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Hydrophobic treatments for natural fibers based on metal oxide nanoparticles and fatty acids

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Abstract

This work describes hydrophobic treatments developed for natural fibers. They involve the coating of fibers and nonwovens by metal oxide nanoparticles, namely titanium dioxide (TiO_2) and zinc oxide (ZnO), followed by the application of a fatty acid. For comparison purposes, the fatty acid treatment was also applied directly on the fibers, i.e. without the intermediate nanoparticle layer. The efficiency of the treatments was assessed on recycled jute in terms of water contact angle and water drop shape retention time. In addition, the effect of the hydrophobic treatment process on the mechanical performance and thermal stability was also measured. The results show the advantage of the metal oxide nanoparticle intermediate layer in providing the natural fibers with stable hydrophobic properties. These treatments provide a nontoxic, low cost solution to make natural fibers hydrophobic, including recycled ones. This opens new opportunities for these fibers as reinforcement for composite parts.

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Keywords: Jute fibers; Hydrophobic treatment; nanoparticles; titanum dioxide; zinc oxide; fatty acids.

1. Introduction

With their low cost, low weight, renewable character, and interesting specific properties, plant-based fibers have generated a renewed interest in several areas, including composite manufacturing [1]. The use of recycled fibers allows reaching even higher summits in terms of cost reduction and sustainability. However, some issues remain, in

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particular the lack of interfacial bonding between the generally hydrophilic natural fibers and the commonly hydrophobic polymer matrices, resulting in cracks and delamination [2]. Making natural fibers hydrophobic could thus improve their compatibility with organic matrices and their application as reinforcement for composite parts.

One avenue relies on the use of nanoparticles to generate superhydrophobic surfaces [3]. In particular, metal oxides have been successfully used to provide the surface of natural fibers with a nano-scale roughness. For instance, hydrothermal treatments were used to grow ZnO nanorods on the surface of cotton fibers, which became surperhydrophobic after application of an appropriate hydrophobic agent [4]. A water repellant treatment based on TiO_2 nanoparticles and the use of octadecanethiol as a hydrophobic agent was developed for cotton woven fabrics [5]; the water contact angle reached 151°.

However, the surface energy modification part of the most of the hydrophobic treatments generally involves the use of toxic chemicals, which diminishes the ecological advantage of the introduction of natural fibers. In addition, most of studies focus on cotton and none of them on recycled fibers. Yet, jute is the second most often used cellulosic fiber after cotton [6]. Even if the plant is principally grown in India and Bangladesh, large quantities of jute are available in industrial countries from discarded bags used for goods packaging.

This work is therefore aimed at developing non-toxic hydrophobic treatments for recycled jute fibers based on the use of metal oxide nanoparticles combined with fatty acids as a hydrophobic agent. In addition to the level and stability of the resulting hydrophobicity, the efficiency of the treatment is also assessed in terms of its impact on the fiber/nonwoven mechanical and thermal performance.

2. Materials and methods

2.1. Materials

The recycled jute fibers were provided by Leigh Textile Inc. (Canada). They had an average diameter of 50 ± 4 µm and an average length of 52 ± 2 mm. Their force and elongation at break were 69 ± 29 cN and 1.6 ± 0.4 %, respectively. Some treatments were also performed on a nonwoven composed of 85% of the recycled jute fibers and 15% of core/sheath polyethylene terephthalate (PET) /co-PET bicomponent fibers. The nonwoven was manufactured by a carded drylaid process and thermally bonded at 230°C using a calendar. It had a weight of 229 ± 24 g/m^2.

2.2. Preparation methods

2.2.1. Direct hydrophobic treatment

In the direct hydrophobic treatment strategy, the fatty acid was applied directly to the jute nonwoven. For that purpose, nonwoven specimens were immersed in different concentrations of stearic acid in anhydrous ethanol for durations ranging between a few seconds to more than 4 hours. Then, they were dried at 100°C for 10 min. The specimens were kept in a dark area until they were tested.

2.2.2. ZnO-mediated hydrophobic treatment

The ZnO-mediated hydrophobic treatment involved four steps: scouring, ZnO nanoseeding, growth of ZnO nanostructures, and hydrophobic conversion with a fatty acid. It was applied on the jute fibers. The initial scouring treatment was performed by immersing the fibers in an aqueous solution of 8 g/L of sodium hydroxide and 1.5 mL/L of Triton X-100, a non-wetting agent, for 60 min at 95°C under stirring conditions. After the fibers were rinsed with cold water and dried at room temperature, they were immersed four times in a ZnO nanoseed solution prepared with 25 mM of sodium hydroxide and zinc acetate dehydrate in ethanol. After each 15 min immersion period, the fibers were dried at 120°C for 15 min. Then the seeded fibers were left for 5 h in a ZnO growth solution composed of 50 mM of zinc nitrate hexahydrate and hexamethylenetetramine at 95°C. Afterwards, they were rinsed with distilled water and dried at room temperature. Finally, the fibers were dipped in a 20 mM solution of stearic acid in ethanol for 3 hours, followed by a 15 min drying period at 100°C. More details about the treatment protocol may be found in [7]. The specimens were kept in a dark area until they were tested.