Strength and Thermal Stability of Fiber Reinforced Plastic Composites made from Rattan Canes

[1*]ADEFISAN O.O., [2]J.S. FABIYI & [3]K. ENGLUND

[1]Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Oyo State, Nigeria.
Email: femiadefisan@hotmail.com

[2]Department of Forestry and Wood Technology, Federal University of Technology, Akure, Ondo State, Nigeria.
[3]Composite Materials and Engineering Center, Department of Civil & Environmental Engineering, Washington State University, Pullman WA
E-mail: jamesreb2004@yahoo.com;

Abstract

Rattans have been used for various purposes ranging from furniture and art works to cement composites. Plastic composites are however more dimensionally stable than cement composites because plastic creates a moisture barrier against water ingress. There is paucity of information on properties of plastic composites made from rattan canes. Therefore, the strength properties and thermal stability of plastic composites reinforced with rattan fibers were investigated in this work. Particles of rattan species (*Eremospatha macrocarpa* (EM) and *Laccosperma secundiflorum* (LS)) were blended with High-Density Polyethylene (HDPE) to produce fiber reinforced plastic composites (FRPC) viz: EM, LS and EM+LS using formulations of 50:41 and 55:36 rattan: HDPE. Flexural tests and dimensional stability (water absorption and thickness swelling) of the rattan composites were determined. The results obtained revealed that the rattan composites possessed adequate strength and had low water absorption and thickness swelling rates. The water absorption of the composites was influenced by the increase in rattan content while the thickness swell and Modulus of Rupture (MOR) were not significantly different for the two rattans. However, Modulus of Elasticity (MOE) of LS-HDPE

composites was significantly higher than for EM-HDPE composites. Increase in rattan content caused reduction in MOR but increased the MOE of FRPC. Thermogravimetric analysis results revealed that HDPE in EM+LS/HDPE were less thermally stable than EM/HDPE or LS/HDPE.

Keywords: Rattans, fiber reinforced plastic composites, dimensional stability, thermal stability

Introduction

The demand for solid wood and wood based products is increasing because they are valued for use in the construction industry. Unfortunately, deforestation resulting from land clearance for agricultural crops cultivation, industrial estates, and residential building construction are problems confronting the supply of solid lumbers. The challenges posed by an increasing market demand for wood products because of a growing world population, disadvantages associated with solid wood (especially dimensional stability, width limitation, biodegradation), and deforestation require the need for alternative products that encompass the attributes that consumers of solid wood want (Fuwape and Fabiyi, 2003). This can be obtained by engineering wood and other fibrous raw materials into a number of alternative products which include cement bonded composites, laminated veneer lumber, fiber reinforced plastic composites (FRPC) etc. (Fabiyi et al., 2010). The abundance and availability of these natural fibers at low cost being derivable from various parts of Non-Timber Forest Products (NTFP) make them viable candidates for fiber reinforced plastic composites. Some of the NTFP like kenaf, bamboo and hemp have been used to produce FRPC (Ribot et al., 2011). This is because incorporation of plastic matrix creates a moisture barrier which prevents the ingress of water. Unfortunately, there is dearth of information on the use of rattan canes for FRPC production.

Rattan (from the Malay *rotan*) consists of approximately 600 species of palms in the Family *Calameae*; the stems are very similar to bamboo but thinner in size. They are fast growing and short cycled harvestable plants commonly found in the tropical regions of Africa, Asia and Australasia (FAO, 2002). Rattan industry was estimated to worth about US$6.5 billion per annum (ITTO, 1997). There are three major rattan species namely: *Eremospatha macrocarpa* (Mann & Wendl.), *Laccosperma secundiflorum* (P. Beauv.) and *Calamus deerratus* (Mann & Wendl.) found in Nigeria (Dahunsi,

2002). Adefisan (1999) reported that *E. macrocarpa* has diameter of 10-17 mm and stem length of 20-25 mm while *L. secundiflorum* has diameter of 10-20 mm and stem length of 10 mm. The most important product of rattan palms is cane; this is the rattan stem stripped of its leaf sheaths. The canes are used extensively by local communities and play an important role in subsistence strategies for many rural populations (Dransfield, 1992; Sunderland, 1998). Rattan is a very good material mainly because it is lightweight, strong, durable and flexible. Also, different rattan species exhibit different physical and anatomical structures which may affects their utilisation (Adefisan, 2010). The range of indigenous uses of rattan canes is vast; from bridges to baskets; from fish traps to furniture; from crossbow strings to yam ties; from handicraft to housing materials (FAO, 2002).

Rattan was chosen for this study because it now constitutes a recognizable waste in the furniture and art industries in Nigeria. They are now being considered as alternative furnish for composites production as they can cushion the effects of the over exploitation and increasing demand for wood (Adefisan, 2010; Fabiyi et al., 2010). However, the choice of natural fiber for plastics applications depends not only on its availability but also on the composite's properties needed for the specific application. It is worth noting that rattan is polar while thermoplastic is non-polar and the compatibility between both materials may cause interface problem. In most cases, the interaction and interface developed between lignocellulosic materials and plastic contribute to the physical and mechanical properties of FRPC. One of the ways to improve this interaction and interface is by incorporating coupling agents. In the production of the rattan FRPC, the effects of coupling agent and other chemical additives need to be investigated. Also, after production of the composites, the evaluation of some fundamental properties like physical (water absorption and thickness swell), mechanical (flexural moduli of rupture and elasticity and toughness) and thermal behaviour of the rattan FRPC are important for its effective utilization and appropriate application.

The main objective of this study therefore was to investigate the effects of rattan species and fiber content on the physical, mechanical properties and thermal stability of *E.macrocarpa*, *L. secundiflorum* and their mixture (50:50 w/w) based fiber reinforced plastic composites.

Methodology

Production of fiber reinforced plastic composites

Rattan cane species (*Eremospatha macrocarpa* (EM) and *Laccosperma secundiflorum* (LS)) were obtained locally, cut into billets of approximately 6 cm long, and hammer milled to provide a 60 mesh fraction that was dried (0.5% moisture content) prior to blending. The polymer matrix used in this study was high-density polyethylene (HDPE, Equistar Petrothene LB01000, MFI = 0.3 g/10 min, and density = 0.950 g/cm^3) together with the rattan cane species fiber as reinforcement/filler in the fiber reinforced plastic composites (FRPC) production. Three types of FRPC were produced based on the rattan fiber sources viz: EM, LS and EM+LS (50:50). However, two formulations were considered: formulation 'A' consisted of HDPE (41%), rattan fiber (50%), talc (6%, Luzenac), zinc stearate (2%) and ethylene bistearamide (EBS) wax (1%) while formulation 'B' consisted of HDPE (36%), rattan fiber (55%), talc (6%, Luzenac), zinc stearate (2%) and ethylene bistearamide (EBS) wax (1%). Materials were compounded and extruded on a 35 mm counter rotating conical twin-screw extruder (Cincinnati Milacron) to a profiled dimension of 9.5 mm × 38 mm. The barrel and die temperatures were set between 149 and 193°C. The extruded profiles were then knife milled to a thickness of 5.0 mm for the physical and mechanical properties testing because many commercial wood plastic composites products are surface finished.

Properties characterization of fiber reinforced plastic composites physical and mechanical properties

Water absorption (WA) and thickness swell (TS) tests were conducted following a modified ASTM D 570-95 (2002) procedure. Five replicate specimens (5 mm × 20 mm × 50 mm) from each HDPE/rattan species and their combination were immersed in tap water at room temperature for 2, 24 and 48 hours. Weight gain and thickness swell were measured on a total composite basis for determination of WA and TS, respectively. Three point flexural tests (modulus of rupture (MOR) and modulus of elasticity (MOE)) were performed in accordance with ASTM D 790-00 (2001). Five replicates were used for each FRPC type (20 mm × 5.73 mm × 115 mm) and test conducted on an Instron 5500R Universal test machine equipped with a 454 kg load cell (speed head was 1 mm/s). Data was collected and processed using Bluehill software (Instron).

Thermal characterization

Thermogravimetric analysis (TGA) was conducted using a Perkin Elmer TGA 7 Thermogravimetric Analyzer. Samples of 4–5 mg were randomly obtained from the thoroughly mixed ground sample. Specimens per FRPC were analyzed at a heating rate of 20°C/min from 25 to 600°C in a nitrogen atmosphere (flow rate 60 mL/min). The weight change was recorded as a function of temperature. Derivative peak temperature was taken as the maximum temperature acquired from the differentiation of the weight change as a function of temperature.

Results and Discussion

Physical property

The water absorption (WA) ranged from 0.8 to 3.9%, 0.8 to 3.5%, and 0.9 to 3.5% for the *E. macrocarpa*, *L. secundiflorum* and their mixtures, respectively after 2 and then 48 h water soak. The thickness swell (TS) were between 0.4 to 1.4%, 0.5 to 1.7%, and 0.5 to 1.4% for EM-HDPE, LS-HDPE and their mixtures respectively (Tables 1 and 2). The rattan composites were dimensionally stable with low WA and TS which compared very closely to those reported in literature (Migneault, 2008; San, 2008; Shirp and Stender, 2010; Fabiyi and McDonald, 2010). The effect of blending ratios of 50:41 and 55:36 (rattan: HDPE) on the physical properties (WA and TS) of the FRPC as shown in Table 1 revealed that the WA increased with increase in the fiber content. This is an indication that increase in rattan fiber content provided more hydroxyl group (water-residence sites) thereby causing more water to be absorbed. The comparison among the rattan fiber types (EM, LS and EM+LS) revealed that the blending ratio of rattan and HDPE and the rattan fiber content significantly ($p>0.05$) affected the WA of the plastic composites (Table 1).

Table 1: Water absorption of rattan fiber reinforced high density polyethylene composites

Blending Ratio (%)	Rattan /HDPE	WA (%)		
		2h	24h	48h
	E. macrocarpa/HDPE	1.2^{G} (0.67)	3.1^{C} (0.28)	3.9^{A} (0.30)
50: 41	*L. secundiflorum*/HDPE	1.0^{GH} (0.04)	2.4^{EF} (0.02)	3.1^{C} (0.04)
	EM + LS/HDPE	0.9^{HI} (0.10)	2.3^{F} (0.06)	3.0^{C} (0.13)
	E. macrocarpa/HDPE	0.8^{I} (0.02)	2.8^{D} (0.10)	3.6^{B} (0.10)
55:36	*L. secundiflorum*/HDPE	0.8^{I} (0.10)	2.5^{DE} (0.08)	3.5^{B} (0.06)
	EM + LS/HDPE	1.0^{GH} (0.12)	2.6^{DE} (0.04)	3.5^{B} (0.02)

- Means with the same letters are not statistically different
- Standard Deviation in Parentheses

The WA of EM based composites was generally higher than those of LS and EM+LS. This observation could be attributed to differences in the anatomical structures of EM and LS canes. While the former have preponderance of parenchymacells (storage tissues), the latter have higher presence of sclerenchyma cells (strengthening tissues) (Dahunsi, 2000; Adefisan, 2010;).

The increase in the rattan fiber content however did not significantly affect the TS of the rattan/HDPE composites irrespective of the fiber type (EM, LS and EM+LS). Additionally, the blending ratio at 50:41 showed that LS composites had higher TS than EM but no significant difference was observed for EM and EM+LS fiber reinforced composites. The reduction in the plastic content from 41 to 36% and increase in rattan content from 50 to 55% did not significantly ($p>0.05$) affect the TS for all the three composites types (Table 2). What this indicates is that irrespective of the plastic and / or the rattan content studied, plastic composites made from rattan particles had low TS. Hence they could be adopted for both indoor and outdoor applications.

Table 2: Thickness Swelling of Rattan Fiber Reinforced High Density Polyethylene Composites

Blending Ratio (%)	Rattan /HDPE	TS (%)		
		2h	24h	48h
50: 41	*E. macrocarpa*/HDPE	0.4^{D} (0.12)	1.0^{C} (0.31)	1.4^{AB} (0.38)
	L. secundiflorum/HDPE	0.6^{D} (0.05)	1.1^{BC} (0.03)	1.4^{AB} (0.09
	EM + LS/HDPE	0.5^{D} (0.26)	0.5^{D} (0.26)	1.2^{BC} (0.13)
55:36	*E. macrocarpa*/HDPE	0.4^{D} (0.04)	1.0^{C} (0.08)	1.3^{B} (0.06)
	L. secundiflorum/HDPE	0.5^{D} (0.08)	1.2^{BC} (0.01)	1.6^{A} (0.09)
	EM + LS/HDPE	0.5^{D} (0.19)	0.5^{D}(0.19)	1.4^{AB} (0.01)

- Means with the same letters are not statistically different
- Standard Deviation in Parentheses

Mechanical property

The modulus of rupture (MOR) ranged between 25.6 to 26.0 MPa, 24.0 to 25.8 MPa and 26.1 to 28.3 MPa for the *E. macrocarpa*, *L. secundiflorum* and their mixtures, respectively while the modulus of elasticity (MOE) were

between 2.67 and 2.77 GPa, 3.21 and 3.53 GPa and 2.95 and 3.24 GPa, respectively (Table 3). These values were comparable with those obtained by Fabiyi and McDonald (2010) who recorded MOR values of 21.1, 22.7, 24.3, 24.9 and 22.7 MPa and MOE of 2.0, 1.8, 2.6, 2.6 and 1.5 GPa for HDPE based white oak, black locust, Douglas fir, hybrid poplar and ponderosa pine composites, respectively.

Table 3: Mechanical properties of rattan fiber reinforced high density polyethylene composites

Blending Ratio (%)	Rattan/HDPE	MOR (MPa)	MOE (GPa)	Work to Max load (J)
50: 41	*E. macrocarpa*/HDPE	26.0 ± 0.8^{B}	2.67 ± 0.05^{B}	1.2 ± 0.1^{B}
	L.secundiflorum/HDPE	25.8 ± 0.9^{B}	3.21 ± 0.42^{A}	0.9 ± 0.1^{C}
	EM + LS/HDPE	28.3 ± 1.4^{A}	2.95 ± 0.22^{AB}	1.5 ± 0.1^{A}
55:36	*E. macrocarpa*/HDPE	25.6 ± 0.6^{AB}	2.77 ± 0.11^{B}	1.1 ± 0.1^{A}
	L.secundiflorum/HDPE	24.7 ± 0.9^{B}	3.53 ± 0.32^{A}	0.9 ± 0.1^{B}
	EM + LS/HDPE	26.1 ± 0.6^{A}	3.24 ± 0.20^{A}	1.0 ± 0.1^{A}

- Means with the same letters are not statistically different

The increase in the rattan fiber content did not significantly affect the flexural MOR of the rattan/HDPE composites produced except for the EM+LS (Table 3). However, the flexural MOE increased significantly with the increase in the quantity of rattan content irrespective of the rattan / HDPE composites type. Increase in fiber content could be responsible for the improvement in a uniform stress distribution between HDPE matrix and rattan fiber as well as enhance good dispersion of rattan fibers. At any given rattan fiber content considered in this study, there was no significant difference in MOR between EM and LS (Table 3). However, the MOR of mixtures of EM and LS at both blending proportions (50:41 and 55:36 of rattan to HDPE ratio) were significantly higher than its corresponding EM or LS composites. Significant differences in MOE were observed for both blending proportions among the three rattan fiber types which ranked as LS> EM+LS >EM (Table 3). Again, the differences in the proportions of sclerenchyma and parenchyma cells in the *L. secundiflorum* and *E. marcocarpa* could be responsible for the higher flexural MOE exhibited by LS than EM based composites. *L. secundiflorum* has higher proportions of sclerenchyma than parenchyma cells while the proportion of sclerenchyma cells is lower than that of parenchyma cells in the *E. marcocarpa* (Dahunsi, 2000; Adefisan, 2010). Therefore, the stiffer composites produced from LS than EM fiber is a reflection of its anatomical property.

The flexural strength (MOR) slightly decreased with increase in the rattan fiber content because of the poor interfacial bonding and the presence of agglomerate fillers (Kord, 2011). The presence of fillers cause reduction in the ductility of WPC but increase its stiffness. This agrees with the fact that fillers added to a polymer restrain the movement of its chains thereby causing its modulus/stiffness reduction (Oksman and Clemon, 1998; Bledzki and Gassan, 1999).

Table 3 showes that the shock resistance (work to maximum load) between the 50:41 and 55:36 formulations was not significantly different ($p>0.05$) for *E. macrocarpa*/HDPE and *L. secundiflorum*/HDPE composites. However, the HDPE based composites produced from the mixture of the two rattan species (*E. macrocarpa* and *L. secundiflorum*) showed that the shock resistance of 50:41 formulation was significantly higher than that of 55:36 formulation ($p<0.05$). This implies that there is no difference in the energy required to cause fracture or crack in the composites of these two formulations irrespective of the rattan species. However, the mixture of these rattan species based HDPE composites required less energy to cause fracture in the composites with higher quantity of rattan fiber.

Thermal stability characterization

The TGA curves of rattan/HDPE composites are shown in Fig.1. All curves show a small weight loss before 100°C, which can be attributed to the evaporation of the insignificant amount of moisture that the rattan/HDPE composites samples contained. The weight loss due to thermal degradation of the FRPC occurred in three distinctive stages. The first and second degradation peaks can be attributed to the lignin and cellulose while the third degradation peak is attributed to the degradation of C-C bonds of plastic matrix (HDPE) (Bledzki and Gassan, 1999; Fabiyi and McDonald, 2010).

The rate of lignin (from rattan) degradation at 309°C for EM, LS and EM+LS based composites differed. The EM/HDPE composites ranked the highest followed by LS/HDPE composites while the lowest degradation rate of lignin was observed in the mixed rattan based composites. Though the cellulose degradation rate at 360°C was similar for both rattan species, the lowest degradation rate was observed in the mixed rattan based composites. The plastic matrix (HDPE) in the composites degraded differently contrary to the rattan species fiber sources in the composites.

The HDPE in the mixed rattan (LS+EM) based composites had the highest degradation rate while the EM and LS based composites had no significant variation in the degradation rate of the HDPE.

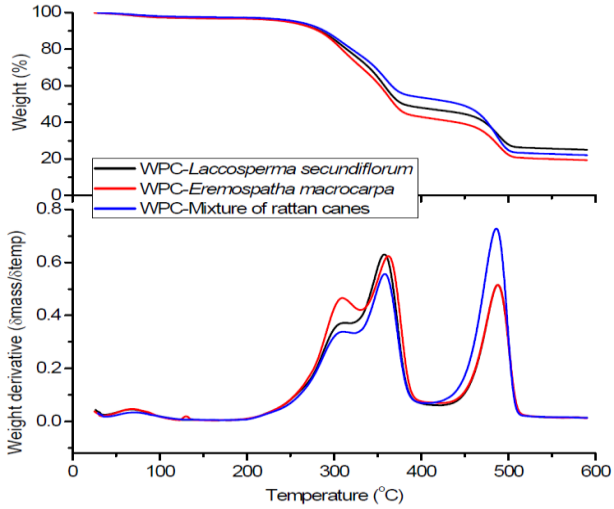

Figure 1: TGA thermograms of the thermal stability of rattan fiber reinforced plastic composites with weight loss (top) and first derivative δmass/ δtemp plots (bottom)

Generally, the mixed rattan based composites experienced low degradation temperatures for the rattan and plastic matrix components; hence, it is less thermally stable than either EM/HDPE or LS/HDPE composites. The thermal stability of both EM/HDPE and LS/HDPE composites in relation to rattan and plastic matrix components was similar. The practical implication is that when rattan/HDPE composites considered in this study are to be deployed for any high temperature applications, it is preferable to employ composites produced from either EM or LS with less consideration for the mixture of the two species. What this means is that when rattan plastics are to be deployed in high temperature situations, it is better to utilise rattan from either ES or LS as furnish instead of their mixtures. The high stability of LS and mixed rattan could be due to higher cellulose content in the LS fiber. This is in agreement with the findings of a study conducted on wood by Tserki et al., (2005).

Conclusions

It is feasible to produce fibre reinforced plastic composites from rattan canes. The rattan plastic composites studied were dimensionally stable with low sorption rates, possessed adequate strength comparable with those in literature and were thermally stable. The differences in the anatomical structures of the rattan species investigated may be responsible for the variation in the observed strength properties of the rattan composites.

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