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Title: ***Analyzing the Mechanical Properties of Thermoplastic Reinforced with Natural Fibers***

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ABSTRACT

Synthetic fibers such as glass, carbon, etc., are used as reinforcement in polymer composites due to their high strength and modulus. However, synthetic fibers contribute to high costs and have a significant environmental impact. To overcome this challenge, various natural fibers, including banana, kenaf, coir, bamboo, hemp, and sisal fiber, as reinforced in a polymer matrix are investigated for mechanical properties. In this study, biocomposites with natural fibers as reinforced are developed and characterized. Treated and untreated natural fibers such as flax, maple, and pine as reinforced in thermoplastic, in this study, polypropylene (PP), are investigated for the mechanical properties, including tensile, flexural, and impact test. Mechanical test results exhibited that adding the natural fibers enhanced the tensile, flexural, and impact properties. It can be inferred that these biocomposites can be used as potential materials for the automobile industry.

INTRODUCTION

Composites, made from combining two or more materials, often polymer matrix filled with fibers, are widely used in the automotive industry, construction, or other industries [1]. Polypropylene (PP) is the most widely used plastics in the automobile industry as the polymer matrix. Polypropylene has an excellent cost-performance ratio and material properties [2]. However, recycling these plastics is complex as these compositions are made from petroleum-based polymer [3]. As a result, environmental and regulatory are pushing the automotive industry to use more sustainable materials [4]. Therefore, automobile and agriculture industries are among many industries shifting their attention to incorporating more sustainable materials.

Biocomposites are defined as polymer matrices reinforced with natural fibers such as flax, jute, ramie, sisal, coir, oil palm, and kenaf fibers [5–8]. Animals, plants, and mineral resources such as igneous rocks rich in magnesium silicates are the primary source of the natural fibers [9,10]. Using natural fibers as reinforcement in plastics delivers many advantages, such as cost reduction, improving mechanical properties, and environmental safety [11–13]. Due to these advantages of the natural fiber, researchers have studied the incorporation of natural fibers into plastics and their effect on the mechanical properties of the resulting composites [13–16].

For instance, Garkhail *et al.* [17] studied the mechanical property of the polypropylene (PP) reinforced with the flax fiber. The average tensile strength and modulus were between 20MPa to 35MPa and 3GPa to 8GPa, respectively. Similarly, Van Den Oever *et al*. [18] investigated the influence of the physical structure of flax fibers on the mechanical properties of flax fiber reinforced polypropylene. Polypropylene reinforced with flax fiber produced tensile strength between 35MPa and 45MPa and tensile modulus on average between 5GPa and 9GPa. It can be observed from these studies that the difference in flax fiber origin and processing method affects tensile strength and modulus.

Birat *et al*. [4] analyzed the material properties of hybrid biocomposites, using sisal fiber(SF) and glass fiber (GF) blended with polypropylene (PP) for structural application. This study showed that SF and GF enhanced flexural properties and thermal properties by 33 and 19%, respectively. Naveen *et al*. [5] developed and characterized coir fiber as reinforcement in polyester composites. This study demonstrated that the percent volume of the reinforcement and length of the fiber influenced the tensile, static, and dynamic properties of composites and implied that coir fiber could be used as fiber filer in composites for structural and nonstructural application.

Natural fibers being hydrophilic, cause moisture absorption and agglomeration that creates the void and hinder the mechanical properties and even dispersion of the fiber [11,13]. Thus, any chemical, physical, and biological treatment are recommended to improve the dispersion and combability of fibers and polymer matrix [11]. Ray *et al*. [19] treated the jute fibers with 5% alkali (NaOH) solutions for 0, 2, 4, 6, and 8 h at 30°C. This study showed that fiber treated for 4hrs was optimal to reach the maximum strength in vinyl ester resin-based composite. Similarly, Morrison *et al*. [20] chemically treated flax fiber with 4M NaOH solutions at 170℃ for 2hrs Van de Weyenberga *et al*. [21] suggested in their study that combination of chemical treatment with alkali and dilute epoxy increase the tensile strength and tensile modulus by 40% in flax fiber epoxy composites. Mishra *et al*. [22] suggested that sisal fiber treated with 5% NaOH solution was optimum in sisal fiber polyester composite to enhance tensile and impact strength. Based on these studies, it can be inferred that treatment on natural fiber improved the mechanical properties by increasing the interfacial adhesion between fiber and matrix [13]. Based on these studies done so far on natural fibers, it can be concluded that natural fibers can be used in composites in the place of synthetic fibers. The main objective of this study is to investigate the effect of treated and untreated natural fibers such as flax, maple, and pine on the mechanical properties of polypropylene composites.

EXPERIMENTAL SECTION

Materials Processing

One type of fiber and two types of wood flours were used as reinforcement in PP. The fiber used in this study was flax fiber, pine as a soft type of wood, and maple flour as a hardwood were kindly provided by RheTech (Whitmore Lake, MI, USA). Polypropylene (PP) was used as the matrix to create the composites. H_3PO_4 (Phosphoric acid) and NaOH (Sodium Hydroxide) chemical for the treatment of fibers.

To perform the alkaline treatment, fibers were immersed into 1500mL of 10g/L sodium hydroxide/ethanol solution at 78 °C for 2hrs. For the phosphoric acid treatment, the 85% H_3PO_4 was diluted to the weak acid solution with pH=4.0. The ratio of H_3PO_4 to distilled water was 5.16 µl: 1100 ml. The diluted solution was brought to a boil. With the temperature of the hot plate kept at 190 ºC, approximately 45g of flax fiber was immersed in the solution and kept there for 2 hours. After each treatment, fibers were passed through a paper filter and then washed with distilled water until no color left in the water. The pH value was measured to be 7.0. Finally, treated fibers were dried in a convection oven (Model 1370FM, VWR).

The loading for all fibers was 20% fiber - 80% polypropylene. All materials compounded in a co-rotating Leistritz (Micro18-GL) dual-screw extruder with a temperature profile from feed throat to the nozzle in 148.9, 157.2, 160, 162.8, 165.6, 168.3, and 173.9, and 173.9°C, respectively. Screw speed is 150rpm at approximately 1.4MPa of backpressure in the barrel at the die. Materials were extruded through a water-cooling bath and subsequently pelletized for injection molding.

Before injection molding, the pellets were dried in a convection oven for 24hrs at 80°C. All materials were injection molded using Maruka FCS (Model FA-100SV) injection molder at barrel profile temperatures from feed throat to the nozzle in 165.6, 168.3, 171.1, and 173.9°C, respectively. A pressure of 3.4MPa was kept for injecting the material into the mold.

Mechanical Properties

Mechanical properties are tested on the biobased composites with natural fibers and without natural fibers. Tensile properties such as tensile strength and tensile modulus performed using Instron Model 5567 (Instron® MA, US) as per ASTM D638 using a 5mm/min crosshead rate [23]. Five specimens prepared in the dumbbell-shaped according to ASTM D638 and tested for each test sample. The strain was measured with MTS extensometer model 632.25B-20 (*Figure 1.a*).

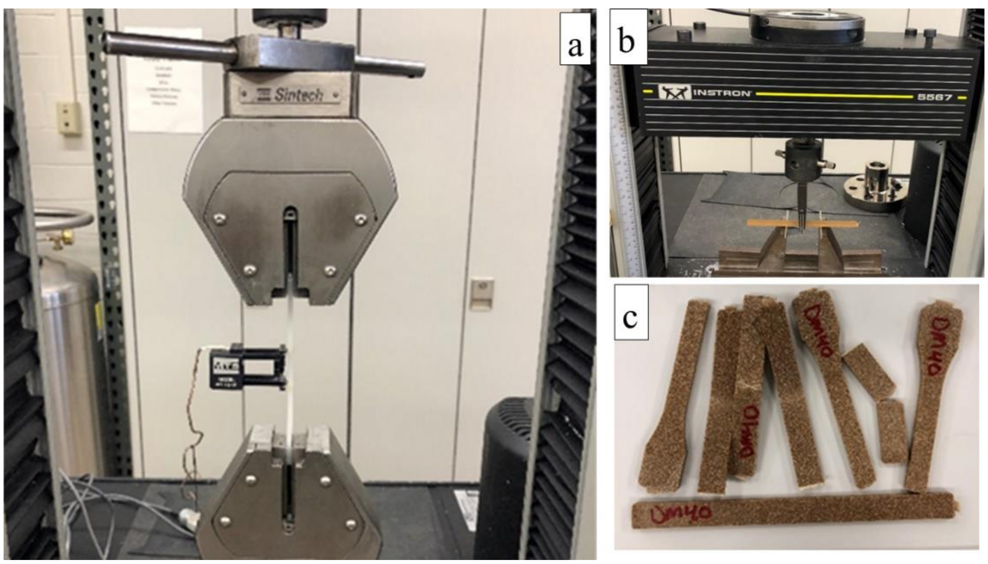


Figure 1: (a) Tensile Test Setup, (b) Flexural test setup (b), and (c) Fractured specimen

Flexure properties such as flexural strength and flexural modulus measured through the three-point bend testing specified in ASTM D790 using Instron 5567 using a displacement rate of approximately 1.4mm/min. The maximum flexural stress and flexural modulus of specimens were calculated based on the ASTM D790 [24]. Figure 1.c shows the 3-point bend setup for the flexural properties.

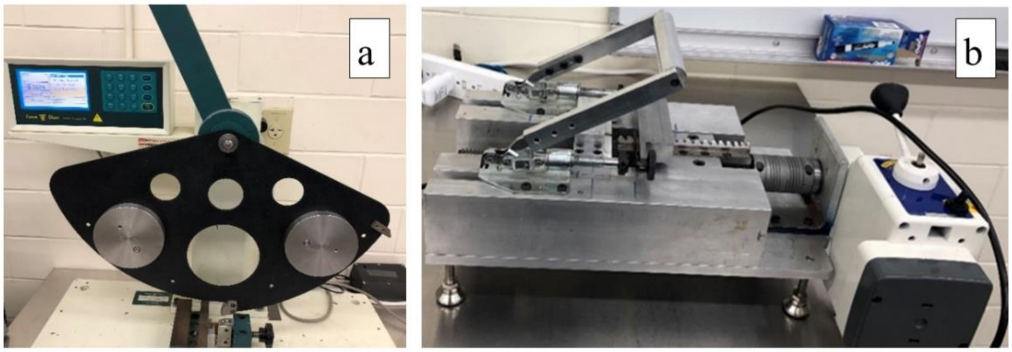


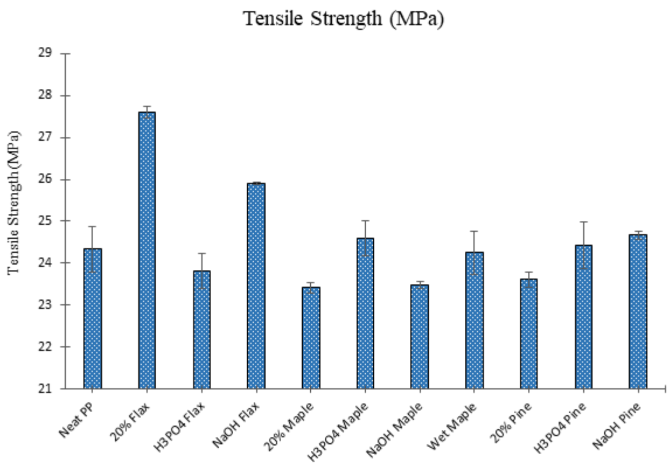
Figure 2: (a) Izod impact test and (b) Notching machine

Impact test performed using Izod model 104 impact machine (Tinius Olsen, PA, USA) as per the ASTM D256 [25]. A rectangular cross-section similar to the flexural test samples was notched after cutting in half with a wet saw. Five specimens are prepared in the rectangular cross-section and tested for each test sample. Then the average of the five measurements is taken for the results. Figure 2 shows the impact and notching machine used to do the impact test.

RESULTS AND DISCUSSION

Figure *3* represents the tensile strength and tensile modulus. PP filled with wet maple and flax fibers presenting a higher tensile strength compared to maple fibers. The highest exhibited tensile strength was 27.6MPa and tensile modulus of 2.14GPa on average for 20% flax fiber comparable to values reported by Garkhali *et al.* [17] and Van Den Oever [18]. 20 % pine fiber produced the tensile strength and tensile modulus of 23.61MPa and 2.70GPa, respectively, similar to the values reported by other researchers [26,27]. Adding flax fibers improved the tensile strength due to fiber size and aspect ratio help in transferring the load.

On the contrary, adding maple fiber increase the modulus of the biobased composites as maple fiber is in smaller particle size. Therefore, it contributes to stiffness, thus increasing the tensile modulus of the biocomposites. While maple flour treated with H_3PO_4 improved the tensile strength, maple four treated with H_3PO_4 has low crude protein and ash content. From the graph, it can be observed that treated fibers enhanced the tensile modulus of the composites.



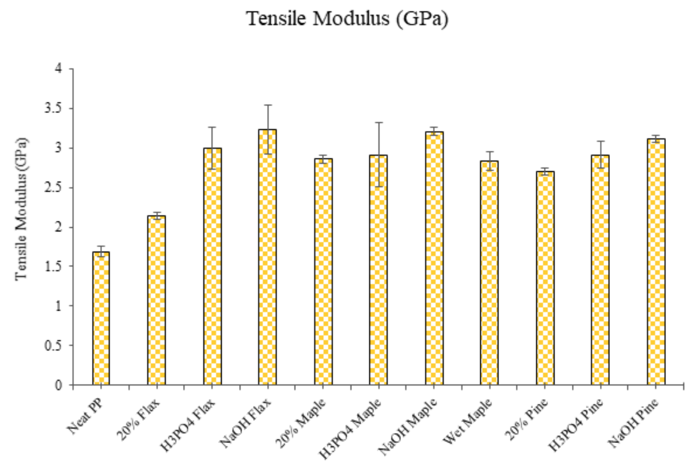
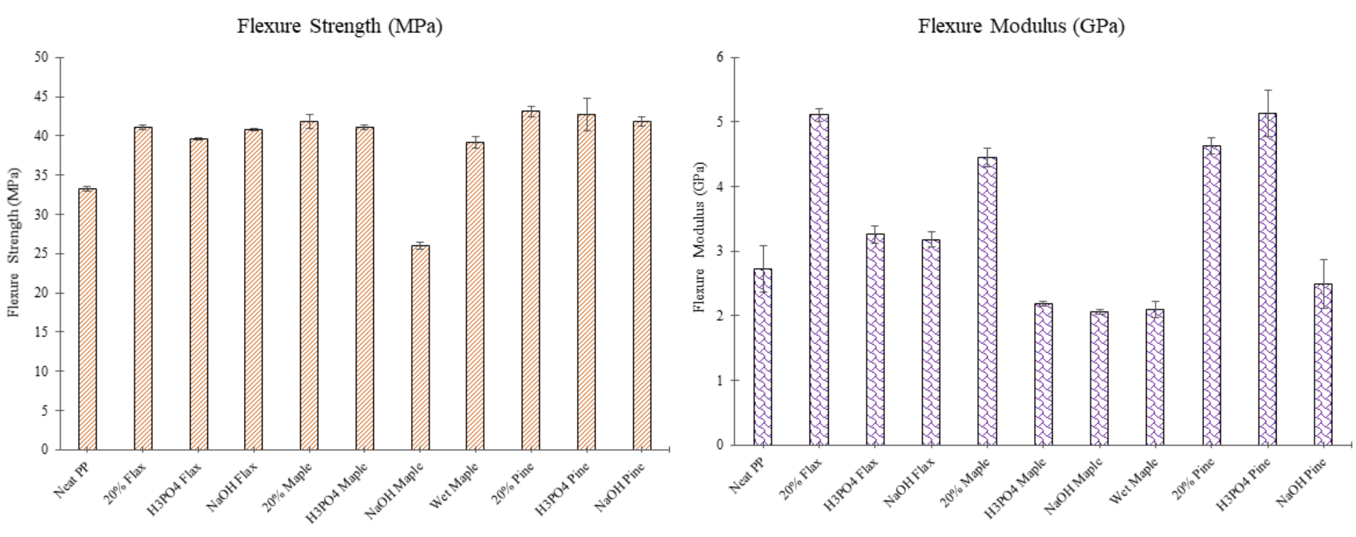


Figure 3: Tensile strength (MPa) and Tensile Modulus (GPa) of the biobased composites

Figure 4 showed the flexural strength, and flexural modulus of the PP reinforced with natural fibers. It can be observed from the graph that 20% pine fiber is producing the highest flexural strength, which is 43.2MPa on average, which is comparable to studies done by Stark *et al*. [28]. In addition of 20% flax fiber produced the highest flexural modulus, 5.1GPa on average, similar to studies done by Van Den Oever *et al.* [18] using the flax fibers. In addition, pine fibers treated with H_3PO_4 producing a higher flexural modulus compared to NaOH treated pine. The H_3PO_4 treated pine fibers have less cellulose and lignin content compared to NaOH treated pine fibers. Based on the tensile and flexural results, it can be inferred that the constituents such as cellulose, hemicellulose, and lignin present in the fibers have an impact on the tensile and flexural properties of the composites.

Figure 4: Flexural strength (MPa) and Flexural Modulus (GPa) of the biobased composites

Adding the 20% natural fibers did not significantly impact the impact strength of the biocomposites, as seen in the figure below. The addition of the 20% NaOH treated flax fiber reported impact strength was 3.88kJ/m^2 on average compared to the 20% untreated flax fibers. As NaOH treated fibers have less hemicellulose and lignin content compared to untreated flax fibers. Adding 20% pine fiber did not affect the impact strength could be due to poor interface between the hydrophilic wood flour and hydrophobic PP; as a result, increase in the crack propagation [28]. On the contrary, NaOH treated pine and maple fibers produce a higher impact strength; it could result from the reduction in agglomeration, thus fewer voids in the polymer matric due to the NaOH treatment.



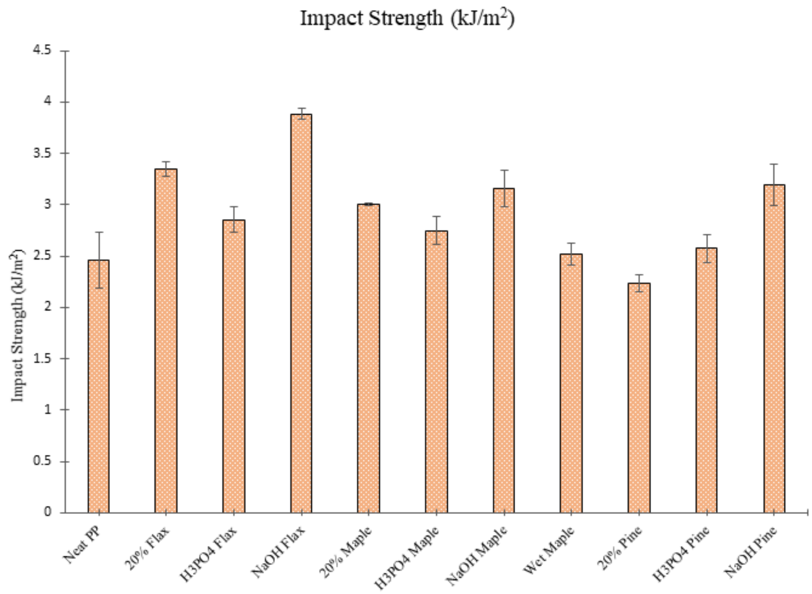


Figure 5: Impact Strength (kJ/m^2) of the biobased composites

CONCLUSION

Synthetic fibers are non-biodegradable and contribute to high costs. In Literature, various natural fibers, including banana, kenaf, coir, bamboo, hemp, and sisal fiber, as reinforced in a polymer matrix, are investigated for mechanical and thermal properties to overcome this challenge. The main goal of this study is to examine the mechanical properties of the thermoplastic reinforced with treated and untreated natural fibers. It can be inferred that adding 20% natural fibers enhanced the mechanical properties of the biocomposites. Tensile strength of the composites increased to 10%, and impact strength increased to 20%, respectively, with 20% flax fibers. Flexural strength increased up to 40% with the addition of the 20% pine fibers. It can be concluded that adding natural fibers in the composites has promising results in mechanical properties.

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