Thermal and Mechanical Properties of Recycled High Density Polyethylene/hemp Fiber Composites

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Abstract

Implementation of "green laws" in several countries hasgeneratedrenewed research interest in natural fiber reinforced composites in different industrial sectors such as automotive, construction, building and electrical. In this study, we have investigated the effect of chemical treatment of hemp fiber on thermal and mechanical properties of hemp fiber composites with recycled high density polyethylene matrix. The chemical composition effect on thesurface modification wasanalyzed by means ofFourier transform infrared spectroscopy (FTIR) and the thermal stability of composites properties were studied bythermo gravimetric analysis (TGA). The mechanical properties of the composites were testedin accordance to ASTM D790 with fiber volume fractions in the range of 20-40%. The results showed that the chemical treatment of hemp fiber improved the thermal stability of the fiber. The maximum flexural strength of hemp fiber composites of 44.6MPa was observed with the composite containing 40% fiber volume fraction.

Keywords: hemp fiber, recycled high density polyethylene, composites, thermal stability,surface treatment

1. Introduction

Demand for sustainable materialsand increased environmental concerns have paved a path for intense research in the field of natural fiber reinforced composites.Natural fibers are favored over synthetic fibers as reinforcement due to positive environmental benefits such as raw material utilization at source and easy disposable of the biodegradable fiber(Mohanty, Misra, & Drzal, 2001)(Kabir, Wang, Lau, Cardona, & Aravinthan, 2011)(Aziz & Ansell, 2004).Other than these environmental benefits natural fibers also provide advantages such as low cost, easy availability, low density, improved toughness and reasonable specific strength(Cantero, Arbelaiz, Llano-Ponte, & Mondragon, 2003). Natural fibers such as hemp, flax, jute, and kenaf are frequently used as reinforcement due to their good mechanical properties. However, the use of natural fibershas few setbacks such as poor compatibility with thermoplastic matrix, high moisture absorption and lower thermal stability(Li, Tabil, & Panigrahi, 2007)(Ray, Sarkar, Basak, & Rana, 2002). To overcome such setbacks natural fibers are subjected to surface modifications such as chemical or physical treatments(Mukhopadhyay & Fangueiro, 2009; Xie, Hill, Xiao, Militz, & Mai, 2010). In this study, we have systematically investigated the surface chemistry change of hemp fiber after sodium hydroxide treatment and the resulting effect on thermal and mechanical properties of the fiber and composite, respectively. The matrix used in the study was recycled high density polyethylene (rHDPE). The rationale of usingrHDPE is to achieve solid waste reduction and further develop sustainable materials. Fourier transform infrared spectroscopy (FTIR) was used to investigate the chemical composition of hemp after chemical treatment.

Thermo gravimetric analysis (TGA) was used to analyze the thermal stability of untreated and treated hemp along with virgin and recycled HDPE. The flexural properties of the composites with various fiber volume fractions ranging from 20-40% were tested according to ASTM D790 standard.

2. Experimental

2.1 Materials

Industrial hemp fibers were obtained from Hempline Inc. (Delaware, Ontario, Canada). The average density of the fiber was 0.86 g/cm^3 and the moisture content was approximately 6%. The recycled HDPE (rHDPE) pellets used in this study were obtained from Customer Polymer Inc. (Charlotte, NC, USA). These pellets were recovered from detergent bottle and have average bulk specific density of 0.98 g/cm^3, a melt index (MI) of 0.45 g/10min at 190°C, and a melting temperature range from 130°C to 190°C.

2.2 Fiber treatment

Hemp fibers were treated with 5wt% of NaOH solution. Fibers were soaked in the NaOH solution for 24 hours at 50°C, followed by wash with running distilled water until the pH value ranged from 6.8 to 7.2. Then the fibers were dried in the oven at 80°C for 10 hours and stored in desiccators prior to composite preparation.

2.3 Composite preparation

Composites were prepared using both untreated and alkali treated hemp fibers. Fabrications were performed by using both, a C.W. Brabender 19.05 mm Extruder and compression at the temperature of 180°C under a constant pressure of 1.5 MPa for duration of 15 minutes. Composites were manufactured by sandwiching a layer of treated hemp fiber in between two layers of HDPE films. The weights of hemp fiber and HDPE layers were controlled to maintain composites with 20%, 30%, and 40% hemp fiber volume fraction.Table 1 gives the details of the composites prepared for this study.

2.4 Fourier transform infrared spectroscopy

Spectra were obtained using a Perkin Elmer FTIR spectrometer model Spectra 100. IR spectra were obtained in the range of 4000-650 cm^{-1} at a scanning speed of 2mm/s, with a resolution of 16 cm^{-1}. The number of scans was set to eight. 1-2 mg of fiber was placed directly on the scanner to obtain the spectra.

2.5 Thermo gravimetric analysis

Thermal stability of untreated and treated hemp fibers along with virgin and recycled polymer was obtained by using TA Q500 with a heating rate of 5°C/minute, from 25 to 750°C (for fibers) and 25 to 500°C (for polymers) in a nitrogen atmosphere. The amount of sample used was in the range of 3 to 5 milligrams. For every sample five duplicates were run.

2.6 Flexural testing

Flexural test was performed using Instron 5582 constant rate of extension (CRT) universal testing machine as per ASTM D 790. The testing conditions adopted were, a cross head speed of 1.3 mm/min, air temperature of 23°C and 65% relative humidity.

3. Results and Discussions

3.1 Fourier transform infrared spectroscopy

Figure 1 indicated that lignin and hemicellulose have been partially removed from hemp fiber after NaOH treatment, as the evidence of reduced the peak intensity at 1250 cm^{-1}and around 1600-1650 cm^{-1}, respectively. The peak around 1740-1750 cm^{-1} in untreated hemp was also removed by NaOH treatment, which indicated that the removal of pectin and wax content from the hemp fiber. Increase in intensity of the peak at 1000 cm^{-1} suggested that the NaOH treatment increased hydroxyl group concentration on the fiber, which would provide more active site for fiber/matrix interface(Mwaikambo & Ansell, 2002).

3.2 Thermo gravimetric analysis

Figure 2 and 3 shows the TGA curves for the treated and untreated fiber and virgin and recycled HDPE. The fiber had two step degradation processes: first degradation was in the range 225 – 275°C due to decomposition of hemicelluloses, and the second one was in the range 325 – 360°C due to decomposition of lignin (Pracella, Chionna, Anguillesi, Kulinski, & Piorkowska, 2006). The thermal degradation of 99wt % polymer started at 402.84°C for virgin HDPE (v-HDPE) and 420°C for r-HDPE (Zabihzadeh, Dastoorian, & Ebrahimi, 2010). The decomposition was completed at 486.52°C for v-HDPE and 486.69°C for r-HDPE with 2-3% residue.

Table 2 summarizes the thermal degradation temperatures of untreated and NaOH treated hemp, along with vHDPE and rHDPE.

3.3 Flexural testing

Three point flexural bending test was conducted using a rectangular test specimen with dimensions of 25.4mm in width, 6.35 mm in thickness and 127 mm in length. Five replicates were tested for each composite tested. Figure 4 presents the flexural stress of the treated hemp/rHDPE composites as a function of the flexural strain. It was observed that as the fiber fraction increased there was a proportional increase in bending strength and stiffness. The most significant improvement in bending strength and stiffness was observed at 40% fiber fraction composite. It can also be noticed that with an increase in fiber volume fraction there is an increase in the maximum flexural strength as presented in Figure 5. Figure 6 represent the flexural moduli of the composites with different fiber volume fraction. The results indicate there is an increase in composite flexural moduli with the increase in fiber volume fraction associated with a corresponding reduction in strain. A summary of the flexural strength properties are presented in Table 3.

4. Conclusion

The thermal and mechanical properties of hemp/rHDPE composites with 5wt% NaOH treated hemp fibers were studied in comparison with the hemp/rHDPE composites with untreated hemp fibers. The properties of the fiber and composites were investigated using FTIR, TGA and mechanical testing. FTIR results suggest that the treatment with NaOH increased the number of hydroxyl group on the fiber along with the removal of pectin and wax. It was also observed that lignin and hemicellulose were partially removed by the treatment. TGA results indicated that NaOH treated fibers have better thermal stability than the untreated hemp fibers, due to the increase of cellulose content. The TGA results indicate that the decomposition temperature of rHDPE compared to that vHDPE is not significantly different. The composites with rHDPE demonstrated promising mechanical properties with regard to their, flexural strength and modulus. The hemp fiber/rHDPE composites with 40% fiber volume fraction yielded very promising results of flexural strength and modulus of 44.6 MPa and 2429 MPa (at 1% strain) respectively. Therefore, the resultant materials have good potential for semi-structural loading applications, such as retaining wall, short span bridges, etc.,

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5. References

Aziz, S. H., & Ansell, M. P. (2004). The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: Part 1 - polyester resin matrix. *Composites Science and Technology, 64*(9), 1219-1230. doi: 10.1016/j.compscitech.2003.10.001

Cantero, G., Arbelaiz, A., Llano-Ponte, R., & Mondragon, I. (2003). Effects of fibre treatment on wettability and mechanical behaviour of flax/polypropylene composites. *Composites Science and Technology, 63*(9), 1247-1254. doi: 10.1016/s0266-3538(03)00094-0

Kabir, M. M., Wang, H., Lau, K. T., Cardona, F., & Aravinthan, T. (2011). Mechanical properties of chemically-treated hemp fibre reinforced sandwich composites. *Composites Part B: Engineering, In Press, Corrected Proof*. doi: 10.1016/j.compositesb.2011.06.003

Li, X., Tabil, L. G., & Panigrahi, S. (2007). Chemical treatments of natural fiber for use in natural fiber-reinforced composites: A review. *Journal of Polymers and the Environment, 15*(1), 25-33. doi: 10.1007/s10924-006-0042-3

Mohanty, A. K., Misra, M., & Drzal, L. T. (2001). Surface modifications of natural fibers and performance of the resulting biocomposites: An overview. *Composite Interfaces, 8*(5), 313-343.

Mukhopadhyay, S., & Fangueiro, R. (2009). Physical Modification of Natural Fibers and Thermoplastic Films for Composites - A Review. *Journal of Thermoplastic Composite Materials, 22*(2), 135-162. doi: 10.1177/0892705708091860

Mwaikambo, L. Y., & Ansell, M. P. (2002). Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. *Journal of Applied Polymer Science, 84*(12), 2222-2234. doi: 10.1002/app.10460

Pracella, M., Chionna, D., Anguillesi, I., Kulinski, Z., & Piorkowska, E. (2006). Functionalization, compatibilization and properties of polypropylene composites with Hemp fibres. *Composites Science and Technology, 66*(13), 2218-2230. doi: 10.1016/j.compscitech.2005.12.006

Ray, D., Sarkar, B. K., Basak, R. K., & Rana, A. K. (2002). Study of the thermal behavior of alkali-treated jute fibers. *Journal of Applied Polymer Science*, *85*(12), 2594-2599. doi: 10.1002/app.10934

Xie, Y. J., Hill, C. A. S., Xiao, Z. F., Militz, H., & Mai, C. (2010). Silane coupling agents used for natural fiber/polymer composites: A review. *Composites Part a-Applied Science and Manufacturing*, *41*(7), 806-819. doi: 10.1016/j.compositesa.2010.03.005

Zabihzadeh, S. M., Dastoorian, F., & Ebrahimi, G. (2010). Tensile Properties and Thermal Analysis of Chemimechanical Pulp-reinforced HDPE Composites. *Journal of Reinforced Plastics and Composites*, *29*(12), 1814-1819. doi: 10.1177/0731684409335455

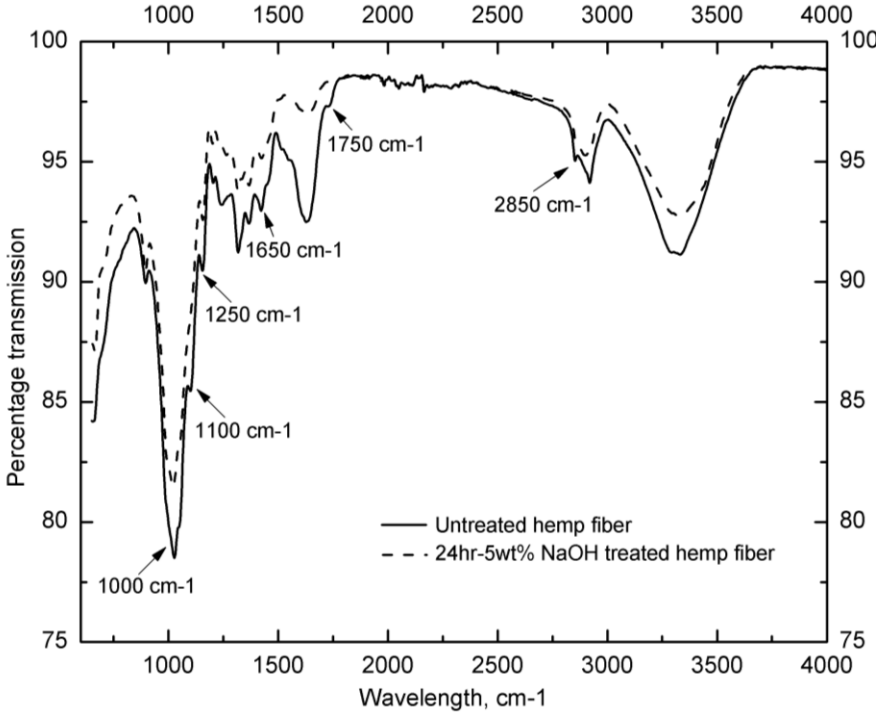

Figure 1: FTIR spectra of untreated and NaOH treated hemp

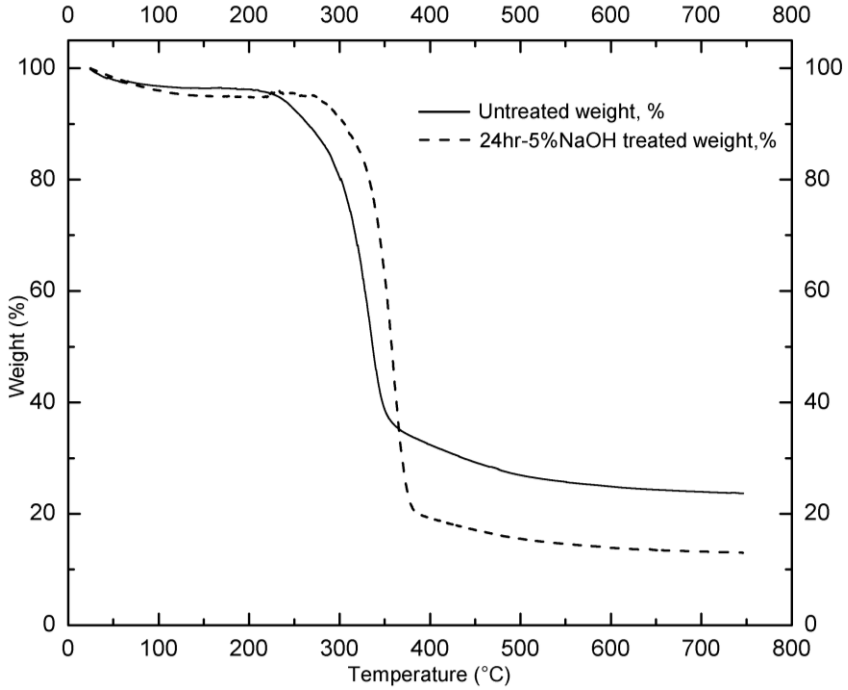

Figure 2: TGA signal of untreated and NaOH treated hemp fibers

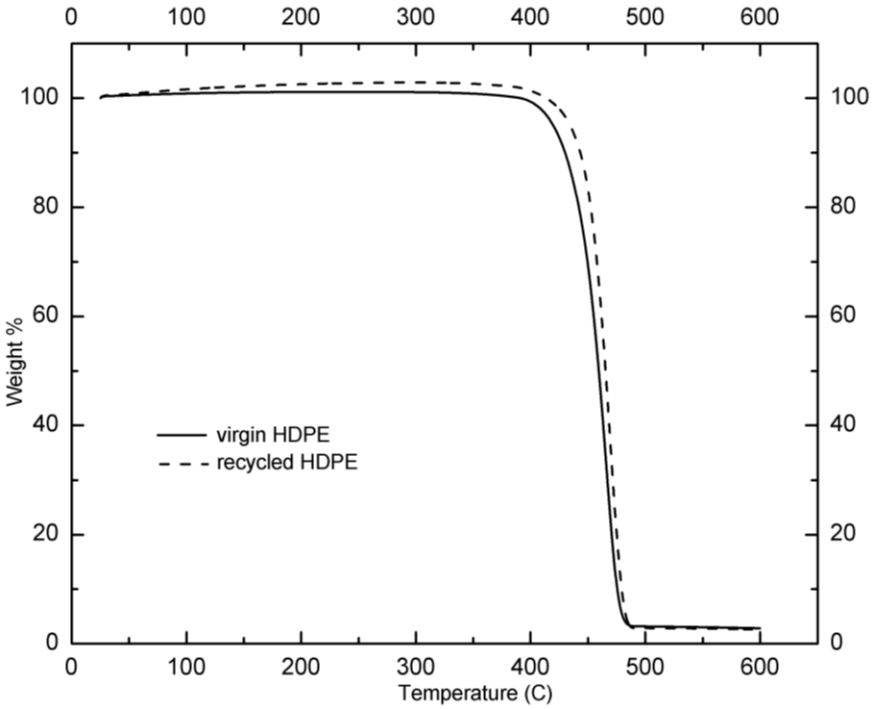

Figure 3: TGA signal of vHDPE and rHDPE

Table 1: Details of the composites prepared for the study

Fiber Treatment	Fiber Percentage	Polymer Percentage
NA	0	100
Untreated	20	80
Untreated	30	70
Untreated	40	60
24hrs-5wt % NaOH	20	80
24hrs-5wt % NaOH	30	70
24hrs-5wt % NaOH	40	60

Table2: Degradation temperature (in °C) of untreated and NaOH treated hemp fibers along with vHDPE and rHDPE

	Temperature at 10% weight loss	Temperature at 15% weight loss	Temperature at 25% weight loss	Temperature at 50% weight loss
Untreated	265.15	287.82	310.91	336.84
24hrs treated 5%NaOH	305.76	322.61	339.32	357.62
v-HDPE	429.93	436.77	446.01	459.35
r-HDPE	443.18	448.43	455.18	465.27

Table 3:Summary of flexural test results for hemp fiber composites

Composite	Maximum Flexural Strength (MPa)	Std. Dev (MPa)	Strain at Maximum Strength (%)	Flexural Modulus at 1% Strain (MPa)	Std. Dev (MPa)	Flexural Modulus at 3% Strain (MPa)	Std. Dev (MPa)
rHDPE	17.8	0.8	3.1	628	27.6	474	23.7
20 Hemp/80rHDPE	32.5	3.6	3.6	1598	177	960	105.6
30 Hemp/70rHDPE	37.1	5.4	5.8	2015	282.1	1217	170.4
40 Hemp/60rHDPE	44.6	8.0	6.0	2429	437.2	1485	265.8

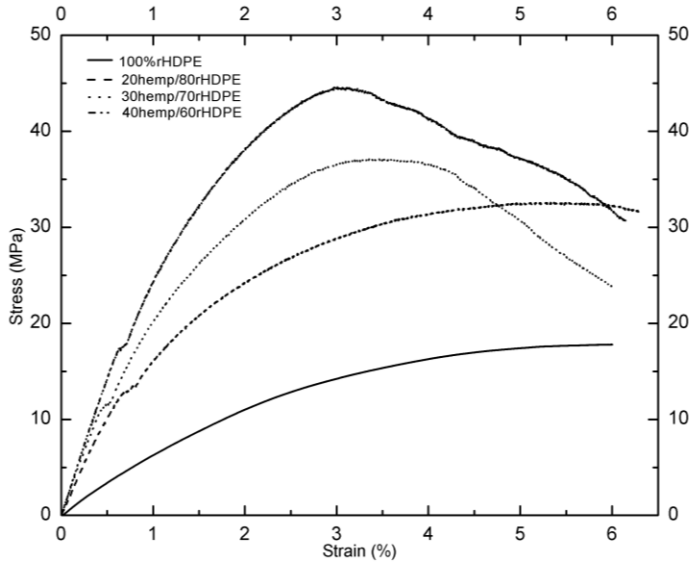

Figure 4: Flexural stress-strain behavior of treated hemp fiber composites

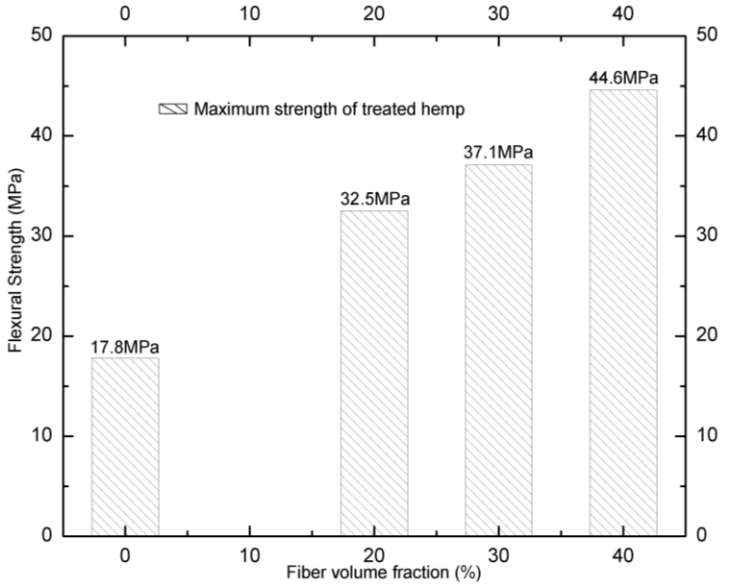

Figure 5: Maximum flexural strength of treated hemp composites

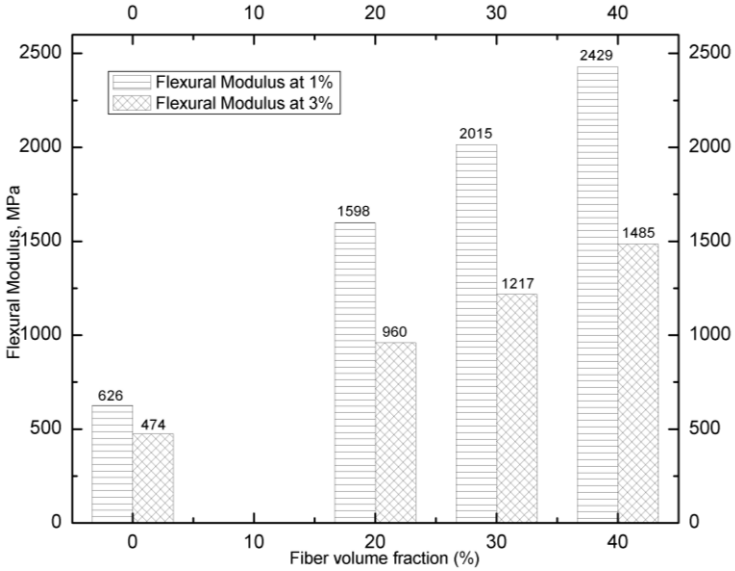

Figure 6: Flexural modulus at 1 and 3% flexural strain of treated hemp fiber composites