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EFFECT OF BARK FIBRE CONTENT AND SIZE ON MECHANICAL PROPERTIES OF BARK/HDPE COMPOSITES

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SUMMARY: Black spruce and trembling aspen bark (BSB, TAB) fibres and high density polyethylene (HDPE) were used to produce bark plastic composites by extrusion. Fine, medium and coarse size bark fibre contents of 50% and 60% were used. The effect of bark fibre content and size on the flexural and tensile properties of the composite, including flexural and tensile modulus of elasticity (MOE), flexural modulus of rupture (MOR) and tensile strength at maximum load, were investigated. The best composites in terms of properties were compared to a control composite made of wood flour. Results show that TAB is less thermally stable than BSB and plastic composites made from bark exhibit different stress-strain behaviours, with higher MOE and strength for BSB than TAB plastic composites. MOR and tensile strength of bark/HDPE composites with 50% BSB and TAB fibre content were higher than those of plastic composites with 60% BSB and TAB fibre content. Plastic composites made from medium and coarse BSB and TAB fibre showed higher flexural and tensile properties than that made of fine fibre.

KEYWORDS: bark/plastic composites, high density polyethylene (HDPE), stress-strain behaviour, flexural and tensile properties

INTRODUCTION

In the plastics industry, wood has been primarily used as an inexpensive filler to increase the strength and stiffness of thermoplastics and to reduce raw material costs. However, research on high filler contents and coupling agents has led to the development of wood-plastic composites

(WPC) that exhibit synergistic material properties. The commercial success of these emerging materials is largely due to improved wood moisture performance, increased recycled and waste material utilization, and efficient product and process designs [1]. Ligno-cellulosic materials are lighter, much less abrasive and renewable compared to other inorganic fillers. They can also improve the product's thermal stability [2].

Bark is available in large quantities in the Province of Québec, Canada, and is mainly used for thermal energy production. Research efforts are being made to promote the use of bark for higher value added products such as particleboard and medium-density fibreboard [3, 4, 5]. Although several natural and biorenewable fibres are used in the fibre/plastic composites industry [6], the use of bark as thermoplastic filler has not yet been investigated. This is due to several factors, including the morphological and chemical differences between bark and other biorenewable fibres. Fibre morphology, including length and length-diameter ratio (L/D), affects the mechanical properties of WPC [7, 8, 9, 10, 11] Moreover, L/D ratio impacts the mechanical properties of the composites more than fibre length. Thus, flexural modulus of rupture and tensile strength increase with increasing L/D ratio [9]. Fine particles fuse more quickly into a PVC matrix and require less energy than coarse particles [12]. Extruded WPC is strongly dependent on species, suggesting that species significantly influence material structure and properties [13].

The general objective of this study was to investigate two species of bark for their potential in plastic composite production. The specific objectives were: (1) to study the effects of species, bark content and size on the flexural and tensile properties of extruded bark/high density polyethylene (HDPE) composites; and (2) to compare their properties to a control composite sample made from wood flour.

MATERIAL AND METHODS

Fresh black spruce (*Picea mariana* (Mill.)) and trembling aspen (*Populus tremuloides* (Michx.)) bark samples were collected from the debarking units of a sawmill and an OSB mill in the Province of Québec, Canada. The collected bark was dried at 60°C to a final moisture content of 5%. The anhydrous density of bark was 639 and 707 kg/m^3 for black spruce and trembling aspen, respectively. The dried bark was refined in a Pallmann double stream mill and sieved into three size groups designated as fine (0.18-0.25 mm), medium (0.25-0.50 mm) and coarse (0.50-1.00 mm). Bark fibre size distribution was investigated using a fibre quality analyzer (FQA) and the length-to-diameter (L/D) ratio of each fibre class was calculated (Table 1).

Wood plastic composites were made according to the condition presented in Table 2. A 20 kg batch of each composite formulation was mixed in a drum blender for 10 min. The mixture was then conveyed to the feed hopper of a 55 mm counter-rotating conical twin-screw extruder. A slit die measuring 15.25 cm by 1.25 cm was attached to the extruder. During extrusion, temperatures of the barrel/screw and die were 163°C and 171°C. Screw rotational rate was 6–7 rmp and 10–12 rmp for BSB and TAB composites, respectively. After exiting the die, the extrudate sized 38.1 x 9.5 mm was spray cooled using 20°C water and air.

Static bending modulus of elasticity (MOE) and modulus of rupture (MOR), tensile MOE, strength at maximum load, maximum strain and rupture energy (Toughness) were determined according to the ASTM D 790 and ASTM D 638 standards, respectively. The factors studied were species, bark content (50% and 60%) and fibre size (fine: 0.19-0.25 mm, medium: 0.25-0.50 mm and coarse: 0.50-1.00 mm). Thus, 12 combinations with 3 replicates, for a total of 36 extrudates were obtained. In addition, 3 control extrudates were manufactured in the same laboratory conditions with 58% wood flour. Statistical Analysis System (SAS), version 9.1, was used to perform the statistical analysis.

Table 1: Bark fibre sizes

Size class	Fibre size (mm)	Screen size (mesh)	L (mm)	D (µm)	L/D	L (mm)	D (µm)	L/D
			Black spruce bark (BSB)			Trembling aspen bark (TAB)		
Fine	0.18-0.25	80-60	0.34	38.40	8.85	0.18	47.00	3.83
Medium	0.25-0.50	60-32	0.36	38.10	9.45	0.24	42.80	5.61
Coarse	0.50-1.00	32-16	0.56	40.50	13.83	0.41	38.40	10.68

L = mean length D = mean diameter L/D = length-to-diameter ratio

Table 2: Bark and wood plastic composite formulations

	Bark fibre	Wood flour	HDPE	Talc	Zn-st	EBS	OP-100	MAPE
	%							
Control	0	58	32	7	2	1	0	0
Bark/HDPE	50	0	45.3	0	0	0	2.7	2
Bark/HDPE	60	0	35.3	0	0	0	2.7	2

HDPE = High density polyethylene; Talc = magnesium silicate hydroxide; Zn-st = Zinc stearate; EBS = ethylene bis stearamide; OP-100 = ester stearate lubricant; MAPE = polyethylene-maleic anhydride.

RESULTS AND DISCUSSION

Compared to TAB, BSB produced composites with higher mechanical properties in terms of bending strength (Figures 1 and 2) and tensile strength (Figures 3 and 4). This result can be explained by the higher fibre lengths and L/D ratios (Table 1) of BSB fibres. The impact of species on maximum bending and tensile strength seemed to interact more with bark content and fibre size (Figures 1 and 3). BSB composites exhibited more linear and brittle stress-strain curves than TAB composites. For similar bark content, and despite lower tensile strength, TAB composites showed higher toughness than BSB composites. This result is explained by the higher maximum strain of TAB composites (results not shown).

Flexural MOR and tensile strength at maximum load decreased with increasing bark fibre content (Fig. 1 and 3). These properties were higher for composites containing 50% BSB and TAB than those with 60% BSB and TAB bark. In contrast, flexural MOE increased with higher bark content (Fig. 2, 4). Flexural and tensile properties of bark/HDPE composites containing 50% BSB and 60% TAB increased with larger fibre size (Fig. 2, 4), whereas tensile strength of samples with 60% BSB and 50% TAB decreased (Fig. 3). In fact, the fibre analysis results of Table 1 show consistently lower length-diameter ratio (L/D) for fine fibres than other composite fibres [9]. In contrast, the low L/D ratio of fine fibres created a stress concentration due to poorer fibre dispersion in the plastic matrix [7]. This resulted in low mechanical properties. Therefore, the prominent role of fibre ratio L/D on the mechanical properties of the composites most likely explains the observed variations of flexural properties for bark plastic composites.

Bark plastic composites made from 50% medium and coarse BSB fibres exhibited the highest MOR and tensile strength, which did not differ significantly from the control composite containing wood flour (Fig. 1 and 3). Similarly, the highest flexural and tensile MOE were obtained with composites containing 60% coarse BSB fibres, corresponding to bending and tensile strength 44% and 32% lower than the control, respectively (Fig. 2 and 4). Tensile toughness of plastic composites containing 60% black spruce bark differed slightly from control, although tensile strength was not as high as expected.

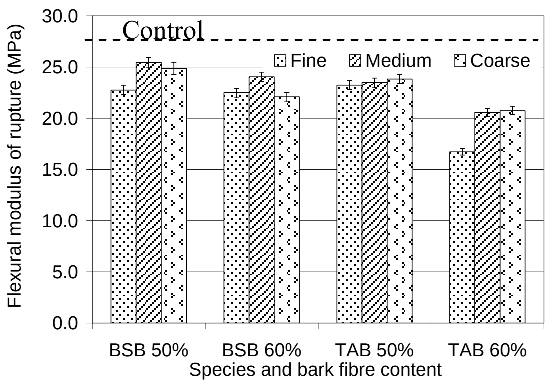

Fig. 1 Effect of species and bark fibre content on the flexural MOR of bark plastic composites.

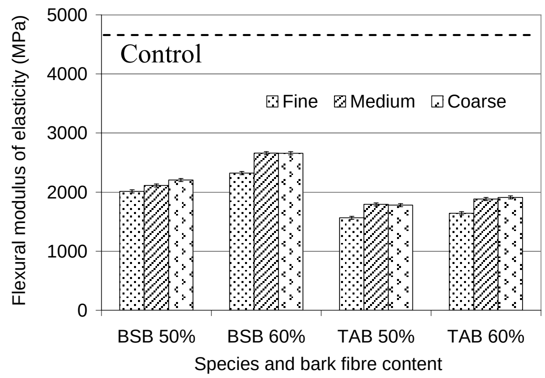

Fig. 2 Effect of species and bark fibre content on the flexural MOE of bark plastic composites.

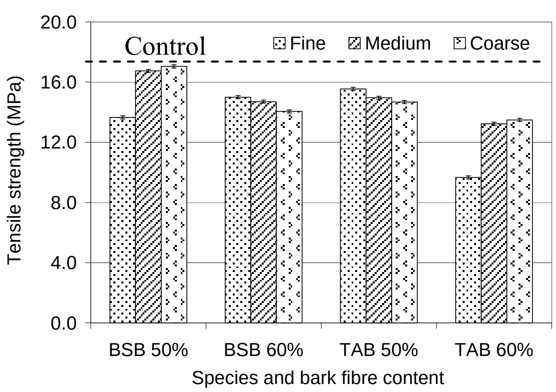

Fig. 3 Effect of species and bark fibre content on the tensile strength of bark plastic composites.

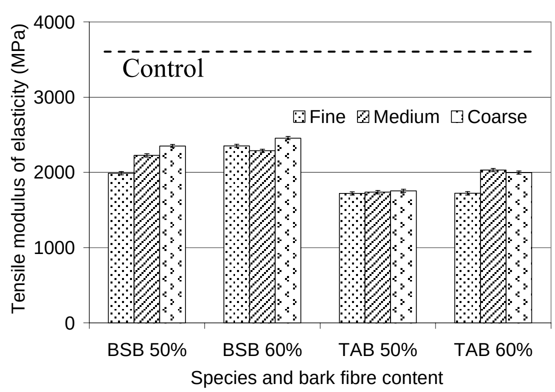

Fig. 4 Effect of species and bark fibre content on the tensile MOE of bark plastic composites.

CONCLUSIONS

Plastic composites made from black spruce and trembling aspen bark (BSB and TAB) exhibited different stress-strain behaviours. BSB plastic composites generally showed higher MOE and strength than TAB plastic composites. Flexural and tensile properties of bark/high density polyethylene (HDPE) composites were related to raw bark properties. Species is therefore an important factor to consider. Modulus of rupture (MOR) and tensile strength of plastic composites made from 50% black spruce and trembling aspen bark were higher than those of plastic composites made from 60% bark fibres. Plastic composites made from medium and coarse black spruce and trembling aspen bark fibre showed higher flexural and tensile properties than composite made from fine fibres.

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