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TOUGHENING EPOXY THERMOSETS AND THEIR CARBON FIBRE REINFORCED COMPOSITES WITH ELECTROSPUN NANOFIBRES

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Introduction

Electrospun nanofibres have emerged as important fibrous materials for diverse applications. They have been shown excellent toughening results when they are applied as interlayer materials between carbon/epoxy laminas in the structural carbon fibre reinforced epoxy matrix composites. They also exhibit synergistic modification effects when they are combined with carbon nanofibres in the thermosetting polymer matrix.

In this study, electrospun polyetherketone cardo (PEK-C) nanofibres were used in two ways: directly electrospun onto the surface of carbon fabric [1], and blended with epoxy resin in the form of PEK-C/VGCNF (vapour grown carbon nanofibre) composite nanofibres [2]. The interlaminar fracture toughness, flexural properties and thermal mechanical properties of the modified systems were investigated.

Experimental

Materials: Formax multiaxial carbon fibre reinforcements [C12K, 450, -45 / +45] were used for preparing carbon/epoxy composite laminates. The epoxy resin was composed of triglycidyl amino phenol (TGAP, Araldite MY0510, Huntsman) with epoxy equivalent 95-106 and a 4, 4’-diamino diphenyl sulfone (DDS, Aldrich, purity > 97%) cure agent. Polyetherketone cardo (PEK-C) was obtained from Xuzhou Engineering Plastics Co. (Xuzhou, China). Pyrograf®-III VGCNFs (grade PR-24-XT-HHT) were provided by Pyrograf Products, Inc. (Cendarville, OH).

Sample Preparations

PEK-C was dissolved in N, N-dimethylformamide (DMF). A laboratory-made electrospinning facility was used for preparing nanofibres [3]. VGCNFs were dispersed by ultrasonication in a PEK-C/DMF solution for 5 hours, followed with further dispersion in the remained PEK-C solution for 2 hours. Both the epoxy resin and its carbon fibre reinforced composites were cured at 175 °C for three hours.

Results and discussion

To investigate the influence of fibre diameter on the mechanical performance of interlayer toughened composites, PEK-C nanofibres with average diameters of 450 nm, 750 nm and 950 nm, electrospun respectively from 23 wt%, 25 wt% and 30 wt% PEK-C solutions, were used. The unmodified composite specimen is used as control. Fig. 1 shows the influence of nanofibre diameter on the interlaminar fracture toughness of modified composites. The average GIC-INI for the control specimen was 151 J/m², whereas the GIC-INI value for the nanofibre-modified specimens with average fibre diameters of 450 nm, 750 nm and 950 nm was 249 J/m², 228 J/m² and 241 J/m², respectively, indicating increased GIC-INI value for the nanofibre-modified composite specimens. It should be noted that the weight loading of the nanofibres in the nanofibre-modified specimens was less than 1 wt% (around 0.4 wt %). The improvement in GIC-INI and GIC-PROP due to such a low interlayer weight loading is quite significant.
The effect of fibre diameter on the flexure strength and elastic modulus is also shown in Fig. 1. By comparison with the control specimen, the flexure strength of the nanofibre-modified specimens decreased slightly when the average nanofibre diameter increased from 450 nm to 750 nm, however, a noticeable decrease in the flexure strength was observed in the specimen with the coarse nanofibre interlayer (950 nm).

VGCNFs were successfully introduced into epoxies through electrospun PEK-C nanofibres. Through phase separation of the PEK-C/epoxy blends at a modifier content of 5 wt %, where a particulate phase structure was generated, CNFs were selectively dispersed in the PEK-C-rich domains throughout the epoxy resin. Such a unique phase and CNF dispersion structure resulted in synergistic increases in flexural strength, toughness and hardness with almost negligible drop in elastic modulus.

The SEM on fracture surfaces of both types of specimens revealed PEK-C-rich particles (Fig. 2). These ductile phases created stress concentrations at their equators and also act as sites for initiating shear bands. In the PEK-C/VGCNF composites, the VGCNFs were distributed through phase separation-generated PEK-C-rich phases.

Conclusions
Interlayer toughening of carbon/epoxy composites was achieved by using PEK-C nanofibre membranes electrospun directly onto carbon fabrics. With the same weight loading of nanofibres, finer nanofibre stabilised the crack propagation during delamination and assisted with maintaining the flexure property.

Through a unique phase and CNF dispersion structure, synergistic increases in flexural strength, toughness and hardness with almost negligible drop in elastic modulus was achieved.

References