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Tensile Strength of Local Materials Used as Ropes in Nigeria

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Editor's note: This article was edited and shortened by the editor of the Journal, who is responsible for any inaccuracies that might have crept in.

The concept of improvisation as well as its necessity in Nigerian school laboratories has, perhaps, been now more understood under the present depressed economy than ever before. The cost of prototype materials is very high and this is affecting the teaching of science in the country. To cope with this, many resourceful science teachers are embarking on improvisation of science materials in teaching. More often than not, this is carried out without a careful study of the properties of the local materials involved. As a result of this negligence, most improvised materials do not yield tangible results.

The view of this article is that improvisation in science can be more meaningful and beneficial if the mechanical, electrical and magnetic properties of local materials are properly investigated.

In Nigeria, some local materials are used as ropes. Prominent among these are piassava and tie-tie (mostly in the eastern parts of the country). These materials come from the palm wine tree and are extensively used in constructing mud houses, building wooden fences, tying yam pegs together in bundles and also tying papers and leaves used in wrapping food items sold in local markets. Unlike internationally used wire (copper and so on), these local materials have not been tested to ascertain their strength and stiffness. The use of these materials in house building, particularly, necessitates the knowledge of their tensile strength. By tensile strength, I mean the ability of a material to withstand force without breaking. It is the ultimate strength of a material as measured under tension. By ultimate strength, I mean the limiting stress (in terms of force per original unit area of cross section at which a material completely breaks down). On the other hand, stiffness is the ratio of tensile stress to tensile strain on a material.

Purpose

This study aims at investigating the tensile strength and stiffness of materials used for local ropes (piassava and tie-tie) in Nigeria. Specifically, the study aims at answering the following questions:
1. What are the tensile strengths of piassava and tie-tie when in a dry state?
2. What are the tensile strengths of dampened piassava and tie-tie?
3. What are the Young's moduli of piassava and tie-tie when in dry and dampened states?
4. Are the dampened piassava and tie-tie of higher tensile strength than the same materials in their dry states?

Methodology

The study was carried out by means of laboratory experiments. Piassava and tie-tie

of different lengths and diameters were obtained from the source. Using weights of various sizes, extensions of each material were measured with corresponding weights attached. The experiments were conducted using dry and dampened materials. The dampening was done by submerging the piassava and tie-tie in water for one day (a common practice in local areas where the materials are used.)

Apparatus

The following instruments were used: micrometer screw gauge, metre rule, weight hanger, retort stand and standard weights.

Theory

To obtain the tensile strength and the stiffness (Young's modulus) of each material, the following expressions were used:

1. Tensile strength $= \dfrac{\text{Maximum force applied before the material breaks}}{\text{Original cross sectional area}}$
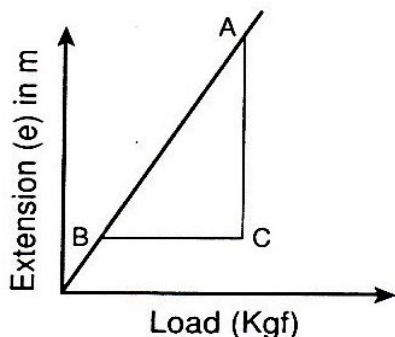
2. Stiffness $= \dfrac{\text{Tensile stress}}{\text{Tensile strain}}$

Where (a) Tensile stress $= \dfrac{\text{Force applied}}{\text{Cross sectional area of the material}}$

$= \dfrac{F}{\pi r^2}$

Where r $=$ radius of the cross section of the material

Where (b) Tensile strain $= \dfrac{\text{Extension obtained (e)}}{\text{Original length } (L_o)}$

The value of Young's modulus can practically be obtained by plotting a graph of mean extension against the load applied:

From the sketch above, the slope $= \dfrac{AC}{BC}$

Experiment

For each sample of the material, original length (L_o) and the mean diameter were measured and recorded. The material under test was loaded until it became just taut. Then the load was gradually increased and the corresponding lengths of the materials were recorded. Loading continued until the material was just about to break. The loads were then gradually removed and corresponding lengths of the material were recorded. For both loading and unloading, extension of the material at each point was calculated, The experiment was repeated for different lengths and mean diameters of piassava and tie-tie in their dry and dampened states. The results are shown in Graphs 1–4, with similar graphs available for tie-tie in dry and dampened states.

Young's modulus (E) $\dfrac{F}{\pi r^2} \Big/ \dfrac{e}{L_o}$ (1)

Where F $=$ Force applied
e $=$ Extension
L_o $=$ Original length of material
r $=$ radius of the cross section of the material

From Equation 1   E $= \dfrac{F}{e} \cdot \dfrac{L_o}{\pi r^2}$ (2)

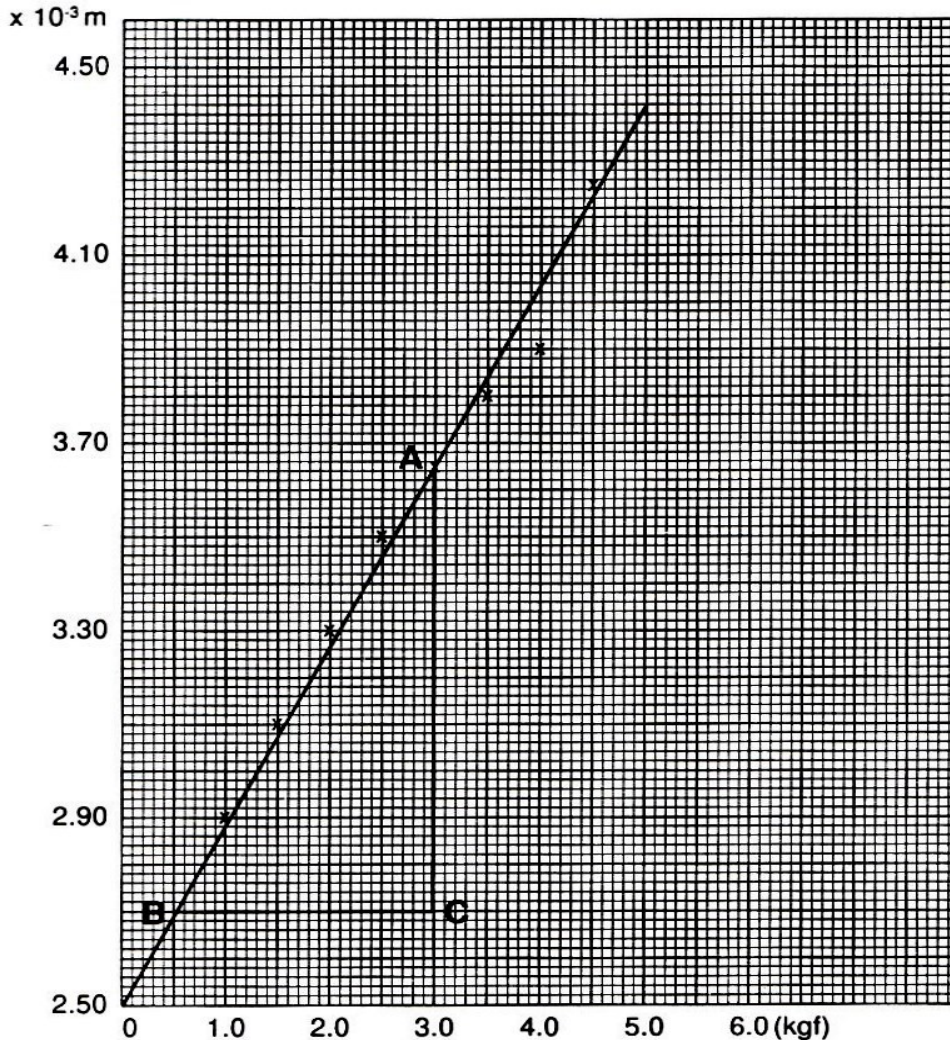Where $\dfrac{F}{e} = \dfrac{1}{\text{Slope}}$

Hence E $= \dfrac{1}{\text{Slope}} \cdot \dfrac{L_o}{\pi r^2}$ (3)

Results and Discussion

The results obtained from the experiments are given as follows.

Graph 1

A plot of extension (e) against force applied (F) using a dampened piassava (DAP-1) of length (L_1) 0.805 m and mean diameter (r_1), 7.42×10^{-3} m. Breaking stress = 5.00 kgf.

$$\frac{BC}{AC} = 2.58 \times 10^4 \text{ NM}^{-1}$$

Graph 1 yields the slope of 3.87×10^{-5} MN^{-1}. The reciprocal of the slope is therefore 2.58×10^4 NM^{-1}. Based on this, the following calculations are made:

1. Tensile strength (TS_1) of dampened piassava (DAP-1)

$$TS_1 = \frac{Mg}{\pi r_1^2} = \frac{4.5 \times 9.81}{3.142 \times (3.71 \times 10^{-3})^2} = \frac{44.15}{43.25 \times 10^{-6}}$$
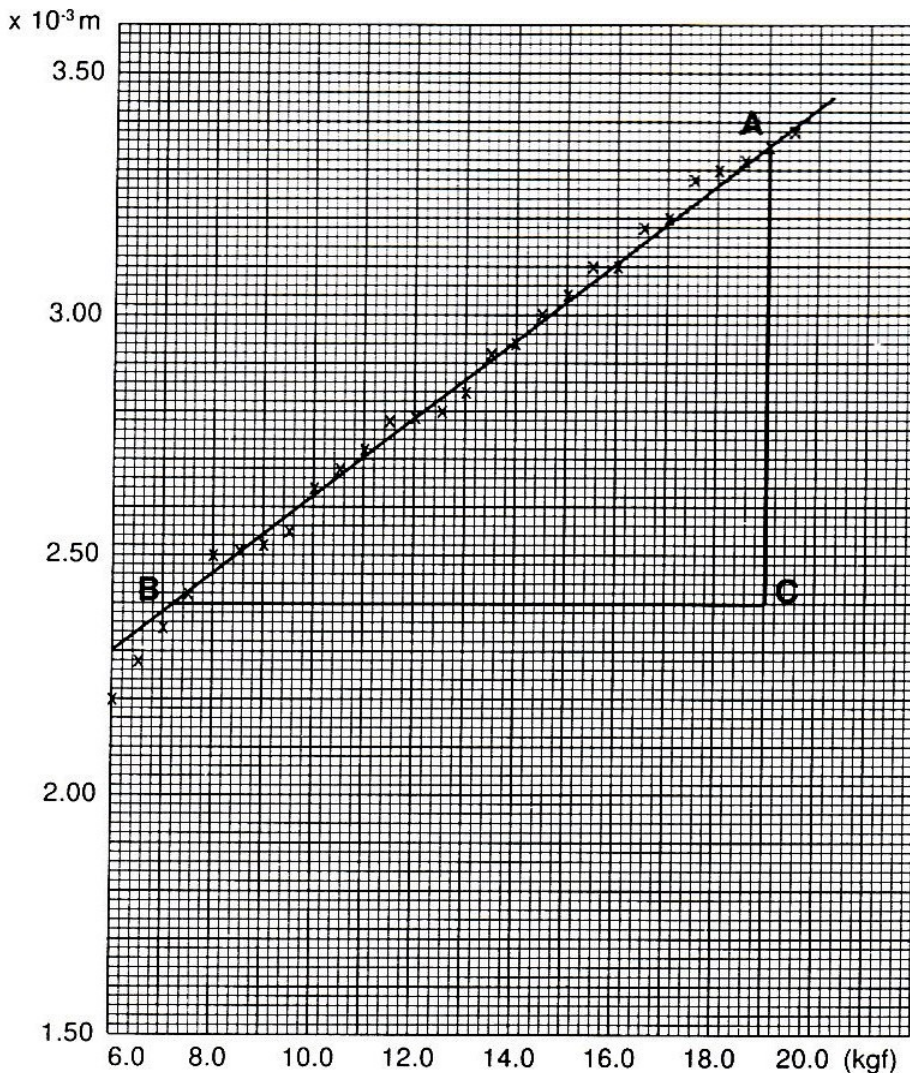
$$= 1.02 \times 10^6 \text{NM}^{-2}$$

2. Young's modulus (E_1) $= \dfrac{1}{\text{Slope}} \cdot \dfrac{L_1}{\pi r_1^2}$

$$= 2.58 \times 10^4 \times \frac{0.805}{43.25 \times 10^{-6}}$$

$$= 4.80 \times 10^8 \text{NM}^{-2}$$

Graph 2

A plot of extension (e) against force applied (F) using a dampened piassava (DAP-2) of length (L_2) 0.92 m and mean diameter (r_2), 5.3×10^{-3} m. Breaking stress = 20.00 kgf.

$$\frac{BC}{AC} = 1.21 \times 10^5 \text{ NM}^{-1}$$

From Graph 2, the slope is $8.29 \times 10^{-6} \text{MN}^{-1}$, giving a reciprocal of $1.21 \times 10^5 \text{NM}^{-1}$. Consequently, the following results are obtained:

1. Tensile strength of dampened piassava (DAP-2)
   $TS_2 = 8.66 \times 10^6 \text{NM}^{-2}$

2. Young's modulus (E_2)
   $E_2 = 5.04 \times 10^9 \text{NM}^{-2}$

From these values of tensile strengths and Young's moduli, the mean values can be calculated for a dampened piassava thus:
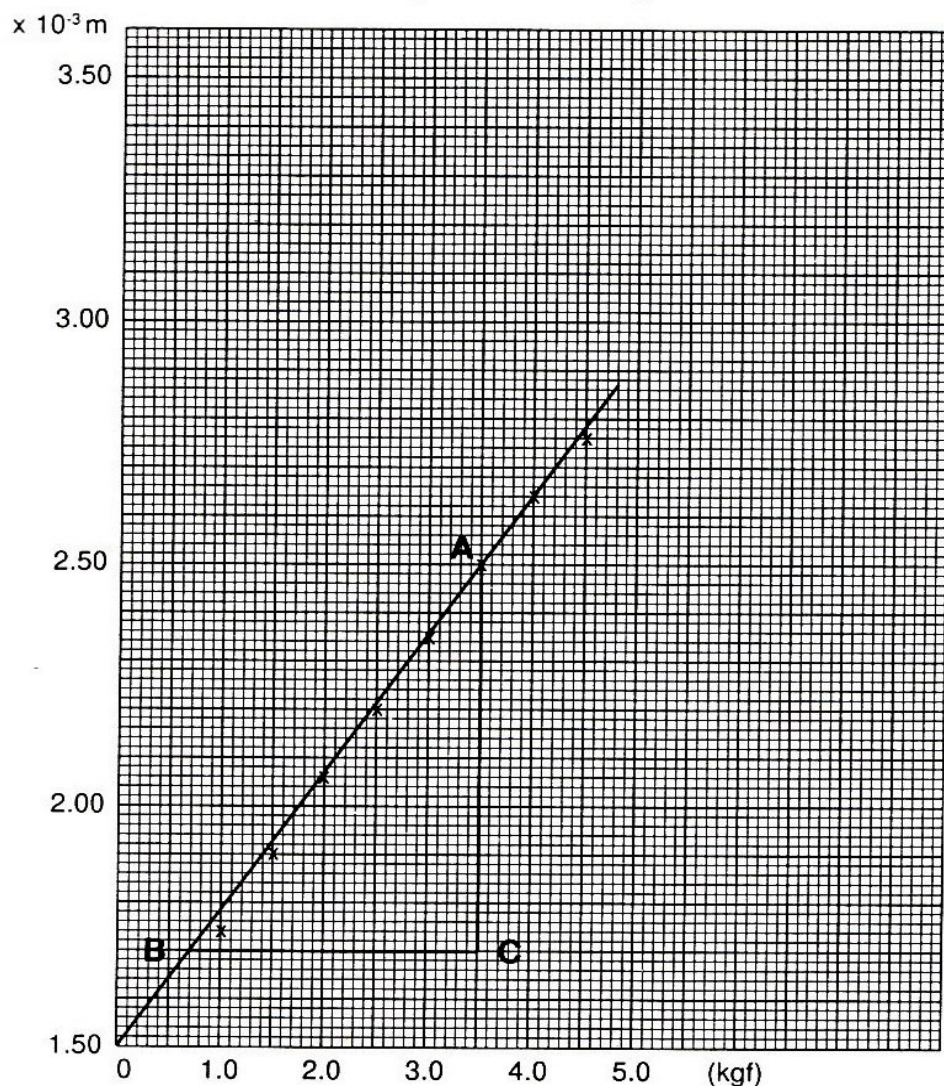
1. Tensile strength of dampened piassava
   $$\frac{TS_1 + TS_2}{2} = \frac{(1.02 \times 10^6 + 8.66 \times 10^6)}{2} = 4.84 \times 10^6 \text{NM}^{-2}$$

2. Young's modulus of dampened piassava
   $$\frac{(E_1 + E_2)}{2} = \frac{(4.80 \times 10^8 + 5.04 \times 10^9)}{2} = 2.77 \times 10^9 \text{NM}^{-2}$$

Graph 3

A plot of extension (e) against the force (F) applied using a dry piassava (DRP-1) of length 0.97 m and mean diameter 7.7×10^{-3} m. Breaking stress = 5.0 kgf.


$$\frac{BC}{AC} = 3.44 \times 10^4 \ NM^{-1}$$

As shown in the graph above, the slope is $2.91 \times 10^{-5} MN^{-1}$, thus giving its reciprocal as $3.44 \times 10^4 NM^{-1}$. Consequently,

1. Tensile strength (TS_3) of dry piassava
$TS_3 = 1.05 \times 10^6 NM^{-1}$

2. Young's modulus (E_3) of dry piassava
$E_3 = 7.17 \times 10^8 NM^2$

Graph 4

A plot of extension (e) against force (f) applied using a dry piassava (DRP-2) of length 1.38 m and mean diameter 5.78 x 10^{-3} m. Breaking stress = 19.50 kgf.
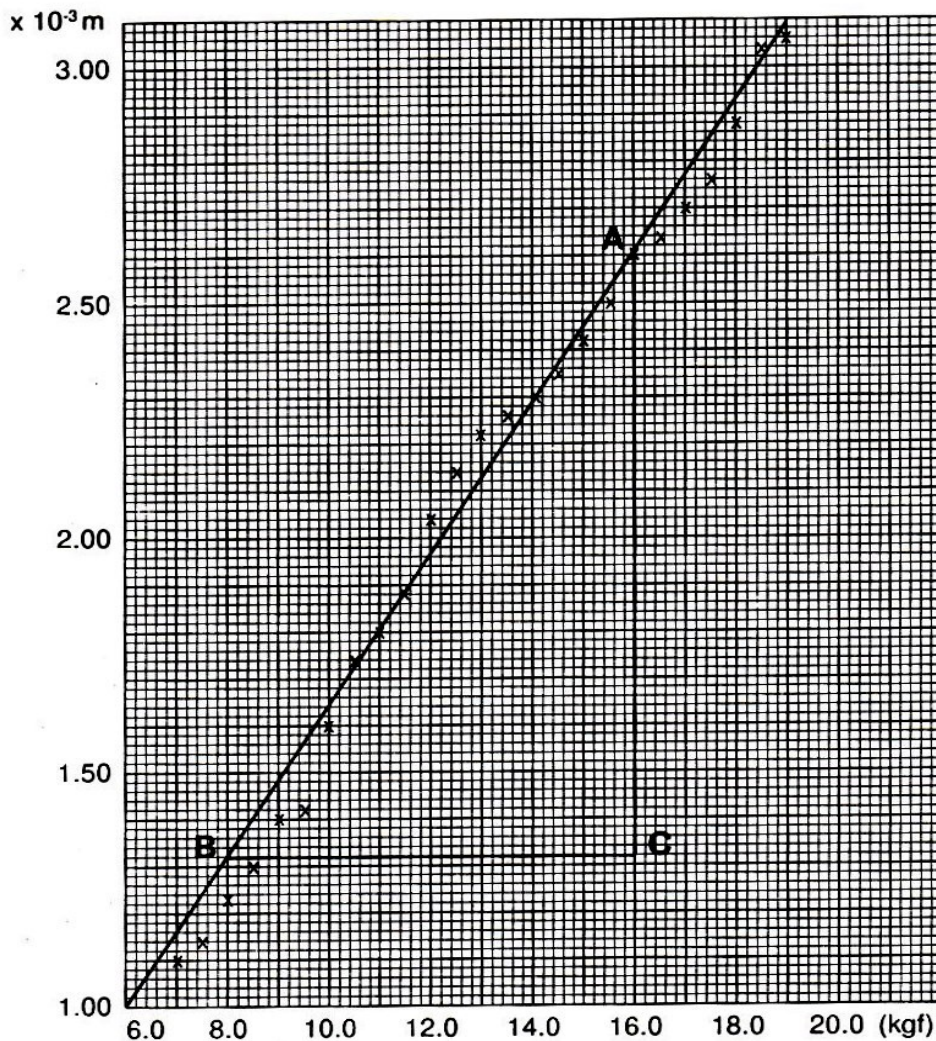
$$\frac{BC}{AC} = 6.13 \times 10^4 \text{ NM}^{-1}$$

From Graph 4, the slope = 1.63 × 10^{-5}MN^{-1}, giving the reciprocal as 6.13 × 10^4NM^{-1}.

1. Tensile strength (TS_4) of dry piassava = 7.10 × 10^6NM^{-2}
2. Young's modulus (E_4) of dry piassava = 3.22 × 10^9NM^{-2}

Considering calculations based on Graphs 3 and 4, the mean values for dry piassava are

1. Tensile strength $\dfrac{(TS_3 + TS_4)}{2}$ = 4.08 × 10^6NM^{-2}

2. Young's modulus $\dfrac{(E_3 + E_4)}{2}$ = 1.97 × 10^9NM^{-2}

Similarly, graphs for extension versus force applied can be made for dry tie-tie (hard), dry tie-tie (soft), dampened tie-tie (hard) and dampened tie-tie (soft). The results are summarized in Table 1.

Table 1

A Table Showing the Tensile Strengths and Young's Moduli of Dry and Dampened Piassava and Tie-Tie (Soft and Hard Types)

Material	State	Tensile strength (NM^{-2})	Young's modulus (NM^{-2})
Piassava	dampened	4.84×10^6	2.77×10^9
Piassava	dry	4.08×10^6	1.97×10^9
Tie-tie (hard type)	dry	3.00×10^7	9.25×10^9
Tie-tie (soft type)	dry	5.39×10^7	2.08×10^{10}
Tie-tie (hard type)	dampened	5.25×10^7	3.24×10^{10}
Tie-tie (soft type)	dampened	1.16×10^8	6.26×10^{10}

Conclusion

From the study, it is observed that the local materials (piassava and tie-tie) have higher tensile strengths and higher Young's moduli in their dampened states than when in the dry states. This observation emanates from the fact that, apart from expansion effect, temperature does influence the strength of materials. It was already known experimentally (Wenham, Darling and Snell 1978) that the soft type of tie-tie is stronger than the hard type. Tie-tie was also found stronger than piassava, in all states. The electrical and magnetic properties of piassava and tie-tie could also be investigated.

Reference

Wenham, E. J., G. W. Darling and J. A. N. Snell. *Physics: Concepts and Models*. London: Addison-Wesley, 1978.