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Interfacial nanoreinforcement improves bamboo fiber/polymer composites

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A fully biobased composite material, composed of bamboo fibers and a nanoparticle-reinforced bio-epoxy matrix, exhibits improved mechanical properties.

Most current fiber-reinforced polymer (FRP) production is based on synthetic fibers that have mineral or petrochemical origins. In recent years, however, interest in renewable materials in industry has increased significantly.[1] Among such materials, natural fibers (NFs) have a number of advantages. They offer, for example, a lower density than conventional synthetic fibers and a number of suitable mechanical properties (e.g., good tensile strength and Young's modulus). These characteristics make them a potential alternative to glass fibers in FRPs. Among NFs, bamboo fibers (BFs) represent one of the most suitable fibers for biobased FRP-composite materials, as BF-reinforced materials exhibit surprisingly good mechanical properties despite their extremely low density.[2] However, BFs have inhomogeneous properties along their surfaces, and they are highly hydrophilic. As a result of these features, BFs interact poorly with polymer matrices. This results in the creation of a weak interface between the fibers and the matrix, and an uneven fiber dispersion. The interface also influences the water uptake of the material. Indeed, a weak interface facilitates water diffusion, which can cause swelling of the materials, thereby degrading their mechanical properties and possibly causing irreversible damage by hydrolysis.[3]

For these reasons, the scientific community has studied a number of different approaches to the development of fiber coatings for FRP applications.[4] Organic materials (e.g., polymers) have, for example, been introduced as coatings to enhance the properties of natural and synthetic fibers. Moreover, the addition of nanoparticles (i.e., nanoreinforcement) leads to a significant enhancement of the interlaminar and ultimate tensile strength of the composites. These particles also increase the toughness at the interface, thereby stopping crack propagation.[5]

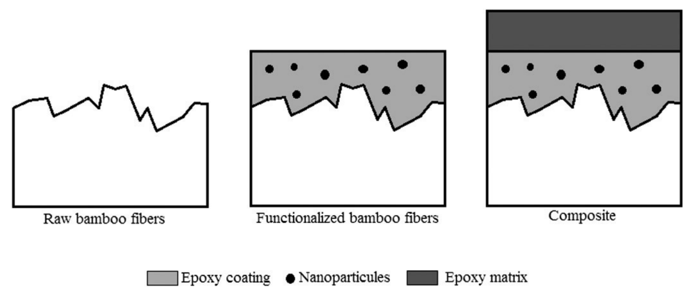

Figure 1. *Schematic illustration of the bamboo fiber (BF) coating process. First, the raw BFs are coated with an epoxy/silicon dioxide (SiO_2) nanoparticle suspension. The coated fibers are then immersed in the epoxy, which makes up the matrix of the composite. After a few hours, the composite is fully cured and ready to be tested.*

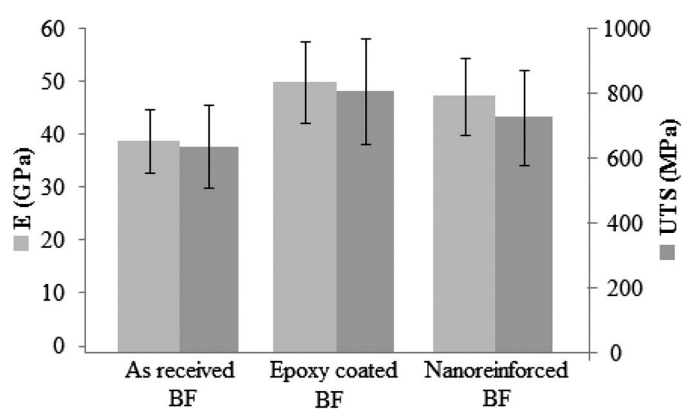

Figure 2. *Young's modulus (E, light gray) and ultimate tensile strength (UTS, dark gray) of uncoated (i.e., as received), epoxy-coated, and nanoreinforced (i.e., coated with an epoxy/SiO_2 composite) BF bundles.*

We have therefore developed a fully biobased composite material, made of BFs and a bio-epoxy matrix, which has an improved

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10.2417/spepro.006648 Page 2/3

fiber-matrix interface.[6] To achieve this, we dispersed silicon dioxide (SiO_2) nanoparticles at a concentration of 5wt% in the biobased epoxy resin (SUPER SAP, provided by Entropy Resins[7]) using a high-shear mechanical mixer at 1500rpm for 30 minutes. Once the bio-epoxy/SiO_2 mixture was homogenized, we diluted it in a large volume of acetone (with a weight ratio of 1:50). We then dip-coated BFs in the solution for 30 seconds. The acetone was subsequently evaporated at room temperature, leading to the formation of a thin film on the surface of the fibers (see Figure 1).

To investigate the mechanical properties of the fiber bundles, we carried out tensile tests (i.e., according to standard procedure ASTM D2343). The results of these tests show that the tensile strength and modulus of epoxy-coated BF and nanoreinforced-epoxy-coated BF increase by up to 28% compared with raw BFs (see Figure 2). The epoxy layer strengthens the fiber bundle by increasing the cohesion between the microfibers that compose the bundle. All of the microfibers are aligned along the same axis and therefore contribute to the composite reinforcement.

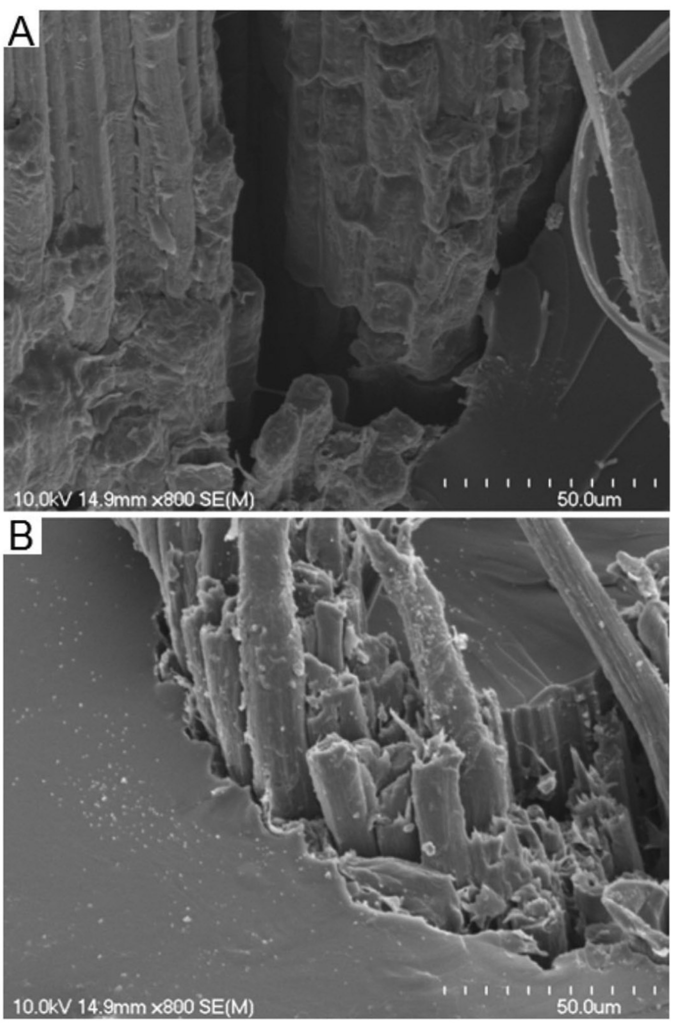

Figure 3. *Scanning electron microscope images of the failure area (after flexion) in BF composites made with (a) epoxy-coated fibers and (b) nanoreinforced fibers.*

We then molded the composites (with 25% fibers by volume) and subsequently characterized them via three-point flexural and tensile tests. These tests (which enable indirect measurement of the interfacial properties of the composites) show that composites made with raw BFs have weak mechanical properties, giving rise to a weak fiber-matrix interface. We find that epoxy-coated fibers exhibit the same behavior. In contrast, BFs that are nanoreinforced by the addition of SiO_2 exhibit greatly improved flexural properties (i.e., by up to 20%) compared with raw BFs. The weak fiber-matrix interfaces exhibited by the untreated and epoxy-coated BF composites are visible in scanning electron micrographs that were obtained after failure from flexion: see Figure 3(a). The nanoreinforced composites, however, display good interfaces between the BFs and the bio-epoxy: see Figure 3(b). The fibers in these composites therefore have a strong bond with the matrix.

In summary, a nanoreinforced coating—composed of epoxy and SiO_2 nanoparticles—enhances the affinity of BF with a polymer matrix and improves the interface between them in composite materials. In our work so far, we have fabricated fully biobased composites from a biobased polymer (bio-epoxy), natural fibers (i.e., BFs), and biosourced nanoparticles (starch nanocrystals).[8] These developments all pave the way for the use of NFs and natural nanoparticles in composite applications. In the next stage of our work, we plan to evaluate the impact of these coatings on the durability of fully biosourced materials, such as flax/polylactic acid composites.

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Continued on next page

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