

# Technical Notes

## Graphite Nanoplatelets Interlayered Carbon/Epoxy Composites

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### I. Introduction

**P**ROPERTY enhancement of a polymer by incorporating nanoparticles such as carbon nanotubes, nanoclays, and graphite nanoplatelets into the polymer is an active research area. Among these nanoparticles, nanoclays and graphite nanoplatelets are layered materials with platelike shapes. Graphite nanoplatelets (GNPs) have high modulus, high strength, and good electrical conductivity of graphite at much lower material cost than carbon nanotubes. This makes GNP an attractive nanoreinforcement material. Several studies have shown that the incorporation of GNPs into a polymer can improve both mechanical and electrical properties [1–5].

The mechanical property improvement of nanocomposites critically depends on the degree of dispersion and the interfacial adhesion. Well-dispersed platelets in the polymer matrix can significantly improve the load transfer efficiency in nanocomposites [6]. Stress concentration can be reduced by a high degree of exfoliation [7]. A good interfacial adhesion is critical to improving the mechanical properties. Without good interfacial adhesion through a proper surface treatment of graphite nanoplatelets, GNPs are just stress raisers, not load carriers. Surface treatment of graphite facilitates –COOH and/or –OH functional groups on the graphite sheets from chemical oxidation [8,9]. GNPs can deflect cracks only if the interface between GNPs and the matrix is strong [10].

Electrical properties might not be sensitive to the size and exfoliation of GNPs as much as mechanical properties. For example, less exfoliated GNPs yielded better conducting composites than highly exfoliated GNPs [4]. The surface treatment does not appear to have any significant effect on the electrical conductivity [5].

In the case of fiber composites, nanoreinforcements have less visible effect on mechanical property improvement, as their overall structural performance is mostly governed by fibers [11,12]. Needless to say, the nanoreinforcement effect will manifest itself in matrix-controlled properties. The in-plane shear and the compressive strength of carbon fiber/epoxy composites with graphite nanoplatelets were increased by 11 and 16%, respectively [13]. Especially when carbon nanotubes (CNTs) were directly grown on the fibers of

a SiC fabric composite, the mode I interlaminar fracture toughness increased about 350% [14].

So far, the most effective way of improving interlaminar properties of fiber composites is to align CNTs along the thickness direction of the laminate [14,15]. However, growing CNTs normally on the reinforcing fibers is not an easy process to implement or a costly method in material and processing. The objective of the present study is to develop a scalable and effective manufacturing method to incorporate GNPs and to improve the mechanical properties and the electrical conductivities of graphite fiber composites. Micrographic studies are also conducted to identify microstructures and reinforcement mechanisms.

This Note consists of two parts. For the first part, laminates with VRM34 epoxy resin were processed to show the effect of different GNP contents (1 and 2 vol%) on tensile and in-plane shear properties and electrical conductivities. Unfortunately, no reference laminate with VRM34 resin was available. For the second part, laminates with Epon862 epoxy resin were processed to show the effect of surface treatment of GNPs on in-plane shear properties and electrical conductivities.

### II. Experimental Procedure

#### A. Materials

AS4 plain-weave graphite fabric was used for the fiber reinforcement. Two different resin systems were used: VRM34 epoxy resin and Epon862 epoxy resin with Epikure W curing agent in a weight ratio of 100/26.5.

Figure 1 shows a scanning electron microscopy (SEM) micrograph of GNPs (Asbury 3775) used in the present study. They are thinner than 100 nm and about 6  $\mu\text{m}$  long in the plane. They have been preexfoliated by rapid heating in a furnace at 600°C after acid intercalation [16]. They were used as received for AS4/VRM34 laminates and after nitric acid treatment to improve the interfacial adhesion to the epoxy resin by introducing carboxylic functional groups for AS4/Epon862 laminates. For the surface treatment, GNPs were immersed in a 67% nitric acid ( $\text{HNO}_3$ ) solution and heated to 100°C for 30 min with a 200:1 volume ratio of nitric acid to graphite [5].

#### B. Fabrication Process

An obvious method to incorporate nanoparticles in fiber composites is to add the nanoparticles to the matrix resin directly. However, in the present study, GNPs were deposited on graphite fabric surfaces first to avoid screening of GNPs during resin infusion process.

GNPs were deposited on an AS4 fabric using an electrostatic spraying method. The electrostatic spraying method is a quick and efficient way of depositing conducting particles such as GNPs on conducting electrodes such as graphite fabric.

A schematic of the electrostatic spraying process used is shown in Fig. 2. The use of no pressurized air and low spraying speed makes it possible to spray nanoplatelets with more precision. The electrostatic spraying setup consists of four main parts: a spraying chamber, a syringe with a needle, a syringe pump, and a high-voltage generator. A syringe pump was used to push out the solution at a constant flow rate. A high-voltage generator was used to generate 20 kV over a distance of 10 cm.

The detailed process steps are as follows:

1) Measure the weight of GNPs and mix them in isopropyl alcohol. The optimal ratio for smooth spray is 17 ml of isopropyl alcohol per 1 g of GNPs.

2) Use an ultrasonic horn (Vibra Cell from Sonic and Materials) at 100 W for 15 min to disperse GNPs and a shear mixer (T8 ULTRA-TURRAX® form IKA) at 13,500 rpm for 15 min for further

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