Wood plastic composites manufactured from hot water extracted wood. Part I: Mechanical evaluation

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Abstract

The University of Maine, through its Forest Bioproducts Research Initiative (FBRI) project has developed a patent pending hot water hemicellulose extraction process for wood to produce a feedstock for chemicals and/or fuels. Depending on the form of the wood feedstock (chips, strands, particles), the remaining extracted wood can be utilized in traditional product forms such as paper, oriented strand board and particle board. In the present study, the utility of using extracted wood flour for producing extruded wood plastic composites has been investigated. Polypropylene was used as the thermoplastic resin and a lubricant was added to produce extruded WPC boards based on un-extracted and extracted wood material. Mechanical characterization was performed according to ASTM standards and consisted of tensile, flexure and impact measurements. In addition, flame, specific gravity, and thermal expansion analyses were also performed. The results indicated that the mechanical properties were not adversely affected by the extraction process and, indeed in several cases the properties increased significantly. Flame, specific gravity and thermal expansion did not present significant differences. Based on the results and considering that the aspect ratio did not suffer a significant change, it is expected that the increase in mechanical properties due to increase in the stress transfer from wood particles to the resin was mainly because of changes in the surface chemistry of the extracted material. Continuing work consists of the evaluation of the microscopic, chemical and surface energy of the extracted material and, adhesion and microscopic characterization of the final composites.

Keywords: Wood Plastic Composites, Wood extraction, Hot water extraction, Mechanical properties, Polypropylene.

INTRODUCTION

Hemicelluloses, one of the main components of wood, are removed during the Kraft pulping process and, the majority of the degraded hemicelluloses are combusted during the Kraft recovery process. The extraction of these wood components before pulping and the fabrication of materials of higher value have been proposed by researchers over the last 4 years [0-0]. It is expected that hemicelluloses removal from wood should result in different chemical properties of the remaining wood material. Akhtar et al. for instance, [0] presented a method for producing a medium density fiberboard from a pulp of a fibrous lignocellulosic material using a pre-treatment which exposes the material to oxalic acid or oxalic acid derivatives. The treated wood is then subjected to a hemicellulose sugar extraction and the final product, after washing and refining processes possesses high water repellency.

The morphological and chemical properties of the raw materials used to produce wood plastic composites are important variables in defining the final properties of the composite [0]; particularly their mechanical properties. As it is widely known, the incorporation of wood based materials into a thermoplastic resin has the effect of increasing the stiffness through stress transfer from fibers to the matrix. However, the significantly different chemical properties of the two major components of WPCs (wood and the thermoplastic resin) may potentially hinder the stress transfer due to their incompatibility. Consequently, compatibilizing additives or chemical modifications are typically performed to address this hydrophilic wood/ hydrophobic resin incompatibility.

The overall goal of the present work was to determine the effect of hot water hemicellulose extraction on the mechanical properties of WPCs that were made from the extracted mixed southern hardwood wood flour. Extracted wood flour deck boards were tested against WPC made from un-extracted wood for tensile, flexure and Izod impact. In addition, the specific gravity, coefficient of thermal expansion and lineal burn rate were evaluated. ASTM standards were followed for all tests.

To the authors’ knowledge, this is the first published work on this topic. The most closely related work to date is that of Winandy et al. [0] who used thermomechanical pulp and compared flexure properties of wood flour filled WPC with WPC containing TMP fiber.

MATERIAL AND METHODS

The raw material used in this study was a mix of southern hardwood chips. The chips were thoroughly mixed (to homogenize them in moisture content) and then, they were screened to remove as many of the fine particles as possible from the chips. The screening process was needed to help prevent clogging of the cooling lines during the extraction process.

The extraction process was performed at the Pulp and Paper Process Development Center of UMaine in a four vessel biomass extractor. The extractor consists four 40 liter vessels which are rotated end-over-end around their central axis (at 2 rpm) to promote even heat distribution throughout the vessel. The degree of extraction was based on H-factor [0] using hot water as the extraction media; the targeted H-factor was 375. Chips were cooked to 95°C when the process was stopped to vent off any non-condensable gases that had been released up to that point. When the process was restarted the chips were cooked until 160°C and then monitored until an H-factor of 350 was reached, at which time the cooling process would begin. H-factor would still accumulate until the chips were fully cooled and removed at which time the H-factor was recorded.

After the extraction process the chips were dried at 177°C to reach approximately 8% moisture content. Un-extracted and extracted chips were subsequently hammer milled to obtain a wood flour material (40 mesh). The final moisture content was between 5% and 8%.

Un-extracted and extracted wood flour were extruded separately with polypropylene to produce decking boards on a 94 mm Davis Standard Woodtruder at a rate of 40 cm/min. 50% wood flour, 44-45% polypropylene (BP Amoco, Houston, TX, USA), and 5-6% lubricant (Struktol, Stow, OH, USA), were used as a formulation in the extruder.

Mechanical properties of WPCs containing un-extracted and extracted wood flour were determined using ASTM standards. Ten samples (1.2 m long, each) were selected to be tested for tensile (modulus and strength) [0], flexure (four point bend, modulus and strength) [ ] and Izod impact [ ] determinations. In addition, specific gravity, coefficient of linear thermal expansion (in the X and Y direction of the extrusion) and rate of burning were also performed [-].

RESULTS AND DISCUSSION

The results of this study, presented in Table 1, demonstrated that overall the mechanical properties were not adversely affected by the extraction process. Indeed statistical analysis of the boards created from the extracted wood indicated that the tensile modulus, tensile strength, and flexural strength all increased relative to the boards created from the un-extracted wood. WPCs created from extracted wood flour showed a significant statistical increase in the lineal burn rate and X direction CTE mm/per °C. Values of the flexural modulus, specific gravity, Y direction CTE mm/per °C and IZOD J/m were found have no statistical difference (see Table 2).

Geometrically the raw material used for the composite preparation was the same for the extracted and un-extracted samples, (e.g. aspect ratio). Consequently it is proposed that the source of the significant increase in mechanical properties may be attributed to chemical changes or micro-roughness changes that occurred during the hot water extraction and aided in stress transfer between wood flour particles and the thermoplastic resin.

During the hot-water extraction not only hemicelluloses are removed, it is known that other water soluble materials, lignin, etc. are solubilized [0]. Presumably removal of a portion of hydrophilic material from the wood results in a comparatively greater proportion of hydrophobic material thereby increasing compatibility with thermoplastic resins. Similarly the extraction may have opened up the structure of the wood increasing surface area or creating beneficial micro-roughness. Based on these preliminary results, a deeper analysis of the surface chemistry and morphology of the wood is clearly necessary. Surface analyses are being performed using inverse gas chromatography (IGC) and diffuse reflectance infrared Fourier transform spectroscopy (DRIFT) to study the surface energy and surface composition of un-extracted and extracted wood flour. The work of adhesion between WPC components and thermoplastic resins is being determined by atomic force microscopy as are morphological studies. Surface area will be determined by BET adsorption.

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- ASTM D 635-03. Standard Test Method for Rate of Burning and/pr Extent and Time of Burning of Plastics in a Horizontal Position.

Table 1: Mechanical properties

	Tensile Modulus (PSI)	Tensile Strength (PSI)	Flexural Modulus (PSI)	Flexural Strength (PSI)	Izod Notched (J/m)	Specific Gravity	CTE (Y) (mm/°C)	CTE (X) (mm/°C)	Lineal Burn Rate (mm/min)
Un-extracted wood flour	271,044	2,328	648,143	5,115	23.19	1.01	0.000896	0.001716	15.40
Standard deviation	7,621	79	55,492	312	2.6	0.0114	7.86%	4.04%	2.96
Extracted wood flour	316,570	2,883	705,724	5,906	21.84	1.02	0.000922	0.001785	19.40
Standard deviation	11,935	114	43,975	289	1.62	0.005	12.94%	3.66%	4.2
Percent Change	14.38%	19.25%	8.16%	13.39%	-6.22%	0.74%	2.83%	3.85%	20.60%

Table 2: Statistical significance between un-extracted (control) and extracted samples.

	Tensile Modulus (PSI)	Tensile Strength (PSI)	Flexural Modulus (PSI)	Flexural Strength (PSI)	Izod Notched (J/m)	Specific Gravity	CTE (Y) (mm/°C)	CTE (X) (mm/°C)	Lineal Burn Rate (mm/min)
P- Value	0.0003	4.71E-05	0.0006383	0.050547	0.775339	0.247537	0.308865	0.0151504	0.020906
Significance	Significant	Significant	Significant	Not Significant	Not Significant	Not Significant	Not Significant	Significant	Significant