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on

Structural Engineering Analysis & Modelling (SEAM 4)

Engineering Design Systems for the 21st Century

PROCEEDINGS

Volume I

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A-A-JIMOH

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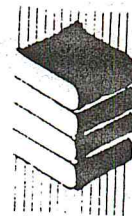
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STATISTICAL ANALYSIS OF STRENGTH PROPERTIES OF FANPALM

by Abdullahi Alao Jimoh *BEng (Civil) MEng (Civil) MNSE Redg Engr (COREN)*

ABSTRACT

Laboratory tests were carried out on air-dried fanpalm to determine the tensile, compressive, and flexural strength properties. Data obtained were analysed statistically to determine the mean strength and mean confidence limits, standard deviation, coefficient of variation, stress-strain relationship, characteristic strength and modulus of elasticity. From regression analysis, a polynomial fit of order three was found appropriate to relate the stress-strain data. The polynomial fit was subsequently differentiated to determine the initial tangent and characteristic tangent moduli of elasticity.

RÉSUMÉ

On a fait de tests de laboratoire sur fanpalme aéro-séché pour déterminer les caractéristiques de force de pression, compressives et flexurales. Les données obtenues étaient statistiquement analysées pour déterminer la force moyenne et les limites de confiance moyennes, la déviation de critère, le coefficient de variation, le rapport de pression, la force caractéristique et le module de l'élasticité. A travers l'analyse de regression, on a trouvé que l'adaption polynôme était juste pour lier les données de pression. L'adaption polynôme fut subséquemment distinguée pour déterminer la tangente initiale et les modules de la tangente caractéristique de l'élasticité.

KEY WORDS: moisture content, coefficient of variation, degree of freedom, characteristic strength, modulus of rupture, standard deviation, level of significance, strain, stress.

A. A. JIMOH obtained his *BEng (Hons)* and *MEng (Hons)* degrees in civil engineering, with specialisation in structural engineering at the University of Ilorin, Nigeria. He is currently pursuing a PhD degree in civil engineering in the same university. His area of interest is reinforced concrete and application of local materials for building purposes.



INTRODUCTION

Fanpalm, (botanical name, *Borassus Aethiopum*) belongs to the palmaceae family and is commonly found in the savannah region of tropical Africa. The outercore of the matured stem is known to be strong, resistant to termite attack, rot and decay and it is dimensionally stable in moist environment (1-3). Because of these inherent characteristics, fanpalm has potential as an indigenous construction material. It has been used as roof rafters, strut and columns in traditional building construction.

A literature survey shows that until recently (2,3), there is no known systematic study of the physical and mechanical strength properties of fanpalm. In order to build confidence in its use as a modern building material, it is necessary to study and document its engineering properties. Results of previous investigations carried out showed that the air-dried (average moisture content (m.c.) of 10%) tensile strength parallel to grain varied from 72 to 134.6 N/mm², with the modulus of elasticity ranging between 18.0 and 23.7 kN/mm², while the compressive strength parallel to grain varied from 40 to 105 N/mm² with compressive modulus not specified (2). Flexural strength reported varied from 70 N/mm² to 95 N/mm² with the modulus of elasticity in flexure ranging between 11 kN/mm² and 26 kN/mm². Ultrasonic pulse velocity tests gave a modulus of elasticity that varied from 18.2 to 28 kN/mm² (2,4).

This article presents the results of laboratory tests performed on air-dried matured outer core of fanpalm to determine the stress-strain relations, the tensile and compressive strength, the modulus of rupture and the modulus of elasticity parallel to grain. Data obtained were statistically analysed to obtain statistical parameters like mean ultimate strengths, standard deviation, coefficient of variation, confidence limits and regression equations relating the stress and grain in tension and compression, respectively.

EXPERIMENTAL PROGRAMME

- a) Test specimens:- Fanpalm materials, from which test specimens were fabricated, were obtained from local plank dealers in Ilorin township, Nigeria. The cross-section is irregular in shape, usually quadilateral, with the largest dimension not greater than 60 mm.

Like other wood material, the strength of fanpalm will depend on the moisture content, age and maturity, location of the material along the stem and the species. Because the fanpalm samples used were obtained from commercial stock, it was not possible to know the age and the location, along the stem of the tree, of the materials from which the specimens were made.

Test specimens used were fabricated using wood working tools from matured outer core of fanpalm which were air-dried to an equilibrium moisture content of 6 to 11%. Fig 1a shows the photograph of a fanpalm tree while Fig. 1b shows the fanpalm tensile test specimen configuration and dimensions. The configurations conform with the British standard for wood testing, except for modification in the dimension because of the size of fanpalm available and also the testing facilities. For example, the dimensions of the compression and flexure specimens were halve those specified by the British standard i.e. 50 x 50 x 300 compression and 50 x 50 x 760 mm for flexure, while only the length of the specimen was reduced for the tension specimen (i.e. 196 mm instead of 456 specified by BS).

Test Procedure:- The tests were carried out on a manually operated hydraulic universal testing machine (Vega model UTM-3B). For the tensile test, elongation was measured with a demountable mechanical strain gauge. Two 6 mm diameter steel gauge seats, centrally drilled, were mounted (glued) on to the specimen at a gauge length of 50mm, to monitor the extension during loading. In the compression test, the shortening was monitored by a dial gauge affixed to the compression space of the testing machine. The shortening of the specimen was monitored by the measurement of the upward movement of the lower platten of the Vega machine.

The flexure test specimens were nominally 25mm square in cross-section and 380mm long. They were simply supported on 330mm span and loaded at third points. Central deflections were monitored by dial gauge with loads and corresponding deflections recorded until the specimens failed.

Failure Modes:- Failure of the tensile, compressive and flexural specimens was by detachment of some of the peripheral fibres. This behaviour could be attributed to non-continuity of a unit fibre throughout the entire length of the specimen and also probably due to bond failure between the fibres.

The tensile specimens fractured with a bang into two and uneven rough fracture surface while some of the compression specimens bellied out at the middle leading to splitting of the specimen into longitudinal strips. Other compression specimens failed by brooming or end rolling; this involved the failure of the end part of the specimen leaving the main body intact. The specimens involved in this type of failure were rejected because of the premature or very low failure load associated with them. At failure, the flexural specimens cracked at the bottom within the middle third, and further increase in load caused the cracked specimens to split parallel to grain.

Fig. 1a: A Fanpalm Tree
(Borassus Aethiopum)

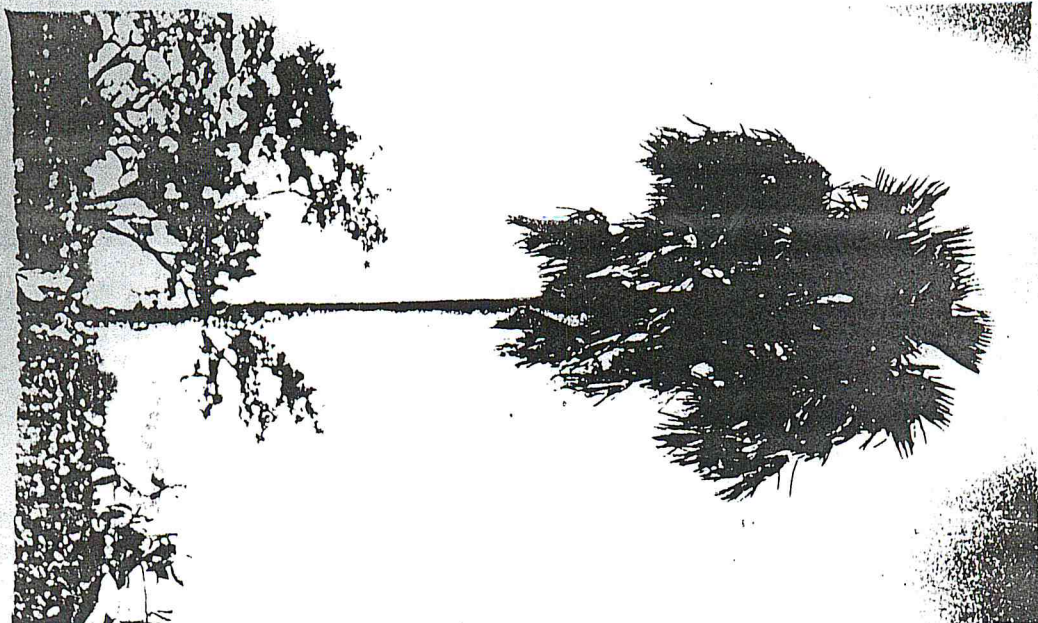
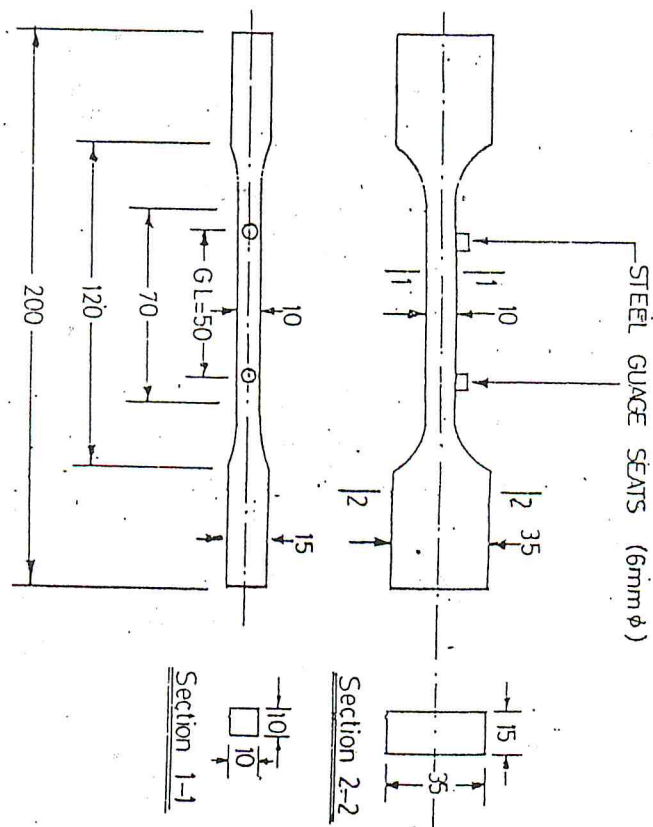


Fig. 1b: TENSION SPECIMEN OF FANPALM (DIMENSIONS (mm))



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TEST DATA AND STATISTICAL ANALYSIS

The experimental test data obtained for tension and compression specimens were the applied loads and the corresponding extension or shortening. Engineering stress was computed by dividing the applied load by the original cross-sectional area and the corresponding strain was also found as the ratio of the measured elongation or shortening to the initial gauge length (gauge length = 50mm).

Stress-strain curves for some specimens are presented in Figures 2a and 2b. Data from twenty-two tension specimens and twenty-eight compression specimens were used in the statistical analysis to obtain the mean ultimate strengths, variances, coefficients of variation, confidence limits for the mean ultimate strengths, the stress-strain relations and characteristic strength properties. Relevant data are presented in tables 1 and 2.

For the flexure tests, loads and corresponding central deflections were obtained and from these data, load-deflection curves were drawn as shown in figure 3. The curves were linear up to the point where the gradient continuously decreased until failure. The modulus of rupture (mbr) was computed from the expression $55Pd/I$, where P is the applied load (KN), d is half of the depth of the specimen and I is the moment of inertia of the cross-section of the specimen. The modulus of elasticity E is obtained from

$$E = \frac{23L^3C}{648I}$$

where C is the slope of the load-deflection curve, and L is the effective span (m).

A total of eight flexure specimens were tested and the data analysed to obtain the mean modulus of rupture, the modulus of elasticity, the standard deviation, the coefficient of variation, confidence limits for the mean strength and the characteristic flexural strength. Some of these results are shown in Table 3.

a) Mean Ultimate Strengths

The mean ultimate strength was found by dividing the sum of the maximum tensile strength of all the specimens by the number of specimens tested. Mean ultimate strength in tension for the specimens tested is 151.91 N/mm^2 while the mean ultimate strength in compression for the specimens tested is 112.55 N/mm^2 . The mean modulus of rupture (mor) is found to be 143.80 N/mm^2 .

b) Standard Deviation

The standard deviation, S , is given by where y is the maximum strength in N/mm^2 of each specimen, $\bar{y}$ is the mean strength in N/mm^2 and n is the number of specimens. Substituting for the parameters in equation (1),

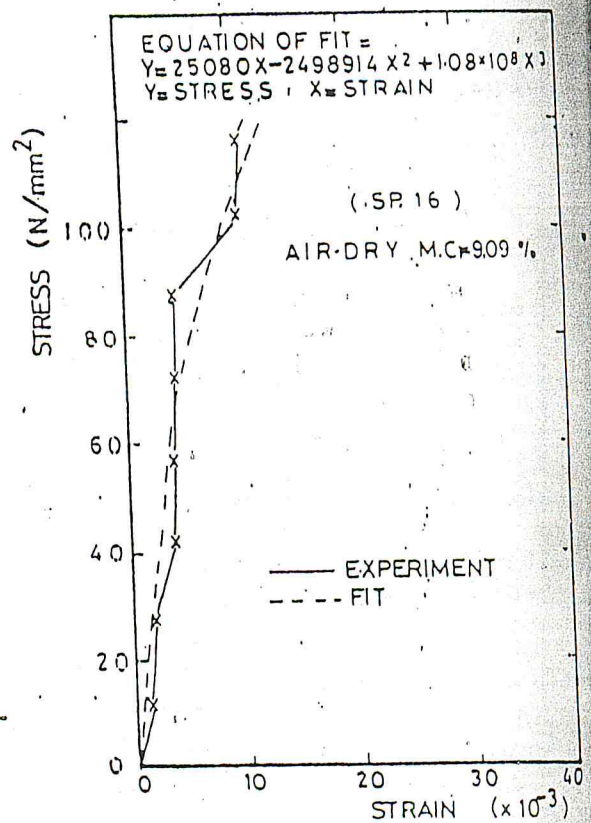
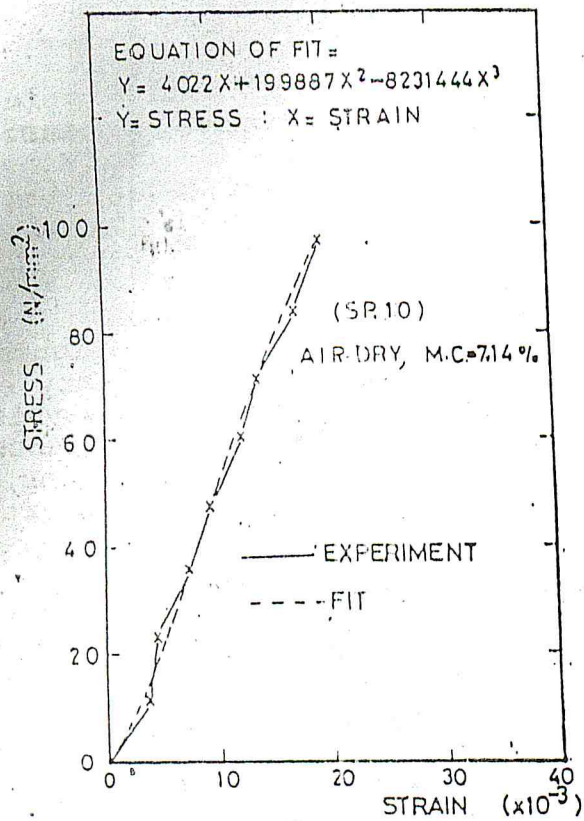


Fig. 2a. Fanpalm tensile stress - strain curves

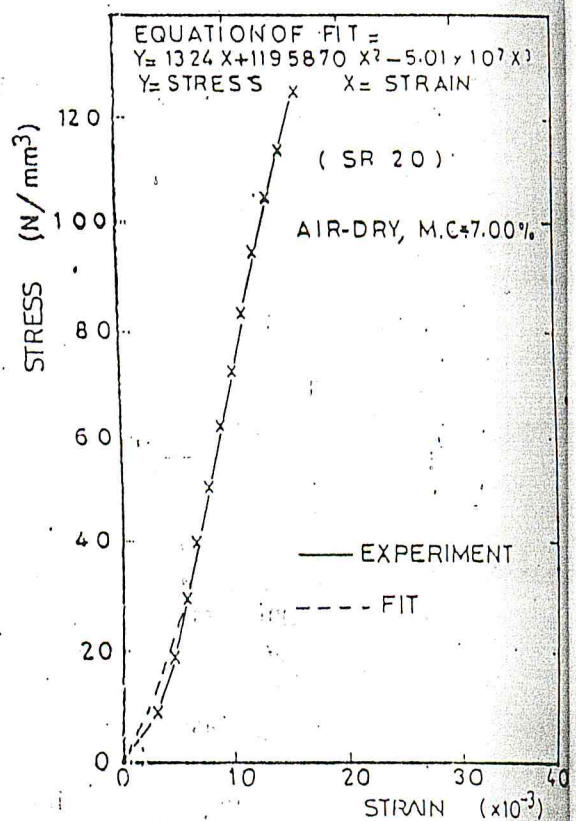
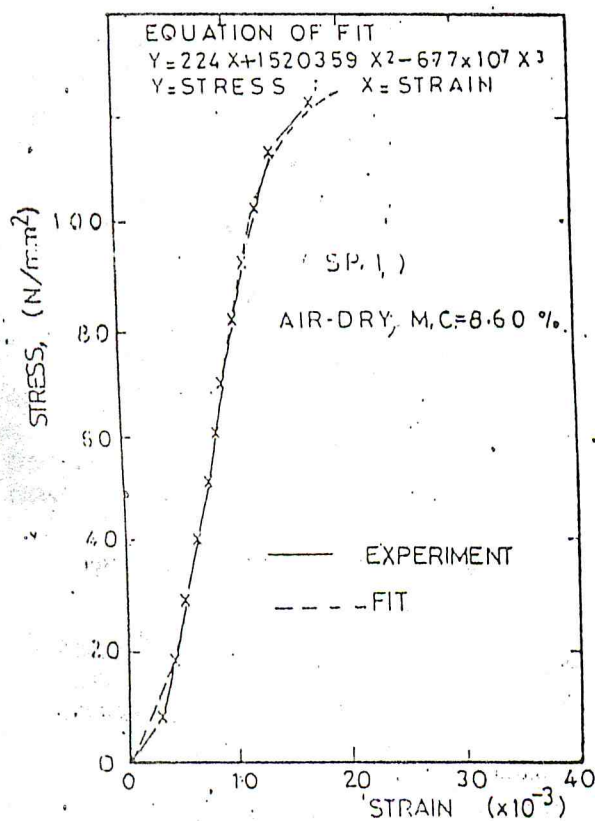


Fig. 2b. Fanpalm compressive stress - strain curves.

27
 28
 Mean

109.89
 90.32
 112.55

14.31
 29.29
 23.98

Table 1: MAXIMUM TENSILE STRENGTH AND MAXIMUM STRAIN

SPECIMEN NO.	MAX. TENSILE STRESS N/mm ²	MAX STRAIN x 10 ³
1	59.20	36.71
2	129.63	31.80
3	132.28	30.11
4	189.50	35.46
5	153.06	19.12
6	132.91	20.34
7	130.57	20.38
8	125.00	55.03
9	104.53	24.90
10	90.01	18.14
11	229.44	15.83
12	186.89	48.26
13	207.80	24.66
14	142.66	47.93
15	200.00	29.93
16	124.83	41.68
17	120.07	11.19
18	146.34	12.19
19	197.53	23.08
20	215.19	25.78
21	149.37	16.69
22	165.14	11.08
Mean	151.91	25.94

Table 2: MAXIMUM COMPRESSIVE STRENGTH AND STRAIN

SPECIMEN	MAXIMUM COMPRESSIVE STRESS N/mm ²	MAXIMUM STRAIN (x 10 ⁻³)
1	116.16	15.71
2	125.71	28.59
3	115.93	20.73
4	116.43	15.71
5	131.61	26.67
6	109.29	19.23
7	88.59	21.20
8	82.56	19.41
9	85.71	18.45
10	126.66	28.39
11	128.36	31.41
12	119.72	31.83
13	115.28	21.60
14	124.82	14.23
15	112.55	29.74
16	121.48	27.78
17	84.71	29.74
18	100.81	15.08
19	124.83	31.83
20	120.82	17.58
21	111.11	27.58
22	117.10	22.45
23	119.35	28.28
24	112.82	25.05
25	122.89	28.87
26	11.5.90	32.20
27	109.89	14.31
28	90.32	29.29
Mean	112.55	23.98

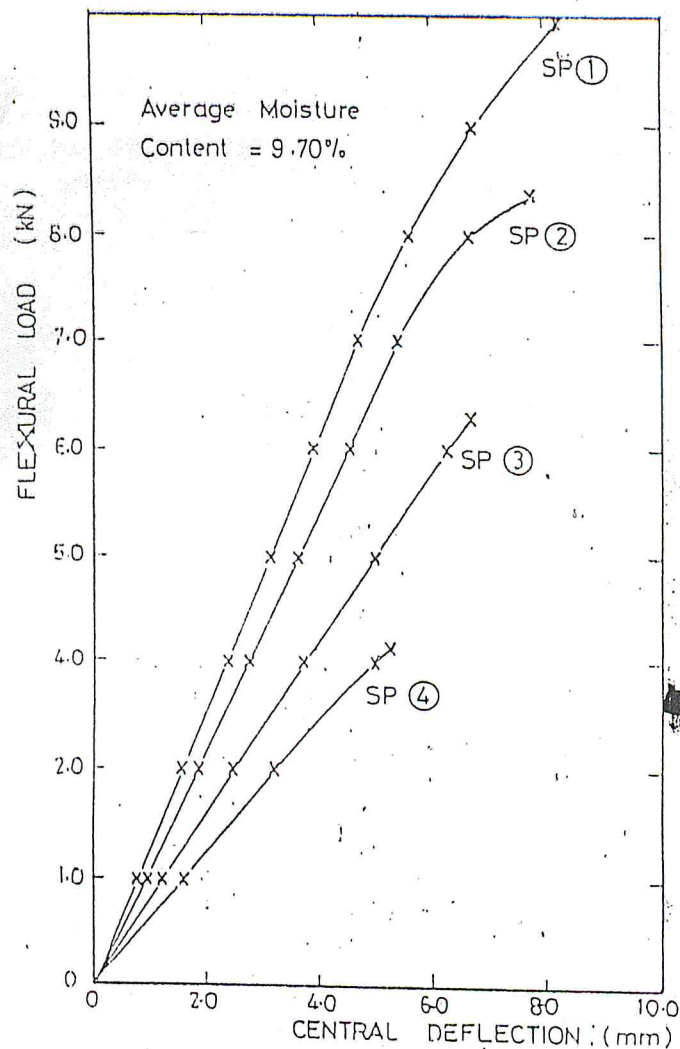


Fig. 3: FANPALM LOAD DEFLECTION CURVES

Table 3: MODULI OF ELASTICITY AND RUPTURE RESULTS FOR FANPALM IN FLEXURE

Speci- men No.	Moment of Inerti- a (I) mm ⁴	Mois- ture Con- tent	Depth h (mm)	Load at propor- tional limit Pl. (kN)	Deflec- tion at prop. limit	Failure load		Modu- lus of Elasti- city kN/mm ²	Modulus of rupture	
						P2 (kN)	P1 P2		Prop limit (N/mm ²)	At Failure (N/mm ²)
1	26836	9.5	23.6	4.0	4.8	4.0	0.80	19.97	96.74	120.92
2	31472	9.5	25.2	6.0	5.5	9.0	0.67	27.20	132.12	198.18
3	22419	9.5	22.7	2.0	3.0	3.0	0.67	18.97	56.43	84.64
4	33300	10.1	25.5	6.0	5.2	7.0	0.86	22.31	119.41	139.32
5	13134	10.3	22.6	5.0	6.6	7.5	0.67	26.06	145.62	218.43
6	28800	9.6	24	5.0	4.4	5.5	0.91	20.10	119.36	131.29
7	21787	9.8	22.6	3.0	3.4	4.0	0.75	25.83	85.77	114.36
8	27648	9.3	24	5.5	6.2	6.0	0.92	20.43	131.29	143.23
Mean		9.7						22.61	110.84	143.23
Standard deviation								0.78	29.31	444.07
Characteristic strength									63.94	73.28
Coefficient of Variation									26%	30%

$$S = \frac{(y - \bar{y})^{\frac{1}{2}}}{n - 1} \dots \dots (1)$$

the standard deviation for the tensile strength is 43 N/mm² while that of the compressive strength is 14 N/mm² and 44.1 N/mm² for the flexure tests.

Coefficient of variation, CV.

This is given by the expression (8)

$$CV = \left(\frac{S}{y} \times 100 \right) \% \dots \dots (2)$$

Substituting the appropriate values for S and y, the coefficients of variation are 28% for tension, 12% for compression and 30% for flexure.

Confidence limits for mean ultimate strength

Although the mean strength of the sample tested has been determined, this is not the same as the mean of the population of the fanpalm material; that is, it is not certain that the true value of the mean of the population is the same as the estimate for the sample. To ascertain the closeness of the true mean, limits are set on either side of the estimated mean ultimate strength of the sample, which contain the most likely values of the population mean. In this case 95% and 99% probability confidence limits were set.

The confidence interval for the estimate of the mean ultimate strength of the population (material) U, is given by (5,8).

$$U = \bar{y} \pm t_{\left(\frac{\alpha}{2}, n-1\right)} \frac{S}{n^{\frac{1}{2}}} \dots \dots (3)$$

where U is the mean ultimate strength of the population, y is the sample mean, α is the level of the significance corresponding to 1% and 5% significance,

$$t_{\frac{\alpha}{2}, n-1}$$

is a value obtainable from statistical t-distribution table, depending on the level of significance, α and the degrees of freedom n-1, S and n are the standard deviation and the number of samples respectively.

Using equation (3), the confidence limits for the mean tensile strength are 151.91 N/mm² $\pm$ 19.06 N/mm² for 95% probability (confidence) and 151.91 N/mm² $\pm$ 25.96 N/mm² for 99%

us of re	At Failure (N/mm ²)
2	120.92
2	198.18
	84.64
1	139.32
2	218.43
6	131.29
	114.36
9	143.23
4	143.23
	444.07
	73.28
	30%

probability. The corresponding values for the mean compressive strength are $112.55 \text{ N/mm}^2 \pm 5.43 \text{ N/mm}^2$ and $112.55 \text{ N/mm}^2 \pm 7.35 \text{ N/mm}^2$.

For the flexure tests, the confidence intervals for the modulus of rupture (m_{or}) are $143.80 \text{ N/mm}^2 \pm 36.84 \text{ N/mm}^2$ and $143.80 \text{ N/mm}^2 \pm 54.53 \text{ N/mm}^2$ for 95% and 99% probabilities, respectively.

e) Regression analysis of stress-strain data

For structural analysis and design purpose, it is handy to have an expression relating the material stress and strain. A regression analysis was done to obtain stress-strain relations for both the tension and compression data. Polynomial of orders 1, 2 and 3 were investigated and it was found that polynomial of order 3 was the most appropriate. That is, theoretically predicted stress-strain data were very close to experimental data. The correlation coefficients between the experimental and the theoretical data for all specimens tested vary between 0.98 and 1.

The approximate polynomial regression model developed for the sets of experimental stress and strain data has the form

$$Y = a_0 + a_1x + a_2x^2 + a_3x^3 \dots \dots \dots (4)$$

where Y is the fitted stress and x the strain and a_0 , a_1 and a_3 are coefficients obtainable from regression analysis. Full details of analysis can be found in reference (1).

The polynomial equations were developed for the stress-strain data of each specimen and a single stress-strain equation was subsequently obtained using the average values of the coefficients. For both tension and compression, the first coefficient a_0 was found to be small and was ignored.

The typical (average) stress-strain equations for tension and compression are

$$Y = 15134x - 794286x^2 + 2.77 \times 10^7x^3 \dots \dots \dots (5)$$

$$Y = 2938x - 800289x^2 - 3.44 \times 10^7x^3 \dots \dots \dots (6)$$

Stress-strain curves for these typical stress strain equations are presented in figures 4a and 4b. Also shown in these figures are the curves with 95% confidence intervals. The confidence intervals for the estimate of stress are given by

$$Y_n \pm (t_{\frac{\alpha}{2}, df}) \times (\text{estimated standard deviation of } Y_n) \dots (7)$$

where $\alpha = 0.05$ (for 95% confidence interval; d.f is the degree of freedom given by $n - (k+1)$; n is the number of data points,

Fig. 4a TYPICAL TENSILE STRESS-STRAIN CURVE WITH 95% CONFIDENCE INTERVALS

Fig. 4b. TYPICAL COMPRESSIVE STRESS-STRAIN CURVE WITH 95% CONFIDENCE INTERVALS

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Fig. 4a TYPICAL TENSILE STRESS-STRAIN CURVE WITH 95% CONFIDENCE INTERVALS

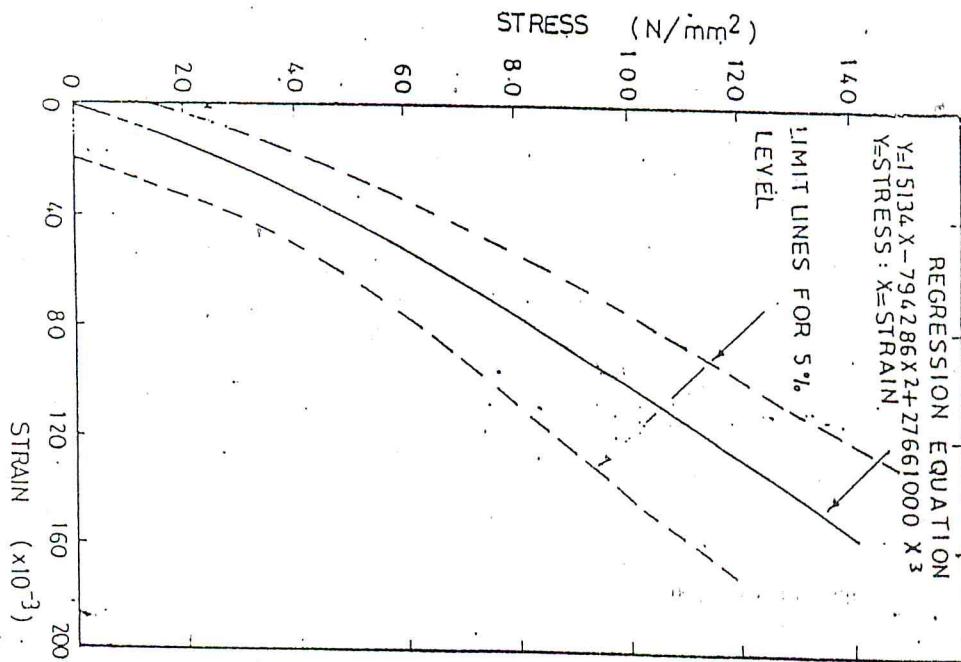
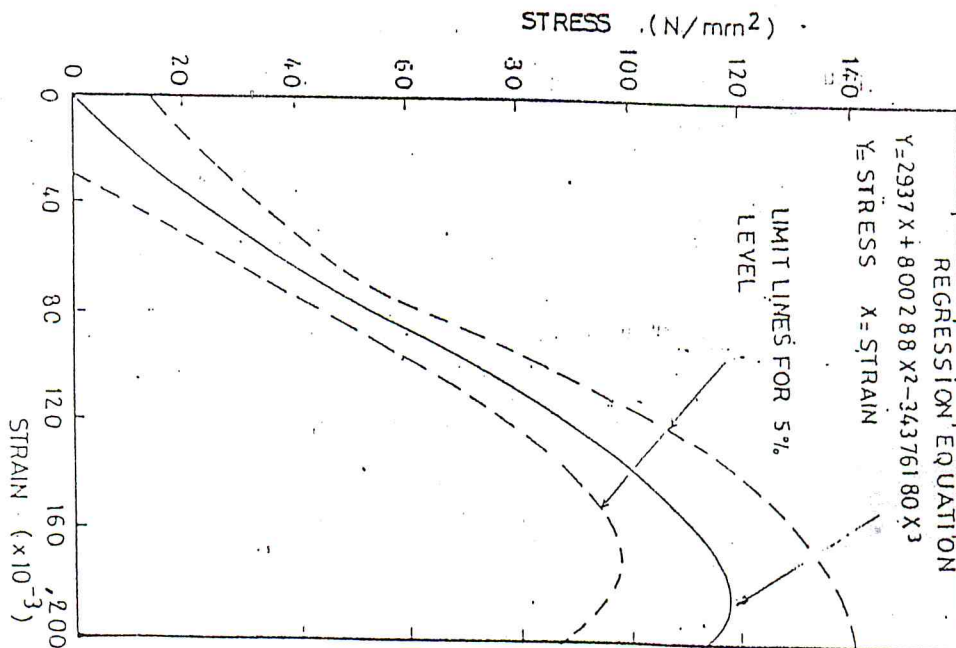


Fig. 4b. TYPICAL COMPRESSIVE STRESS-STRAIN CURVE WITH 95% CONFIDENCE INTERVALS



k is the order of the polynomial; Y is the estimated or theoretical value of Y (stress). The procedure of obtaining the confidence intervals is given in reference (1).

f) Modulus of elasticity and characteristic strength

Because of the non-linear nature of the stress-strain relation, the modulus of elasticity will vary depending on the stress and strain levels. Thus the modulus is better obtained from the first derivative of the stress-strain relations. The initial tangent modulus is obtained by substituting into the first derivative a zero value for the strain and this gives 15.13 kN/mm² for tension and 2.94 kN/mm² for compression. In flexure, the modulus of elasticity is 22.61 kN/mm² with a standard deviation of 0.78 kN/mm² (coefficient of variation is 3.5%).

One of the aims of this study is to find the characteristic strength of fanpalm. Characteristic strength is defined as that strength below which it is unlikely that more than a prescribed percentage of the strength will fall. A relationship between the mean strength and characteristic strength for a pre-assigned reliability is

$$f_s = \bar{y} - kS \dots \dots (8)$$

where f_s is the characteristic strength, $\bar{y}$ is the mean strength, s is the standard deviation and k is a statistical parameter indicating levels of probability of failure. For 5% probability of failure k is about 1.64, assuming normal distribution for the strength. Using this value in equation (8), the characteristic strength of fanpalm is 81.44 N/mm² in tension, 89.44 N/mm² in compression and 73.28 N/mm² in flexure.

DISCUSSION

For the air-dried fanpalm tested (m.c. = 6 to 11%), the mean strengths and mean modulus of elasticity in flexure are the important properties. The mean tensile strength is about 60% of the specified yield strength of mild steel while the modulus of elasticity in flexure is about one-tenth that of steel, showing that fanpalm will deflect more than steel under load.

Considering the inherent variability of natural material, the coefficients of variation obtained for fanpalm were not high as they fell within acceptable limits of 10-30% for wood materials. The coefficient is even less than 10% for the modulus of elasticity in flexure.

The typical stress-strain equations given by equations (5) and (6) can be used for stress-strain computations for fanpalm but should be taken as approximate and not absolute. The experimental

average strains are 2.6% in tension and 2.4% in compression. However, limiting strain values of 0.76% and 1.18%, corresponding to the characteristic stresses in tension and compression respectively were obtained analytically from the stress-strain equations.

Substituting these limiting strains in the first derivative of the stress-strain equations, gave characteristic tangent modulus in tension and compression as 18.72 kN/mm² and 7.48 kN/mm² respectively. The corresponding initial moduli when strains are zero are 15.13 kN/mm² and 2.94 kN/mm² for tension and compression, respectively. It is noteworthy that for the fanpalm the ratio of the characteristic tangent modulus in tension to that in compression is 0.4; this value is comparable to similar moduli ratio of 0.46 and 0.36 obtained for seasoned Bamboo culms with and without node respectively (11).

In obtaining the characteristic strength values given, an assumed probability of failure was used which may be conservative or otherwise. It is desirable to establish a value for the probability of failure to use based on extensive field and laboratory data.

CONCLUSIONS

The following are the conclusions derived from the analysis of the data obtained from the tests carried out on air-dried, matured outer-core of fanpalm specimens.

The strength of fanpalm varied considerably for the tensile, compressive and flexural tests. In the case of tensile tests, the maximum strength ranged from 59.2 N/mm² to 299.44 N/mm²; the mean ultimate strength is 151.9 N/mm² with a coefficient of variation of 12%. The confidence intervals at 5% and 1% levels of significance are ± 28.23 N/mm² and ± 25.96 N/mm², respectively. The mean value of the ultimate compressive strength is 112.6 N/mm² (coefficient of variation of 12%) with confidence limits of ± 5.43 N/mm² and ± 7.35 N/mm² for 5% and 1% levels of significance respectively.

The modulus of rupture (mor) ranged between 84.6 N/mm² and 218.43 N/mm² with a mean of 143.8 N/mm² and coefficient of variation of 3%. For 5% and 1% levels of significance, the confidence intervals for the mean mor are ± 36.84 N/mm² and ± 54.53 kN/mm² (coefficient of variation 3%).

The following equations, derived by regression analysis, are proposed for the stress-strain relations of fan-palm.

$$Y = 15134x - 794286x^2 + 2.77 \times 10^7 x^3 \text{ (for tension) and}$$

$$Y = 2938x + 800289x^2 - 3.44 \times 10^7 x^3 \text{ (for compression)}$$

where Y = represents the stress, in N/mm², and x the strain.

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