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Experimental Study on Injection Molding of Wheat-Straw/High-Density Polyethylene Composites

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Now-days, most polymeric composites with natural fibers are typically processed by compression-molding. It is a challenge to embed natural fibers for manufacturing injection-molded parts. This study examined the feasibility of manufacturing wheat-straw flour and high-density polyethylene composites by employing injection molding method. The melt flow index (MFI) and thermal analysis (DSC and TGA) of composites with different wheat-straw flour contents were characterized. The tensile, flexural and impact properties of injection molded wheat-straw/high-density polyethylene samples were measured. It has been found that the melt points of composites were about 135ºC when wheat straw content was less than 30 wt %. In addition, the results show that the fluidity, tensile strength and impact strength of the composites decreased while the wheat-straw content increased. However, the flexural strength of the composites increased slightly with the increase in wheat straw flour content.

Key Words: Wheat-straw/HDPE composite, Injection molding, Mechanical properties.

INTRODUCTION

Wood plastic composite (WPC)[1-6] is one kind of composite materials, consisting of thermoplastic resins, wood fillers and small amounts of additives. There is growing interest in the use of wood and cellulosic fibers for the reinforcement of thermoplastic composites because the wood fibers have high aspect ratio and high specific stiffness and strength. They are also environmentally friendly by being renewable and biodegradable and have low cost.

The most commonly used fillers include wood flour, wood fiber, plant straw, jute fiber, bamboo fiber and non-metal particles of circuit board[7,8]. The properties of the composite were influenced by the filler types and their dimensions[9]. The typical thermoplastic matrixes include virgin resin and recycled resin, such as HDPE, PP, PVC, PS, PLA *etc*.[5,10]. These plastics are preferred because of the lower processing temperatures (150-220 ºC)[11]. In order to increase the compatibility of the wood fillers and polymeric matrix and improve the mechanical properties of the composite products, coupling agents and compatibilizer are used as additives[6,12-15]. Wood plastic composites (WPCs) have a variety of commercial applications, such as, automotive interior substrates, packaging, furniture and housing[11] due to their unique properties mentioned above. However, there are some shortcomings, which restrict the wide and effective applications of WPCs. One less desirable characteristic of WPCs is the drastic reduction in toughness. Another less desirable property of WPCs is relatively low fluidity and low burning point, which makes difficult to process WPCs by injection molding. Nowadays extrusion and hot pressing molding are popular for processing WPCs parts. They can produce WPCs parts with higher wood filler contents. However, more complicated or multi-step post-processing is required and only products with simpler shape can be achieved. Injection molding is able to process complicated and manifold parts with higher production rate and precision. In addition, microcellular foam injection molding processing method can improve the fluidity of WPC and allow the higher content of the wood fillers[16-18].

Most studies of WPCs have been done on interior morphology and microstructure to improve the composites toughness. Researches and reports on conventional injection molding of WPCs are insufficient. This study investigates the wheat-straw flour/high-density polyethylene composites processability of conventional injection molding. Wheat-Straw flour of 20-mesh was used as the wood filler and the high-density polyethylene was used as polymeric matrix. First these two materials with some additives were compounded to make granules and then the injection molding method was introduced to produce the composite parts. The fluidity of the composite with different wheat-straw contents was tested and the melt temperature and decomposition temperature were characterized by DSC and TGA. In addition, the tensile strength, impact strength and flexural strength were tested. The experiment results were helpful to determine the processing parameters.

EXPERIMENTAL

The high-density polyethylene used for WPC formation was HDPE-2911 and it was provided by Fushun Petrochemical Company, China. The HDPE has a melt flow index of 19.6 g/10 min and a density of 960 kg/m^3. A 20 mesh (0.9 mm) grade wheat straw flour was made by our research group was used as filler. Silane KH-550 was selected as coupling agent, which made by Jinan Zeyu Chemicals Co. Ltd., China.

Compounding and extrusion of composites: The wood flour and plastic were blended at room temperature for 10 min. Four compositions were made by mixing HDPE and wheat straw flour at different compositions The four compositions have 100, 90, 80 and 70 % of HDPE (with the remainder being maple wood flour), respectively. After mixing, the materials were fed into a twin-screw extruder SHJ120 (Nanjing Giant Machinery Co. Ltd., China). The extruder was powered by a 3 kilowatt motor with maximum length to diameter ratio of 40:1. The processing conditions for each WPC sample are summarized in Table-1. After extrusion, the samples were cooled at room temperature for about an hour before granulated.

TABLE-1
EXTRUDER CONDITIONS FOR VARIOUS WPCS

Wheat straw (wt %)	Temperature (ºC)	Screw speed (rpm)
0/10/20/30	160-165-160-160	10

The granulated samples were then dried at 90 ºC for *ca.* 4 h and loaded in a Haitian HTF80 injection molding machine (Haitian Plastics Machinery, China). The processing conditions used in the injection molding machine are listed in Table-2. The injection molded samples were characterized by flexural, tensile and Izod impact tests.

TABLE-2
PROCESSING CONDITIONS OF INJECTION MOLDED WPC PARTS

Processing conditions	Values
Barrel temperature (ºC)	165/170/160/155
Mold temperature (ºC)	45
Cycle time (s)	30
Injection velocity (cm^3/s)	50
Injection pressure (MPa)	96

Melt flow index measurements: The melt flow index (MFI) of the wheat straw flour and HDPE composites was determined by a Capillary rheometer (RL-21, Shanghai, China) using a weight of 2.16 kg and a die orifice of 2.1 mm in diameter and 8 mm in length. The temperature was set to be 190 ºC according to the GB3682-2000. The MFI results of the composites with different wheat straw contents were show in Fig. 1.

Thermal analysis: Thermal analysis includes the characterization by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).The melt temperatures of all the materials were detected by a differential scanning calorimetry (DSC 2920 from TA Instruments). Samples for the DSC experiments were taken from compounded pellets with the weight about 8 mg. The samples were heated from room temperature to 160 ºC at a ramp rate of 10 ºC/min under a nitrogen purge and then cooled down at an uncontrolled rate by air. During all the heating processes, the melting and crystallization patterns of the samples were recorded. Melting peak integrals were taken from 102-140 ºC on the melting curves (cf. Fig. 2).

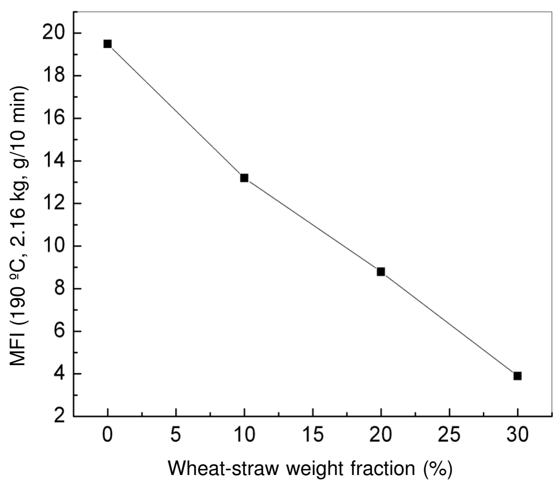


Fig. 1. Fluidity of the composites with the content of wheat-straw

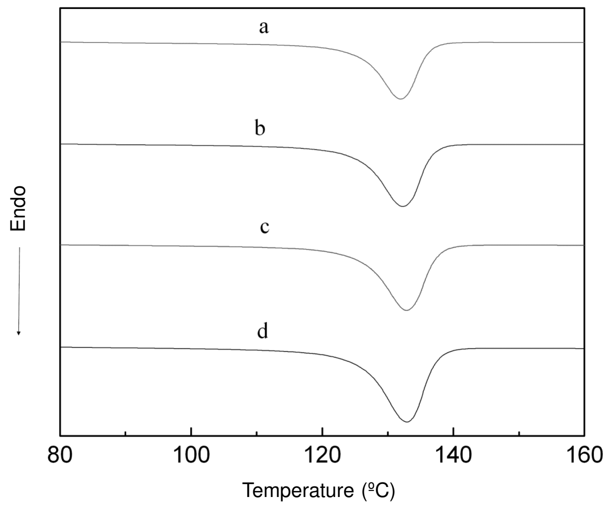


Fig. 2. DSC curves of different wheat straw contents ,and the wheat-straw weight fraction a (30 %), b (20 %), c (10 %), d (0)

To compare the thermal stabilities of the four composites, TGA measurements were taken by using a TGA Pyris-1 (PE Instruments, USA). A dried pellet with the weight of 10 mg was heated from room temperature to 600 ºC with a heating rate of 10 ºC/min under a nitrogen atmosphere. During the heating, the weight of the sample was recorded as a function of temperature and time. The TGA results were shown in Fig. 3.

Mechanical properties testing: Flexural, tensile and notched Izod impact tests were all conducted in a room with temperature of 23 ± 2 ºC and relative humidity of 65 ± 4 %. Prior to testing, the specimens were kept in this room for 48 h. Flexural and tensile properties testing were conducted on Instron 5585H testing machine in the same environment. Three-point flexural testing was done by GB/T9341-2000 with

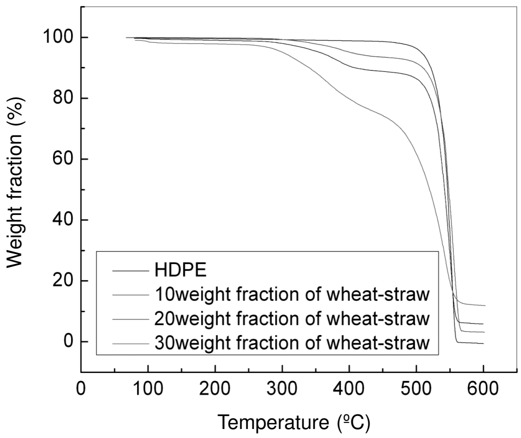


Fig. 3. TGA curves of different wheat straw contents

a crosshead rate of 2 mm/min. Tensile testing was also done with a crosshead rate of 2 mm/min and the guidelines of GB1049-92. For both tests, at least five samples from each type of composition were tested in order to obtain a reliable mean and standard deviation. The Izod impact test was conducted to record the impact resistance of each sample, measured in J/m. The testing was done in conformance with GB/T1843-1996. The samples were were V-notched at a 45º angle by specimen notcher (model HY-2, Hebei, China) and then tested on Hebei XJU-22 impact tester. Ten samples were tested for each type of composites with various wheat straw flour contents.

RESULTS AND DISCUSSION

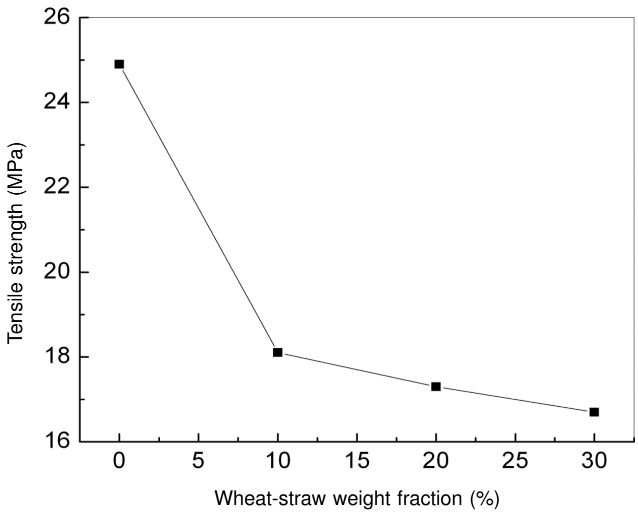
Fluidity: MFI results were useful for the judgment of the processability and rheological stability of HDPE/wheat straw composites. The MFI of WPCs decreased significantly and almost linearly with the increase in the wheat-straw flour content (Fig. 1). MFI of neat HDPE was 19.6 g/10 min. The composite with 30 wt % wheat-straw was 3.9 g/10 min, about one-fifth of the neat HDPE. It is due to the poor dispersion and poor fluidity of wheat straw. Adding olefin was helpful to increase the MFI.

Low MFI or poor fluidity is the reason for hard processing of WPCs by injection molding machine. In this study, the processing conditions of injection molding machine for all composites were similar. However, some small adjustments of the processing conditions had to be made to make products as the wheat straw flour content increased, especially the injection pressure.

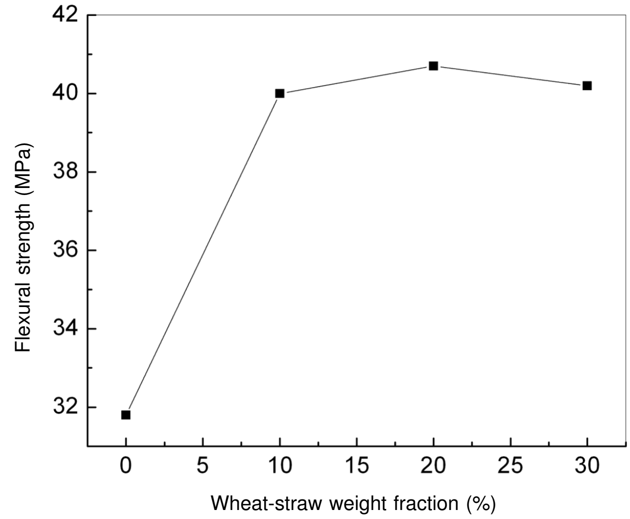
Thermal properties: The effect of wheat straw flour and saline on the melting behaviour of HDPE composite was determined by DSC measurements. The baseline of melting behaviour of the neat HDPE was established by conducting DSC measurements at 65 ºC < T < 160 ºC, which is presented by curve 'd' in Fig. 2. As can be seen from this figure, a single endothermic peak was observed with the peak temperature located at 135 ºC. This endothermic peak represents the melting transition of HDPE. There was no statistically significant shift observed in the melting transition temperature of HDPE composites. Thus, it can be concluded that the addition of wheat straw flour did not affect the melting transition of compositions. This is because the size of wheat straw flour used in composites was too large to change the branch structure of HDPE. The melt points of wheat straw/HDPE composites were exactly the same as the neat HDPE.

The TGA data was plotted as temperature *versus* derivative of weight percentage, from which peak decomposition temperatures were obtained. TGA curves (TG) of the neat HDPE and its composites were shown in Fig. 3. The thermal stability of the samples showed the weight-loss behaviour as a function of temperature. The TG curve of neat HDPE showed a single weight-loss zone and neat HDPE started degrading at 450 ºC and completely decomposed (0 % wt. char residue) at around 600 ºC. Thermal stability of the wheat straw/HDPE composites was reduced with the increase in wheat straw flour content. The TG curves of wheat straw/HDPE composites showed multiple weight loss zones due to the heterogeneous structure of wheat straw. There were two zones in the composites. One was at 170-450 ºC, where the mass loss is mainly due to the moisture, wheat straw flour and saline etc. The other zone was at 450-550 ºC, where the mass loss is because of the decomposition of HDPE and all fillers. When the temperature was above 600 ºC, all materials were relatively stable. In this study, it has been found that for WPCs, the more the wheat straw flour is in, the worse the thermal stability they have.

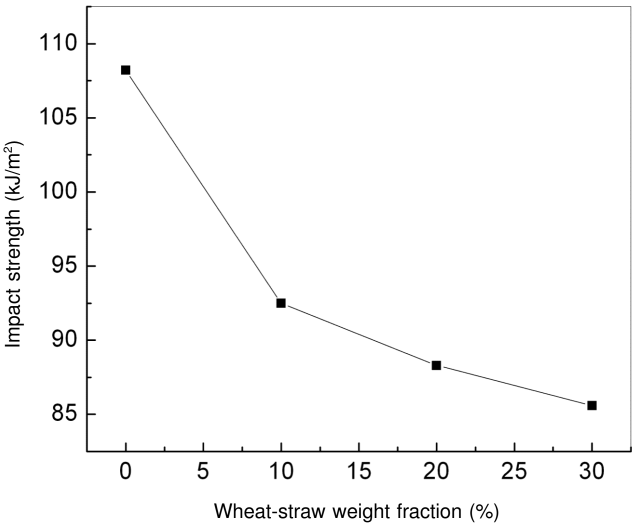
Mechanical properties: The mechanical properties of the specimens were showed in Fig. 4. For wheat straw/HDPE composites, a few trends can be noticed. The tensile strength was adversely affected by the amount of wheat straw flour (Fig. 4(a)). The tensile strength decreased almost linearly as the filler content increased from 10-30 %, which was 24.9 and 16.7 MPa for neat HDPE and composite with 30 wt % wheat straw flour, respectively. This reduction may be due to the weak interfacial bonding between hydrophilic wheat straw flour and polymer matrix. To increase tensile strength, the bonding quality between the polymer and the filler needs to be improved as it will ensure the effective transfer of stress from the HDPE to the wheat straw flour particle. Since the stiffness of wheat straw four is higher than that of HDPE, good bonding will help increase the tensile strength of composites.



(a) Tensile strength



(b) Flexural strength



(c) Impact strength

Fig. 4. Mechanical properties of different wheat straw flour percents

Flexural strength did not show much dependence on the content of wheat straw flour in the composite within the range used in this study [10-30 %, as shown in Fig. 4(b)]. The flexural strength remained almost the same at all levels of wood flour content. The flexural strength of WPCs is slightly higher than that of neat HDPE, which is 31.8 MPa. That the flexural strength [Fig. 4(b)] was higher than the tensile strength [Fig. 4(a)] is probably because of the fiber alignment in the injection-molded specimen.

The notched izod impact strength tests show a drastic reduction in impact strength as the wood flour content increased from 0-10 % (Fig. 1). The impact strength of neat HDPE is 108.2 kJ/m^2. The impact strength of WPCs decrease almost linearly as the wheat straw content increased from 10-30 % (Fig. 4(c)). The wheat straw flour particles are stiff fillers, so their presence in the composite generally reduces the impact strength. This effect became pronounced as the filler content increased (cf. Fig. 4(c)). To improve the impact strength of composites with wheat straw flour, it is important to obtain an optimum bonding level between the filler and the polymer and use long wood filler particles above critical length as well.

Conclusion

In this study, it has been shown that 20 mesh wheat straw flour/HDPE composites can be produced using similar processing equipments and conditions that are used for other WPCs. Wheat straw flour/HDPE composites went smoothly through the extruder and did not present significant problems during the injection molding process when wheat straw content was less than 30 wt %. Wheat straw flour had negative effects on the fluidity of composites. MFI decreased obviously with wheat straw content increased. Microcellular injection molding with supercritical gas (N_2 or CO_2) might be used to overcome the shortcoming of poor fluidity of WPCs. The thermal analysis of DSC showed that the melting point of the composites was almost the same as the virgin HDPE when the wheat-straw content was less than 30 wt %. The thermal degradation temperature of the composite varied from 170 -550 ºC. Thermal stability was worse as wheat straw flour increased. Low melt point and easy degradation are less desirable properties for injection molding the WPCs parts.The strength of HDPE and wheat straw composites tended to decrease with an increase in the amount of wheat straw flour. The exception to this was in flexural strength, which increased slightly with the increase in wheat straw content. To improve the mechanical properties and rough surface of the WPCs, co-injection molding would be helpful.

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