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Interfacial toughening of carbon/epoxy composite by incorporating styrene acrylonitrile nanofibers

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ABSTRACT

In this research, Styrene Acrylonitrile (SAN) nanofibers, produced by the electrospinning method, were used in order to improve out-of-plane and impact properties of a conventional carbon fiber/epoxy composite. The prepared SAN nanofibers were directly deposited on the surfaces of conventional carbon fiber fabrics. Vacuum assist resin transfer molding (VARTM) was employed for fabricating carbon/epoxy composite. The morphological study of the electrospun SAN nanofibers indicated the prepared SAN nanofibers were smooth, continuous, and without any formation of beads, with average diameters assessed to be 480 ± 102 nm. Mechanical properties studies of the composites indicated that embedding SAN nanofibers in the hybrid composite (carbon/epoxy composite containing SAN nanofibers) led to 26%, 37%, 27%, and 8% of flexural strength, flexural work to fracture, interlaminar shear strength, and impact absorption energy, respectively compared to acquired results from control composite (without nanofibers). Statistical analysis was furthermore carried out to prove the significant differences of the obtained results. Finally, fractographical analysis by field emission scanning electron microscope (FE-SEM) confirmed that embedding nanofibers in the hybrid composite caused tougher fracture during composite breakage.

1. Introduction

Carbon/epoxy composites have been widely used in plenty of applications due to their excellent specific mechanical properties and manufacturability as well as superior corrosion resistance compared to metals which make them suitable for substituting metals in many applications including aerospace, ground vehicles, and wind turbines [1–4]. The mechanical properties of polymer matrix composites are predominantly determined by the mechanical properties of the components (matrix and reinforcement phase), the volume fraction of each phase, fiber-matrix interfacial interactions between matrix and reinforcement phase, fiber alignments, etc. [5]. In particular, the laminated structure causes anisotropicity in materials with the in-plane mechanical properties dominated by properties of reinforcement phase (fibers). Therefore, the in-plane properties of laminated structures are strong enough for a lot of applications., while properties of the matrix dictate the out-of-plane mechanical properties of the laminated composite [6]. The mechanical properties of the matrix are significantly weaker than mechanical properties of reinforcement phase leads to weak out-of-plane properties of laminated polymer matrix composites. In addition, the ply-by-ply nature of the laminated polymer matrix composites can be vulnerable to delamination because of the microcracks creation and propagation in the frail resin-rich layer. This serious problem prevents employing these type of materials in the critical applications [5]. Therefore, numerous researches have been conducted in order to boost the mechanical properties of the matrix such as using carbon nanotubes [7–11], inorganic and rubbery micro/nanoparticles [12–15], using metallic micro/macro-fibers [16–20], curing process modification [21,22], blending [23–26], and even combination of these techniques [27]. Despite the aforementioned methods have led to mechanical properties improvement of the matrix, but causes in considerable limitations that restrict their usefulness in composite materials including troubles in the nanofillers distribution and dispersion, and increase in the viscosity of resins [28] which adversely influence the manufacturing process and consequently mechanical properties of fabricated parts. In addition, the researches confirm that modifications

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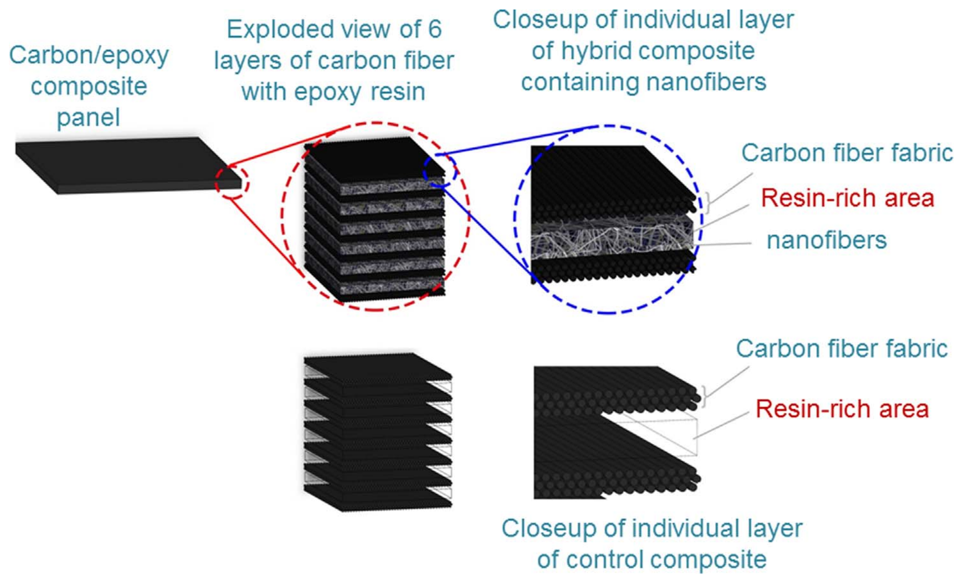

Fig. 1. Schematic cross sections of the hybrid composite and control composite.

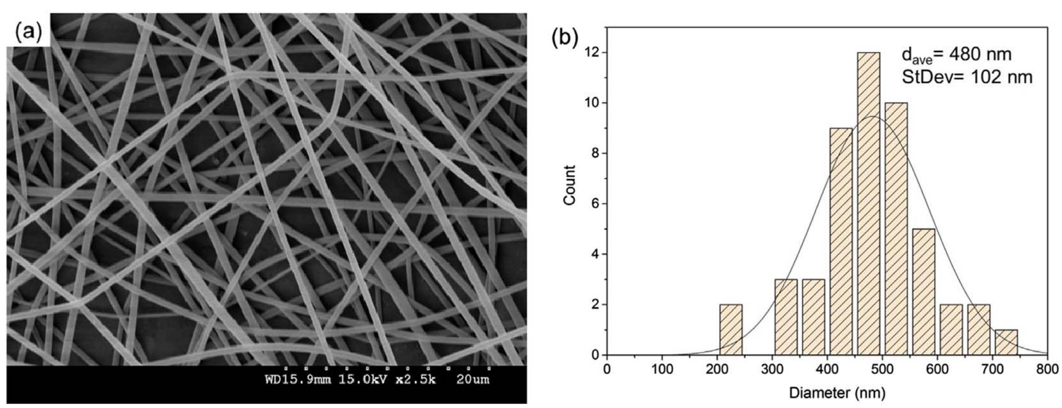

Fig. 2. (a) FE-SEM images of the electrospun SAN nanofibers (b) the diameter distribution.

in curing process cannot impressively improve the mechanical properties of the resins [29].

Dzenis and Reneker firstly proposed a developing composite strengthening method, with use of nanotechnology, which has since gathered much research interest. The technique involved embedding un-oriented electrospun nanofiber mats between layers of the reinforcement phase in order to improve the mechanical properties of the weak resin-rich area [29]. Using electrospinning technique for fabricating nanofibers with surface area-to-volume ratios greatly higher than their conventional micro fiber counterparts offers the facile and economical method for improving mechanical properties of the resin-rich area with minimal effects on the manufacturing process [5]. The use of electrospun nanofibers in boosting the mechanical properties of resin-rich layers of laminated composites has therefore been keenly investigated during recent years [30,31] as well as enhancing fracture toughness of epoxy adhesives [32] and neat resins [33,34]. Previous researches showed the nanofibers diameter, the nanofiber mat thickness, the nanofiber type, and the interaction between nanofibers and matrix strongly influence mechanical properties of the laminated polymer matrix composites [35]. Chen et al. showed that surface-functionalization of electrospun carbon nanofibers is highly effective in improving impact energy absorption, interlaminar shear strength, and flexural properties for both nano-epoxy resins and hybrid multi-scale conventional carbon/epoxy composites [36].

The present research aims to study the influence of incorporating SAN nanofibers on interfacial toughening of a conventional carbon/epoxy composite. Therefore, the SAN nanofibers were directly deposited on the surfaces of carbon fabrics and subsequently, subjected to a wet-layup process (followed by VARTM) in order to fabricate hybrid carbon/epoxy composite which the resin-rich area enriched with the SAN nanofibers. The hybrid composite panel was then evaluated by three-point bending, interlaminar shear strength, and impact tests to determine the effect of SAN nanofibers incorporation on the interfacial toughening of the prepared hybrid composite.

2. Experimental

2.1. Materials

SAN powder (M_w = 185 g/gmol, acrylonitrile 30 wt%) was provided by Sigma-Aldrich. N, N-dimethylformamide (DMF, 99.8%) were also purchased from Sigma-Aldrich and used as the solvent of SAN powder for electrospinning process. Same as our previous works [37,38], the unidirectional carbon fiber fabric was supplied by Shanghai Horse Construction. Moreover, the epoxy resin (EPON™ Resin 828), and its curing agent (EPIKURE™ Curing Agent F205) were purchased from Hexion Inc and used as epoxy matrix.

2.2. Electrospinning

Based on the obtained results in our previous work [39] the 25 wt% of SAN powder was dissolved in DMF using a magnetic stirrer for 24 h