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The Influence of Fiber Content on Properties of Injection Molded Flax Fiber-HDPE Biocomposites

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Abstract

Oilseed flax fiber could be used as reinforcement for composites because it is readily available, environmentally friendly and possesses good mechanical properties. Flax fiber was mixed with high density polyethylene (HDPE) with fiber content from 10 to 30% by mass and processed by extrusion and injection molding to biocomposites. The mechanical properties, surface properties, and thermal properties of biocomposites were measured and analyzed to compare the effect of different flax fiber concentrations on the biocomposites. Results showed that increasing fiber content increased tensile and flexural strengths and modulus, increased water absorption, and decreased melt flow index, molding shrinkage and melting point of biocomposites.

Keywords: Flax fiber-HDPE biocomposites, fiber content, tensile strength, flexural strength, water absorption, melt flow index, molding shrinkage, melting point.

Introduction

Plastic matrix composites using natural fibers as reinforcement has attracted a lot of interest in recent years. This is because natural fibers exhibit many advantageous properties such as low density, low cost, reduced energy consumption and it is a renewable resource. These natural fibers including sisal, jute, flax, hemp, and henequen and many others, have attracted attention from researchers and potential users (Fung 2003; Karmaker and Youngquist 1996; Garkhail et al. 2000; Keller 2003; Herrera-Franco et al. 1996). Canada, America and China are the three largest oilseed flax production countries in the world. Traditionally flax straw was burned by farmers and there is no sustainable utilization of this raw material is existing in Canada. A new way to utilize flax straw has to be explored.

Some of 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). Thermoset was first studied by researchers as matrix to be reinforced with natural fibers (Garkhail et al. 2000). Recently, developments shifted to thermoplastic matrix composites. It was concluded that polyethylene and polypropylene are well suited for use as matrix material in flax fiber-reinforced composite (de Velde and kiekens 2001). Most studies on natural fiber-reinforced composites have concentrated on polyolefin, especially polypropylene (Karmaker and Youngquist 1996; Garkhail et al. 2000; Fung 2003).

High density polyethylene (HDPE) is easily molded in mass-production quantities by injection molding. HDPE has very low glass transition temperature (T_g= - 110°C) associated with a good retention of mechanical properties including flexibility and impact resistance at low temperatures (Charrier, 1991). It is suitable to be matrix in composites especially in country as cold in winter as Canada.

It is often observed that the presence of fiber or other reinforcement in a thermoplastic matrix increases the composite strength and modulus (Karmaker and Youngquist 1996; Herrera-Franco et al. 1997; Ota et al. 2005). It was also shown that the mechanical properties such as strength, modulus and toughness increase generally with increasing fiber length (Fu et al. 2000). But composites with thermoplastic matrices tended to have shot fibers because the fibers must be able to go through small clearances when being extruded or injection molded. And the shorter fiber length, the higher was the adhesion between fiber and matrix (Karmaker and Youngquist 1996). This study investigated the effect of flax fiber content on the mechanical and other physical properties of injection molded short flax fiber-HDPE biocomposites.

Materials and Methods

Materials

Flaxseed fiber grown in Saskatchewan was purchased from Durafibre Inc. (Canora, SK). High density polyethylene (HDPE) was procured from Nova Chemicals (Mooretown, ON). One percent wax (Conros Corp. North York, ON) was added into the mixture of fiber and HDPE before extrusion to improve processability.

Specimen preparation

Flax fiber was washed in 2% detergent solution and dried at 70ºC in a convection oven for 24 h. It was ground by the grinding mill (Falling Number, Huddinge, Sweden) using a screen size of 2 mm, mixed with HDPE at fiber content ranging from 0 to 30% by mass. The mixture of fiber and HDPE and wax was fed into the twin-screw extruder (Werner & Pfleiderer, Ramsey, NJ, USA). The screw speed was 150 rpm. The five heating zones of the extruder were set to 90, 120, 130, 140, 160ºC, respectively. The extrudates were then chopped into pellets and injection molded to test specimens using an injection molding machine (Battenfeld, Meinerzhagen, Germany) with a barrel to die temperature of 165°C (335°F), 182°C (360°F), 188°C (370°F), and 188°C (370°F), respectively, and Injection pressure of 5.5MPa (800 psi).

Tensile test

The tensile strength of specimens was determined using five samples for each biocomposite with an Instron Universal testing machine (SATEC Systems Inc., Grove City, PA) at a crosshead speed of 5 mm/min following ASTM Standard D638 (ASTM 1997a). Tensile elongation is the percentage increase in length of the specimen at its breaking point calculated from the following equation:

$$\%Elongation = \frac{L - L'}{L'} \qquad (1)$$

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

Flexural test

Flexural tests were carried out on an Instron model 1011 testing machine (Instron Corp., Canton, MA) according to ASTM Standard D790 (ASTM 1997b). The three-point testing method was used with specimens having nominal dimensions of 3.2mm x 12.7mm x 64mm. Each test was repeated five times.

Water absorption

Water absorption tests were conducted according to ASTM Standard D570 (ASTM 1998). The 24 h water immersion method was chosen. Three specimens for each sample were tested. Water absorbed during the test was expressed as percentage of the original mass of the specimen and the results were presented as average of tested specimens.

Melt flow index (MFI) test

Melt flow index was conducted on a Thermodyne plastometer (Tinius Olsen, Willow Grove, PA) at temperature of 190 ºC. Testing follows ASTM Standard D1238 (ASTM 2001) 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.

Differential scanning calorimetry (DSC)

DSC analyses on HDPE and flax fiber-HDPE biocomposites were performed in a TG-DSC 111 machine (Scientific & Industrial Equipment, Caluire, France) at a heating rate of 5 ºC/min. The charts of heat flow versus temperature were produced.

Molding shrinkage

Biocomposite molding shrinkage is calculated as a percentage molding shrinkage (MS in %) from equation (2). Three specimens per sample were tested.

$$MS = \frac{L_0 - L_1}{L_0} \times 100 \qquad (2)$$

Where L_0 = length of the dimension of the mold (5.5 in);

L_1 = length of the corresponding dimension measured on the test fiber-HDPE composite specimen.

Results and Discussion

Effect of fiber content on mechanical properties

The flax fiber-HDPE biocomposites with fiber content ranging from 0 to 30% wt. were processed by injection molding and their mechanical properties were tested. Results of biocomposite tensile strength and elongation are shown in figures 1 and 2, respectively, which indicate that the tensile properties of flax fiber-HDPE biocomposites are dependent on flax fiber content. Aaddition of flax fiber effectively enhanced the ultimate tensile strength of the composite and higher tensile strength was obtained from higher fiber content composite. Adding 5% flax fiber in HDPE, the tensile strength was increased by only 1%, while adding 30% flax fiber in HDPE, the tensile strength increased by 17%. Figure 2 shows the tensile elongation of composites. It was found that tensile elongation of composites dramatically decreased with increased fiber content. A lower tensile elongation indicates a higher tensile modulus because a high tensile modulus means that the material is rigid - more stress is required to produce a given amount of strain. Therefore, the tensile modulus of biocomposites increased with increased fiber content.

The effect of flax fiber content on flexural properties is shown in figures 3 and 4. The flexural strength of injection molded pure HDPE was found to be 22.14 MPa. Increasing fiber content in biocomposites from 5 to 30% increased the flexural strength of biocomposites 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. Composites made with 30% wt. fiber had the highest flexural modulus which improved the flexural modulus by 128% over that of pure HDPE.

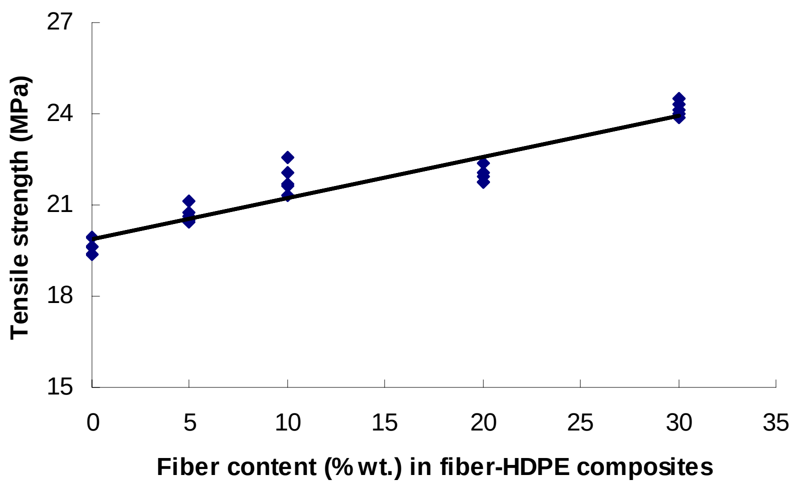

Figure 1. Tensile strength of biocomposites as affected by fiber mass concentration

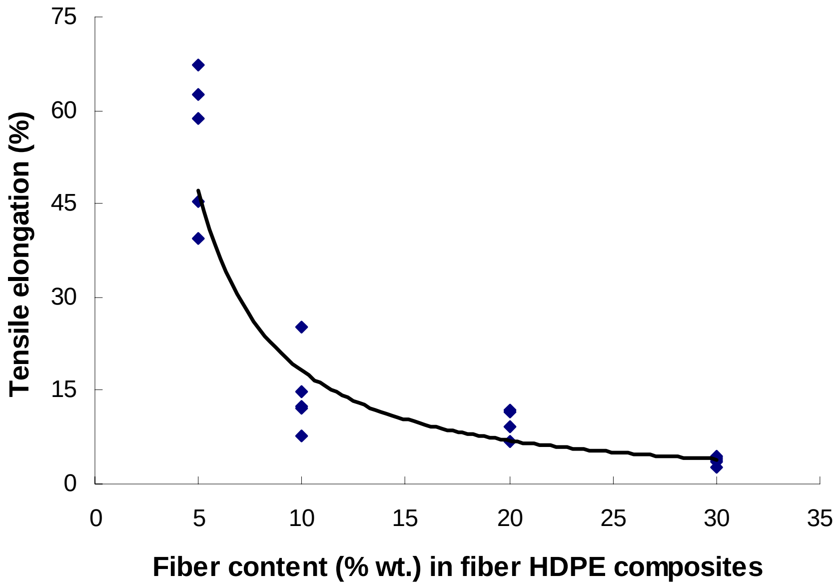

Figure 2. Tensile elongation of biocomposites as affected by fiber mass concentration

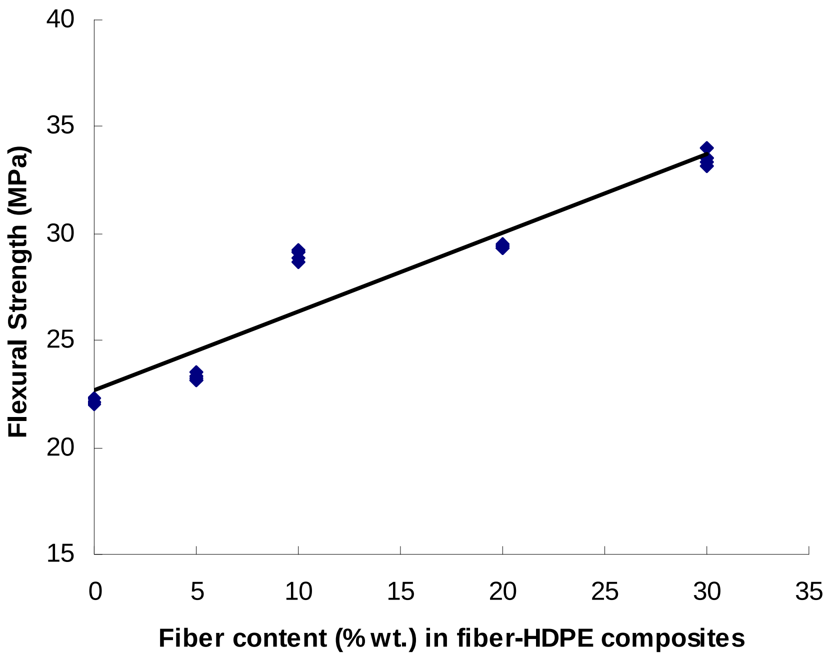

Figure 3. Flexural strength of biocomposites as affected by fiber mass concentration

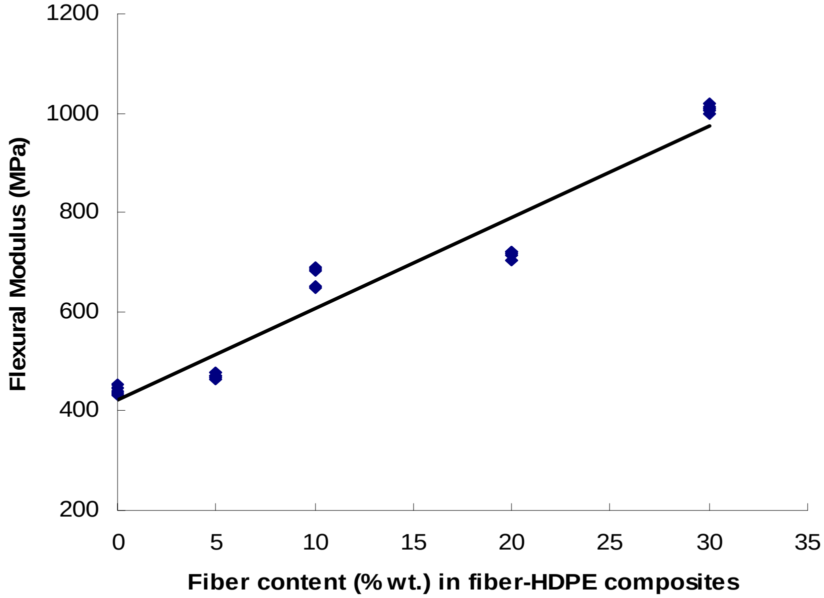

Figure 4. Flexural modulus of biocomposites as affected by fiber mass concentration

Effect of fiber content on water absorption

Natural fibers are highly hydrophilic and more permeable to water compared to polyethylene. Incorporation of natural fibers into polymeric matrices thus generally increases the water sorption ability. Figure 5 shows the water absorptions of flax fiber-HDPE biocomposites. The water absorption of fiber-HDPE biocomposites with 30% wt. flax fiber was less than 0.3%, but it was still much higher than pure HDPE. Because water absorption affects the physical properties of composites and the fiber-matrix interface, lower water absorption is expected in the processing by adjusting operation parameters.

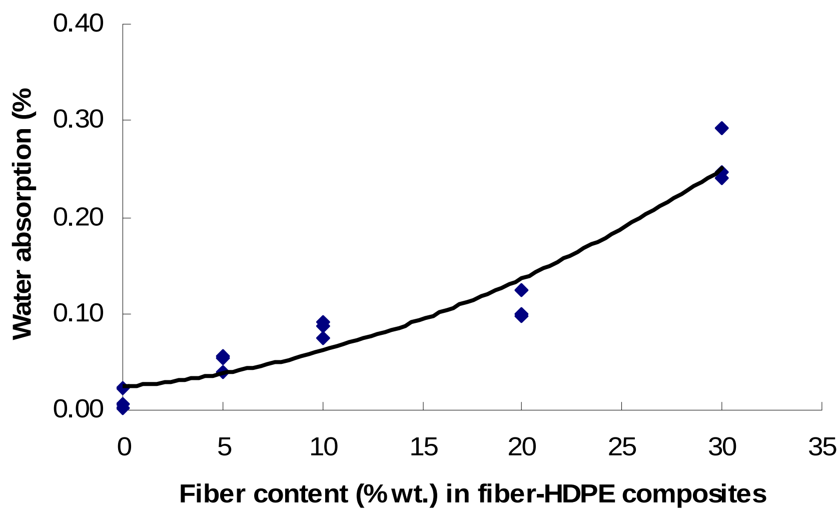

Figure 5. Water absorption of biocomposites as affected by fiber mass concentration

Effect of fiber content on physical properties

Molding shrinkage is the difference in dimensions between the mold and the cooled molded part and it is a very normal phenomenon in injection molded plastic materials. The principal cause is polymer density change which occurs as the melt solidifies (Rosato 2000). Molded HDPE has 2.8% molding shrinkage, adding flax fiber in HDPE could reduce biocomposite shrinkage as shown in figure 6. The molding shrinkage of biocomposite with 30% flax fiber was reduced to 1.4%.

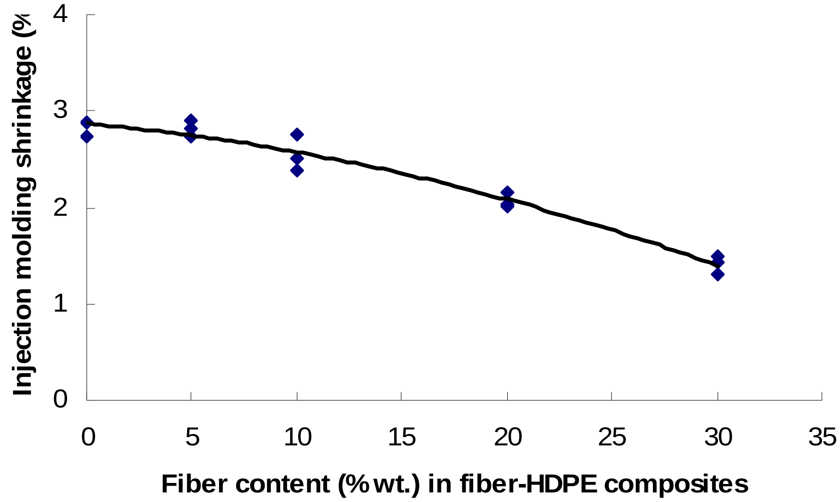

Figure 6. Molding shrinkage of biocomposites as affected by fiber mass concentration

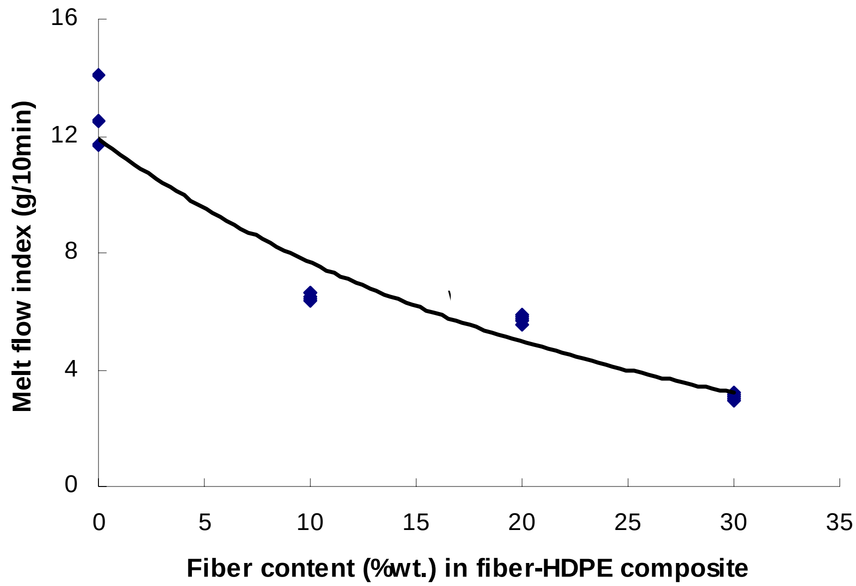

Figure 7. Melt flow index of composites as affected by fiber mass concentration

The results of the MFI measurements are presented in Figure 7, showing a continuous decrease of MFI value as the proportion of flax fiber in composites increased. This is understandable because fibers partially misalign in melts affecting the dynamics of viscoelasticity of the melts and hindering the mobility of molecular chains (Ota et al. 2005). The major decrease (75%) was observed with 30% fiber content biocomposite, indicating a decrease of composite fluidity; while 54% decrease was obtained from 20% fiber content biocomposite.

The influence of fiber content on thermal properties of biocomposites

Thermal properties of HDPE and flax fiber-HDPE biocomposites were determined by DSC analysis. The melting point for pure HDPE material is 139.3°C as shown in figure 8. Adding flax fiber in HDPE decreased the melting point of biocomposites (figure 9). The melting point of biocomposites with 10, 20, and 30% flax fiber were 138.9, 138.6, and 137.5°C, respectively. Comparing with HDPE, the addition of 30% wt. flax fiber in biocomposites lowered the melting point by approximately 2°C. The exothermic peaks of fiber-HDPE biocomposites were a little complex compared with that of pure HDPE curve, but this indicates that the degradation temperature of biocomposites is lower than pure HDPE.

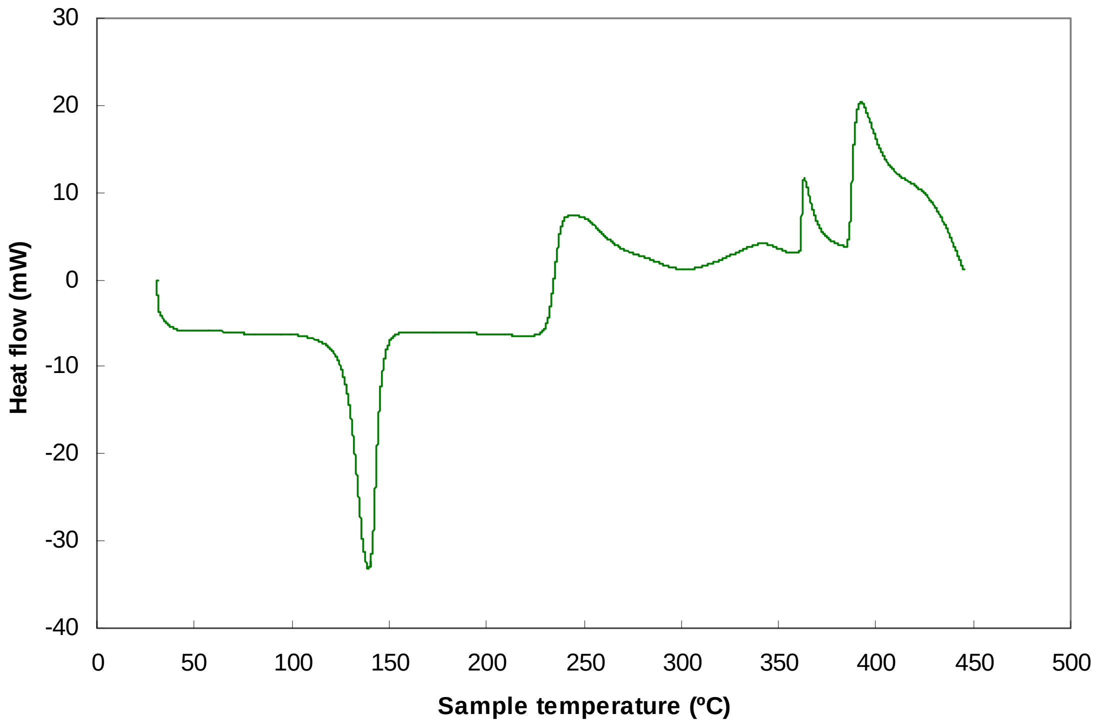

Figure 8. DSC heating curve of pure HDPE material

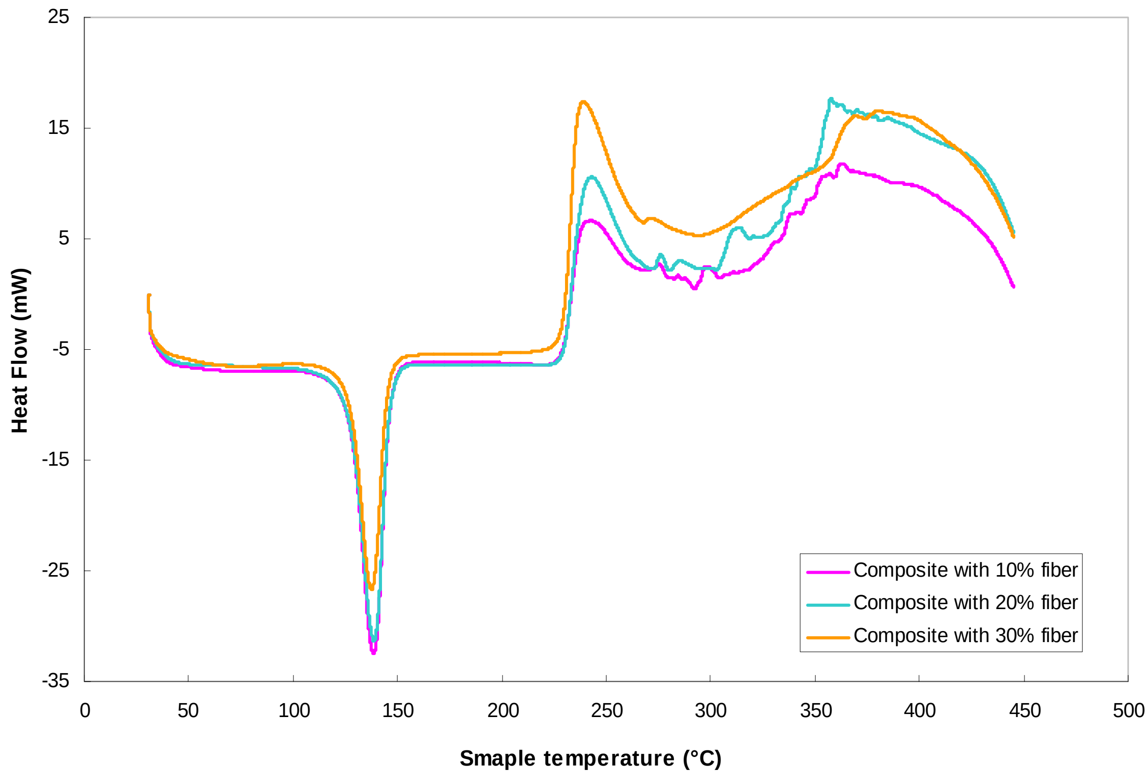

Figure 9. DSC heating curves of composites at different fiber mass concentration

Conclusion

The effect of increasing fiber content on the mechanical and other physical properties of flax fiber-HDPE biocomposites was investigated in this study. Results showed that tensile and flexural properties of flax fiber-HDPE biocomposites were dependent on fiber content. Tensile and flexural modulus of biocomposites was more dependent on fiber content compared to tensile and flexural strength. At flax fiber contents below 30% wt., the presence of flax fiber contributed to the increase in tensile and flexural strength and modulus. Adding flax fiber in HDPE decreased biocomposite molding shrinkage, melt flow index, melting point and degradation temperatures. The reduced molding shrinkage is a positive influence on biocomposite quality. The decreased melt flow index and melting point may influence injection molding operation and required adjusting of operation parameters based upon the fiber content of biocomposites. Besides mechanical properties, water absorption increased with increased fiber content, which was a disadvantage of natural fiber reinforced biocomposites.

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