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Characteristics of three western Nigerian rattan species in relation to their utilisation as construction material

E. B. LUCAS [1] and B. I. O. DAHUNSI [2,*]

[1] *Department of Agricultural Engineering, University of Ibadan, Nigeria*
[2] *Department of Civil Engineering, University of Ibadan, Nigeria*

Abstract—Physical and mechanical properties of three rattan cane species, *Calamus deerratus, Eremospatha macrocarpa* and *Laccosperma secundiflorum*, were evaluated. The objective was to determine their suitability for construction, especially for structural members. Proximate analyses as well as mineral contents were also determined. The moisture content and density of green samples were 155% (dry basis) and 587 kg/m^3, respectively. *L. secundiflorum* had the highest carbohydrate content while *C. deerratus* had the least. Radial shrinkage and swelling exceeded longitudinal shrinkage and swelling in all the rattan species, suggesting high anisotropism in movement. Moisture content had significant effect ($P < 0.05$) on the moduli of elasticity and rupture of all the rattan species. The moduli of elasticity of *C. deerratus*, *E. macrocarpa* and *L. secundiflorum* were 3396, 516 and 11 106 N/mm^2 respectively. The strength properties of the rattan canes were found to be lower than those of timber species of comparable densities. The physical and mechanical properties of the rattan canes studied were found to be adequate for use as reinforcement in lowly stressed concrete elements, such as frameworks for ferrocement and complex shaped formworks.

Key words: Rattan species; physical properties; mechanical properties; construction material; proximate analysis; mineral analysis.

INTRODUCTION

Rattans are non-wood forest products, whose economic value is well exploited in the far Eastern Countries, especially Malaysia, Indonesia, Singapore and the Philippines. More than 700 million people, spread all over the world, trade in or use rattan for a variety of purposes [1]. Furniture, however, is the most popular rattan product. In Nigeria, rattans remain a great potential, only now being slightly tapped. The share of rattan and cane products in Nigeria's gross domestic products is negligible [2]. Knowledge of their properties should enhance industrial utilization

*To whom correspondence should be addressed. E-mail: biodahunsi@engineer.com

locally and improve on its possible contribution to Nigeria's economy. There are about 600 species of rattan belonging to 13 genera. Sunderland [3] reported that 20 species from 4 genera have been identified in West and Central Africa. He further stated that the four genera of African rattan are easy to differentiate, particularly through the morphology of their climbing organs. The rattan stem diameter varies greatly, from 2 to 3 mm among the smallest species to 100 mm in exceptionally large species [4]. Rattans with a stem diameter of 18 mm and above are classified as large-diameter canes, while the others are the small-diameter canes. Rattans have been found to grow to great heights; usually around 46 m, but may reach as much as 150 m [5].

Rattan canes, when soaked in water for a day or two, depending upon the temperature of the water, become a softer and more pliable material that can be readily bent into contorted curved shapes [6]. The cortical or outer portion of rattan stem is extremely hard and durable while the medullary or inner portion is soft and somewhat porous [7]. The toughness and appreciable tensile strength of rattan canes have been harnessed to produce highly-stressed articles such as nooses for catching elephants [8]. Purseglove [9] reported the use of rattan for the construction of a swinging bridge over the gorge in Assam, India. He further mentioned the use of rattan as tether-, guy- and tow-ropes. Rattan bridges have also been encountered in some parts of West and Central Africa [3]. Rattans have also been utilized as drag rope for hauling timber and tethering buffaloes [10]. The use of rattan canes for building and general construction works in Southern and Western parts of Nigeria has been observed [2, 11]. The areas of application include frames, walls, partitions, rafters and ceilings of mud houses. They have been used in the construction of articles such as barn, granaries, fishing traps, sieves and winnowers, mats and trays, and also as reinforcement for wall partitions and frames of structures used as stores, market stalls and residential abodes of forest communities. The excellent performance of some rattan canes under stress led Burkill [10] to conclude that there is no natural product that would be able to compete with rattan if adequate supply can be guaranteed at a reasonable price. Dransfield [4] stated that few products have the strength and flexibility for utilization as material for furniture production like those of true rattan.

Dransfield [12] reported that studies on the physical properties of rattan are in their infancy. He stated that the diameter of the internodes and indeed the stem itself does not usually vary significantly along their length and that the cross section is usually more-or-less circular. An investigation to determine the steady state water permeability of some rattan species [13] showed that they obeyed Darcy's law and that permeability of internodal and nodal samples did not differ significantly. The Reynolds number (Re) obtained for rattans was 0.44–2.38, indicating that the flow of liquid in rattan was laminar. A study by Goh [14] concluded that the strength properties of the species of rattan studied by him (*Calamus manan*) were greater in the air-dried condition than those in green condition. He further observed that air-dried material (14.4% moisture content) had a density of 750 kg/m^3 and compression strength parallel to grain of 30 MPa. Kadir [15] mentioned that mechanical properties of rattan canes, as observed in two species investigated by him (*C. scipionum* and *Daemonorops angustifolia*), decreased from the basal to the top portion of the stem. The mechanical properties are also significantly affected by the age of the plant, with the highest values obtained in 12-year-old plants.

The specific and interactive properties of Nigerian canes are hardly documented, unlike in Asia where much work has been done on the properties of Asian rattan species of economic importance. Most of the research efforts on rattan canes in Nigeria have been on its trade and utilization, especially for furniture [2, 16–18]. No records of the physical and mechanical properties of Nigerian rattan canes appear in published works. Sunderland [3] reported that recent research on African rattan has concentrated on providing information on the taxonomy, ecology and utilization. Kadir [15] mentioned that there is a dearth of information on the properties of rattan species. Hence, some of them have remained unutilised. Further research is needed to determine the properties and also the appropriate utilization technology of such species. The chemical and mineral compositions of biological materials are known to have effect on their physical and mechanical properties. Knowledge of the properties of Nigerian rattan canes would indicate the extent to which they can be adopted for structural usage, including as reinforcement in concrete and framework for ferrocement. These areas appear presently untouched.

MATERIALS AND METHODS

The canes from three species of rattan palms were studied. The species are *C. deerratus, Eremospatha macrocarpa* and *Laccosperma secundiflorum*. Matured samples from wild stocks, whose actual ages could not be determined, were obtained from Epe (Lagos State) and Okada/Sapoba (Edo State) forests in Western Nigeria. The rattan samples were carefully collected and their morphological characteristics studied for the purpose of identification. References were made to the stocks of rattan samples kept in the herbarium of the Department of Botany, University of Ibadan, Nigeria.

The following physical properties were determined for the three species of rattan cane; moisture content, density and shrinkage and swelling coefficients. The test samples used in this study were mainly from the middle portions of the harvested plants. Moisture content was determined using the oven-drying method. The dimensions of the rattan canes were measured with vernier calliper and micrometer screw gauge while the weight was determined using an electronic balance.

Proximate and mineral analyses were carried out. Moisture and dry matter contents, fat, crude fibre content, protein content, ash content, carbohydrate content and energy value were determined by the methods recommended by Association of Official Analytical Chemists (AOAC) [19]. The mineral contents determined include calcium, magnesium, potassium, sodium, manganese, iron, copper, zinc and phosphorous. All the minerals, except phosphorous, were determined by use of atomic absorption spectrophotometer as recommended by the AOAC [19]. The phosphorous content was determined using the Vanado-Molybdate method [19].

Static bending tests were carried out on 40 test samples of each species, at four different moisture content levels (20, 16, 12 and 8%) and perpendicular to direction of grains, to determine fibre stress at elastic limit and moduli of rupture and elasticity. This was done by adapting the method used by Sekhar and Rawat [20], in their experiment on the strength properties of an Indian cane (*C. tenuis*). One set was tested with node at the centre while the other was tested without nodes at the centre. For each test, a sample measuring 250 mm was prepared and mounted on two supports of an adapted test jig, at a span of 150 mm. Load was applied at the centre of the specimen till it failed as recommended by ASTM D143 [21]. Deflection of the neutral plane at the centre of the specimen was recorded against load through a dial gauge and load-deflection characteristics were determined for each test specimen. The loads and deflections at the elastic limit were used to evaluate the fibre stresses at elastic limit and modulus of elasticity, while the load that caused complete failure was utilised for modulus of rupture.

RESULTS AND DISCUSSION

Physical properties

The moisture contents and densities of green rattan samples are as shown in Table 1. Green samples of *E. macrocarpa* had the highest average moisture content (188%), while *C. deerratus* had the lowest average moisture content (135%). The results obtained in this study were close to the general values of between 130 and 160% recorded for rattan canes by Liese [22]. The high moisture content of green samples of rattan cane has implications on the weight of freshly harvested rattan cane materials. Therefore, it would be good management practice to season fresh rattan canes before transporting them. High moisture content could also make them susceptible to attack by fungi and insects. It may also result in dimensional instability.

Density of green samples of the rattan species ranged from 487 to 667 kg/m^3 with *C. deerratus* having a density value of 648 kg/m^3, while those for *L. secundiflorum*

Table 1.
Moisture content (green) and density of rattan canes

Rattan species	Moisture content (green) (%)		Density (kg/m^3)	
	Mean	Range	Mean	Range
L. secundiflorum	142	136–181	573	557–606
C. deerratus	135	131–164	648	581–667
E. macrocarpa	188	156–225	539	487–561
Average	155	131–225	587	487–667

and *E, macrocarpa* were 573 and 539 kg/m^3, respectively. The density of biological materials could give an indication of their strength properties, although some lighter species have been known to possess higher strength than denser materials.

Radial shrinkage was higher than longitudinal shrinkage for all the rattan species (Table 2). The average value of radial shrinkage coefficient found to be 720.37×10^{-6} mm/mm per 1% change of moisture content was lower than the average value of 1730×10^{-6} mm/mm per 1% change of moisture content obtained by Lucas and Ogedengbe [23] in their study of the shrinkage characteristics of bamboo (*Bambusa vulgaris*). Radial shrinkage coefficient of *E. macrocarpa* was 423.24×10^{-6} mm/mm per 1% change in moisture content while those for *L. secundiflorum* and *C. deerratus* were 622.24×10^{-6} and 115.62×10^{-6} mm/mm per 1% change of moisture content. The values of longitudinal shrinkage coefficient of the rattan cane species was relatively small, ranging from 61.08×10^{-6} to 130.91×10^{-6} mm/mm per 1% change of moisture content. Radial shrinkage of rattan canes was from 0.0948 to 0.1534 mm/mm. This was higher than the average value of 5% (0.05 mm/mm) recorded by Wijensinghe [24] for woods dried from green to oven-dry condition. The longitudinal shrinkage ranged from 0.0137 to 0.0180 mm/mm. This compared well with the value of around 1% estimated by Wijensinghe [24]. Anisotropic shrinkage of rattan canes may cause distortion that could lead to incipient failure. Some samples of *L. secundiflorum* were observed to have cracks on their surfaces, along their lengths when dried from green to oven-dry moisture levels. These cracks, which are areas of incipient structural failure, can be attributed to differential drying rate of the core to the outer parts of cane, resulting in shrinkage stresses at the outer portions whose drying rates were lower, leading to crack propagation.

The swelling characteristics of the rattan canes are as shown in Table 3. The radial swelling values are 0.1371, 0.1422 and 0.0829 mm/mm for *L. secundiflorum, C. deerratus* and *E. macrocarpa*, respectively. The radial swelling of *L. secundiflorum* was observed to be higher than the corresponding longitudinal shrinkage, while those for the other rattan species were found to be lower. The longitudinal swelling was found to be lower than radial shrinkage for all the rattan species. The

Table 2.
Shrinkage characteristics of rattan canes

Rattan species	Radial shrinkage, S_r (mm/mm)	Longitudinal shrinkage, S_l (mm/mm)	S_r/S_l	Radial shrinkage coefficient (mm/mm per 1% mc $\times 10^{-6}$)	Longitudinal shrinkage coefficient (mm/mm per 1% mc $\times 10^{-6}$)
L. secundiflorum	0.1172	0.0142	8.26	622.4	75.33
C. deerratus	0.1534	0.0180	8.52	1115.62	130.91
E. macrocarpa	0.0948	0.1037	6.92	423.24	61.08
Mean	0.1218	0.0153	7.96	720.37	89.11

Table 3.
Swelling characteristics of rattan canes

Rattan species	Radial swelling, R_s (mm/mm)	Longitudinal swelling, L_s (mm/mm)	R_s/L_s	Radial swelling rate (mm/mm per s$\times 10^{-7}$)	Longitudinal swelling rate (mm/mm per s$\times 10^{-7}$)
L. secundiflorum	0.1317	0.0140	9.79	6.48	6.85
C. deerratus	0.1422	0.0109	13.05	6.58	5.05
E. macrocarpa	0.0829	0.0133	6.28	3.84	6.16
Mean	0.1207	0.0130	9.28	5.59	6.02

differential swelling and shrinkage characteristics may set up stresses within the cane leading to cracks, warping and loss of integrity.

Proximate and mineral analyses

The results of the proximate analyses of rattan canes are given in Table 4, while those of mineral analyses are shown in Table 5. Samples from all the rattan species have more than 70% carbohydrate content with *L. secundiflorum* having the highest value of 79.44% while *C. deerratus* had the least value of 76.90%. Tests using iodine indicated that the carbohydrate content of *L. secundiflorum* was concentrated mainly in its inner portions. Dahunsi [11] reported that the inner portion of *L. secundiflorum* was the main target of subterranean termite due to its high concentration of carbohydrates. The termites ate the inner portions while leaving the outer portions relatively untouched.

The protein content of the rattan canes tested was found to range from 2.94 to 4.62%, while the percentage ash ranged from 0.96 to 1.93%. The dry matter content of air-dried rattan canes was 85.16, 85.98 and 83.84% for *L. secundiflorum*, *C. deerratus* and *E. macrocarpa*, respectively. Fat content of rattan cane samples was between 0.46 and 0.82%.

Calcium, magnesium and potassium were the major mineral constituents of the three species of rattan investigated. This is similar to the mineral composition of woody plants in which the above minerals constitute up to 70% of the mineral content [25].

The energy values of the three species of rattan are as given in Table 6. The average energy value of 13.40 MJ/kg at 16% moisture content, for rattan cane was less than the average of 18.15 MJ/kg estimated for oven-dried wood by Dinwoodie [26]. This was attributed to the fact that the analysed samples were not oven-dried. Dinwoodie [26] confirmed that when wet wood is burnt, the oven-dry energy value is reduced due to extra energy required removing the extra water present in the wood. The theoretical energy value for the three species of rattan calculated from Dulong Petit's equation used by Lucas and Fuwape [27] was 17.00, 17.02 and 17.00 MJ/kg for *L. secundiflorum*, *C. deerratus* and *E. macrocarpa*,

Table 4.
Proximate composition of samples from three rattan species

Rattan species	Constituents (%)						
	Protein	Crude oil	Ash	Fat	Moisture	Dry matter content	Carbohydrate
L. secundiflorum	2.94	37.10	0.96	0.82	15.84	84.16	79.44
C. deeratus	4.62	39.96	1.93	0.62	15.02	84.98	77.81
E .macrocarpa	3.86	38.64	1.62	0.46	16.16	83.84	77.90

Table 5.
Mineral composition of samples from three rattan species

Rattan species	Mineral composition								
	Ca (%)	Mg (%)	K (%)	Na (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)	PO_4 (ppm)
L. secundiflorum	0.2116	0.0353	0.1652	674	108.5	59.5	5	31.5	0.07
C. deeratus	0.1378	0.0518	0.4416	901.5	84.5	130.5	6	36	0.14
E. macrocarpa	0.1872	0.0388	0.2639	566	78.5	42.5	5	28	0.12

Table 6.
Energy value of samples from three rattan species

Rattan species	Energy value (MJ/kg)	Theoretical energy value (MJ/kg)*
L. secundiflorum	13.59	17.00
C. deeratus	13.24	17.02
E. macrocarpa	13.36	17.00
Average	13.40	17.01

*Calculated from Dulong Petit's equation by Lucas and Fuwape [27].

respectively. The energy value of rattan canes, which compared well with those for other wood products, indicated that their waste products could be used as fuel wood. However, the high ash content (0.96–1.93%) compared to domestic fuel-woods show that much residue would be left after combustion. This may result in disposal problems. Rattan canes are, therefore, not expected to be a popular source of energy, except during emergencies when shortage of more efficient fuel sources exists. The use of rattan canes as fuel would, therefore, not be expected to be a source of competing demand, since more efficient fuel sources exist. This would, therefore, not put pressure on availability of canes for structural applications.

Mechanical properties

The moduli of elasticity (MOE) for the rattan canes are given in Fig. 1. At 12% moisture content, *L. secundiflorum*, *C. deerratus* and *E. macrocarpa* have MOE

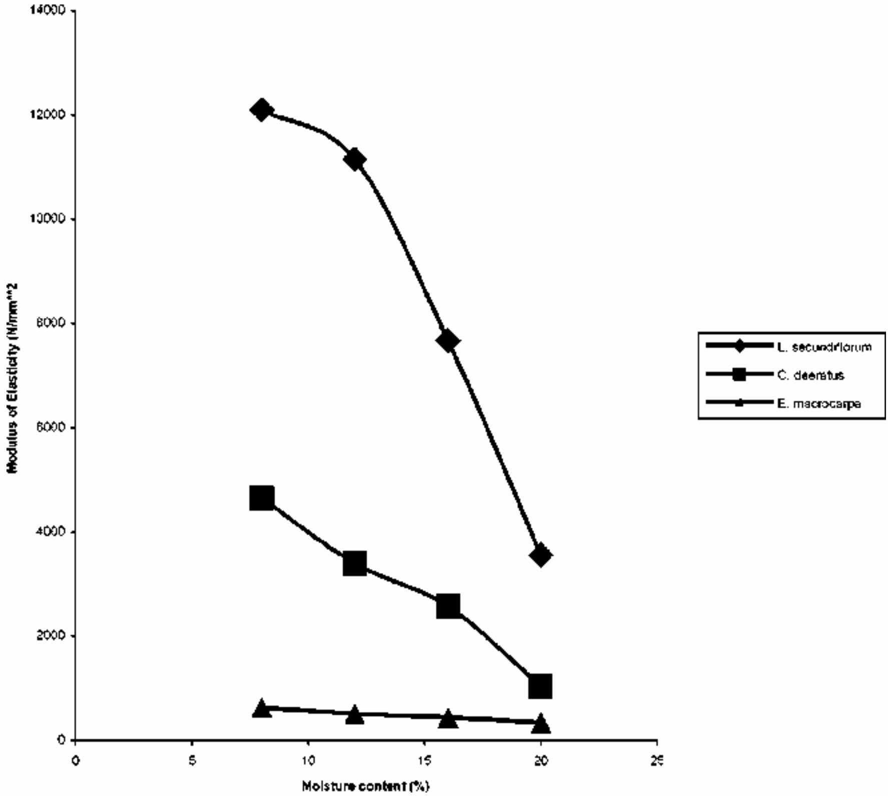

Figure 1. Modulus of elasticity (N/mm^2) of rattan cane samples at four moisture content levels.

values of 11 106, 3396 and 518 N/mm^2, respectively. The MOE of *L. secundiflorum* falls within the N_3 strength group when compared to wood [28]. The MOE for *L. secundiflorum* and *C. deerratus* were higher than the values of 1143 and 1430 N/mm^2 obtained by Kadir [15] for 12-year-old samples of *C. scipionum* and *D. angustifolia*, respectively, from the middle portion of rattan stems. The mean MOE for *C. deerratus* and *E. macrocarpa* were found to be lower than those of the N_7 strength group [28]. The MOE values were higher in nodal specimens compared with internodal samples, with the exception of that for *L. secundiflorum* at 20% and *E. macrocarpa* at 8% MC. However, it was found that the differences in the MOE values of nodal samples compared to MOE values of internodal samples were not significant ($P < 0.05$) for both *L. secundiflorum* and *E. macrocarpa.* The presence of node had significant effect ($P < 0.05$) in the MOE values of *C. deerratus*. The modulus of elasticity is a measure of the stiffness of material. High stiffness would be required to confer appreciable resistance to deflection resulting from imposed load.

The moduli of rupture (MOR) for *L. secundiflorum*, *C. deerratus* and *E. macrocarpa* at 12% MC were 91.15, 40.7 and 10.66 N/mm^2, respectively, as shown in Fig. 2. The MOR values were higher than those for *C. scipionum* and *D. angustifo-*

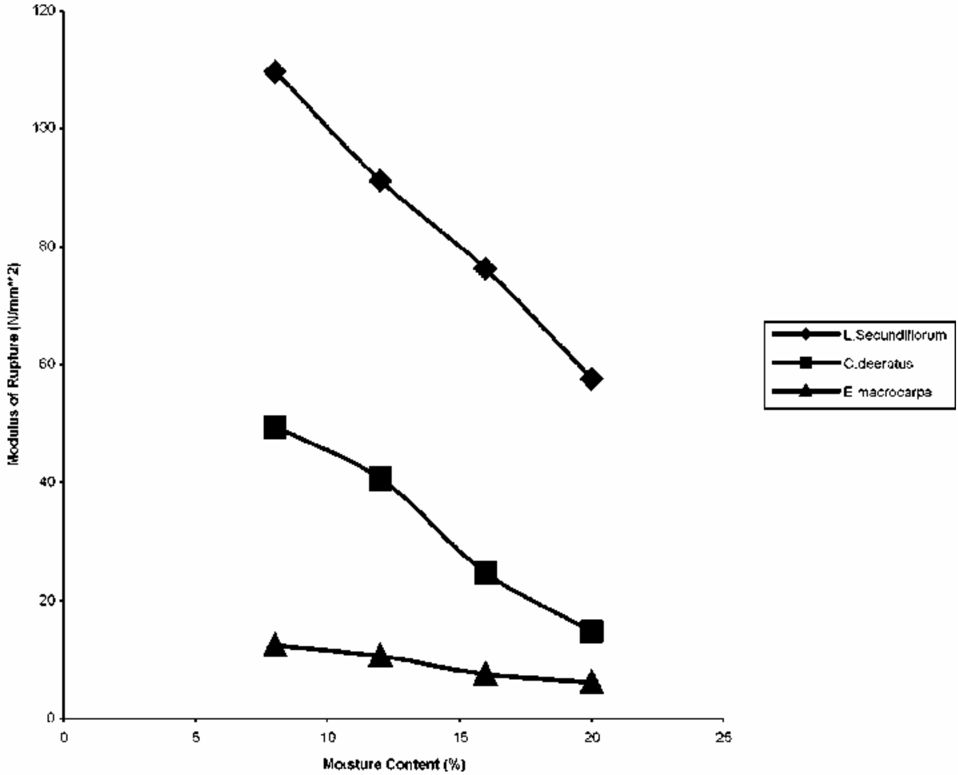

Figure 2. Modulus of rupture (N/mm^2) of rattan cane samples at four moisture content levels.

lia [15]. Moisture content was found to have a significant effect ($P < 0.05$) on the MOR of rattan canes. MOR of nodal samples was generally higher than those for internodal samples. This finding was at variance with the observations of Sekhar and Rawat [20] that nodal samples of rattan have lower MOR values than internodal samples. Statistical analysis however did not show any significant difference ($P < 0.05$) in the MOR of the rattan species for nodal and internodal samples. The higher MOR and MOE values of nodal samples could be attributed to the morphology of the rattan stem. The stems of rattan at the node could be likened to two cylindrical drums being tightly fitted into one another. The point of attachment thus becoming strengthened due to the thickening of this region containing high quantity of mechanical supportive tissues.

The fibre stresses at elastic limit of the rattan species are illustrated in Fig. 3. The relationship between the fibre stresses at elastic limit and moisture content was similar to those obtained for moduli of elasticity and rupture.

The failure mode of samples from *L. secundiflorum* was by sliding shear, mainly through gradual propagation of cracks along its length, especially in samples with moisture content less than 16%. The other type of failure notice in some samples from this species was that of brittle failure without complete detachment of the

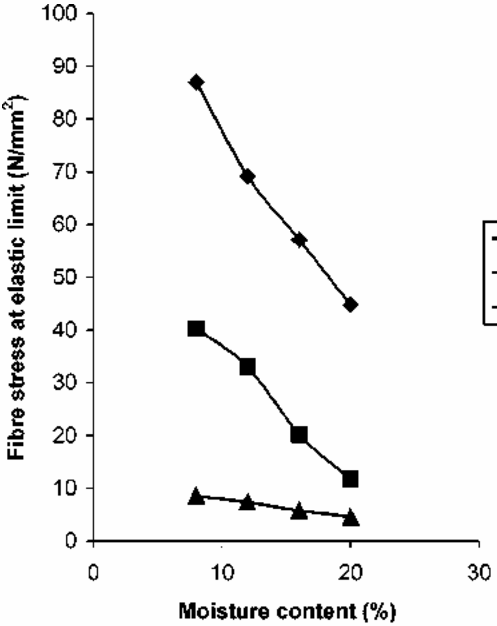

Figure 3. Fibre stress at elastic limit (N/mm^2) of rattan cane samples at four moisture content levels.

cane. The cane being held together by fibre strands of the epidermis which have been shown by anatomical studies to be made up of largely mechanical tissues [11]. Failures in both *C. deerratus* and *E. macrocarpa* were of plastic type with initial linear load-deflection characteristics and then predominant plastic deformation until they could support no further increase in load. At this point, the rattan canes continue to deflect even without further application of load.

The performance of forestry products under applied loads is closely related to their physical and mechanical properties. Several Investigators including Panshin and de Zeeuw [25] have reported that the strength properties of forestry materials are related to their specific gravity. In this study, the density of the rattan species was found to relate to their mechanical properties.

CONCLUSIONS

From the study, the following conclusions on the technical properties of rattan canes could be drawn:

(i) The rattan species studied, have high amount of carbohydrate that can cause them to be susceptible to attacks by termites and other insects.

(ii) Mineral composition of rattan canes is similar to those of woody plants.

(iii) The strength properties of the rattan species are lower than those of timber species that have comparable densities.

(iv) The result of the various physical and mechanical properties shows that rattan canes may be used in reinforcing lowly stressed concrete elements such as framework for ferrocement, concrete casings, slabs on grade and for complex shaped formwork frame.

(v) Moisture content has effect on the mechanical properties of rattan cane species. Improvements in mechanical properties were achieved by reductions in moisture content level.

(vi) Knowledge of the physical and mechanical properties of rattan canes would be needed in order to design machines required for the mechanization of the harvesting and processing operations. The values obtained from this work could also be used to predict the behaviours of rattan canes when subjected to loading.

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