was much higher with CNT than with equal concentration of CNF. Addition of only 0.1 wt.% nanotube led to an improvement of 90% in Young's modulus, 31% in tensile strength, 76% in compressive modulus and 41% in compressive strength of carbon/epoxy composites. Further improvement in the mechanical properties of three phase composites was possible using functionalized CNF. However, the expected improvement using functionalized CNT was not obtained due to considerable nanotube re-agglomeration during processing. In addition to mechanical properties, thermal and electrical conductivity of carbon/epoxy composites also improved considerably by dispersing these nanomaterials. Maximum improvements of 29% in thermal conductivity and 20 times in electrical conductivity were achieved by dispersing up to 1.0 wt.% CNF. Similarly, dispersion of only 0.1 wt.% SWCNT led to improvements of 78% in thermal conductivity and 6 times in electrical conductivity of carbon/epoxy composites. Therefore, the three phase composites studied in this thesis have much enhanced mechanical, thermal and electrical properties and thus have a lot of potential applications in diverse fields such as aerospace, transportation, sports etc. due to their distinct advantages over conventional carbon/epoxy composites.

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