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Polybutene as a matrix for wood plastic composites

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ABSTRACT

This study examined the feasibility of using polybutene-1 (PB-1), a ductile plastic, as a matrix for manufacturing wood plastic composites (WPCs) with improved toughness and ductility compared to currently commercialized WPCs. The processability, tensile, flexural, and impact properties of injection molded PB-1/wood-flour composite samples with varying proportions of wood flour were characterized. Analysis also included the morphology of fractured samples surface and adhesion between the polymer and wood flour using SEM. Comparisons of the mechanical properties and adhesion in the PB-1 composites to those of HDPE and PP-based WPCs found the composites made with PB-1 matrix significantly inferior in strength and stiffness (both in tensile and flexural) than their counterparts made of HDPE and PP matrices. In contrast, the processability, elongation at break, impact strength and adhesion in PB-1/wood-flour composites, superior to those of HDPE and PP, confirmed their suitability for use as a matrix in composites intended for applications subjected to high impacts.

1. Introduction

Wood plastic composites (WPCs) have experienced significant market expansion in recent years as a replacement for solid wood, mainly in outdoor applications such as railings, decking, landscaping timbers, fencing, playground equipment, windows and door frames, etc. The acceptance of WPCs into the construction industry contributes to their popularity [1–10].

Polyolefin (PE and PP) matrices (over 80%) and wood flour/fibers comprise the majority of materials in North American WPC manufacturing. Currently, polyvinyl chloride (PVC) represents only a small portion of thermoplastics used in WPCs but its use will continue to grow due to its superior performance and excellent weatherability compared to olefins [1,11]. Lower processing temperatures (150–220 °C) that prevent the degradation of cellulosic materials contribute to the selection of these commodity plastics in manufacturing [4,12].

While WPC products have emerged as a new class of materials used as an alternative to solid wood in a variety of applications, they do not offer mechanical performance similar to that of solid wood [1,5,13]. For example, WPCs made with commodity plastics have about two to three times lower flexural strength than that of pine (softwood) or oak (hardwood), with about one-half flexural modulus of pine or oak [5,13]. This lowered stiffness implies that, for the same load, a deck constructed with WPC products will bend more than a similar wood deck [5]. By contrast, commodity plastic filled with wood fibers differ in brittleness and have lower impact resistance (or toughness) than unfilled polymers [14,15]. The incorporated brittle wood fibers account for the brittleness and lower impact resistance of WPCs since they alter the ductile mode of failure of the matrix, making the composites more brittle than neat polymer [14]. Brittleness and low impact resistance constitute some of the adverse characteristics of WPCs [15,16]. Enhancing these deficiencies of WPCs could not only improve their acceptance in structural and automotive applications but also open new applications for these products, thus expanding their market share [1,5].

A number of factors such as the nature of matrix resin, fiber volume fraction, interfacial bond quality, and fiber characteristics (aspect ratio, particle size, orientation), among others, can influence the toughness of filled polymers [16]. Along with these factors, the nature of the polymeric matrix plays a vital role in improving the toughness of filled polymers [17]. Enhancing the ductility of the matrix significantly improves its toughness. The use of additives such as impact modifiers, plasticizers, lubricants, or by blending with another polymer allow for the control of the ductility of a polymer. Consequently, the use of ductile polymers as polybutene-1 in WPCs would increase the toughness of the composites.

Polymerization of butene-1 and ethylene, and/or propylene comonomers creates Polybutene-1 (PB-1), a high molecular weight polyolefin. Its properties combine the typical characteristics of polyolefins with high flexibility and excellent creep resistance over a wide temperature range. Similarity of molecular structure allows PB-1 to blend with PP, PE, and propylene-based thermoplastic elastomers, modifying some of their characteristics such as flexibility, softness, elasticity, and resistance to creep. Its specific properties allow for use in water heaters and pipes, easy-open packaging (flexible packaging), pressure piping, polyolefin modification, and

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hot melt adhesives [18]. Selection in this study designated polybutene-1 (PB-1) as a ductile polymer matrix for the WPCs to attain higher impact strength and toughness compared to other commodity plastics. WPCs with improved impact resistance and toughness properties best suit applications where materials are subjected to high impacts and vibrations such as in automobiles.

Therefore, this study examined the feasibility of using polybutene-1 (PB-1) as a ductile polymer matrix for the WPCs. Particular emphasis focused on assessing the effect of wood flour content on the processability and mechanical properties of the PB-1 based wood flour composites. Additionally, the processability and performance of PB-1/wood-flour composites were compared to those of HDPE and PP-based counterparts.

2. Experimental

2.1. Materials

Basell USA (Lansing, MI) supplied the polybutene-1 (grade DP 0401 M) used as the matrix for WPCs. It had a melt flow index of 15 g/10 min at 190 °C and a density of 0.915 g/cm^3. American Wood Fibers (Schofield, WI) supplied a 40 mesh (0.425 mm) grade maple wood flour used as filler. The wood flour was oven-dried at 105 °C for approximately 48 h before processing to remove moisture. The HDPE (IG762-A) supplied by NOVA Chemicals Corporation Canada (Calgary, Alberta) had a melt flow index of 7.0 g/10 min and a density of 0.962 g/cm^3. Eastman chemical company (Kingsport, TN) supplied the PP with a melt flow index of 5.2 g/10 min (at 190 °C and a 2.16 kg load) and a density of 0.910 g/cm^3.

2.2. Processability tests

A 60 ml electrically heated three-piece internal mixer/measuring head (3:2 gear ratio) with roller style mixing blades (C. W. Brabender Instruments, Inc., South Hackensack, NJ) was used to assess the processability of the PB-1/wood-flour composites in comparison to HDPE and PP-based counterparts. A 5.6 kilowatt (7.5 hp) Intelli-Torque Plasti-Corder Torque Rheometer® (C. W. Brabender Instruments, Inc., South Hackensack, NJ) drove the mixer. The experiments used a constant mixer temperature of 160 °C and sample charge weight of 45 g. The tests ran for 8 min using a rotor speed of 40 rpm with a 5 kg dead weight put on top of the ram throughout the tests. The Brabender Mixer Program (WINMIX, Version 3.2.11) recorded the mixing characteristics (time, temperature, torque, and energy) and the data were analyzed with Brabender Correlation Software (MIXCORR, Version 2.0.10) [19].

2.3. Compounding of composites

The wood flour and plastics were dry blended in a 20-L high intensity mixer (Papenmeier, Type TGAHK20) at room temperature for 10 min. Three compositions mixed for polybutene-1 based composites varied by the proportion of wood flour at 30%, 40%, and 50% based on the total weight of the composites. After dry mixing, the materials were melt blended in a 32 mm conical counter-rotating twin-screw extruder with a length to diameter ratio of 13:1 (C.W. Brabender Instruments Inc., South Hackensack, NJ) fitted with a rectangular profile die. A 5.6 kW (7.5 hp) Intelli-Torque Plasti-Corder Torque Rheometer® powered the extruder. The HDPE and PP-based composites for comparison contained only 40% wood flour content and were compounded in a similar manner to PB-1/wood-flour blend described above.

After melt blending in extrusion, the mixed materials were cooled for about an hour at room temperature and granulated in a Conair Wortex granulator (model JC-5). The granulated samples were then dried for about 12 h and injection molded using a BOY 30T2 equipment to produce 3 mm thick specimens for flexural, tensile (Type I, ASTM D638), and Izod impact testing. Table 1 summarizes the extrusion compounding and injection molding processing conditions in the manufacture of the PB-1, HDPE, and PP-based wood plastic composites.

Table 1
Extruder and injection molding conditions for WPCs made with various matrices and 40% wood flour content.

Matrix types for WPCs	Extrusion conditions		Injection conditions	
	Temperature from hopper to die (°C)	Screw speed (rpm)	Temperature from hopper to die (°C)	Feed rate (kg/h)
PB-1	160–155–150–140	50	160–160–155–150	23 (50 lb/h)
HDPE	160–155–150–140	50	170–160–160–160	25 (55 lb/h)
PP	170–160–155–145	40	170–160–160–160	25 (55 lb/h)

2.4. Property evaluation

The three-point flexural, tensile, and notched Izod impact tests were performed in a conditioning room at 23±2 °C and 65±4% relative humidity. The specimens remained in this room at least 48 h prior testing. Flexural and tensile properties testing were carried out in an Instron 5585H testing machine according to the procedures outlined in ASTM standard D790 and ASTM standard D638, respectively. Eight replicates were tested from each composition to obtain a reliable mean and standard deviation. Notched Izod impact test was conducted on Tinius Olsen Izod impact tester (Model 892) in conformance with ASTM standard D256. The specimens were V-notched at 45° angle using Tinius Olsen specimen notcher (model 899). Each composition included 10 tested specimens.

2.5. Scanning electron microscopy (SEM)

The fractured surface morphology of tensile tested specimens was examined using a JEOL JSM-6400 scanning electron microscope with an acceleration voltage of 12 kV at two different magnification factors (50× and 400×). Samples first coated with osmium tetroxide and then with gold prevented charging during the microscopy due to the several crevices on the fractured surfaces.

2.6. Statistical analysis

Design-Expert v.7 software from the Stat-Ease Corp. (Minneapolis, MN) was used to perform statistical analyses. A two-sample *t*-test and Duncan's multiple range tests were employed to determine the statistical differences among the variables investigated at a 95% significance level.

3. Results and discussions

3.1. Processability of WPCs

The torque generated during mixing of polymers measures the rheological behavior and processability of the melts. If all the experimental conditions, including the processing temperature, the rotor speed, and the amount of material in the mixing chamber, are kept constant, the maximum and/or stabilized torque attained may give the indication of the extent of melting of various materials. Fig. 1 shows the plastographs describing the torque versus