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Effect of NH_2-MWCNTs on crosslink density of epoxy matrix and ILSS properties of e-glass/epoxy composites

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ABSTRACT

Crosslink density is one of the important parameters that govern the physical properties of fiber reinforced polymer (FRP) composites. Enhancement of crosslink density by effective matrix modification through nanoparticle incorporation is the most prominent way to improve mechanical and thermo-mechanical properties of FRP composites. In this study, at first, 0.1–0.4 wt.% amino-functionalized multi-walled carbon nanotubes (NH_2-MWCNTs) were incorporated in SC-15 epoxy system and the variation in crosslink density was investigated using rubber elasticity theory. Subsequently, the effect of these MWCNTs on interlaminar shear strength (ILSS) of e-glass/epoxy composites was studied. Result obtained from the tests showed a linearly increasing trend in crosslink density and ILSS properties from 0 to 0.3 wt.% MWCNTs loading. Better dispersion of MWCNTs facilitated more crosslinking sites, whereas, the three-way reaction between amine functional groups of MWCNTs with epoxide groups of resin and epoxy silanes of fiber surfaces improved the crosslinking and thereby ILSS properties of e-glass/epoxy composites.

1. Introduction

Interlaminar shear strength (ILSS) of fiber reinforced polymer (FRP) composites is a limiting design characteristic. It is one of the most important matrix dominated mechanical property in the design of composite structures. In general, the load on a composite material is transferred from the matrix to fibers through the interface for which fiber/matrix interfacial strength is critical and directly affects the toughness and strength of a composite to a great extent [1]. Therefore, enhancement in ILSS of FRP composites has always been a major aim for the successful application in various structural sectors subjected to transverse load. As ILSS depends largely on the matrix properties, enhancement of ILSS is possible by the modification of matrix through incorporation of inorganic nanoparticles [2–5]. Since the discovery by Iijima in 1991 [6], carbon nanotubes (CNTs) have been potential candidates for enhancement of in-plane and out-of-plane properties of polymer based composites.

Carbon nanotubes have attracted attention worldwide for their excellent mechanical, thermal and electrical properties. Most highlighted feature of CNTs is their high surface area which provides desirable interfaces for load transfer from matrix to nanotubes and hence increases reinforcement efficiency of the final composites. However, this feature induces undesirable strong inter-tube attraction via Van Der Waal forces between CNTs which leads to excessive agglomeration [7]. In addition, the interfacial interaction between the epoxy and MWCNTs is a major problem due to lack of reactive functional groups on surfaces of MWCNTs. As a result, uniform dispersion of CNTs and interfacial interaction of CNTs with matrix remains a major problem. Many researchers have investigated effective methods to improve the dispersion and interfacial reactivity of CNTs with epoxy polymer matrix [8–10]. Among the physical methods, sonication and calendaring process are considered to improve the dispersion of CNTs. Some researchers found that chemical functionalization of CNT surface enhances the interfacial interactions between CNTs and matrix and hence the dispersion of CNTs into the matrix [11–13]. Chemical functionalization of CNTs with amino functional group forms a covalent bonding with the epoxy functional groups thereby reducing the reagglomeration tendency of CNTs and thus strengthening interfacial interaction between them [14]. However, ability to disperse CNTs in polymer matrix still remains a technical challenge in producing high performance CNTs reinforced nanocomposites.

In the last two decades, very few studies have been conducted regarding ILSS properties of glass fiber reinforced polymer (GFRP) composites incorporated with MWCNTs. Fan et al. [2] introduced injection and double vacuum assisted resin transfer molding (IDVARTM) method. It was found that adding 2 wt.% MWCNTs into

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glass fiber reinforced epoxy composites increased the ILSS by 33%. Gojny et al. [3] reported 19% improvement in ILSS by adding 0.3 wt.% amino-functionalized double-walled carbon nanotubes (DWCNTs) in fiber reinforced epoxy composites. Wichmann et al. [15] also showed 16% enhancement in ILSS properties at 0.3 wt.% MWCNTs loading.

However, to the best of our knowledge, an in-depth study examining the degree of crosslinking between the epoxy matrix and MWCNTs, and the relation of crosslink density to interlaminar shear strength is not yet reported. In this work, we report a detailed study of dynamic mechanical behavior of MWCNTs incorporated epoxy composites. We have evaluated the effectiveness of incorporating functionalized MWCNTs on ILSS properties of e-glass/epoxy composites by calculating apparent crosslink density using rubber elasticity theory based on the results of dynamic mechanical analysis. Dynamic mechanical behavior of epoxy nanocomposites has given a basic understanding of the cross-linking kinetics and mechanical behavior of the systems. The dynamic mechanical properties such as storage modulus and glass transition temperature obtained have been directly correlated with the behavior of interlaminar shear properties of a GFRP composite system.

2. Experimental

2.1. Materials

SC-15 epoxy resin system, amino functionalized multi-walled carbon nanotubes (MWCNTs-NH_2) and woven e-glass plain weave fiber fabric were used to fabricate composite laminates. The matrix SC-15 resin is a two part cycloaliphatic amine type epoxy resin (Part-A: diglycidylether of bisphenol A, aliphatic diglycidyl and Part-B: amine hardener). Amino functionalized multi-walled carbon nanotubes (MWCNTs-NH_2) having an average diameter of 10 nm, length of 1 micron and carbon purity >95% were used. As reinforcement in composites, commercially available e-glass woven fabric with a density of 2.58 g/cm^3 and a single fiber diameter of 14–16 μm was used.

2.2. Manufacturing process

2.2.1. Mechanical dispersion of MWCNT-NH_2 into Part A epoxy resin

A novel technique was used to disperse MWCNTs effectively in epoxy resin through a combination of calendaring and sonication processes. At first, MWCNT-NH_2 was mechanically mixed with

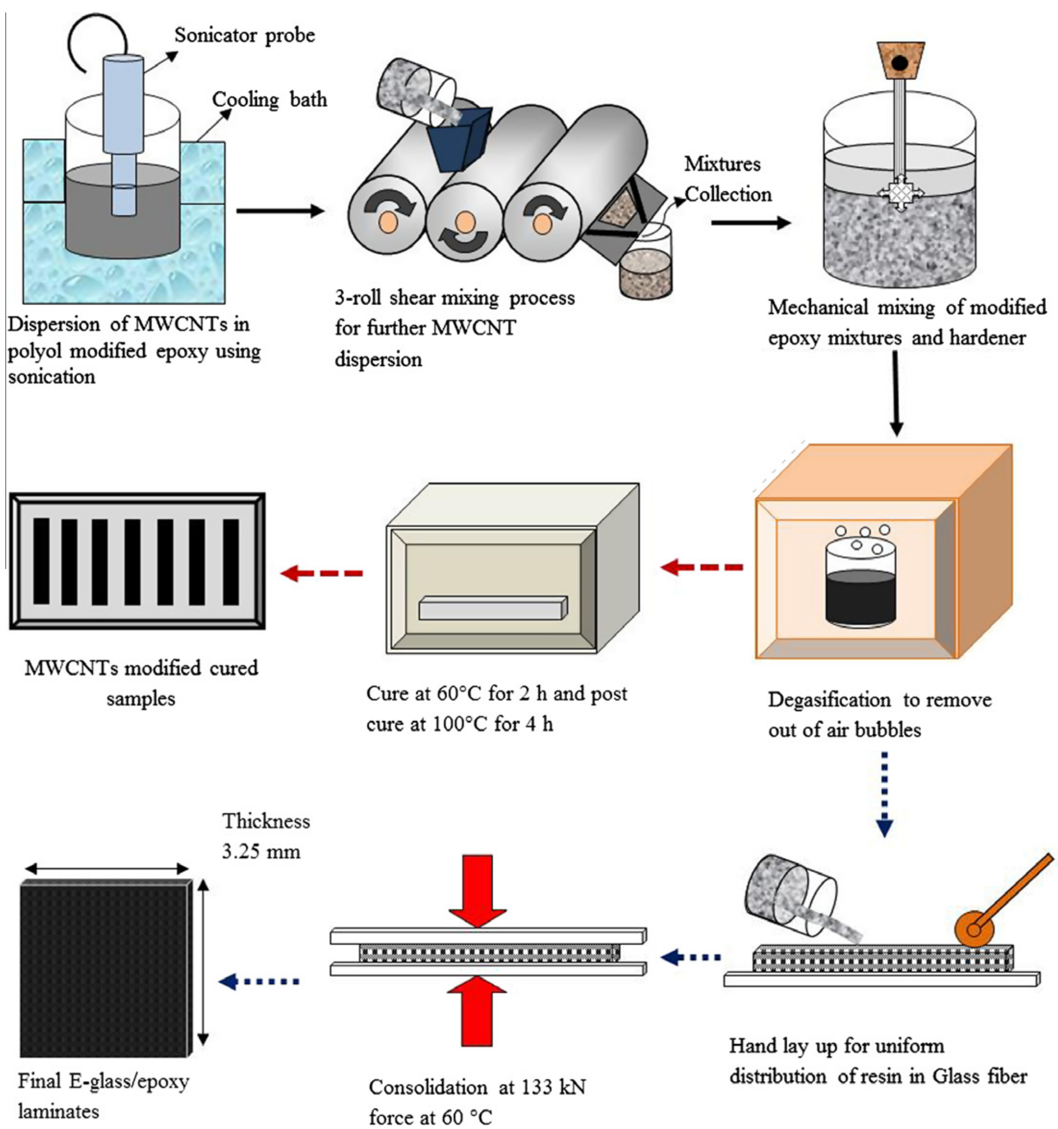

Fig. 1. Fabrication process of epoxy nanocomposite and e-glass/epoxy nanocomposites.