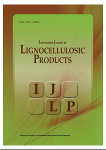

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Investigation on mechanical properties of composite made of sawdust and high density Polyethylene

A. Rafighi[a*], A. Dorostkar[b], M. Madhoushi[c]

[a]Assistant Professor, [b]Former MSc Student, [c]Associate Professor, Department of Wood Engineering and Technology, Gorgan University of Agriculture Science and Natural Resources, Gorgan, Iran

*Corresponding author, e-mail: Dr.Rafighi@gmail.com

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Abstract

In this research, the effect of wood species and particle size on mechanical properties of wood plastic composites (WPC) made of fir (*Abies alba*) and beech (*Fagus orientalis* L.) sawdust and high density polyethylene (HDPE) were investigated. Wood plastic composite (WPC) were made with 30% HDPE in a batch process at 185°C, at two particle sizes of 40 mesh and 80 mesh. Maleic anhydride polypropylene (MAPP) was used as a coupling agent. The MOE (modulus of elasticity) and MOR (modulus of rupture), maximum tensile strength increased with increasing particle size.

***Keywords*:** Wood-plastic composite, Mechanical properties, Wood species, Particle size, Polyethylene.

1. Introduction

Wood plastic composites (WPC) are as common materials for structural and non-structural application comprising of wood flour as a filler and reinforcement of thermoplastic polymer as the matrices (Aina et al. 2013). WPCs can be made from many wood species, and mainly are formed by introducing wood flour from softwoods and hardwoods in a continuous extrusion process. Presently, there is tremendous interest in understanding the behavior of the wood particles and the surrounding plastic matrix behave at both macroscopic and microscopic levels (William, 2008). In WPCs production, the preferred method for manufacturing are extrusion and injection molding, where temperatures of about 200 ˚C and high pressures are normally used (Wolcott and Englund, 1999). Mechanical properties of wood plastic composites (WPCs) generally depend on the properties of their components and the ratio of these components (Kociszewski et al. 2012). The two main variables that distinguish wood productions are wood species and particle size (Bouafif et al. 2009, Ghanbari et al., 2014). One of the factors affecting properties of a wood component is wood particle size. There are a variety of available wood species in the Iran that are potentially useful for the production of WPC, wood species such as poplar, alder, beech, fir, pine, maple and oak are commonly used whereas polyethylene, polypropylene (PP), and polyvinyl chloride are usually used as the thermoplastics (Dorostkar et al. 2014). Wood species have an important influence on the properties of wood thermoplastic composites (Stark and Rowlands, 2003; Fabiyi et al. 2009). Khalil et al. (2006) have shown that mechanical properties are decreased with increasing particle sizes and wood species have not significantly affect on mechanical properties of wood plastic composite.

In recent years there are concerns for the production of wood structures and other materials. To achieve these, one of the requirements is to have compatibility between wood properties (mechanical, chemical) and the other materials that will allow obtaining a new product, with uniform structure and default properties (Terciu et al. 2012).

An optimal cost composite can be obtained by embedding in its component the waste from other manufacturing processes or recycled materials. The waste sawdust is an important resource of raw material. A report by FAO shows that the amount of wood of different species cut by sawmills in Europe in the year 2010 is about 125.36 million m^3. The sawdust losses resulting from sawing processes are between 5-11% of the total log volume. At a minimal loss value of 5% results in a volume of 6.27 million m^3 sawdust. So sawdust is an important renewable raw material and can be used in other areas moreover than heating.

The aim of this study was to investigate the mechanical properties of the thermoplastic composites that can be affected by different particle sizes of filler (wood-fiber) and different wood species (fir and beech) with high density polypropylene content and to maximize the use of wood residues to produce modified wood-based products and most importantly to reduce the environment pollutions.

2. Materials and Methods

2.1. Sample preparation

HDPE (specific gravity 960 kg/m^3 and MFI=18 g/10 min from Arak Petrochemical Plant) was used in powder form. fir and beech sawdust were supplied from wood workshops in Gorgan and Kordkoy and were screened using mesh 40 and mesh 80. The screened sawdust was placed inside an oven (103±2 ˚C) for 24 hours until the moisture content was <2%. MAPP was supplied by Kimiya Javid Sepahan Co. (content: 0.6% Maleic anhydride and 99.4% polypropylene).

The sawdust, HDPE and MAPP were mixed at a composition of 68.7%, 29.3% and 2% respectively. The mix was compressed in form of a board using an OTT press and based on Table1 with following properties: 20×15 size, 1 g/cm³ gravity and 1 cm thickness (Madhoushi et al., 2009).

Table1. Compression condition.

Condition	Stage 1	Stage 2	Stage 3	Stage 4
Pressure (bar)	30-35	---	30-35	30-35
Temperature (°C)	185	185	185	---
Time (min)	1	4	10	5

The mix was poured into a cast and it was compressed initially [185˚C, 30-35 bar for 1 minute (step1)] and it was interrupted for 4 minutes with constant temperature(step2) and then the final compression was executed [185˚C, 30-35 bar for 10 minutes (step 3)]. The board was removed out of oven and compressed for 5 minutes with 30-35 bars without heating (step 4).

The produced boards were placed in room temperature for two weeks. The samples were dissected and their water absorption rates were tested. The tests were executed for wood-plastic mix using 70% sawdust of fir and beech woods in two meshes (40 and 80) on 4 treatments with 6 iterations based on Table 2. Panels were 25×15 cm², and 1 cm in thickness. Three replicate panels were produced for each composite formulation so that the total number of panels was 12. From each panel, tow replicate specimens were prepared. The total number of replications for each treatment was 6, totaling 24 specimens for all treatments. Panels were kept at room conditions for two weeks before specimens were cut for physical and mechanical tests.

Table 2. The mix components rates and percentages used in the treatments.

No. of treatment	Code of treatment	Wood species	Particle size (Meshes)	Sawdust (%)	PE (%)	MAPE (%)
1	A_1B_1	fir	40	68.7	29.3	2
2	A_1B_2	fir	80	68.7	29.3	2
3	A_2B_1	beech	40	68.7	29.3	2
4	A_2B_2	beech	80	68.7	29.3	2

2.2. Test procedure

2.2.1. Strength properties of wood plastics composite (WPC)

Evaluation for strength properties was carried out on WPC. The evaluation was conducted according to ASTM D-4761 and ASTM D-6109 standard respectively. Flexural properties of WPC were tested for MOE and MOR.

The strength properties of wood are measures of its resistance to exterior forces which tend to deform its mass (Erwinsyah, 2008). The resistance of wood to such forces depends on their magnitude and the manner of loading (bending, compression, shear, tension, etc.). Tsoumis (1991) stated that wood exhibited different strength properties in different growth directions; therefore it is mechanically anisotropic. According to Bowyer et al. (2004) strength properties are usually the most important characteristics of wood product used in structural applications. Structural application is any constructional usage governed by the strength property which is the primary criteria for material selection. Structural uses of wood product include floor joint and rafters, wall sheathing and sub-flooring (Erwinsyah, 2008).

2.2.2. Flexural testing

Two point bending tests (flexural MOR and MOE) were performed according to ASTM D-6109 with a crosshead speed of 2 mm/min on an Instron 5500R-1137 test machine using the BlueHill v_2 software. The nominal size of flexural specimens was 160×30×10 mm.

2.2.3. Tensile strength

The objective of tensile test is to determine the strength of bonding between the wood particles and plastic (polypropylene) in accessing the value of Maximum Tensile Strength using Instron Machine Testing and was carried out by using ASTM D-4761. The nominal size of tensile specimens was 170×30×10 mm. Tensile strength is defined how good will the material reacts under a certain pressure of forces. This testing has been done until it complete failure or break.

Finally the results of tests were analyzed full randomly as factorial test using SPSS13 and the averages were categorized using a Duncan Test.

3. Results

Table 3 shows all test data. This Table was assessed and analyzed using ANOVA and the General Linear Model (Tables 4 to 6). The MOE, MOR and Maximum Tensile Strength of the WPC formulations were generally shown to increase (8-25%) with an increase in Particle size. This trend was also seen by Stark and Rowlands (2003), where MOE, MOR and Maximum Tensile Strength significantly increased with an increase in particle size. The MOE, MOR and Maximum Tensile Strength of beech are more than fir. Results shown that maximum value of MOE, MOR and Maximum Tensile Strength respectively 1362, 14.6 and 8 (MPa) are seen at beech 40 mesh.

Table 3. Average of Mechanical Properties.

Wood species	Particle size (Meshes)	MOE (MPa)	SD	MOR (MPa)	Std deviation	Max tensile strength (MPa)	SD
fir	40	1348.7	31.77	13.6	0.72	6.4	0.78
fir	80	1151.7	34.54	11.4	0.39	5.1	0.51
beech	40	1362	40.06	14.6	0.42	8	0.30
beech	80	1262.3	48.57	12.7	0.64	7	0.25

SD, Standard deviation.

Table 4. Variance analysis for flexural MOE.

Source	SS	(df)	MS	F	p	Sig
A (wood species)	11532.000	1	11532.000	1.278	0.291	ns
B (particle size)	66008.333	1	66008.333	7.314	0.027	*
(A*B)	7105.333	1	7105.333	0.787	0.401	ns
Error	72196.000	8	9024.500			
Total	198534598.0	12				

(**) Significant at the 0.01 level, (*) Significant at the 0.05 level, (ns) No significant

Table 5. Variance analysis for flexural MOR.

Source	SS	(df)	MS	F	p	Sig
A (wood species)	4.0215	1	4.0215	3.454	0.100	ns
B (particle size)	12.302	1	12.302	10.555	0.012	*
A*B	0.099	1	0.099	0.419	0.667	ns
Error	1.166	8	9.324			
Total	2075.384	12				

(**) Significant at the 0.01 level, (*) Significant at the 0.05 level, (ns) No significant

Table 6. Variance analysis for Maximum tensile strength.

Source	SS	(df)	MS	F	p	Sig
A (wood species)	5.603	1	5. 603	22.191	0.002	**
B (particle size)	4.563	1	4.563	18.073	0.003	**
A*B	0.020	1	0.020	0.475	0.510	ns
Error	2.020	8	0.253			
Total	561.760	12				

(**) Significant at the 0.01 level, (*) Significant at the 0.05 level, (ns) No significant

The results of analysis of variance carried out at an alpha=0.05 to test for significant differences among particle sizes and flexural MOE of wood plastic composites are presented (Table 4). The results showed there were significant differences in wood plastic composites produced from different particle sizes and flexural MOE ($p<0.05$). According to Table 4 there were differences between wood species (fir and beech) but this difference did not significantly affect, however beech has slightly better Property. Amount of flexural MOE increased with increasing particle size.

The results of analysis of variance carried out at an alpha=0.05 to test for significant differences among particle sizes and flexural MOR of wood plastic composites are presented in Table 5. The results showed that, there were significant differences in wood plastic composites produced from different particle sizes and flexural MOR. According to Table 5 there were differences between wood species (fir and beech) but this difference did not significantly affect, however beech has slightly better property. Amount of flexural MOR increased with increasing particle size.

Also according to Tables 3 and 6, there were significantly differences at alpha=0.01 probability level between different particle sizes and wood species on maximum tensile strength. It can be seen that beech has better property. Amount of maximum tensile strength increased with increasing particle size.

4. Discussion

Increased wood-fiber sizes decreased the strength and stiffness of the thermoplastic composites. With increasing particle size, decreases homogeneity of wood composite, and decreases material coverage in some parts of matrix thus particles don't have enough contacts with matrix. Since matrix rate was lower in this study, the results are not consistence with what predicted before because particle size is decreased and surface/volume ratio is therefore increased and substrate rate is not sufficient for particle coverage. Then flexural MOE, MOR and maximum tensile strength are increased significantly in this study due to higher particle size. This is in contrast to the results of Khalil et al. (2006). It seems that second reason is production method, since production method in this research is batch system but in other researches such as Khalil et al. (2006) production method is extruding system. In extruder system, matrix materials are lapped fillers very better than batch system.

5. Conclusions

This study was successfully carried out to investigate the effect of two indigenous wood species and two particle sizes on mechanical properties of sawdust that mixed with HDPE as WPC were those of modulus of rupture, modulus of elasticity and maximum tensile strength.

The results led to the following conclusions for particle size and wood species effects:

1. In wood/plastic ratio 70:30 and in Batch production method mechanical properties (MOE, MOR and Maximum Tensile Strength) increased as particle size increased.
2. There were no significant differences between wood species.

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