PROCESSING AND CHARACTERIZATION OF HEMP FIBER REINFORCED POLYPROPYLENE COMPOSITES

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Abstract
Natural fibers possess high specific strength properties, low density, low abrasiveness, high biodegradability, low production energy requirements, and low cost that makes it more favorable than the use of synthetic fiber-reinforced polymer composites. In this paper, the processing and characterization of industrial hemp fiber reinforced polypropylene (PP) are discussed. Maintaining critical fiber length, content, and minimizing fiber breakage would provide superior mechanical and dynamic mechanical properties. Fiber attrition due to twin screw compounding and low shear extrusion compression molding resulted in 32% reduction in length for 15% hemp reinforcement. Treatment with NaOH and usage of MA as a coupling agent helped increase the flexural strength by approximately 50% and the modulus by 32%.

1 Introduction
Natural fibers have been the leading potential alternative fibers for automotive, industrial and commercial composite components. Natural fibers are biodegradable and when used with thermoplastics resins, offer great advantages such as recyclability, light-weight, high strength to weight ratio and non-toxicity. However, natural fibers continue to have drawbacks such as variable fiber quality, poor binding to matrix materials, chemical modification are required for improved composite adhesion, lower strength than synthetic fibers. There are also many challenges in processing of natural fiber composites due to low thermal degradation and fiber breakage which hinder the strength of the composites.

The most important types of natural fibers are bast fibers: flax, hemp, jute, kenaf, and ramie due to their properties and availability. These materials can be extremely cost effective in the construction and automotive industry. Hemp and flax are the main bast fibers that are used due to their higher mechanical properties. However, there are few studies combining different types of natural fibers. So, it can be possible to process various material mixtures to compare and contrast. Hybrid fibers are also starting to become of interest to the automotive industry. As an example, addition of a small weight percentage of recycled carbon fiber has significant improvement in stiffness [Mauhar, Mark, personal communication, February 10, 2012]. Hybrid fiber composites can be very versatile and help improve the needed properties that natural fibers alone cannot achieve.

Natural fibers are hydrophilic in nature due the low interfacial properties between the fiber and the polymer matrix. This disadvantage reduces the potential of natural fibers as a reinforcing agent. Natural fibers are derived from lignocelluloses that are strongly polarized hydroxyl groups. Temperature, relative humidity, and air velocity are the three factors that determine the rate at which moisture is removed from lignocellulosic materials [1]. Thus, chemical modifications are considered to optimize the interface of fibers, improve the reinforcing capabilities of fibers, and impart dimensional stability and thermoplasticity. Some of the most common chemical treatments are the alkaline, silane, and maleated chemical treatments.

Thermoplastic processing has become more common than the use of thermosets. Thermoplastic matrix materials have a greater design freedom. Thermoplastic natural fiber composites have two physical limits: the processing temperature, and the surface energy between fiber and polymer matrix [2]. Fiber degradation occurs around 150°C for long processing durations and 220°C for short-term exposures. When natural fibers are degraded, the fibers have poor interfacial adhesion, discoloration, and lower properties. Extrusion processing and injection molding are suitable for thermoplastic materials. Injection molding is the most widely used process for making natural fiber composite components; however, the fiber is degraded due the high shear and processing temperature. In consideration of formability, the use of natural fiber reinforced thermoplastic matrix has the ability to obtain very high draw ratios without the formation of thinning or wrinkles [3]. Researchers are focusing on natural fibers reinforced with thermoplastic polymer synthetic matrices such as polypropylene (PP). There are numerous studies on natural fiber/PP composites that have promising properties compared to the typical glass fiber/PP composites in the automotive industry.

The purpose of this research was to analyze the hemp fiber attrition at each stage of processing 15 % hemp/PP. Modifying and retaining the fiber length were evaluated by means of chemical surface treatments and coupling agent: 5 % NaOH, 10 % NaOH, and 5 % MAPP. Composites were produced comparing untreated and treated hemp fiber reinforced polypropylene and mechanical and physical properties were analyzed.

2 Materials and Testing Method

2.1 Materials

Industrial hemp fiber mat (*Cannabis Sativa* L.), supplied by the Composites Innovation Centre (CIC), Canada, was used as the composite reinforcement in this research. The polypropylene was obtained from the DOW Chemical Company. Sodium hydroxide (NaOH) in pellet form was supplied by the Fisher Scientific and the maleic anhydride modified homopolymer polypropylene (MAPP), Polybond 3200 was supplied by Chemtura.

2.2 Experimental

2.2.1 Fiber Length Characterization

To analyze the fiber length, the hemp fibers were processed with polyvinyl alcohol (PVA). Untreated hemp fibers before and after processing with the twin screw was analyzed. The processing parameters used are the same as seen in the Composite Extrusion section below. The tape extradite was then immersed in warm water until all PVA was dissolved. The processed fibers were then placed in an oven at 50 °C for a period of 48 hours until all the moisture was evaporated. Figure 1 shows the hemp fiber length distribution with the average

fiber length before processing 30.66 mm and 20.79 mm after processing. Overall, there was a 32 % reduction in hemp fiber length after processing.

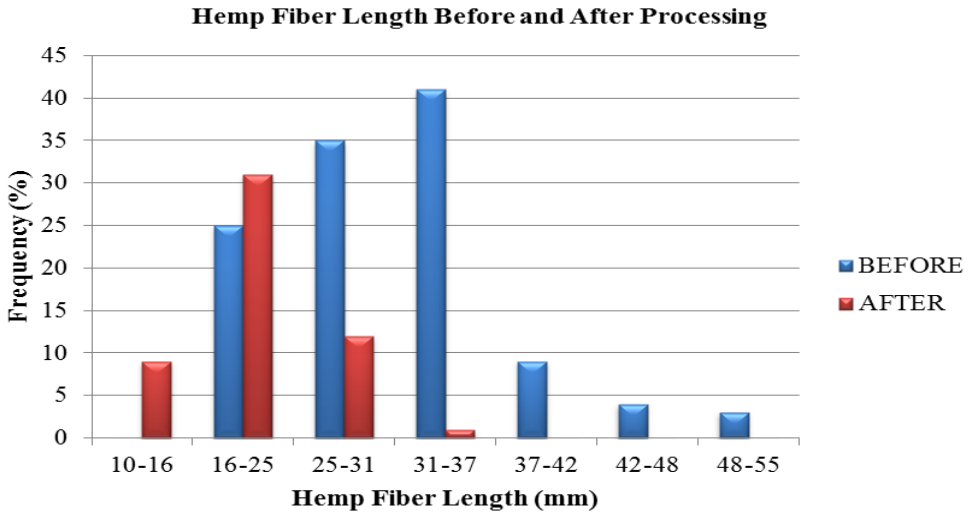


Figure 1. Hemp fiber length distribution before and after processing.

2.2.2 Fiber Treatment

Sodium hydroxide (NaOH) and maleic anhydride polypropylene (MAPP) was used as the chemical surface treatment and coupling agent. The hemp fiber mat was first cut into 150 mm long 25-30 mm wide strips and weighed out accordingly for each set. All the pre-weighed hemp fiber batches were placed in the oven at 50 °C for 48 hours before any treatment or processing were done.

Pre-dried hemp fibers were soaked in 5 and 10 wt % NaOH solution at ambient temperature. The fibers were kept immersed in each of the solution for one hour. The fibers were then rinsed with tap water to eliminate any traces of alkali on the fiber surface. The treated fibers were then placed in an oven at 50 °C for 48 hours. Then, 5 wt % Polybond 3200 was added to the pre-weighed polypropylene batch in respect to the 15 wt % hemp fiber. The MAPP mixture was then simply blended with the PP before processing/compounding of the composite.

2.2.3 Composite Extrusion

Before processing, the untreated and treated hemp fiber batches were 'fluffed' out. The hemp fibers and PP were compounded first in the Leistritz MICRO 18 twin screw extruder, with the temperature not exceeding 185 °C. The hemp fibers were fed through a side stuffer, at the middle of the barrel, at a screw speed of 40 rpm. The PP was fed through the main feeder at an average rate of 48.76 g/min with a screw speed 80 rpm. The extruded tape composite was air cooled and chopped. The chopped composites were then fed in a single screw plasticator. The temperature in the plasticator did not exceed 190 °C. The extruded charge was then compression molded into a 152 by 152 mm plate at 17 MPA and held for 2 minutes. The tool temperature was set at 77 °C.

2.3 Flexural Testing

Flexural testing was conducted according to ASTM D 790-03 [4]. Nominal specimen dimensions were 118 x 24 x 5.7 mm with a span length of 92 mm. The tests were conducted using a SATEC screw driven machine with a crosshead speed of 5 mm/min. Five samples of each of the four sets were tested and then recorded for its average flexural strength and modulus.

3 Results and Discussions

The surfaces of the untreated, 5 wt % NaOH, and 10 wt % NaOH hemp fibers were observed by means of a scanning electron microscope (SEM) as seen in Figure 2. The untreated fibers in Figure 2a have uneven deposit of pectin, lignin, and other impurities on its surface. In contrast, the alkali treatment of the fibers led to have a cleaner yet rougher surface than seen in the untreated fiber surface as shown in Figures 2b and c. The increase in NaOH concentration removed most of the lignin and pectin resulting in a rougher, cleaner surface. The 10 wt % NaOH hemp fibers had rougher surfaces than the 5 wt % NaOH hemp fibers. The alkali treatment is expected to increase the surface roughness by distributing the hydrogen bonding in the network structure to provide additional sites for mechanical interlocking [5]. The bonding/adhesion between the fiber and matrix at the interface should improve.

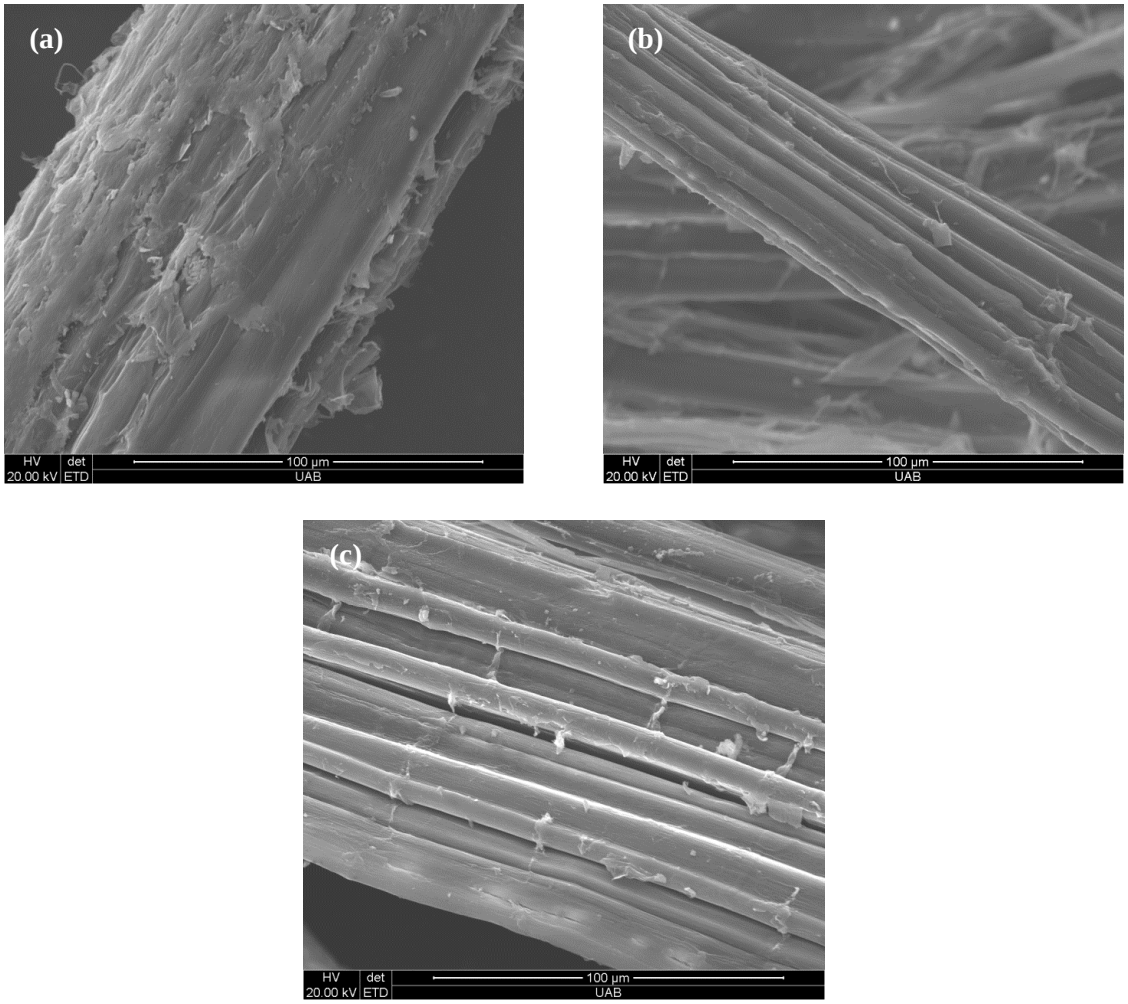
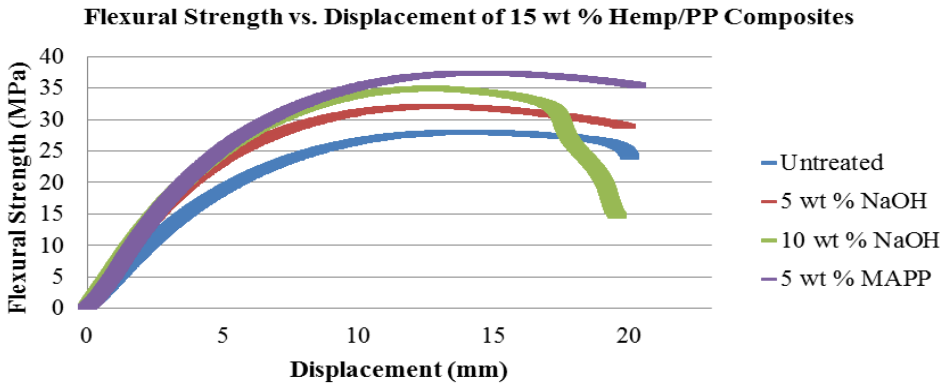
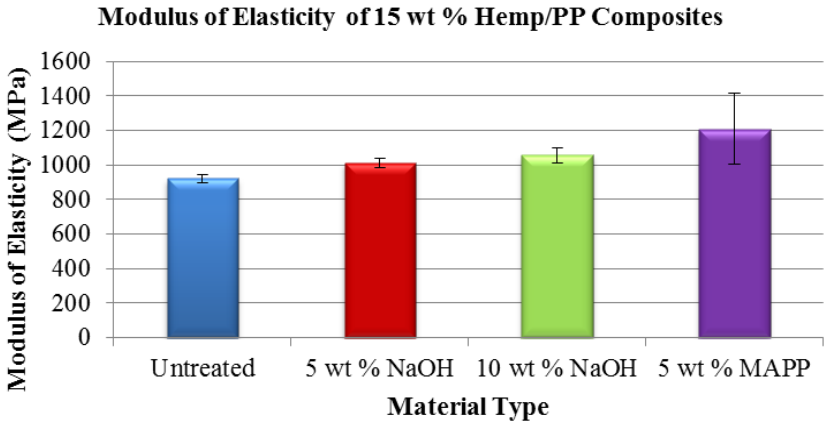


Figure 2. SEM images of (a) untreated, (b) 5 wt % NaOH, and (c) 10 wt % NaOH hemp fiber surfaces.

The removal of lignin, pectin, and other impurities and increase in surface roughness increased the flexural strength of the hemp/PP composite. Figure 3a and b compared the four sets' flexural strength and modulus of elasticity. The maximum flexural strength obtained from the untreated, 5 wt % NaOH, 10 wt % NaOH, and 5 wt % MAPP 15 wt % hemp/PP composites were 25.03 MPa, 32.41 MPa, 34.97 MPa, and 37.38 respectively. The modulus of elasticity obtained were 920.6 MPa, 1013.29 MPa. 1055.65 MPa, and 1210.26 MPa for the untreated, 5 wt % NaOH, 10 wt % NaOH, and 5 wt % MAPP 15 wt % hemp/PP composites respectively. The 5 wt % MAPP coupling agent had the highest flexural strength 37.38 MPa and modulus of elasticity 1210.26 MPa out of the four sets. The surface of the fiber with MAPP addition allowed direct bonding between the MA functional group and microfibrils cellulose OH groups [6]. This interaction allowed the flexural properties to increase. The increase in NaOH concentration increased both the flexural strength and modulus of elasticity due to the cleaner and rougher surfaces as seen in Figure 2 b and c. However, the addition of MAPP showed greater results than the NaOH treated hemp fibers.



(a)



(b)

Figure 3. Mechanical properties of untreated and treated 15 wt % hemp/PP composite for (a) flexural strength and (b) modulus of elasticity.

The SEM images in Figure 4 showed the untreated and treated fracture surfaces of the 15 wt % hemp/PP composites. Figure 4a showed the untreated 15 wt % hemp/PP composite having poor fiber-matrix interfacial adhesion. There a number of fibre breakage and some fiber pullout/debonding are evident. The protruding hemp fibers show the poor bonding of the PP

to the fibers with gaps around the fibers on the matrix. Both the NaOH treated fibers showed an improvement of the bonding between fiber and matrix as seen in Figures 4b and c. Very few hemp fibers were damaged, although there were some fibers damaged seen in Figure 4c when the fibers protruded out of the matrix. Figure 4d showed the best fiber-matrix interfacial adhesion. PP was definitely seen adhering to the surface of the hemp fibers. There were less damaged on the fibers than the untreated and NaOH treated hemp fibers. MAPP addition greatly improved the fiber-matrix adhesion thus increasing the flexural strength and modulus of elasticity as seen before. Without chemical modifications or coupling agent additives to hemp fibers, the interfacial bonding between fiber and matrix is poor and lowers the mechanical properties as seen in the flexural strength and modulus of elasticity.

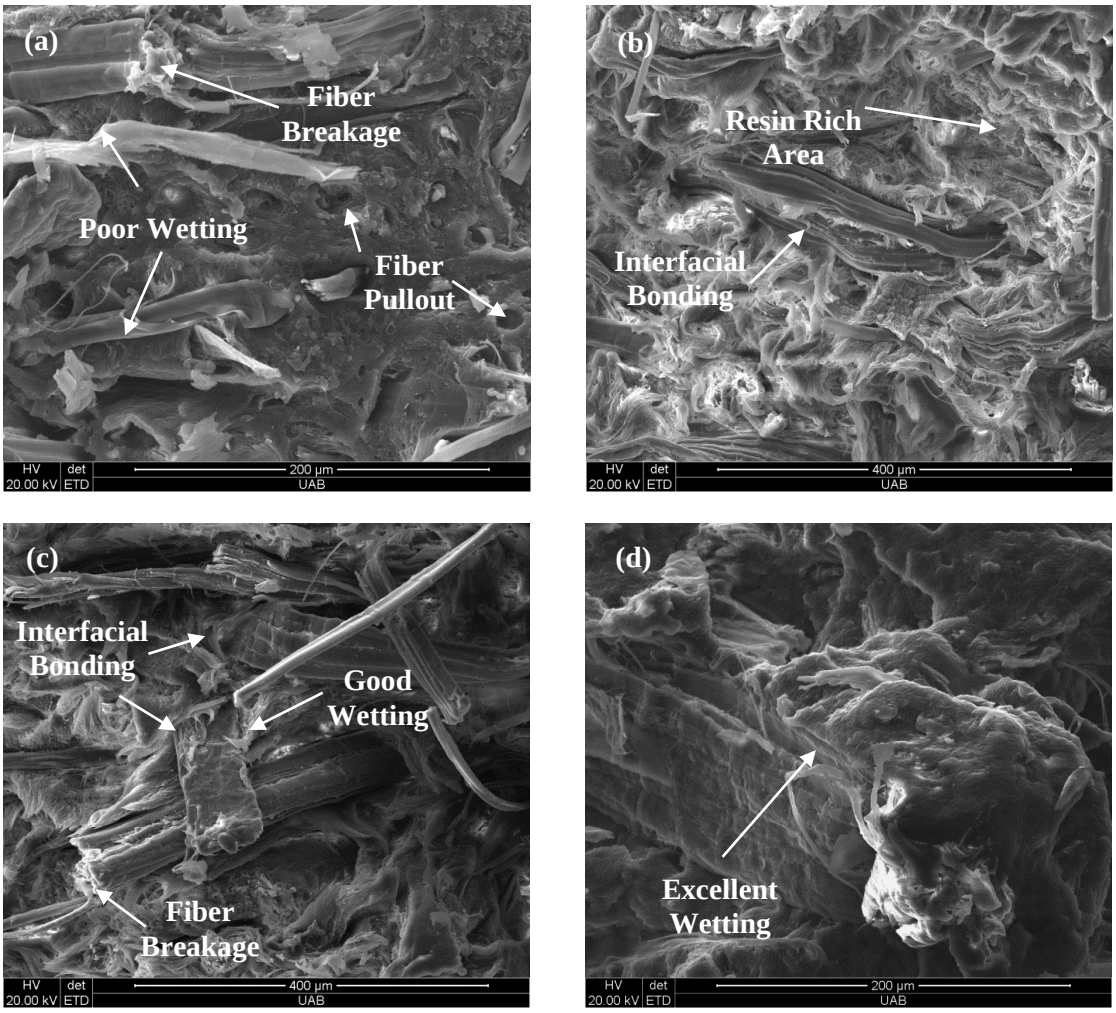


Figure 4. SEM images of 15 wt % hemp/PP composite fracture surfaces of (a) untreated, (b) 5 wt % NaOH, (c)10 wt % NaOH, and (d) 5 wt % MAPP.

4 Conclusion

The use of an extrusion compression molding process had little damage on the length of the hemp fibers. Maintaining most of the fiber length will maximize the properties of the composites. The effects of alkali chemical treatment and addition of MAPP greatly improved the interfacial bonding thus the properties of the composite. The 5 wt % addition of MAPP had the highest flexural strength and modulus of elasticity, 37.38 MPa and 1210.26 MPa respectively. This result is due to the removal of lignin, pectin, and other impurities on the

fiber surface. The cleaner yet rougher surface allows additional sites for mechanical interlocking between fiber and matrix. The 5 wt % MAPP showed the best interfacial adhesion between fiber and matrix from the NaOH treated fibers. These observations are supported by SEM observations. The addition of a coupling agent and treatment of the hemp fibers will improve the properties of the hemp/PP composite as was seen in this paper.

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