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Biomechanical Properties of Rattan Cane in the Design and Fabrication of Prosthetic Foot

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ABSTRACT---- ***In designing prosthetics for amputees, quality and quantity of materials determine device tensile, flexural, extension and compression strength as well as energy distribution when load is applied. Biomechanical properties contribute in combination to any device longevity and resolution force effect to gait expression. Four different dry rattan canes were sampled and subjected to biomechanical analysis, and sample 3 had highest tensile strength with ultimate tensile strength of 11.5N/mm^2 revealed when load at break of 668.18N applied, and modulus 1033.90MPa with ductility of 7.33mm were resultant. While average ultimate tensile strength of 8.68N/mm^2 was sustained by load at break of 396.66N, modulus of 1119MPa and ductility of 9.5mm was confirmed of rattan cane. Highest flexural strength of 34.43N/mm^2 resulted from load at break of 32.82N, modulus 255.65MPa and elongation of 66.81mm was dictated of sample 3, and an average Flexural strength of 26.4 N/mm^2 occurred when load at break of 16.04N, modulus 229.16MPa produced elongation (ductility) of 55.1mm on rattan cane. The highest load resistance was shown by sample 3 at compressive strength of 8.79MPa when on load at break of 330N, modulus 622.53MPa resulted. While sample 4 had the highest compressive strength of 9.94MPa when load break at 309N exerted modulus 283.14MPa. Gait analysis revealed terminal swing and heel strike of chosen height 8cm and deformity 0cm while early and mid stance of 0.3cm and 7.7cm were respectively for deformity and height.***

Keywords---- Rattan Cane, Biomechanical Properties, Fabrication, Prosthetic Foot

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1. INTRODUCTION

Man-made Prosthetic devices are used for the replacement of missing body parts popular of which is limb of an amputee sequel to disease condition incident or accident. Many of such artificial are fashioned to meet the needs and satisfy natural fruition level of human lost part that is replaceable. Therefore the convenience, pattern of lifestyle, limitation within micro-environment or sustainable major environment of adaptation by an individual amputee contribute immensely to the discomfort experience at the replaced lost part remains. While type of prosthetics chosen and biomechanical composition of the biomaterial used in the device influence design and fabrication. Hence the ability of an amputee to maintain day to day activities is as the foot allows the amputee freedom to ambulatory gait adapted [1]. To each type of prosthetics the layout of fabrication though may differ depending on biomechanics of material particularly for prosthetic foot. It is expected that psycho-physiological and anatomical freedom be harnessed by each user. Major activities of the amputee when compensated by principles of design, means that the pattern of fabrication engraved as a proviso takes credit in the type of material for convenience and must meet the acceptance of the amputee without undermining the extent of lost and possible stigma.

Rattan canes obtained from the stem of the rattan plant have received consideration because of its strength, light weight, durability and other mechanical properties first realized in structural engineering such as bridge construction and household furniture design [2] and others. Also rattan cane has special qualities gained from the biochemical structural arrangement that formed the physical factors apparent. This may have been reason elsewhere for its use irrespective of the level of dryness [3]. When subjected to relative amount of heat rattan cane shows ductility such that it can easily be realigned and readjusted into several structural design shapes without structural molecular strain or damage [4]. Studies have shown the pliability of rattan cane as distinct engineering material derived from linear expansive- like quality [5].

Rattan cane exists as relatively durable and elastic slim wood often used in furniture industry for the production of household utensils and as special commodity made from handicraft industries [6]. Most Nigerian rural communities where rattans grows as wild plant harvest the stem for commercial purposes and depend on it to majorly boast their socio economic wellbeing and improve standard of living [7-8]. In the ancient African setting, rattan is a major raw material for virtually all home utensils [9]. As a forest plant the slimy wood is usually processed for mechanized farming as well as craft works for sustainable income [10-11].The cane is common among many communities and the most useful and popular part of rattan can easily be processed for use either as raw material or shaped into furniture [12-15]. Also the leaves, roots and fruits are sometimes used by rural farmers for medicinal purposes. About 20% of the four popular rattan species in West Africa are found useful in several forms of community resource values, while the remaining 80% are counted among lost value due to poor processing. This also has resulted in breakage and unsatisfactory utilization of the mechanical properties, while the biological and molecular rarity is a question of underdevelopment of the community of origin [15-17].

Therefore, in selecting a prosthetic foot for an amputee, biomechanical and mechanical properties as tensile, compressive strength, and resistance to corrosion were considered. Also durability which influence cost efficiency was regarded [18] important match with the desire of the amputee. This is because an ideal and classed prosthetic foot should be able to perform Range of Motion (RoM) as; dorsiflexion range of motion up to an angle of 20°, eversion movement through a 20° angle (ankle) with 117% energy return efficiency. These can be achieved when the molecular composition of the prosthetic foot and the principal mechanism of fabrication are considered [19]. In addition to the attributes stated, prosthetic feet should also be readily accessible, not difficult to mend, easy to don and doff, flexible, easy to change and remain affordable [1].

Good understanding of foot biomechanics is important to the choice of basic material for a particular prosthetic. A device effective and efficient functional property is not dependent on alignment alone. The durometer of the heel cushion, width of the keel may influence flexibility of the keel. But length of the toe lever - arm, and fit of the prosthetic foot within the shoe are possible in design and fabrication. Therefore rattan cane mechanical properties have proved good in design works particularly in areas where load and stress are of fundamental consideration [6 and 18]. Also the rattan cane size and the pliability can be related to molecular arrangement that form the stem stuff. Other molecular characteristics of material for prosthetic foot are prompt and smooth articulation with the suspension system used. That is the type of socket design and shaped for opposite material interfacing composition and the residual limb tissue, and the pylon ability to in or let out compressive forces that support the rigidity of the heel and forefoot keel [20].

The mechanical property of prosthetic material determines the weight bearing ability, and this property has been exhibited by rattan cane in furniture making [13-14]. Though that the contortion of the foot is controlled by its stiffness. This consequently influences absorption, conservation and discharge of energy as work is done partly over load [21]. A prosthetic foot structured and patterned is to operate under load. It is expected to support directional ripples while at gait performance and hazy characteristic stylish motions in stride. When it is fashioned to sustain running and dance, such fabricate is superior. The mechanical properties of rattan cane may vary supportively to include springing; compactness, contractile, and extensor. These are often said to sustain gait cycle and give understanding to prosthetic period of modification, optimal operation and shelf life. Almost all properties in design material science have been found basic, and were extended to shoe heel height and shape during motion [22].

Shock is a vital characteristic of work done on load and the retention or dissipation by any prosthetic feet. It is also the function of biomechanical structure of biological or chemical of material type. Several types of materials have been found useable in medical rehabilitation technology because of advances in material science and biology [23] without consideration on rattan cane. These include prosthetic foot made of titanium, stainless steel, aluminum, polymer, plant and animal composites. Although, for the foot connecting adapters. Other materials like leather and latex [24] and carbon fiber [23] are also considered impressive.

Therefore, in consideration of the spring property and other biomechanical characteristics, rattan cane is viewed as bio-material in medical rehabilitation technology application. Consequently, it is considered for the design and fabrication of prosthetic feet. The biomechanical properties were searched for and were related to the efficiency, durability and cost effectiveness of prosthetic foot made from rattan cane.

2. MATERIALS AND METHODS

The biomechanical test sought to determine the tensile strength over load and compression resistance of the entire device against pressure to spring. All sample pieces (labeled sample 1to 4) of rattan canes were reduced to 10mm from the natural 20mm size to ensure proper alignment into the Instron Ultimate Testing Machine (Model 3369). The choice of four samples for the tests was considered based on the fact that there is suspicion of rattan cane to show difference in strength and compression at different weight and dryness rather than specie. Therefore biomechanical analysis considered on rattan cane excludes the molecular structure arrangement and energy conservation within bonds.

2.1 Instron Ultimate Testing Procedures

Instron machine was preferred because it has the capability to test for mechanical properties of several material objects when the enabling accessories are involved. It has a running time of 4 hours, 44 minutes to estimate compression, torsion, fatigue, hardness, tension, and flexure tests among others of material objects. Strain was analyzed from ε = d L and σ = F/A gave stress. Therefore, in the machine was appropriated Young's Modulus as is delivered by $E = \sigma/\varepsilon$.

The essential characteristics of material may vary consistently even with same type, and this depends on constitution. This can be explained by an equation that addresses stress and strain relationships. The equivalent stress to associated equivalent strain can be explained by von Mises yield test [25]

$$\sigma_{eq} = \frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)\right)^{1/2}, \quad \varepsilon_{eq} = \frac{1}{1+\nu}\frac{1}{\sqrt{2}}\left[(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_1)^2\right]^{1/2} \qquad 1$$

Where σ_i and ε_i are the main stresses and strains, respectively, and ν is the Poisson ratio.
Consequently material properties under stresses produce shear strain may have essential equation to the relationship thus; $\sigma_{eq} = f(\varepsilon_{eq})$ [26].

Since the rattan cane samples were not completely dried at onset of study, factors like volume of fluid and the consequent hydrostatic pressure are expected to be analyzed by the machine thus;

$$p = \frac{(\sigma_1 + \sigma_2 + \sigma_3)}{3}; \ \Theta = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \qquad 2$$

As there exist hydrostatic pressure and volume change during analysis. From equation 1, $\sigma_1 = \sigma_2 = \sigma_3$, and in resolution $\sigma_{eq} = 0$ and $\varepsilon_{eq} = 0$

Therefore, the estimation of tensile, compression and shear stresses serve as measure for elastic modulus (E). Elasticity defines the mechanical properties associated with object springing ability. As restoration force is proportional to elongation (stretch) and Hooke's law described this in linear and nonlinear material. Hence, equations 1 and 2 have addressed stress – strain relationship to be linear throughout.

The machine was allowed to run throughout at a standard rate, condition and control specified by the manufacturer for the parameters required as follows;

2.2 Tensile test

The load pointer was adjusted to zero using the initial setting knob.

The dial gauge and specimen were secured to the ultimate testing machine in order to measure elongation of small amounts.

The sample was attached between the upper and middle cross head of the machine and the automatic graph recording system was set appropriately.

The machine started for full circle and readings obtained were recorded as each sample loaded is followed gradually by another. Elongation is also noted until the failure of each sample.

2.3 Compression Test

The samples were aligned (each) at the center, between two compressive plates with the mid-point of the moving head vertically above the center of the samples.

Load is applied on the samples by moving the movable head.

The movable head applies load on the samples and the corresponding change were recorded. Load was applied until the sample failed.

To distinguish compressive strain from plastic work, rattan cane behavior should be seen as arbitrary. Hence initial strain and second divergent strain though invariant are represented as I_1, J_2 while the secant elastic bulk modulus K_s and elastic shear modulus G_s give [27-28]

$$I_1 = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 = \Theta, \sqrt{J2} = \frac{1}{\sqrt{2}}[\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_1)^2]^{1/2} \qquad 3$$

2.4 Flexural Test (3 Point Bend Test)

Each sample was placed on two support anvils. Force was applied directly on the sample between the support anvils. The applied force was continually increased until the samples break. The increasing amount of force and amount of load at each breaking point by the machine were recorded.

Supposing that total behavior of rattan lies as a function of I_1 and J_2, and is described by [29-30]

$$K_s = K_s (I_1, J_2), Gs = Gs (I_1, J2) \qquad 4$$

This applies in the Instron machine, and if constutitive equation of an arbitrary material in the engineering space is considered and the curves are applied, T_V represents elastic strain energy stored for volume changes, T_D available elastic strain energy density while plastic work coexist, equations 1 and 2 still hold for isotropic material. To analyze T_V and T_D quantities of rattan cane means that dilatational strain energy density T_V is the ultimate elastic and T_D estimates elastic distortional strain energy density, and these coexist with plastic work. Therefore as rattan cane failed on compression plastic flow point, either $T_V = T_{V,O}$ or $T_D = T_{D,O}$, where $T_{V,O}$, $T_{D,O}$ are the critical elastic strain energy densities [31].

Failure can be determined in two ways (i.e. dilatational and distortional), and nonlinear material can be generally captured by [32-33]

$$T_V = \int_0^{I1,O} \frac{1}{2} K_3 (I_1, J_2)\, dI \frac{2}{1} = T_{V,O} \text{ for failure by cleavage, } T_D = \int_0^{J2,o} 2Gs\, (I_2, J_2) DJ_2 = T_{D,O} \text{ for failure by slip} \qquad 5$$

This defines T-criterion (Andrianopoulos and Boulougouris 1994), Failure by cleavage (brittle fracture) occurs when T_V reaches a critical value $T_{V,0}$ and failure by slip (plastic flow) occurs when T_D reaches a critical value $T_{D,0}$ for all materials.

2.5 Methods of Rattan Cane Prosthetic Foot Fabrication

The fabrication of a dynamic response prostatic foot for lower limb transfemoral, transtibial, knee disarticulation, and other forms of amputees are common. It requires the understanding of biomechanics, bioenergetics and performance in gait. The tensile and compression forces sheared from patient's weight among others allow for step by step directional motion that is a derivative. Quality of materials and design pattern were considered prime factors that can militate against efficiency, ductility, and robustness of the device fabricated. Considerably, material turf, molecular characteristics methods of procession may constitutively affect the longevity of the device. Hence biomechanical properties of material and bio-efficiency were primary in the prosthetic foot design and fabrication.

2.6 Gait Analysis

The patient gait testing with the device was carried out to check the ability of the device to withstand load and Shock. Selected patients were amputees who have been on gait activities with another type of device prior to this performance test with the new fabricate at foot size of 8cm.

Five patients recruited were transtibial amputees using a Transtibial Prosthesis with SACH foot for the past 6 months. They have no obvious diagnosable disease condition and were psychophysiological balanced over time.

Each patient SACH foot was disconnected and the Rattan foot fitted in position. Patients were videoed with a steadily and stably camera, as he or she ambulates along a parallel walking beam. The video was zoomed on a computer screen, and every step by step motion and each step accessed of gait were analyzed.

To understand and analyze gait with foot prosthesis requires that standard method of testing be applied. Such is that which measures springy retained energy properties in an exerted path by load. Assuming that the prosthetic foot has total strain energy density T, the resultant gait activities will be translated from actual stresses and strains when weight on and off.   Hence the equation which applies on principal stresses and strains of a material suffices and is thus [26], [34];

$$T = \frac{1}{2}\sum_{i-1}^{3}\int_{0}^{\sigma i}\sigma i\ (\varepsilon i)d\varepsilon i \qquad 6$$

Resulting in deviation and deformity characterized by both hydrostatic pressure and volume shape changes of rattan cane in part.

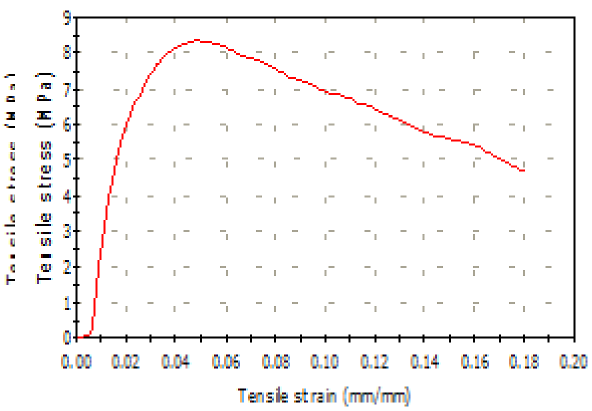
To ensure validity and accuracy of the configuration of each slide, the prosthetic rattan foot length (Heel to Toe) was used as a reference or a buffer.

As the patient performs gait, the deviations in the foot height were measured with graduated Meter-rule in centimeters and recorded accordingly. Applying equation 3, Stress is proportional to Strain over which hydrostatic pressure and volume changes characterized density. Therefore the Load (Patient weight) transferred to the prosthetic rattan cane foot is proportional to the Height deviations. These deviations are measurable values of the shock absorption.

3. RESULTS AND DISCUSSION

Four samples of rattan canes were selected based on the bio-rigged quality and physic-mechanical nature to weight and smoothness. It was observed that after rain rattan cane though partially dried did not soak water rather allow water to drain away. Consequently the bio-mechanical test results express values as follows;

3.1Tensile Test Result



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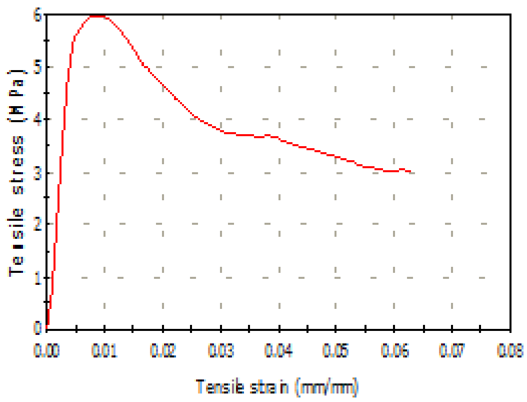

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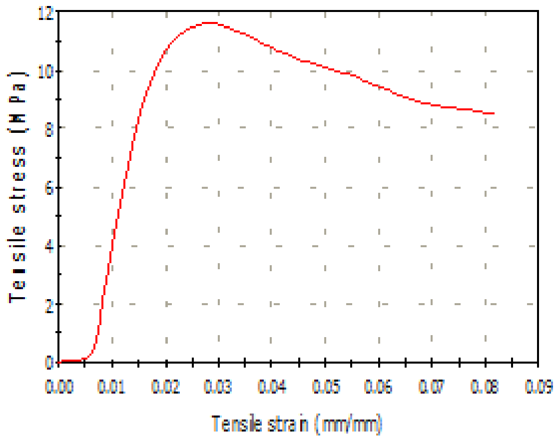

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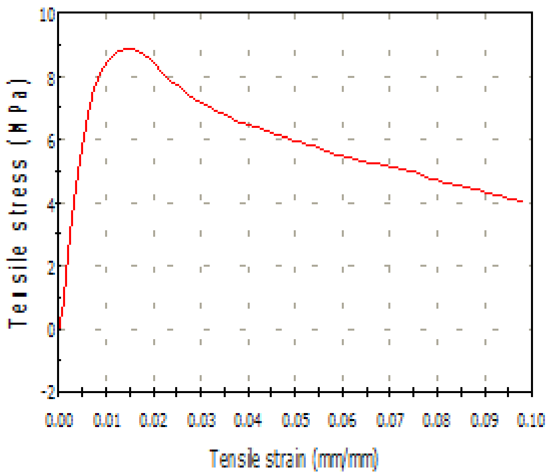

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Figure 1: **A.** Graph Showing Tensile Stress and Strain of Sample 1. It had UTS (tensile strength) of 8.35N/mm^2, load at break of 367N, modulus 573.63MPa and elongation (ductility) of 16.25mm. **B.** Graph Showing Tensile Stress and Strain **of** Sample 2. Shows UTS of 6N/mm^2, load at break of 236.6N, modulus 1433.71MPa and elongation (ductility) of 5.58mm. **C.** Graph Showing Tensile Stress and Strain of Sample 3. Revealed UTS of 11.5N/mm^2, load at break of 668.18N, modulus 1033.90MPa and elongation (ductility) of 7.33mm. **D.** Graph Showing Tensile Stress and Strain of Sample 4. Shows had UTS of 8.86N/mm^2, load at break of 314.86N, modulus 1434.74MPa and elongation (ductility) of 8.83mm.

Table 1. Showing Load, Extension, Tensile Strain and Stress at Break of the Samples

Sample	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Break (Standard) (MPa)
1	367.06070	16.25031	0.18056	4.67356
2	236.67477	5.58328	0.06204	3.01344
3	668.18036	7.33344	0.08148	8.50754
4	314.86391	8.83344	0.09815	4.00897

Table 2. Showing Energy at Break, Modulus, Load and Energy at Yield of the Samples

Sample	Energy at Break (Standard) (J)	Modulus (Automatic) (MPa)	Load at Yield (Zero Slope) (N)	Energy at Yield (Zero Slope) (J)
1	8.02920	573.63460	655.88499	1.87295
2	1.75566	1433.71708	471.42857	-----
3	4.98099	1033.90968	903.5713	-----
4	4.13338	1434.74068	696.38710	0.66349

Table 3. Showing Extension, Tensile Strain at Yield, Ultimate Tensile Strength and tensile extension at Break of the Samples

Sample	Extension at Yield (Zero Slope) (mm)	Tensile strain at Yield (Zero Slope) (mm/mm)	Ultimate Tensile Strength (N/mm^2)	Tensile extension at Break (Standard) (mm)
1	4.33344	0.04815	8.35099	16.25031
2	-----	0.008	6.00	5.58328
3	-----	0.026	11.500	7.33344
4	1.33359	0.01482	8.86668	8.83344

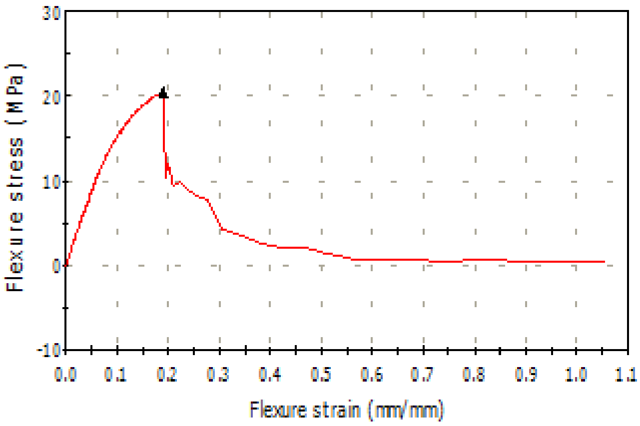
Table 4. Showing Final Area at Area Reduction and True Stress at Yield.

Samples	Final Area at Area Reduction (mm^2)	True stress at Yield (Zero Slope) (MPa)
1	78.53982	8753081.39982
2	78.53982	-----
3	78.53982	-----
4	78.53982	8998059.82947

Average UTS 8.68N/mm^2, load at break of 396.66N, modulus of 1119MPa and elongation (ductility) of 9.5mm.

Experimental Observation - Sample 3 has the highest UTS followed by sample 4, 1 and 2. The most ductile is sample 1 followed by 4, 3 and 2. The highest modulus (stiffness) is sample 4.

3.1.2 Flexural Test Result



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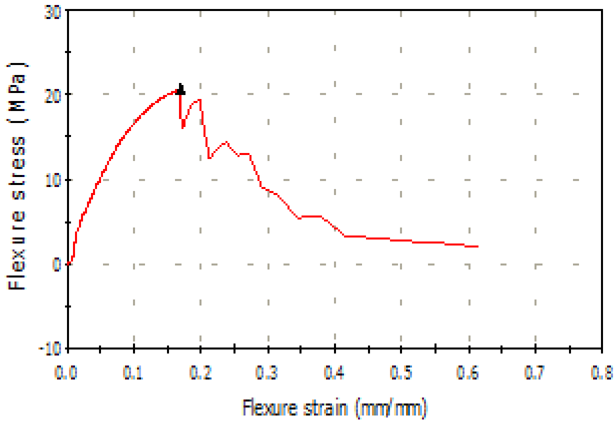

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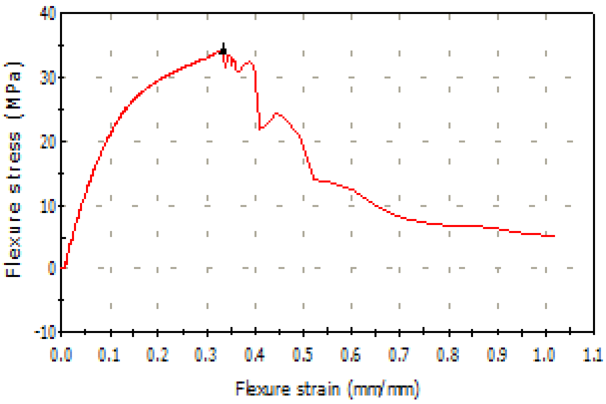

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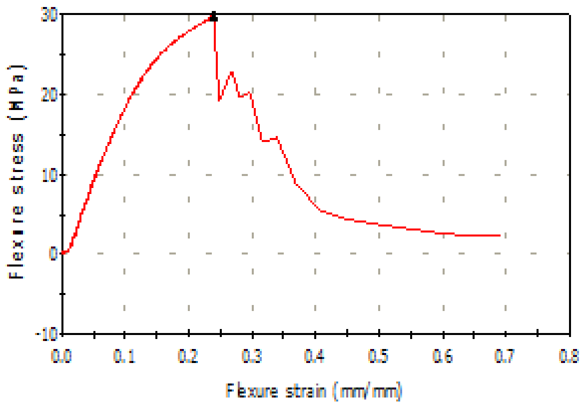

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Figure 2: A. Showing Flexural Stress and Strain of Sample 1. Revealed flexural strength 20.57 N/mm^2, load at break of 3.99N, modulus 180.24 MPa and elongation (ductility) of 69.76 mm. **B**. Showing Flexural Stress and Strain of Sample 2. It had flexural strength 20.81 N/mm^2, load at break of 13.95N, modulus 250.52 MPa and elongation (ductility) of 40.59 mm. **C.** Showing Flexural Stress and Strain of Sample 3**.** Shows flexural strength 34.43 N/mm^2, load at break of 32.82 N, modulus 255.65 MPa and elongation (ductility) of 66.81mm**. D.** Showing Flexural Stress and Strain of Sample 4**.** It had flexural strength 29.91 N/mm^2, load at break of 14.86N, modulus 230.22 MPa and elongation (ductility) of 43.25 mm

Table 5. Showing the Thickness, Width, Energy at Break and Load at Yield

Samples	Thickness (mm)	Width (mm)	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)
1	10	-----	1.80354	-128.26384
2	10	-----	2.21020	-129.73611
3	10	-----	6.95085	-214.58303
4	10	-----	3.21809	-186.43081

Table 6: Showing Load at Break, Modulus, Flexure Load and Extension at Break

	Load at Break (Standard) (N)	Modulus (Automatic) (MPa)	Load Flexure at break (Standard) (N)	Flexure Extension at break (Standard) (mm)
1	-3.98953	180.24946	3.98953	69.75626
2	-13.95001	250.52019	12.95001	40.59484
3	-32.81620	255.65332	32.81620	66.80907
4	-14.86060	230.21981	14.86060	43.25047

Table 7: Showing Flexure Strain at Break, Flexure Stress at Break, Energy at Yield and Flexure Extension at Yield

	Flexure strain at Break (Standard) (mm/mm)	Flexure Stress at break (Standard)	Energy at yield (Zero slope) (J)	Flexure extension at yield (Zero slope) (mm)
1	1.05452	0.64003	1.02557	12.53687
2	0.61368	2.23797	0.94334	11.22391
3	1.00996	5.26464	3.31765	22.12000
4	0.65382	2.38406	1.83023	15.82422

Table 8: Load at yield, Flexure Strain and Stress at yield

	Load at yield (N)	Flexure Strain at yield (Zero Slope) (mm/mm)	Stress at yield (Zero Slope) (MPa)
1	128.26384	0.18952	20.57714
2	129.73611	0.16967	20.81333
3	214.58304	0.33439	34.42517
4	186.43082	0.23922	29.90876

Experimental Observation – sample 3 has highest flexural strength followed by 4, 2 and 1. The most flexural is sample 1. The highest modulus is sample 3. Average Flexural strength 26.43N/mm^2, load at break of 16.04N, modulus 229.16MPa and elongation (ductility) of 55.1mm.

3.1.3 Compression Test Result

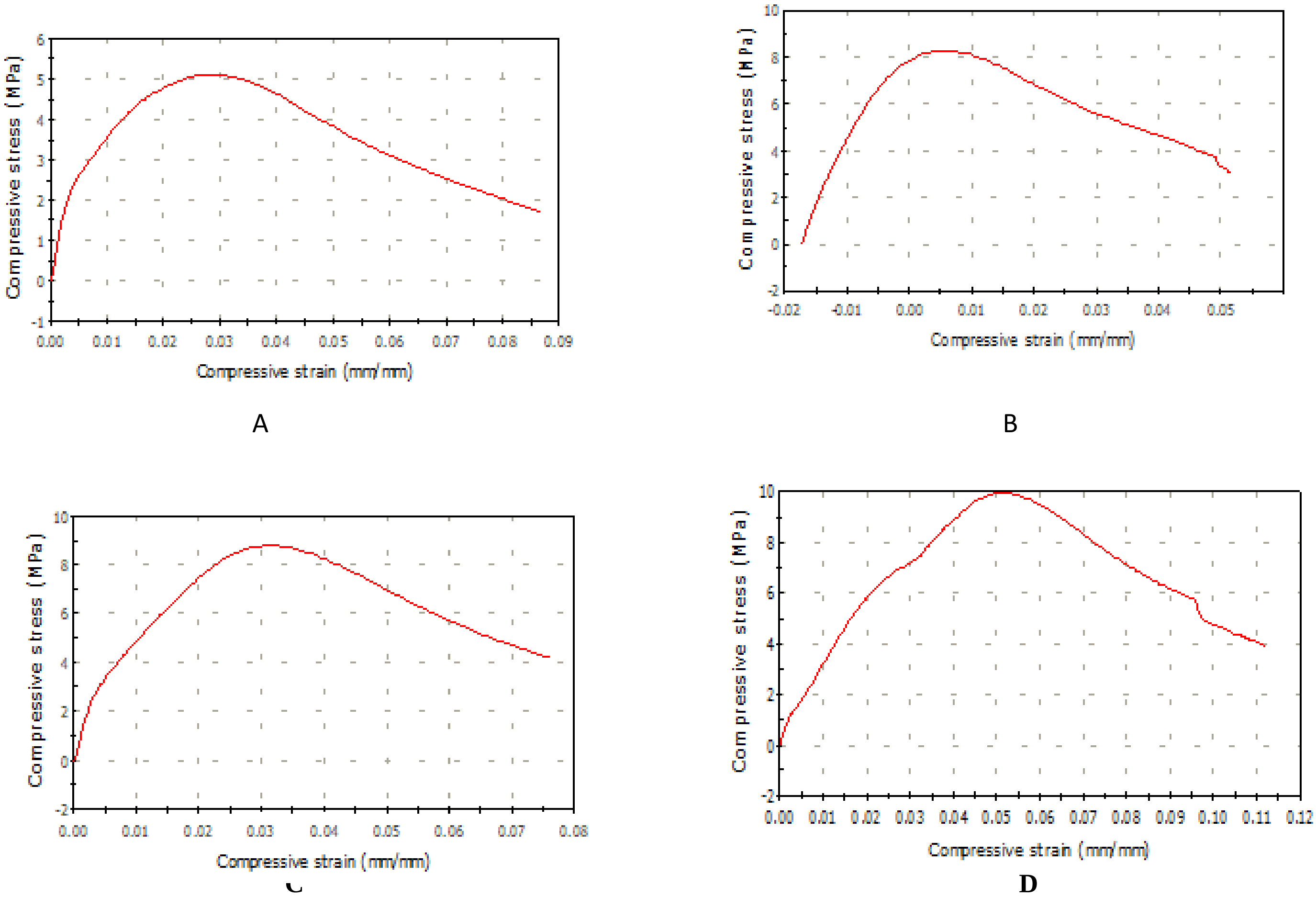

Figure 3: **A.** Showing Compressive Stress and Strain of Sample 1. It had compressive strength of 5.1MPa, compressive load at break of 135.87N, modulus 523MPa. **B.** Showing Compressive Stress and Strain of Sample 2. Compressive strength of 8.28MPa obtained, at compressive load at break of 242.89N, modulus 683.37MPa. **C.** Showing Compressive Stress and Strain of Sample 3. Had compressive strength of 8.79MPa, compressive load at break of 330N, modulus 622.53MPa. **D.** Showing Compressive Stress and Strain of Sample 4. Had compressive strength of 9.94MPa, compressive load at break of 309N, modulus 283.14MPa

Table 9: Showing Compressive Extension, Compressive Strain, Compressive load and Compressive Stress at Break of Sample 1, 2, 3 and 4 of Rattan Cane

Samples	Compressive extension at break (Standard) (mm)	Compressive strain at break (Standard) (%)	Compressive load at break (Standard) (N)	Compressive stress at break (Standard) (MPa)
1	10.35031	8.62526	135.87352	1.73000
2	6.15203	5.12669	242.88120	3.09246
3	9.10000	7.58333	330.06693	4.20254
4	13.40016	11.16680	309.04013	3.93482

Table 10: Showing Energy and Extension at Break, Compressive Load and Compressive Strain at Maximum Compressive Extension of Cane samples

Samples	Energy at Break (Standard) (J)	Extension at Break (Standard) (mm)	Compressive load at Maximum Compressive extension (N)	Compressive strain at Maximum Compressive extension (%)
1	2.87794	-10.35031	134.66585	8.66328
2	3.75961	-6.15203	240.88321	5.15169
3	4.51703	-9.10000	328.24210	7.61576
4	6.99279	-13.40016	307.82941	11.19675

Table 12: showing Maximum Compressive Extension, Compressive Stress at maximum Compressive Extension, Area and Diameter of the Cane Samples

Samples	Maximum Compressive extension (mm)	Compressive stress at Maximum Compressive extension (MPa)	Area (cm^2)	Diameter (mm)
1	10.39594	1.71462	0.78540	10.00000
2	6.18203	3.06702	0.78540	10.00000
3	9.13891	4.17931	0.78540	10.00000
4	13.43609	3.91941	0.78540	10.00000

Table 13: Showing Modulus, Poisson's Ratio, Compressive Load at Yield and Compressive Extension at Yield

Samples	Modulus (Automatic) (MPa)	Poisson's Ratio (Chord)	Compressive load at Yield (Zero Slope) (N)	Compressive extension at Yield (Zero Slope) (mm)
1	523.00939	-----	401.32556	3.30016
2	683.36692	-----	650.67346	0.65219
3	622.53276	-----	690.63397	3.75016
4	283.13789	-----	780.93927	6.10000

Table 14: Showing Compressive Strain and Stress at Yield, Anvil Height and Thickness

Samples	Compressive strain at Yield (Zero Slope) (%)	Compressive stress at Yield (Zero Slope) (MPa)	Anvil height (mm)	Thickness (mm)
1	2.75013	5.10984	120.00000	10.00000
2	0.54349	8.28463	120.00000	10.00000
3	3.12513	8.79343	120.00000	10.00000
4	5.08333	9.94323	120.00000	10.00000

Experimental Observation – sample 4 had the highest compressive strength followed by 3, 2 and 1. The highest load resistance was shown by sample 3 and is followed to tail by 4, 2 and 1. Average compressive strength is 8.02MPa, compressive load at break of 254.44N and modulus 528.01MPa.

3.1.5 Gait Analysis

The reference Foot length on the first slide was 8cm and this was maintained and used to ensure accuracy throughout the analysis at assumed height of deformation for the prosthetic foot measured on loading weight of the body transferred to the foot device.

3.1.5.1 Terminal Swing showed chosen (normal) height as the amputee was about to load the prosthetic foot device and hence no deformity at a height = 8cm.

3.1.5.2 Heel Strike showed height of 8cm and immeasurable deformity of 0cm as loading commenced heel strike positioned.

***3.1.5.3 Early Stance*:** At early stance, the amputee performed Toe off of the contra lateral limb less anchored weight, and load was on the prosthetic foot to produce deformity of 0.3cm and reduced height of 7.7cm as less inclined load is distributed possibly even.

3.1.5.4 Mid Stance: At mid stance, the amputee performed a single stance on the prosthetic limb with maximum weight and load excited. Deformity 0.6cm produced reduced height to 7.4cm.

3.1.5.5 Early Toe Off/Terminal Stance: At this stage, the limb is at maximum dorsiflexion moment in preparation for the propulsive toe off. Weight restoration is compensatory to height 8cm as deformity is off to give 0cm.

3.1.5.6 Late toe off: At this stage Toe off is almost complete. The Heel is off the ground. The Toe region presses into the ground to generate the propulsive force of deformity 0.3cm as if weight draws on height from 8cm to 7.7cm.

4. DISCUSSION

In order to meet with the increasing demand of prosthetics by amputees in the globe, numerous types of natural and artificial materials are often used in rehabilitation technology. Common materials used in prosthetics are such that conform to standard requirements [35] and they are various types of metals and plastics. Depending on region of the globe, traditional materials for special prosthetic foot is as elsewhere [14] to include combination of metal and plastic, plant and animal preparatory, metallic alloys and hydrocarbon. Therefore in this study, the biomechanical properties of rattan cane plant were randomly searched among four sample stems species selected without consideration to degree of dryness to obtain enhanced feet in need nowadays [15].

The biomechanical properties of phyto-biomaterials often reveal the structural formation and possibly serve as one of the basic factors to the strength and biocompatibility. Consequently application of biological materials in biomaterial science and biomedical engineering follow after concrete analysis of structure, biomechanical, and molecular compositions especially when rehabilitation technology focuses on pliability. Rattan cane being one of such materials had four samples from different stems selected and same were subjected to biomechanical analysis. Thus findings were recorded as in figures 1 to 3 and tables 1 to 14. This type of study design and to the extent of analysis carried out is not recorded about any phyto-biomaterial to our knowledge in rehabilitation engineering save for metals and hydrocarbon [1, 16 and [17] and the work on physical property [18] in combination for civil engineering [36]. Also elsewhere rattan wood had been used in combination with certain elements as calcium and other to form bone subjected to implantation trial on pigs and other animals in 2010.

Though this study is not holistic when molecular composition and structural arrangement is core consideration. The findings revealed that rattan cane wood may have pliability which possibly is related to stuff arrangement and molecular biochemistry [37]. Could these physical properties be the reasons why the cane lack the ability to retain water molecules when left at atmospheric condition in the open field as observed in this study? Or could it be the same property observed add up to the 20 channels structure that inspired industrialist to use rattan specie for oil wicking and avotion [38-39]. These assertions were made plausible when load is leveled at standard break limit on the four samples with varied outcomes as in all the figures and tables herein.

The biomechanical analysis was conducted to obtain the ultimate tensile strength (UTS) of rattan cane. The revelation was minimum range of 6.0N/mm^2 and maximum of 11.5N/mm^2 with ultimate average possible standard of 8.68N/mm^2 obtained from four randomly selected samples at different dryness when on average load at break point 396.66N weighed (Figures 1-3). Though a study have shown that spruce with 16% moisture has maximum compressive strength reduced by 50% [40] but rattan cane was not one of the woods considered for the standard of 13N/mm^2. This suggests that rattan cane when at ultimate tensile strength range and on discrete differential load at break point ranges from 236.6N to 668.18N (as given by four samples), can sustain modulus range of 573.63Mpa to 1434.74MPa at producible ductility range of 5.8mm to 16.25mm. Therefore an approximate average ductility of 9.50mm length of rattan cane can only be possible if weight at break point of 396.66N exert UTS 8.68Nmm^2 and modulus 1119MPa. Consequently the four samples characteristically showcased tensile strain and stress measurable as shown in Table 1 as in a work [41] and, that average of 0.10556mm/mm and 5.05088mm/mm distributed respectively when exceeded, irrespective of molecular structural cohesion force, rattan cane damage results as in a study [42]. Such tensile strain absorption power has not been recorded of plant biomaterial in any literature to our knowledge save possibly for raffia rope in furniture making [43]. This outcome seems comparable to metallic springs and that obtainable from certain metals used in prosthetic limbs fabrication even composite materials [44]. Also records exist that informed the use of rattan cane in civil and structural engineering works, ancient armory making like swords and shield for Art and combats [45-49], even in house hold furniture. In engineering tensile extension property is said to sustain, conserve, and encourage structural rearrangement for energy distribution through sudden change in configuration as load is increased. From this study, rattan cane has show strength at load break point standard often similarly observed with metals like aluminum, steel, titanium and others. Therefore energy yields at zero slope found to be between zero to 1.87295J is retained by rattan cane (Table 2) and is not that responsible for bond molecular structure and sudden configuration change. This energy was searched for as in Table 5 but failed to tally, in that carbon- nitrogen-hydrogen bonding was not aimed at. More work is needed to confirm the molecular structure binding energy of rattan cane. Again, the final area to area reduction is constant at 78.53982mm^2 for true stress at yield and is in the range of zero to

8998059.82947MPa for rattan cane (Table 4). This remained consistent throughout the whole 8cm length (test chosen length) of rattan cane for lower limb prosthetic foot fabricated.

Flexural strength analysis of rattan cane revealed strain and stress demonstration and absorption when load at various break ratio points were exerted as in all the Figures. An average flexural strength 26.43N/m2 was expressed when load at break of 16.04N was given to rattan cane and modulus 229.16MPa inclusive resulted to ductility of length 55.1mm. The result further revealed that flexural stress and strain ranges 0.16967 to 0.33439mm/mm respectively and modulus 20.57714 to 34.42517MPa at zero slope (Tables 5-8) can possibly support multi-shaping with rattan cane. The insight adduced in this case is that at UTS, flexural strength encourages energy distribution (from the skeletal muscles) [41] along the entire length of rattan cane first to allow pliability (at which occasion multi-shaping can be possible) as load at break point applies. Hence, energy dispersion along the length, area, and possible shapes originated during fabrication (in the case of prosthetic foot and structural engineering) do occur. This is retained even when load at break points is incident on planted biomaterial [42- 43]. This was made sustainable by the results from compressive strength at load break points (Figures). This behavior is comparable to that of ferrous irons which gives elongation even without increased force and still remain durable [44].

It is obvious from the results of biomechanical test that rattan cane has the required parameters necessary to engineering weight bearing. Also that compression at various limits stress and strain has resilient energy conservation for shear in time. Again, the choice of rattan cane was enhanced by the fact that the compressive load yield at zero slope of 690.63397N which when above gives longevity over time, was well compensated by the 4.17931Mpa and 7.61576Mpa modulus. Compressive stress and strain had maximum compressive extension at area of 0.078540cm^2 .But when average maximum load at point extension of 328.24210N yield -9.10000mm length it can be related to break standard as energy at break is 4.51703J to shear. These constituted to the firm turf consistency observed throughout fabrication and gait analysis in other studies [50- 51].

Reference height of 8cm was chosen during the gait analysis to ensure easy and accuracy in the measurement of deformity height that may occur on the prosthetic foot on load. The body weight of patient generated energy on the rattan cane prosthetic foot resulting in dynamic ripple distribution and partial retention to allow terminal swing, heel strike, early and mid stance, early toe off/terminal stance and late toe off [52].

At terminal swing the amputee weight had full resolution and load not applied, hence there is no deformity on the dynamic rattan cane prosthetic foot. Consequently there is reduction on vertical and horizontal height even at heel strike and on leg swing set which would not happened if there was reinforcement as is also shown in studies [53- 54]. During early and mid stances there were deformities of 0.3cm and 0.6cm length short observed respectively? These were because of less inclination and full weight exertion on the device. The deformities from 8cm to 7.7cm and 7.4cm were restored at early toe off/terminal stance when there is dorsiflexion moment in preparation for propulsive toe off as oxygen uptake by the Amputee increases [55]. At late toe off when the heel is off the ground there is energy instance conservation [56], and this is comparable to a study where 1mm deformity in height was recorded [57]. The dynamic (springing) revelation can only be explained in consideration of biomechanical factors of rattan cane as recorded above and is in total agreement with Hooke's law. Also studies have revealed that inflexibility contributes too little energy conservation and distribution [[55-58].

The gait analysis results support the biomechanical findings from rattan cane than biomolecular structural arrangement in that load was well bear and shear while energy was transmitted and restored along the entire device, to support the multi-shape constructed and give balance comparable to basic gait parameters [59]. Therefore rattan cane plant has shown dynamism, stiffness, pliability to cushion the lower limb. Absorption and transmission of energy supported performance of gait at undetermined or specific dryness state . It is possible that rattan cane can be used for lower-limb prosthetics and may require re-enforcement [58] at high stress areas where energy retention is needed for compensation as in some studies [60]. Rattan cane is readily available locally and can easily be processed at fabrication work places to obtain cheap prosthetic limb.

5. CONCLUSIONS

The design for dynamic response was in the curves made with the cane which when compressed via patient weight/loading will flatten, thereby storing potential energy. This energy can consequently be released to the load in accentuation during toe off and helps to reduce the amount of energy required for gait. The gait analysis clearly shows the dynamic nature of the foot during patient gait. The prosthetic foot can therefore replicate the dynamic response found in carbon fiber feet at a very cheap price. Active patients can now afford a dynamic response foot which quality performance is comparable.

The mechanical test however needs more research as the results from the mechanical tests were very low and competitively high with same species of rattan cane when compared to with previously resembling studies. The study has shown that rattan cane possesses the tensile and compression strength good enough to be employed as bio-engineering material in medicine specialty.

More works are needed on rattan cane to ascertain the reason for the low and high mechanical test readings obtained from four species as to understand the effect of drying on procession and construction.

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