The Canadian society for engineering in agricultural, food, and biological systems

CSAE SCGR

La société canadienne de génie agroalimentaire et biologique

Paper No. 05-033

Processing Flax Fiber-reinforced Polymer Composites by Injection Molding

Xue Li, Lope G. Tabil, Satyanarayan Panigrahi, William J. Crerar

Department of Agricultural and Bioresource Engineering
University of Saskatchewan
57 Campus Drive, Saskatoon, SK, CANADA S7N 5A9

Written for presentation at the
CSAE/SCGR 2005 Meeting
Winnipeg, Manitoba
June 26 - 29, 2005

Abstract

Canada is the largest flaxseed producer in the world. Traditionally, flax straw has been burned by farmers. In recent years, research on the replacement of man-made fibers with natural fibers as reinforcement in plastic composites has increased dramatically due to the advantages of natural fibers, such as low density, low cost, and recyclability. In this project, flax fiber-reinforced composites consisting of flax fiber as the reinforcing component and high density polyethylene (HDPE) as the matrix were manufactured. The injection molding technique was used to process fiber polymer composites into ASTM test pieces. Relatively lower temperature was chosen in injection molding to avoid thermal degradation of flax fiber in composites. Mechanical properties such as tensile and flexural properties of composites after injection molding were measured. It was found that an increase in fiber content in composites increased both the tensile and flexural strength. Slight changes in injection temperatures within appropriate range did not significantly affect mechanical properties.

Keywords: Flax fiber, fiber-reinforced polymer composites, tensile strength, flexural strength, fiber content

Introduction

The study on using natural fibers to reinforce composite materials increased dramatically during the last few years. Fiber-reinforced composites consist of reinforcing fibers and a polymer matrix, which acts as a binder for the fibers. Many fiber-reinforced composite materials offer a combination of strength and modulus that are either comparable to or better than many pure materials. Traditional fiber-reinforced composites use various types of glass, carbon, aluminum oxide etc. as reinforce component. Natural fibers are renewable resources with low specific mass, reduced energy consumption, and relatively low cost (Mohanty et al. 2003; Velde and Kiekens 2001). These advantages make natural fibers as potential replacement for glass fibers in composite materials. Amongst the most suitable of these are the bast (bark) fibers, such as flax, hemp, jute, henequén, sisal, etc. (Velde and Kiekens, 2001; Sankari, 2000; Rana et al., 2003; Valadez et al.,1999; Li et al., 2000). Some of the potential applications of natural fiber-reinforced composites are door and instrument panels, package trays, glove boxes, arm rests, and seat backs (Pervaiz and Sain, 2003).

Canada is the largest flaxseed production country in the world. Flaxseed mainly grows in Saskatchewan, Manitoba and Alberta (Warick, 2001). Traditionally, flax straw has been burned by farmers and there is no sustainable utilization of this raw material. A new way to utilize flax straw needs to be explored. Both thermoplastic and thermoset materials can be reinforced and made into composite materials, but composites with very short fibers tend to have thermoplastic matrices. This is because fibers must be able to go through small clearances, such as the gap between the extruder screw and the extruder wall or the gate that connects the mold cavity with the runner system in both injection molding and transfer molding when being extruded or injection molded. Another reason for the predominance of thermoplastics as matrices for very short-fiber composites is that thermoplastics often need the additional strength or additional stiffness gained from reinforcing with short fibers. From this point, the research on flax fiber-reinforced polymer composites cannot only benefit flax growers, but also the plastic industry.

Nowadays, the techniques of polymeric composites such as extrusion, compression, rotational, and injection molding are applied into short fiber-reinforced composites processing. Injection molding is an important plastic processing method with the characteristic of rapid production rates. The composite material is heated and pumped into a permanent mold, where it takes shape and cools. The objective of this project is to investigate a method of processing flax fiber plastic composites by injection molding. The specific objectives are: a) to investigate the influence of fiber content on the properties of composite; and b) to investigate the effect of different injection temperatures on the mechanical properties of composites. Flax fiber were added to polyethylene material, and then processed to required specimens through extrusion and injection molding. Tensile and flexural properties of the products were tested.

Materials and Methods

Materials

Flaxseed fiber grown in Manitoba was purchased from Biolin Research Inc. (Saskatoon, SK) High density polyethylene (HDPE) was procured from Nova Chemicals (Mooretown, ON). The density and melt index (g/10 min) of HDPE are 0.9626 g/cm^3 and 12.5 respectively.

Processing

The schematic overview of processing scheme of flax fiber to reinforced polymer composites is shown in Fig.1. Flax fiber was washed by 2% detergent solution and dried at 70ºC for 24 h. Then flax fiber was ground by the grinding mill (Falling Number, Huddinge, Sweden) to powders and mixed with HDPE in a blender (Waring Products Corporation, New York, NY, USA) at 10% weight fiber content. The mixture of fiber and HDPE was fed into the twin-screw extruder (Werner & Pfleiderer, Ramsey, NJ, USA) to be mixed and heated. This step was performed to avoid the separation of fiber from the polymer during the molding process. The screw speed was set at 150 rpm. Barrel zone temperatures were 90, 120, 130, 140, 160ºC from first to fifth.

The extrudates were then pelletized using a grinding mill (Retsch GmbH 5657 HAAN, West Germany) to make them ready for injection molding.

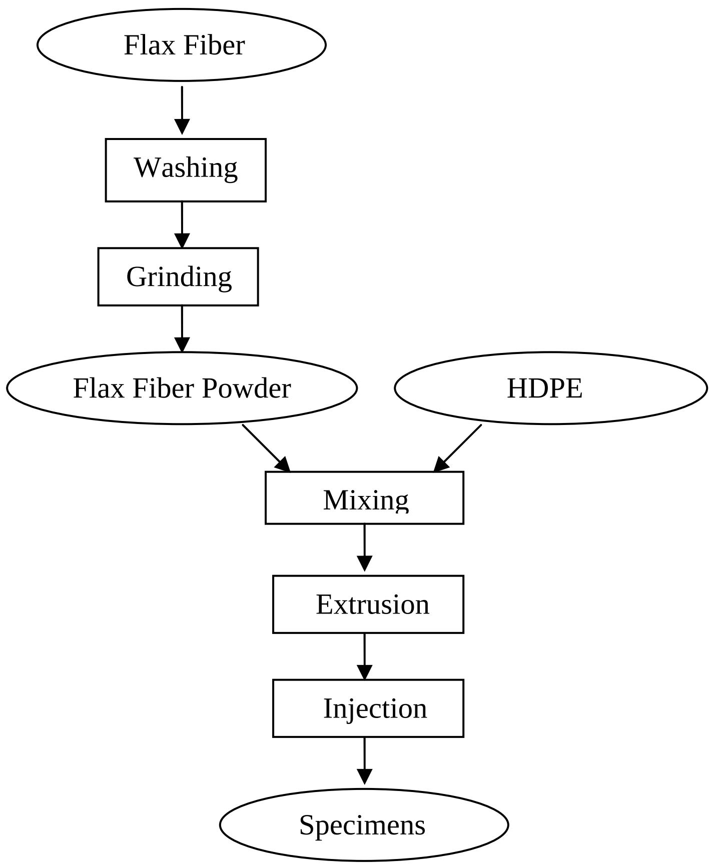

Fig. 1. Processing scheme of flax fiber-reinforced plastic composites.

Injection Molding

The pelletized mixture was then processed through the injection molding machine (Battenfeld Maschinen. Austria) to tensile and flexural test specimens. The injection temperatures from barrel to die are shown as Fig. 2. The temperatures set were A-370°F (188°C), B-370°F (188°C), C-360°F (182°C), and D-330°F (165°C). The processing time was set as: injection - 10s, hold - 20s, back - 20s, open - 15s. Injection pressure was 800 psi (5.5 MPa). Another group with higher injection temperatures of A-390°F (200°C), B-390°F (200°C), C-380°F (190°C), and D-350°F (177°C) was also injection molded as comparison. The dimensions design of specimen mold was according to test standard ASTM D638-97 and D790-97.

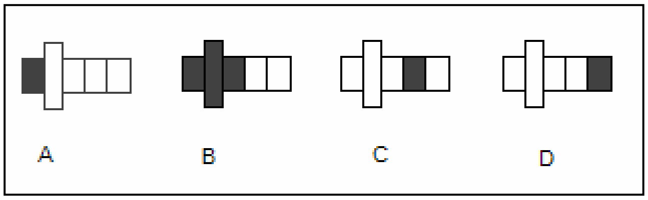

Fig. 2 Temperatures setting at injection molding machine (Battenfeld Maschinen, Germany).

Tensile Test

Tensile test followed ASTM Standard test method D638 (ASTM, 1997). The tests were conducted using an Instron Universal testing machine (SATEC Systems, Inc., Grove City, PA) at a crosshead speed of 5 mm/min. Each test was repeated five times. The maximum (peak) load (F_{max} in N) is recorded by the instrument. The tensile strength (σ_t) is calculated from the following:

$$\sigma_t = \frac{F_{max}}{A} \qquad (1)$$

Where A is the cross-sectional area (m^2).

%Elongation is the percentage increase in length of the specimen at its breaking point and calculated from the following equation:

$$\%Elongation = \frac{L - L_0}{L_0} \qquad (2)$$

Where L is the length of the specimen at its breaking point (mm), L_0 is the original measured length (91 mm).

Flexural Test

Flexural tests after conditioning at 25°C was carried out on an Instron model 1011 testing machine (Instron Corp., Canton, MA) according to ASTM D790 (ASTM, 1997). The three-point testing method was used under specimens with nominal dimensions of 3.2mm x 12.7mm x 64mm. Each test was repeated five times. Flexural strength and modulus can be read from the computer connected to the testing machine.

Melt Flow Index (MFI) Test

Melt flow index is defined as measure of the viscosity of a polymer at a specified temperature and pressure. ASTM D1238 (ASTM, 2002) test method covers measurement of the rate of extrusion of molten resins through a die of a specified length and diameter under prescribed conditions of temperature, load, and piston position in the barrel as the timed measurement is being made. Operation follows procedure A which is based on the time used for materials having flow rates that fall generally between 0.15 and 50 g/10 min.

Results and Discussion

Influence of fiber content on mechanical properties of the composite

To compare the influence of fiber content on the mechanical properties of composites, the fiber was mixed with HDPE at fiber content ranging from 0 to 30% wt. respectively and processed to composites. Tensile strengths of fiber-reinforced HDPE composites at different fiber contents are presented in Fig. 3. The addition of flax fiber effectively enhanced the ultimate strength of the composite. Moreover, higher strength composites were obtained at higher fiber content. The tensile properties of flax fiber-HDPE composites were dependent on the flax fiber content. Adding 5% flax fiber in HDPE, increased the tensile strength by only 1%, while adding 30% flax fiber in HDPE, increased the tensile strength by 17%.

Table 1 shows the results of the composites tensile elongation at break measurements. It was noted that the incorporation of flax fiber dramatically decreased this parameter, more than 60% decrease for 30% fiber-HDPE composite in relation to pure HDPE. It was reported that this behavior was typical for fiber-reinforced composites (Santos and Pezzin, 2003).

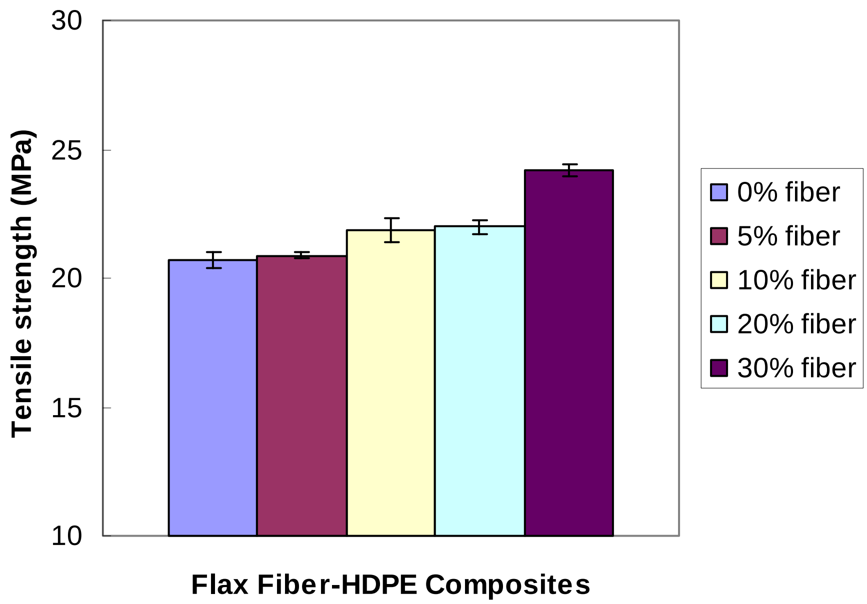

Fig. 3 Tensile strength of flax fiber-HDPE composites with fiber content increasing (Replicates N = 5)

Table 1. Tensile %Elongation of flax fiber-HDPE composites (N = 4)

	Fiber content (% wt.) in fiber-HDPE composites			
	5	10	20	30
% Elongation	>55%	46%	12%	4%

The effect of flax fiber content on the flexural properties is shown in Figs. 4 and 5. The flexural strength of injection molded pure HDPE was found to be 22.14 MPa. It was observed that with increasing fiber content from 5 to 30%, the flexural strength of HDPE composites increased from 23.29 to 33.53 MPa. By adding 30% wt. flax fiber, the flexural strength of composite was increased by about 51%. Similar result was obtained from flexural modulus measurement. Flexural modulus of fiber-HDPE composite was better than that for pure HDPE specimen because flax fiber had higher stiffness than the polymer. Composites made with 30% wt. fiber had the highest flexural modulus.

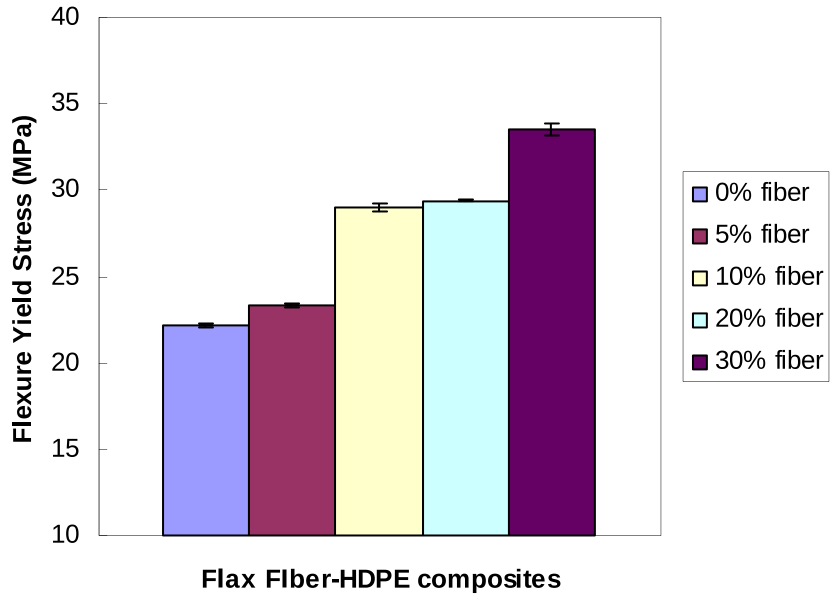

Fig. 4 Flexural strength of flax fiber-HDPE composites as a function of fiber content (N = 5)

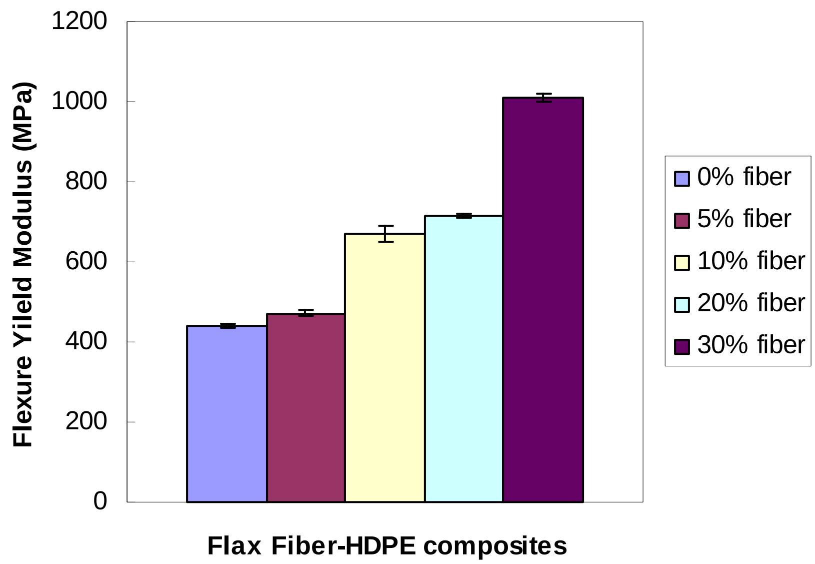

Fig. 5 Flexural modulus of flax fiber-HDPE composites as a function of fiber content (N = 5)

The results of the MFI measurements are listed in Table 2, showing a continuous decrease of MFI value as the proportion of flax fiber in composites increased. The major decrease (75%) was observed from 30% fiber content composite, indicating a decrease of composite fluidity; while 54% decrease was obtained from 20% fiber content composite.

Table 2 MFI in function of flax fiber content (% wt.) in fiber-HDPE composites (N = 5)

Fiber content (% wt.) in fiber-HDPE composite	Melt Flow Index (g/10min)
0%	12.5
10%	6.5
20%	5.7
30%	3.1

Influence of injection molding temperature on mechanical properties of composites

Fiber-HDPE composites including 10% wt. flax fiber were produced using two groups of injection temperatures in order to compare the influence of injection molding temperatures on mechanical properties. To determine the effect of injection molding temperatures, the melting and processing temperatures of plastic and the degradation temperature of flax fiber had to be considered. The melting temperature of HDPE is 130 to 137ºC and the recommended processing temperature for HDPE is 177 to 260ºC (Rosato et al., 2000). Decomposition temperature of HDPE is relatively high, which is 340 to 440ºC. However for flax fiber, temperatures higher than 200ºC result in fiber degradation and weight loss. So the processing temperature should be limited to 200ºC, although higher temperatures can be used for short periods of time. Therefore, the injection molding temperature was limited to 200ºC to avoid flax fiber degradation. But temperatures cannot be too low because if that happens, molding will be difficult, requiring excessive injection pressures and longer plunger-forward times.

Two groups of injection molding temperatures were used on the machine. One group was set as lower temperatures with zone temperatures from 165 to 188°C. Another group was at higher temperatures with 177 to 200°C zone temperatures. Tensile and flexural properties of composites are shown on Table 3.

Table 3 Tensile and flexural properties of composites on different injection temperatures (N=5)

Temperature	Tensile strength (MPa)	Flexural strength (MPa)	Flexural Modulus (MPa)
Lower	21.85	29.02	670.56
Higher	21.84	28.67	637.38

Independent Samples t-Test at 95% confidence interval was conducted to compare mean difference of two injection molding temperature groups by using SPSS. It was noted there was no significant difference on all mechanical properties of composites at two injection molding temperatures groups. Lower temperature with 165 to 188°C showed a relative better result on properties. With increasing temperature, tensile and flexural strength of composite showed a tendency of decreasing, as well as flexural modulus. So injection temperatures between 160 to 180ºC are recommended in flax fiber–HDPE composites processing.

Conclusion

Each year, flaxseed straws are disposed in the fields of West Canada and this is a resource waste and an environment problem. The potential use of flax fiber as a reinforcement for plastic composite has been investigated in this paper. Flax fiber was ground and mixed with HDPE and processed through extrusion and injection molding to composites. Fiber content in composites varied from 5 to 30% wt. The composite mechanical properties such as tensile and flexural properties were measured. It was observed that the increasing the fiber content of composites resulted to an increase in the tensile and flexural strength, as well as flexural modulus. Two groups of injection temperatures were tested in injection molding of flax fiber-HDPE composites. Slight changes in injection temperatures below fiber degradation temperature did not significantly affect mechanical properties of composites. But relative lower temperature of 160 to 180ºC is recommended in injection molding to avoid thermal degradation of flax fiber and keep better mechanical properties of composites.

Acknowledgements

The authors would like to acknowledge the Centre for Agri-Industrial Technology (CAIT) and Northern Alberta Institute of Technology (NAIT) in Edmonton, AB for the use of extrusion and injection molding equipment, and financial support from Natural Sciences & Engineering Research Council (NSERC), Agriculture and Agri-Food Canada (AAFC) Research Partnership Program, Canada-Saskatchewan Agri-Food Innovation Fund, and Agriculture Development Fund (ADF).

References

ASTM Standard Vol. 08. 01. 1997. D638-97: Standard Test Method for Tensile Properties of Plastics. New York, NY: American Society for Testing and Materials.

ASTM Standard Vol. 08. 01. 1997. D790-97: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. New York, NY: American Society for Testing and Materials.

ASTM Standard Vol. 08. 01. 1997. D1238-97: Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer. New York, NY: American Society for Testing and Materials.

Li, Y., Y-W. Mai, and L. Ye. 2000. Sisal fibre and its composites: A review of recent developments. *Composites Science and Technology.* 60: 2037-2055.

Mohanty, A. K., A. Wibowo, M. Misra, and L. T. Drzal. 2003. Effect of process engineering on the performance of natural fiber reinforced cellulose acetate biocomposites. *Composites Part A: Applied Science and Manufacturing.* 35:363-370.

Pervaiz, M. and M. M. Sain. 2003. Carbon storage potential in natural fiber composites. *Resources, Conservation and Recycling.* 39: 325-340.

Rana A. K., S. Mandal, and S. Bandyopadhyay. 2003. Short jute fiber reinforced polypropylene composites: effect of compatibiliser, impact modifier and fiber loading. *Composites Science and Technology.* 63: 801-806.

Rosato, D V., V. D. Rosato and G. M. Rosato. 2000. *Injection Molding Handbook 3rd Edition.* Kluwer Academic Publishers. Norwell, Massachusetts, USA.

Sankari, H. 2000. Comparison of Bast Fiber Yield and Mechanical Fiber Properties of Hemp. *Industrial Crops and Products.* 11: 73-84.

Santos, P. and S. H. Pezzin. 2003. Mechanical properties of polypropylene reinforced with recycled-pet fibres. *Material Processing Technology.* 143-144: 517-520.

Valadez-Gonzalez, A., J. M. Cervantes-Uc, R. Olayo, and P. J. Herrera-Franco. 1999. Chemical modification of henequén fibers with an organosilane coupling agent. *Composites Part B: engineering.* 30: 321-331.

Velde, K. V. de and P. Kiekens. 2001. Thermoplastic polymers: overview of several properties and their consequences in flax fiber-reinforced composites. *Polymer testing.* 20: 885-893.

Warick, J. 2001. GM Flax Seed Yanked Off Canadian Market - Rounded Up, Crushed. The StarPhoenix. Available at http://www.thestarphoenix.com. Accessed at 30 June 2004