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STRENGTH AND SORPTION PROPERTIES OF BAMBOO (Bambusa vulgaris) WOOD-PLASTIC COMPOSITES

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Abstract:
The study investigated the strength and water sorption properties of plastic composites produced from the sawdust of bamboo and recycled Low Density Polyethylene (LDPE). Three levels of board density (500kg/m^3, 600kg/m^3 and 700kg/m^3) and three levels of plastic/fibre mixing ratio (1:1, 2:1 and 3:1) were adopted. The thickness swelling (TS), water absorption (WA), tensile strength, modulus of elasticity (MOE) and modulus of rupture (MOR) were investigated. The sorption properties were measured after 24hour water-soak test exposure. The mean values of the properties ranged from 4.15% to 1.40% for thickness swelling; 31.96% to 4.83% for water absorption; and 2.55Mpa to 6.98Mpa, 5564.11Mpa to 10771.65Mpa and 0.60Mpa to 4.29Mpa for tensile strength, modulus of elasticity and modulus of rupture respectively. The result revealed that as the plastic/fibre mixing ratio and board density increased the tensile strength, MOE and MOR increased, while TS and WA decreased. Strength properties of composites boards produced with the higher production variables had higher strength properties and decreased sorption assessment. Bamboo particles are suitable for the manufacturing of Wood Plastic Composites (WPC) using LDPE

Key words*: bamboo; properties; composites; thermoplastics.*

INTRODUCTION

Wood Plastic Composites (WPCs) are defined as a thermoplastics reinforced with wood or other natural fibers, are principally produced from commodity thermoplastics such as polyethylene (PE), polyvinyl chloride (PVC), or polypropylene (PP) (Wolcott 2001). WPCs may be identified as sustainable materials, due to the wood particles predominately being a byproduct of sawmill and other wood-processing waste streams, and because much of the plastic is derived from consumer and industrial recycling efforts. WPC materials have several benefits compared to the traditional wood material. First, it is resistant to insects, marine borers and rot when used for structural members. Also, reduced production costs make wood-plastic economical for many structural applications (Bowyer et al. 2010). WPCs have shown that they have good potential to improve the water resistance of woody composites, because thermoplastic polymers are highly hydrophobic (Xiaolin et al. 2007). One of such fillers/natural fibre that can be used in WPCs production is bamboo fibre which is considered as one of the alternatives for wood resources.

The main applications of WPCs are in products such as rails, decking, door and window profiles, decorative trims, roof tiles, sheathing etc. New applications and end uses of wood plastics composites include decking, flooring and outdoor facilities, window frames etc. with improved thermal and creep performance compared with unfilled plastics (English and Falk 1995, Verhey et al. 2002). These composites are also gaining acceptance in automotive, industrial and marine applications (Bledzki and Gassan 1999). WPCs exhibit improved resistance to checking, decay, termites, and marine organisms (Balma and Bender 2001). WPCs do not corrode and are resistant to rot decay and marine borer attack. They have good work ability and can be shaped using conventional wood working

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tools. WPCs are often considered a sustainable material because they can be using recycling plastic and the waste of wood industry.

Bamboo (Bambusa vulgaris) is perennial, giant, woody grass. The dominant bamboo in Nigeria is commonly referred to as the Indian bamboo (FAO 2005). Bamboo is fast becoming a promising wood substitute and one of the chief reasons for this is that bamboo can be harvested in 3-4 years from the time of plantation as opposed to timber which takes decades (Anatole 2007, cited in Verma et al. 2012). Bamboo is characterized by fast growth, easy propagation, vigorous regeneration, high productivity, quick maturity abundant availability and good mechanical properties from longitudinally aligned fiber structure. According to (Matoke 2012), bamboo utilization is confined to domestic use due to lack of modern skills, inappropriate processing skills and technology. Despite the high utilization potentials of bamboo in the wood products sector, the wood industry in Nigeria has been on a gradual decline in terms of capacity utilization (Ogunwusi 2011a). This has resulted in wasteful processing and utilization.

In addition, there has been an incredible increase in the volume of wastes generated daily in the country. This is due to a number of reasons including the increasing human population, urbanisation, industrialisation and economic growth. Polythene consumption most especially has increased exponentially in the past decades (David 2012) due to inadequate disposal technique. These are non-degradable materials that have the potential to remain buried in the soil for years to come. Their disposal creates environmental pollution which includes soil, water and air contamination and blocking of drains and sewage lines in and around cities. Since polythene is non-degradable, it remains intact in water and soil for many years; and is not productive to the soil (Aziegbe 2007, Sharma and Kanwar 2007).

These drawbacks thus led to the research study of the production and assessment of the strength and sorption properties of the bamboo plastic composites. This will thus enhance efficient utilization of bamboo, as well as reduce or divert over-dependence on forest and forest resources. The use of pure water sachet will also enhance recycling of the thermoplastics so as to reduce its environmental nuisance.

MATERIALS AND METHOD

The bamboo (*Bambusa vulgaris*) used for this study was purchased from building materials market, Bukuru, in Jos, Plateau state. The bamboo wood culms (3½ years at maturity) had their nodes removed and then cut into billets. Thereafter, the billets were processed into particles using the hammer mill and sundried for 21 days to reduce the moisture content. The bamboo particles were screened by using a 2μm wire mesh. The recycled low density polyethylene (pure water sachets) were gathered and collected from refuse dumping sites, thoroughly washed to remove impurities, sundried and then shredded into powder using the shredding machine at a recycling and shredding company, Aleshinloye, Ibadan Oyo State.

Board Formation

The board was based on plastics/fiber mixing ratio of 1:1, 2:1 and 3:1 (plastics/fiber) and nominal composites density of $500kg/m^3$, $600kg/m^3$ and $700kg/m^3$ by weight. The dried homogenous composite mixture was formed uniformly by spreading the particle mix inside a fabricated mould of dimension 200mmx200mmx10mm. The mould containing the homogenous mix was placed inside the hot press and compressed for 5 minutes under exerted constant pressure of $1.23N/mm^2$ and lowered temperature of 175°C±5 to prevent degradation of the bamboo particles. Thereafter, the mould was then removed immediately from the hot press and the boards demoulded and allowed to cool to a temperature of 25−40°C. The edges of the final board were then trimmed off and the boards were cut into standard sizes for tests.

Mechanical Strength Assessment

The mechanical properties (tensile strength, modulus of rupture and modulus of elasticity) were carried out according to ASTM D 638 by using INSTRON Universal Testing Machine. The test samples were machined to specimen according to ASTM D638 (Type I tensile bar) of predetermined dimensions. Specimens were placed in the grips of the INSTRON at a specified grip separation and pulled until failure occurred. Other samples were subjected to three-point bending force. The tensile strength (TS), modulus of rupture (MOR) and modulus of elasticity (MOE) were recorded and obtained from the machine. The boards were cut into 50 mm (width) × 195 mm (length) for assessment of MOE, MOR and TS which were calculated using equations 1, 2 and 3:

$$MOE = \frac{PL^3}{4bd^3H} \quad (1)$$

$$MOR = \frac{3PL}{2bh^2} \quad (2)$$

$$Tensile\ Strength = \frac{load\ at\ break}{original\ cross\ sectional\ area} \quad (3)$$

where: Pb is the maximum load (N), Pbp the load at the proportional limit (N), Yp the deflection corresponding to Pbp (mm), b the width of the specimen (mm), h is the thickness of the specimen (mm), L the span (mm), and original cross sectional area = original width x original thickness.

Water Absorption Assessment

The sorption properties were determined according to the procedures of ASTM, (2005). The dimension of the test samples used for this test was 50mmx50mm. The initial thickness and weight of the samples were measured and recorded before and after 24 hours immersion in water 25°C. The percentage water absorption and thickness swelling for each test samples were calculated using equations 4 and 5:

$$WA(t) = \frac{W(t)-W_0}{W_0}\ x\ 100 \quad (4)$$

where: WA (t) is the water absorption at time t, W_0 is the dried weight and W (t) is the weight of specimen at a given immersion time t.

$$TS(t) = \frac{T(t)-T_0}{T_0}\ x\ 100 \quad (5)$$

where: TS (t) is the thickness swelling at time *t*, T_0 is the initial thickness of specimens and T (t) is the thickness at time t.

Experimental Design and Statistical Analysis

The experimental design for the study was a 3x3 factorial experiment in a Completely Randomized Design (CRD), the combination of which gives nine (9) treatments. This consists of three (3) mixing ratio (1:1, 2:1 and 3:1) and three (3) board density (500kg/m^3, 600kg/m^3 and 700kg/m^3). The data collected were subjected to Analysis of Variance (ANOVA), while Mean Separation was carried out for significantly different parameters by using the Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Water absorption (WA) and thickness swelling (TS)

The mean values for WA and TS of the bamboo plastic composite board as presented in Table 1 ranged from 31.96% to 4.83% and 4.15% to 1.40% respectively after 24h of water immersion in cold water. The WA and TS of the plastic composites decreased with increase in the board density (BD) and mixing ratio (MR) as illustrated in Fig. 1 and 2. Bamboo Plastic Composites produced at the highest BD of 700kg/m^3 and plastic/fibre mixing ratio of 3:1 had highest dimensional stability. On the other hand boards produced at the lowest board density of 500kg/m3 and mixing ratio of 1:1 had the lowest dimensional stability. This implies that at the highest level of board density and mixing ratio, the WA and TS of the composites were highly stabilized and resistant to moisture intake with less movement and spring back.

The Analysis of Variance as shown in Table 2 revealed that the board density and mixing ratio had significant effects on WA and TS of the composites produced 5% probability level. Conversely, the two-factor interaction of the BD and MR (BD*MR) had no significant effects on WA and TS of the composites.

The result of the Duncan's Multiple Range Test (DMRT) analysis as presented in Tables 3 and 4 revealed that significant differences exist in the WA for BD of 500kg/m^3 and 600kg/m^3; 500kg/m^3 and 700 kg/m^3; and 600kg/m^3 and 700 kg/m^3 at 5% probability level. Similarly, for TS there are significant differences between BD of 500kg/m^3 and 600kg/m^3; 500kg/m^3 and 700 kg/m^3; while there is no significant difference between BD of 600kg/m^3 and 700 kg/m^3. There are significant differences in the WA and TS for mixing ratio of 1:1 and 2:1; 1:1 and 3:1; and 2:1 and 3:1 at 5% probability level of significance. The occurrence observed above suggests that BD and MR have significant effects on the WA and TS of the Bamboo Plastic Composites.

Generally, WA in WPCs is governed by two significant mechanisms: the hygroscopic nature of natural fillers/fibers and the penetration of water into the composites (diffusivity) via gaps and flaws at the interfaces between fibers and plastics (Baysal *et al*. 2007, Beg and Pickering 2008). Joseph *et al*. (1995) reported that when WPC material comes in contact with water, the wood particles at the surface absorbs water and starts to swell resulting in localized yielding in polymer matrix. He further stated that, micro-cracks start to form in polymer matrix, which decreases mechanical properties and facilitates water intrusion into the core of the cross-section. The decreasing WA with increasing MR as observed validates the findings of Nemli, (2006) who affirmed that there is a tendency in which the WA decreases with increasing of adhesive ratio. WA is directly proportional to TS. This is an indication that higher proportion of the thermoplastics enhances the composite board stability as similarly observed by Aina *et al*., (2012) Ajayi and Aina (2010a) and Ajayi and Aina (2012).

The values of WA which ranged between 4.83% and 31.96% as obtained far exceed values reported by Aina *et al*., (2012) which range between 0.12% and 10.33% and values reported Jack (2007) on commercial Trex and Nexwood WPCs products. The reported WA rate for Trex was 1.7% for unsanded and 4.3% for sanded samples. The reported value for Nexwood was less than 0.8%. Conversely, Anatol, (2007) asserted that WPC materials will absorb variable amounts of moisture, some more, some less. This can be attributed to the method of production such as extruded and injection methods which will impact more internal bond strength to the WPC particles unlike the compressed method adopted in this study, as similarly observed in the study of Ayrilmis *et al*., (2012) on the effects of fire retardants on physical, mechanical, and fire properties of flat-pressed WPCs using polypropylene (PP), and fire retardant (FR) powders with maleic anhydride-grafted PP. Types of production machine play a big role in WPC processing and output quality. Moreover, the composites produced did not contain any water fixated additives that are commonly used in commercial samples to decrease water absorption. The incorporation of water phobic additives in WPC can further reduce water absorption significantly.

Tensile strength, modulus of elasticity (MOE) and modulus of rupture (MOR)

The mean values obtained for tensile strength, MOE and MOR of the Bamboo Plastic Composites as presented in Table 1 range from 2.55Mpa to 6.98Mpa, 5564.11Mpa to 10771.65Mpa and 0.60Mpa to 4.29Mpa respectively. The tensile strength, MOR and MOE increased with increase in BD from 500kg/m^3 to 700kg/m^3 and MR from 1:1 to 3:1. This implies that the composites with highest strength and stiffness were produced at the highest BD 700kg/m^3 and MR of 3:1. This therefore suggests that the higher the BD and MR, the higher the resistance to stress elongation, stiffness and bending strength of the composite board (Fig. 3 to 5).

The analysis of variance as presented in Table 2 showed that the board density (BD) and mixing ratio (MR) had significant effects on the tensile strength, modulus of elasticity and modulus of rupture of the composites produced 5% probability level. The two-factor interaction of the BD and MR (BD*MR) also had significant effects on for tensile strength and modulus of rupture of the composites, while the effect of the two-factor interaction of the BD and MR (BD*MR) for modulus of elasticity was not significant.

The result of the DMRT analysis in Tables 3 and 4 revealed that significant differences exist between BD of 500kg/m^3 and 700kg/m^3; 600kg/m^3 and 700kg/m^3 for tensile strength, 500kg/m^3 and 600kg/m^3; 500kg/m^3 and 700kg/m^3; and 600kg/m^3 and 700 kg/m^3 for modulus of rupture, and between 500kg/m^3 and 700 kg/m^3 for modulus of elasticity at 5% probability level. In the same vein, there are significant differences in the tensile strength and modulus of rupture for mixing ratio of 1:1 and 2:1; 1:1 and 3:1; and 2:1 and 3:1. Significant differences also exist between MR of 1:1 and 3:1; and 2:1 and 3:1 for the modulus of elasticity at 5% probability level of significance. The implication of the above inference is that the BD and MR of the Bamboo Plastic Composite board had significant effects on the tensile strength, MOE and MOR properties of the board (Table 3).

Ajayi (2006) reported that the rigid nature of the board at the highest levels may be attributed to increase in binder content, which is responsible for increase in hardness of the board as it showed highest resistance to bending force. The higher proportion of plastic and low bamboo particles in the composites according to Ajayi and Aina, (2012) may cause enhanced flexural property of the board. When plastic occupy more volume in the composite, the area of stress concentration around the component particles are more compacted, resulting in increased resistance to applied stresses. The trend of result of findings is in line with preceding result studies of Aina and Fuwape, (2008); Ajigbon and Fuwape, (2005); and Aina, *et al*., (2012). Andrea *et al*., (2008) and Ajayi and Aina (2010b) acknowledged that most of the physical and mechanical properties WPC depend mainly on the interaction developed between wood and the thermoplastic material. The findings of this study corroborated with the assertion of Anatol, (2007) that decrease in density and increase in porosity affects practically all important properties of WPC boards. The lower the density, the lower the flexural strength and flexural modulus. According to him, correlation relationship exists between board density and strength properties of WPC.

Table 1
Board properties of Bamboo Plastic Bonded Board

Density	Mixing Ratio	WA (%)	TS (%)	Tensile (MPa)	MOE (MPa)	MOR (MPa)
500kg/m^3	**1:1**	31.96	4.15	2.55	5564.11	0.60
	2:1	24.03	3.46	3.18	7498.24	0.69
	3:1	10.71	2.76	4.48	7830.09	1.10
600kg/m^3	**1:1**	26.66	3.59	2.57	6661.93	0.67
	2:1	12.33	2.35	4.06	7591.78	1.35
	3:1	6.15	1.64	4.89	10410.02	2.91
700kg/m^3	**1:1**	18.20	2.97	3.13	8261.31	1.14
	2:1	11.97	2.19	4.24	9131.47	2.22
	3:1	4.83	1.40	6.98	10770.65	4.29
SE±		**1.85**	**0.37**	**0.18**	809.73	**0.17**

*values represent means of five (5) replicates MPa: Megapascal

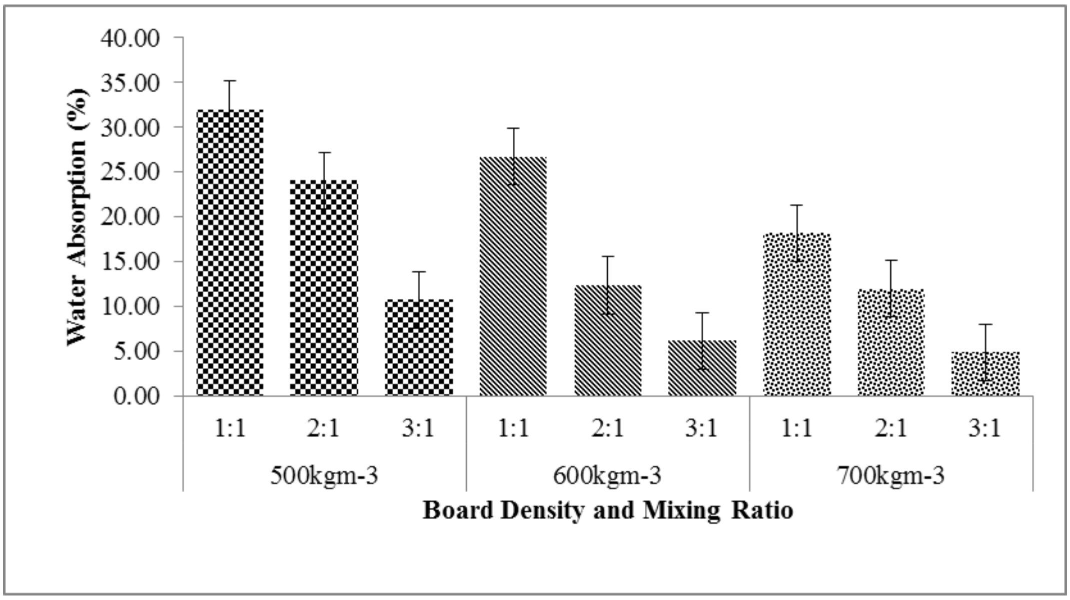

Fig. 1.
Effect of Board Density and Mixing Ratio on Water Absorption of the Bamboo Plastic Composites.

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Vol. 11 N° 3 2015
pp. 21-30

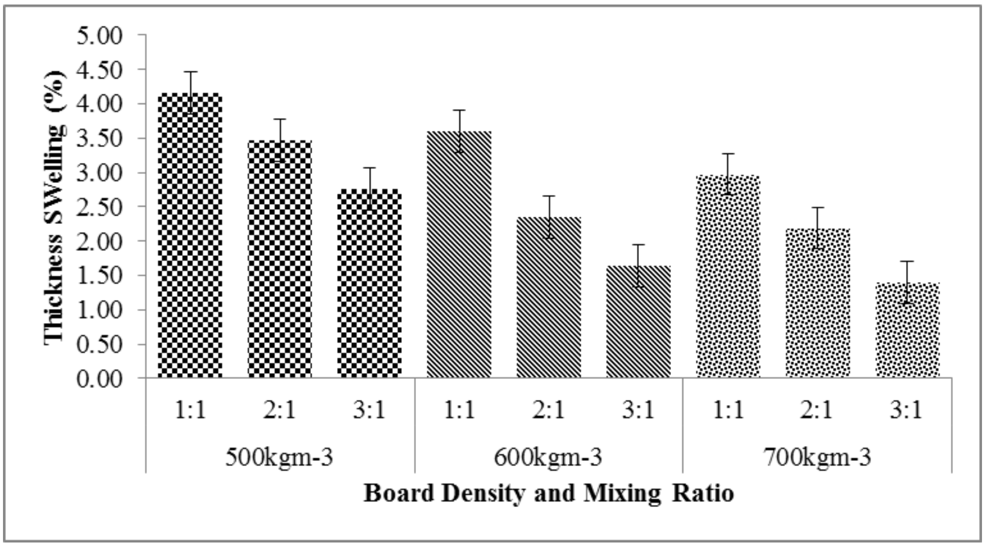

Fig. 2.
Effect of Board Density and Mixing Ratio on Thickness Swelling of the Bamboo Plastic Composites.

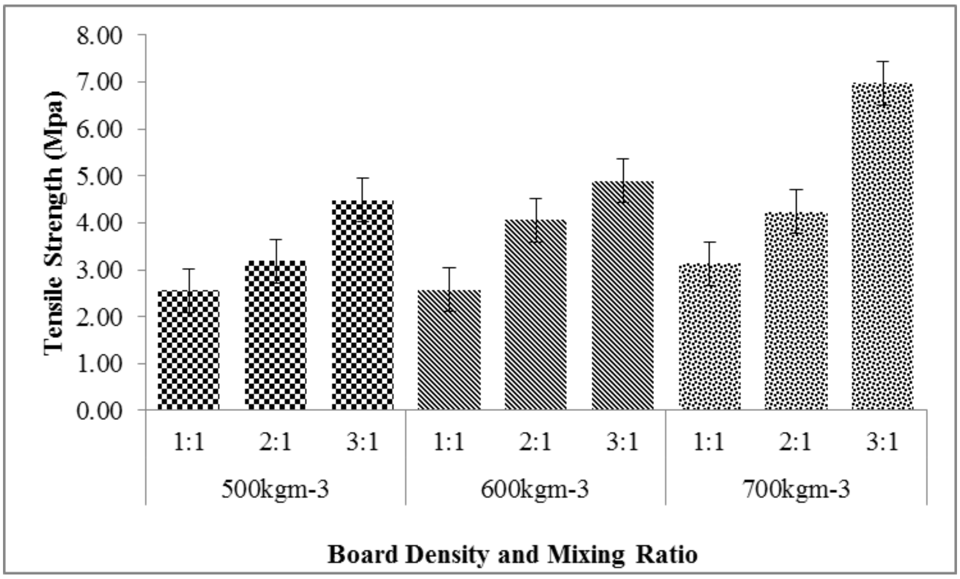

Fig. 3.
Effect of Board Density and Mixing Ratio on Tensile Strength of the Bamboo Plastic Composites.

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PRO LIGNO
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Vol. 11 N° 3 2015
pp. 21-30

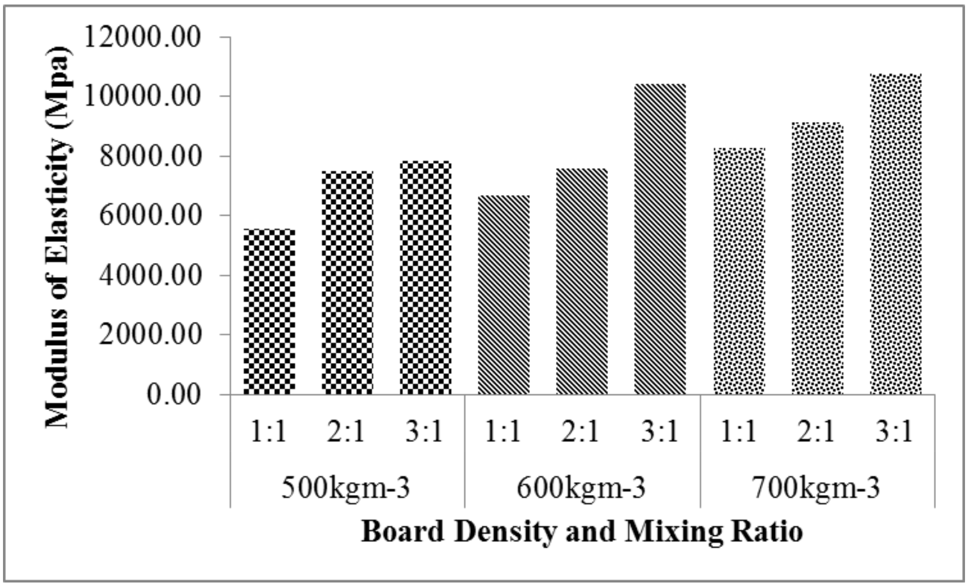

Fig. 4.
Effect of Board Density and Mixing Ratio on Modulus of Elasticity of the Bamboo Plastic Composites.

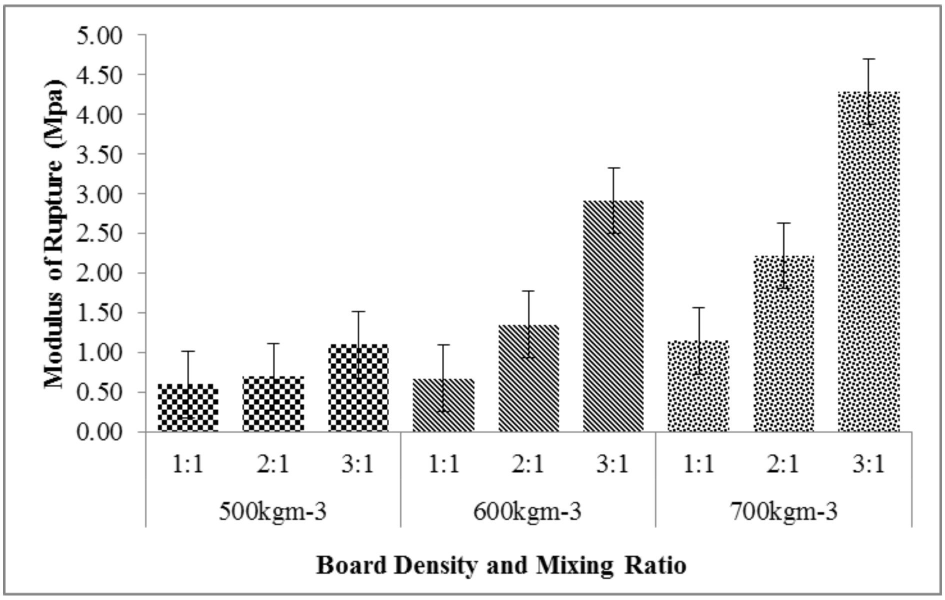

Fig. 5.
Effect of Board Density and Mixing ratio on Modulus of Rupture of the Bamboo Plastic Composites.

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www.proligno.ro
Vol. 11 N° 3 2015
pp. 21-30

Table 2
Analysis of Variance for the effects of Board Density and Mixing Ratio on Properties of the Plastic Composites

		Sig.				
Source	**df**	**WA**	**TS**	**Tensile**	**MOE**	**MOR**
BD	2	0.000*	0.001*	0.000*	0.007*	0.000*
MR	2	0.000*	0.000*	0.000*	0.002*	0.000*
BD * MR	4	0.077ns	0.927ns	0.020*	0.638ns	0.006*
Error	18					
Total	26					

* significant ($p \leq 0.05$) ns - not significant

Table 3
Result of Duncan's Multiple Range Test of Effects of Board Density on Properties of the Plastic Composites

Board Density	WA (%)	TS (%)	Tensile (Mpa)	MOR (Mpa)	MOE (Mpa)
500kg/m^3	22.23^a	3.46^a	3.40^b	0.79^c	6963.9^b
600kg/m^3	15.05^b	2.53^b	3.84^b	1.64^b	8219.6^{ab}
700kg/m^3	11.66^c	2.19^b	4.78^a	2.55^a	9387.7^a
SE±	1.07	0.21	0.18	0.17	4.67

Means in the same column having the different superscript are significantly different ($p \leq 0.05$)

Table 4
Result of Duncan's Multiple Range Test of Effects of Mixing Ratio on the Properties of the Plastic Composites

Mixing Ratio	WA (%)	TS (%)	Tensile (Mpa)	MOR (Mpa)	MOE (Mpa)
1:1	25.61^a	3.57^a	2.75^c	0.80^c	6828.6^b
2:1	16.11^b	2.67^b	3.83^b	1.42^b	8073.0^b
3:1	7.23^c	1.93^c	5.45^a	2.77^a	9669.6^a
SE±	1.07	0.21	0.18	0.17	4.67

Means in the same column having the different superscript are significantly different ($p \leq 0.05$)

CONCLUSION

The study revealed that plastic composites can be effectively produced at lab scale from bamboo fibers. As the board density and mixing ratio increased, tensile strength, MOE and MOR increased, while WA and TS decreased. Bamboo Plastic Composite produced at the highest BD of 700kg/m^3 and highest MR of 3:1 showed the highest dimensional stability and thickness reduction, as well as improved bending and stiffness properties. BD and MR had significant effects on WA, TS, MOE, MOR and tensile strength properties of the composites. Composite materials are not load-bearing or structural members and they are not as strong as traditional hardwood. And as such WPCs are mostly used for non-structural applications where high strength properties are not required but high water and humidity resistance. This study has opened up a platform for investigating the suitability and compatibility of LDPE such nylon, polybags, packaging nylons and other forms of plastic materials for the manufacturing of WPC, enhance environmental cleanliness alleviate poverty through plastic gathering and sales.

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