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Hemp fiber reinforced polypropylene composites: The effects of material treatments

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ABSTRACT

Natural fiber reinforced thermoplastic matrix composites have been increasingly used in semi-structural applications in automotive applications because of their good specific strength and modulus, low carbon footprint and recyclability. This research work studies the effects of material treatment(s) on the mechanical behaviors of hemp fiber reinforced polypropylene (PP) composites. The material treatment(s) are realized by chemically treating the hemp fiber with different concentration NaOH and/or adding maleic anhydride grafted polypropylene (MAPP) to the PP matrix. The purpose of the material treatment(s) is to enhance the bonding between the hemp fibers and the polypropylene matrix which otherwise has low surface energy and limited bonding. The mechanical behaviors are investigated with different combinations of material treatment(s) such as 5 wt% MAPP, 5% NaOH treated hemp fiber, 10% NaOH treated hemp fiber, and 5% NaOH + 5 wt% MAPP. 15 wt% and 30 wt% hemp fiber loadings are used in the composites with these material treatments. It is found that the material treatment(s) result(s) in composites with better mechanical properties compared to the composites without any treatment(s). The composites with 5 wt% MAPP addition show the best mechanical properties.

1. Introduction

Natural fibers are receiving increasing attention from engineers because of their low cost, good mechanical properties, low density and biodegradability and have become increasingly suitable alternative reinforcements in composites to synthetic fibers such as glass fibers. Natural fibers, when used with thermoplastic polymers, offer great advantages such as recyclability, low density, good damping, low abrasiveness, enhanced energy recovery, high strength to weight ratio and non-toxicity [1–3]. These renewable natural fibers offer the potential to replace conventional synthetic fibers in various applications including semi-structural automotive components, such as seat back, door inserts, underbody panels, and instrument panels [4,5]. The increasing interest has resulted in large demand of natural fiber composites in the last several years. The amount of natural fiber composite used in 2010 in the European Union was 315,000 tons, which accounted for 13% of the total composite with any reinforcements materials such as glass, carbon and natural fibers. It was forecasted that approximately 830,000 tons of natural fiber composites will be consumed in Year 2020 and the share will go up to 28% of the total composite materials [6]. The global market size for natural fiber composites is projected to reach $5.8 billion by 2019 with compound annual growth rate of 12.3% between 2014 and 2019 [7]. Demand for natural fibers will continue to grow due to rising prices of petroleum-based products, strong government support to eco-friendly products, increasingly competitive properties, positive growth of end-use industries, efforts to reduce global warming and higher acceptance among consumers [8–10].

Despite the advantages natural fibers possess over synthetic fibers, natural fibers have several disadvantages that affect their capabilities and properties used in the thermoplastic industry. Some of their main drawbacks are poor binding/adhesion to hydrophobic polymer matrix materials such as polypropylene (PP) and an affinity for moisture absorption [11,12]. Researchers have made progress in enhancing the bonding/adhesion between the natural fibers and matrix by material treatments. Alkaline treatments or mercerization are the most commonly used chemical treatment of natural fibers to reinforce thermoplastics [13].

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Treating natural fibers with aqueous sodium hydroxide (NaOH) results in the ionization of the hydroxyl group to the alkoxides. It selectively degrades a certain amount of lignin and pectin and facilitates the exposure of reactive OH groups on the fiber surface. This removal increases the bonding between the fiber and the polymer matrix. In addition to the extraction of lignin and hemicellulose compounds, the alkaline treatment increases the number of reaction sites by increasing the amount of cellulose exposed on the fiber surface [14,15]. Alkaline processing directly affects the cellulosic fibril, degree of crystallinity and extraction of lignin and hemicellulosic compounds. Li et al. [16] studied sisal fibers at different variables such as NaOH concentrations, temperature, time and pressure. Both of the sisal fibers treated with 5% aqueous NaOH for 72 h at room temperature and another set with 2% NaOH for 90 s at 200 °C at 1.5 MPa pressure had a positive effect on the fiber surface by increasing the amorphous cellulose content at the expense of crystalline cellulose [16], which is in agreement with the findings from Sreekala et al. [17]. Ray et al. studied 5% NaOH treated jute fibers at various time of treatment. After 4, 6 and 8 h of treatment with 5% NaOH, the jute fibers increased their flexural modulus by 12%, 68% and 79%, respectively [18].

Another method to enhance the bonding between the PP and natural fiber for PP based composites is to add maleic anhydride (MA) to the PP matrix [19–21]. This coupling agent acts as a compatibilizer that provides better interfacial bonding and mechanical properties of the composite. The PP chain interacts with the MA and form maleic anhydride grafted polypropylene (MAPP). MAPP coupling agent acts as a connection between the polar natural fibers and the nonpolar PP matrix. The fiber surface interacts strongly with the MA functional group through covalent and hydrogen bonding. By polymer chain entanglements, the unreactive PP matrix is then combined with MAPP. The polymer chain entanglement is an important factor in determining the mechanical properties up to and above the glass transition temperature of the matrix [19]. However, the addition of the coupling agent results in viscosity increase and possibly poor fiber wetting. The wettability of the natural fibers can be increased by increasing the surface energy of cellulose fiber to a level close to the surface energy of the matrix [16]. It has been reported that this coupling agent can reduce the water absorption and increase the modulus, hardness, and impact strength of the natural fiber-reinforced composites [19,20]. Sanadi et al. [21] investigated 3 wt% MAPP with 50 wt% kenaf fiber reinforced composites. It is found that the tensile strength and Young's modulus increased 88% and 350%, respectively. Mfala reported that 6 h of 20% maleic acid treatment on flax fiber reinforced PP composites increased the flexural strength by 150% from that of neat PP [22].

The purpose of this work is to study the effects of the material treatment(s), the fiber chemical treatment and/or polymer matrix treatment with coupling agent, on the mechanical properties of the hemp fiber polypropylene matrix composites. The study of fiber length change during the processing is also included.

2. Material and methods

Hemp fibers were supplied by Composites Innovation Centre (CIC), Canada, as the composite reinforcements in a mat format. PP pellets were procured from DOW Chemical Company as the matrix material. NaOH pellets are supplied from Fisher Scientific and Polybond 3200 (MAPP) from Chemtura.

In the chemical treatment, hemp fibers were dried at 50 °C for 48 h before any treatment or processing was done. Pre-dried fibers were soaked in 5 wt% NaOH and 10 wt% NaOH aqueous solution at ambient temperature. Wt% NaOH is defined as the ratio of NaOH pellet mass to water mass. The fibers were kept immersed in the NaOH solution for an hour and then thoroughly rinsed with water to remove any traces of alkali on the fiber surface. The treated fibers were then dried at 50 °C for 48 h in an air circulation oven. 5 wt% Polybond 3200 was added to the pre-weighed PP batch with respect to the 15 wt% and 30 wt% hemp fiber. The MAPP mixture was then blended with the PP before processing. The nomenclature for each of the samples with different material treatment(s) is listed in Table 1.

Flexural testing was conducted based on ASTM D790-Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials using an INSTRON SATEC APEX T5000 testing frame with a crosshead speed of 5 mm/min. Five specimens were prepared and tested according to the standard. Tensile samples were prepared and tested based on ASTM D638-Standard Test Method for Tensile Properties of Plastics using an MTS 810 Material Test System with a MTS Extensometer to measure the strain. Five dog-boned specimens were prepared from each material treatment variance, and the average tensile strength and modulus were calculated.

Fig. 1 shows the overall process and the manufactured hemp fiber PP composite plates from which the testing samples were prepared. In the process, hemp fibers and PP pellets were fed into a twin extruder and compounded. This compounding process results in the impregnation of the fibers with melted polypropylene polymer. The compounded mixture was extruded through a rectangular shaped die and cooled to form tape. The compounded tape form was chopped into 25 mm long pieces and fed into a low shear plasticator. After the charge was extruded in the low shear plasticator which was set to 180 °C for melting PP, it was then placed into a mold (152 × 152 mm) and compression molded into a plate at a pressure of 17 MPa. The compression mold temperature was set at 77 °C. The compression molded plate was then demolded after 2-min hold. All of the molded plates have similar thickness of approximately 6 mm. The testing samples were prepared with the same orientation from plate to plate to eliminate the effect of possible directionality resulted from material flow.

3. Results and discuss

Fig. 2 shows the SEM images of the surfaces of the untreated, 5 wt% NaOH and 10 wt% NaOH treated hemp fibers. The untreated

Table 1
Nomenclature used for hemp fiber/PP with 15 wt% and 30 wt% fiber loading.

Abbreviation	15 wt% fiber loading	Abbreviation	30 wt% fiber loading
PP	Neat PP		
PP-5MAPP	Neat PP + 5 wt% MAPP		
15-UT	Untreated Hemp Fiber	30-UT	Untreated Hemp Fiber
15-5NaOH	5 wt% NaOH	30-5NaOH	5 wt% NaOH
15-10NaOH	10 wt% NaOH		
15-5MAPP	5 wt% MAPP	30-5MAPP	5 wt% MAPP
15-5NaOH-5MAPP	5 wt% NaOH + 5 wt% MAPP	30-5NaOH-5MAPP	5 wt% NaOH +5 wt% MAPP