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MECHANICAL PROPERTIES OF SUGAR PALM (*Arenga pinnata*) ROPES AND NETS FOR AGRICULTURAL PURPOSES

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ABSTRACT

Sample of Arenga Pinnata (AP) fibres, ropes and nets were prepared from AP ropes using traditional tools. The ropes and nets were used as agricultural material such as vertical farming of vines (passion fruit, grape, bitter gourd, and melon) in Gorontalo and Japan. The combination of nets and vines acts as green curtain (GC) which could mitigate the thermal energy in outdoor as well as indoor buildings. and tested with the deformation rate of up to the point of rupture. To avoid the failure of ropes and nets on supporting the weight of the vines, the Universal Testing Machine Model WDW-50 were used to determine the ultimate tensile forces. While the physical size of the AP fibres, ropes and nets also being measured to confirm the uniformity of the individual ropes and nets.The average tensile strength and elongation at break of the AP fibres is 8.14 MPa and 3.7%; which is suitable to support the load of vines. The average density of AP fibre is 1.16 $g.cm^{-3}$ are lighter compared to man-made fibres.

1. Introduction

Fibre of Arenga pinata (AP) has been studied its mechanical strength for development of composite materials (Bachtiar et al. 2010; Ishak et al. 2013; J. et al. 2012). Compared to other natural fibres AP fibre is ready to be processed without further purification for the following purposes as ropes, brooms, mats, cushion and shelters for fish breeding (Mogea, Seibert, and Smits 1991). Recently it is demonstrated as thermal neutron radiation shield (Sitepu et al. 2019). Unfortunately, polymer-based fibres have been replacing those because of its uniformity, sustainability of raw materials. The latter have found as a threat for global plastic pollution and needs to be reduced or even stop to become free from plastic.

Combating plastic pollution as well as mercury pollution in the environment RIHN collaborate with UNG initiates the Sustainable Regional Innovation for Reducing Environmental Pollution (SRIREP). The Natural fibre research group of SRIREP focused on transforming the society to combat environmental pollution by innovating the product based on the local natural fibre available: Ijuk (Arenga Pinnata) fibre and pandanus fibres.

AP nets has found much attention as agricultural material such as GC curtain since the launching of SRIREP project (SRIREP 2022). Since then, the production of AP nets by local people in Gorontalo Province increased and opens new jobs in the poor village of Gorontalo and Bonebolango regency, Indonesia. The use of AP nets in Gorontalo Province ranging from green curtain (GC), green roof (GR) and erosion control blanket (see Figure 1). In Japan the campaign of AP nets use is expands to School (Ryotan Nichinichi Shimbun 2022), Espec mic corporation, RIHN and homes(NHK 2022).

Although the use of GC and GR based on AP nets and ropes has been widely demonstrated in Japan and Gorontalo, the study on their physical properties of AP ropes and AP nets are very rare compared to their fibres components (Hraběl et al. 2018).

(a) (b) (c)

Figure 1. AP Rope and grape (a) and net and passion fruits (b) and net as Erosion Control Blanket (ECB) as agricultural materials (c).

The aim of this article is to elaborate the strength of the AP fibres, ropes, and nets to maintain the weight of the vines. To convince the user of how strong the material is?. We conducted tensile tests as well as the field observation on the behaviour of the nets under viners load.

2. Method

Sample

AP fibres obtained from Mananggu, Gorontalo Province Indonesia, were used for experiments. The preparation of AP fibres, ropes and nets was carried out in several stages, the first was taking palm fibre from the tree. The amount of fibre in one tree is 3-5 rolls shaped like irregular webbing. The fibre that sticks to the tree is taken using a sharp machete and how to cut it is cut slowly at the bottom of the fibre. This is done so that the fibre is not easily damaged, and the condition of the fibre is still in good condition. After that, it is dried and cleaned of any adhering dirt.

Doing this research, the first prepare for 2 small stakes with a size of approximately 10 cm then tie the fibre to the end of a traditional bamboo tool (**Fig. 2a**) and rotate it slowly while taking the fibre little by little until the fibre takes the form of a long rope or spun. After the fibre is in the form of a long rope, it is then put back into the small shell and tied at the end of the rope so that the density of the rope is maintained. The process of winding each part of the woven fibre has an average of 900-1000 turns and the length of the rope obtained is 32-45 m. The number of fibres in each rope is 120-145 strands (**Fig. 3**).

In the next stage, the manufacture of woven is carried out for 4 days by carrying out techniques such as making fishing nets. Making the webbing is done by measuring the rope 1 x 1 meter (see **Figure 4**), then the next step is the rope is rolled on a small piece of wood instead of a needle, the rope ties as the centre of the webbing and then start knitting. After that, weave the rope sequentially down and don't forget

(a) (b)

Figure 2. Separation of fibers from stick plates.

(a)

(b)

Figure 3. Traditional bamboo tool (a) used to wind the AP fibres into rope (b)

Figure 4. AP nets with size of 1m x 1 m.

to tie it with dead rope ties so that it doesn't shift easily and doesn't change shape and size easily

Size and weight measurement

Length and diameter of AP fibres, ropes and nets were measured using 12 inches mm scale ruler and digital micrometre screw gauge, respectively. While the mass of the fibres and ropes are determined using analytical balance (KERN-ABS-N, Kern & Sohn GmbH, Balingen, Germany) at Physics laboratory of UNG. Density of fibres and ropes were calculated using linear density method as described by (Truong et al. 2009).

Tension test

The tensile test was using a tensile tester with large specimens for the Universal Testing Machine Model WDW-50 woven fibre (was conducted at the Laboratory of Industrial Engineering, State University of Gorontalo). This tensile testing machine is a tensile testing machine with a maximum tensile capacity of 50 kN. Furthermore, for fibre testing with small specimens using the ASTM C1557 standard and the NTC.13.04.2 test machine with a maximum load of 2 kN (200 N). The shape of the tensile test specimen is in accordance with what is stated in the standards, both ASTM, ISO and SNI standards.

The samples of single fibre (**Fig. 1a**), spun fibres (rope) (**Fig. 1b**), and woven were fastened to directly into grips of testing machine. The experiment was repeated three times with each randomly selected fibres, and ropes.

Each sample was taken and tested repeatedly 3 times with each sample. This is done to see the changes in data generated by single, spun and woven fibres. For single and spun fibres, the initial length and diameter have been measured, put into the tensile tester, and analyse the changes in the fibres after the test. Before testing, the sample being tested must be adjusted to the standard testing tool which will display data in the form of a graphical presentation of the sample.

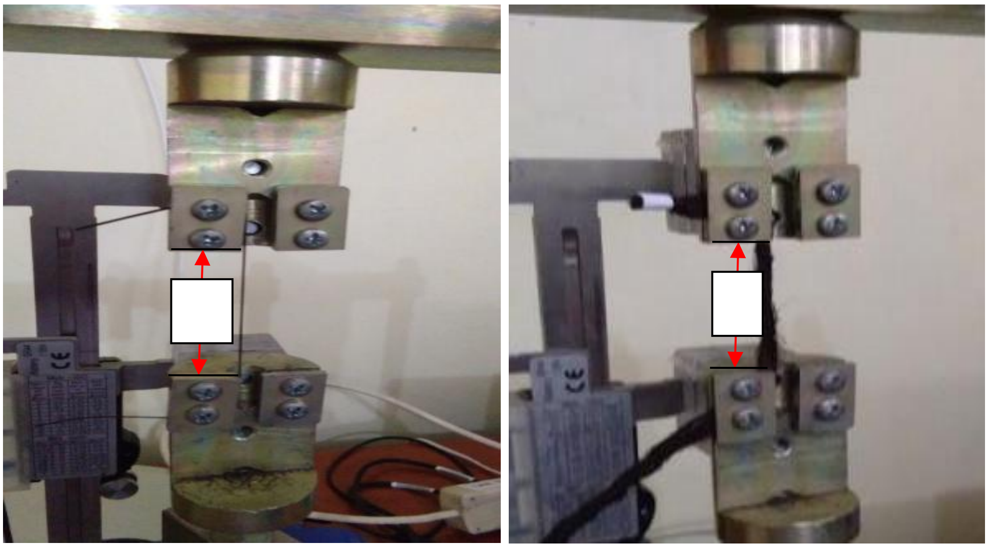
Tests for the 3 sample sections were almost the same, only the specimens and tools for single fibre, spinning and plaits were different. Prior to testing of single fibre, twine and plaited is carried out with the test names T_1, T_2 and T_3 for single fibre, P_1, P_2 and P_3 of spun fibre, A_1, A_2, A_3 for plaited respectively. In the woven samples, three tests were carried out with the thickness and width estimated to be the same for all specimens.

The sample (fibres and ropes) size (length (L), diameter (d)) and weight was measured and followed by calculation of cross-section are (S) using Eq. (1)

$$S = \frac{\pi d^2}{4} \tag{1}$$

where d (mm) is the diameter of fibre and rope.

Stress-strain curve



(a) (b)

Figure 3. Fasting the fibres (a) and ropes (b) to the tensile test.

Stress-strain curves of sample is plotted and data such as ultimate tensile stress (σ_{uts}), elongation at break etc. During the tension test, the tension force (F) applied to the surface of the fibre or ropes which has cross section (S) of diameter d produces amount stress (σ). The σ (Mpa) is calculated using Eq. (2) while the amount of additional length (ΔL) due to σ is quantified using unitless measurement ε called strain in Eq. (3). In the linear regime the relation between σ and ε is written as Eq. (4) where E is known as Modulus Elasticity or Modulus Young, measured in gigapascals (Gpa).

$$\sigma = \frac{F}{S} \tag{2}$$

$$\varepsilon = \frac{\Delta L}{L_0} \tag{3}$$

$$E = \frac{\sigma}{\epsilon} \tag{4}$$

Field Observation

The behaviour of ropes and nets under vines load are being monitored and documented (with camera).

3. Result and Discussion

The length measurement of palm fibre produces an average length of 986 mm (see **Fig. 6**) and a diameter of 0.36 mm at the lower end of the fibre (d_1), the middle of the fibre is 0.37 mm (d_2), and the top of the fibre is 0.24 mm (d_3). Subsequent measurements for the average mass and total mass used a digital analytical balance with the results obtained that the total fibre mass was 3195.6 mg, and the average mass was 122.9 mg. The average density of the palm fibre 1.16 mg.mm^{-3} (g.cm^{-3}).

From the curve (**Fig. 7**), we can see that when the sample is loaded, it begins to pass through the linear area and continues to be loaded, it will experience a new yield point, there will be an increase in stress, which means that the strength of the material increases until at the breaking point there is a change in length increase of 3.75 mm. The ultimate tensile stress (σ_{uts}) is 286.63 N mm^{-2} achieved at strain 0.02

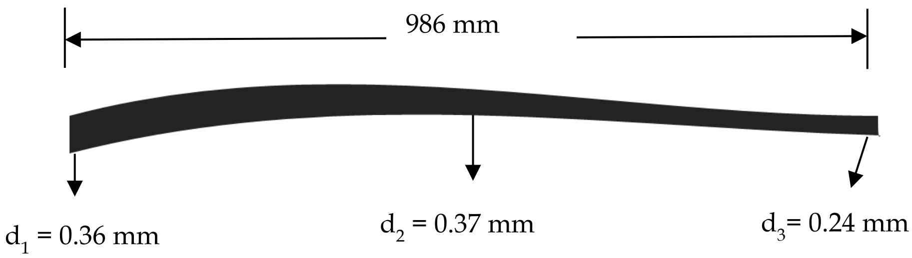


Figure 4. Typical length and diameter at the middle (d2) and both ends (d1 and d3) of AP fibre.

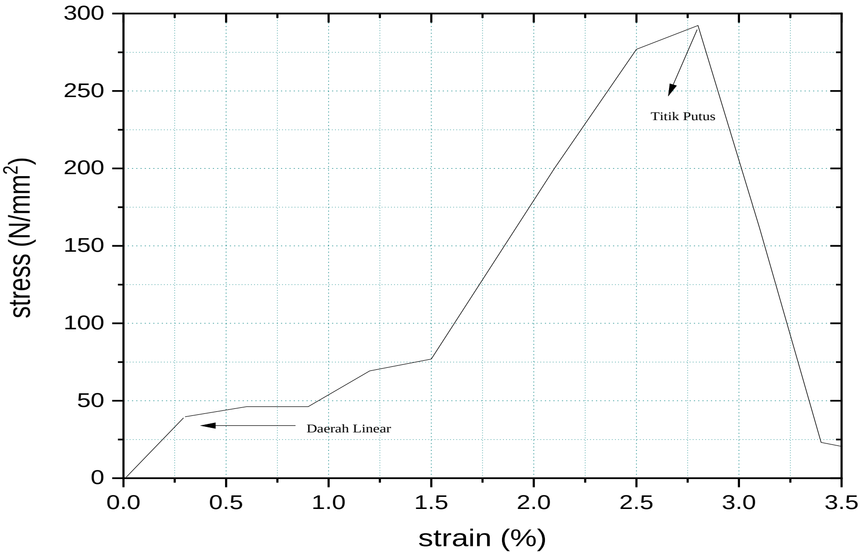


Figure 5. Stress strain curve of single fibre (T1).

(2.27 %) and the elastic modulus obtained in this curve is 12.184 Gpa. The results for all set of the characterization using a tensile testing machine on a single fibre with a diameter of 0.40 mm show cross-sectional area (A_0), tensile load F_m (N), stress, strain (ϵ) are shown **Table 1**. The obtained results is in agreement with data from published studies (Bachtiar et al. 2010; Hraběl et al. 2018).

Table 1. Mechanical properties and geometric of sugar palm (Arenga Pinnata) fibres.

Set	d (mm)	Lo (mm)	L_1 (mm)	ΔL (mm)	A_0 (mm^2)	F_m (N)	σ_{uts} (N/mm^2)	Elongation (%)	Modulus Elasticity (Gpa)
T1	0.40	165.00	168.75	3.75	0.13	36.00	286.63	2.27	12.184
T2	0.37	165.00	175.05	10.05	0.11	28.00	260.55	6.09	4.17
T3	0.40	165.00	169.40	4.40	0.13	28.00	222.93	2.67	8.07

The spun fibre curve above has an initial length of 165.00 mm which was measured before testing. From the curve (**Fig. 8**), we can see that when the sample is loaded, it begins to pass through the linear region and continues to be loaded, it will pass through the plastic region to the yield point. After that, the loading continues until the maximum tensile strength is experienced, then there will be an additional stress, which means that the strength of the material increases up to the breaking point. The increase in length after loading was 12.30 mm resulting in a stress of 44.30 N mm^{-2} and a strain of 0.07 with an elongation of 7.45% and a modulus of elasticity of 5.94 GPa.

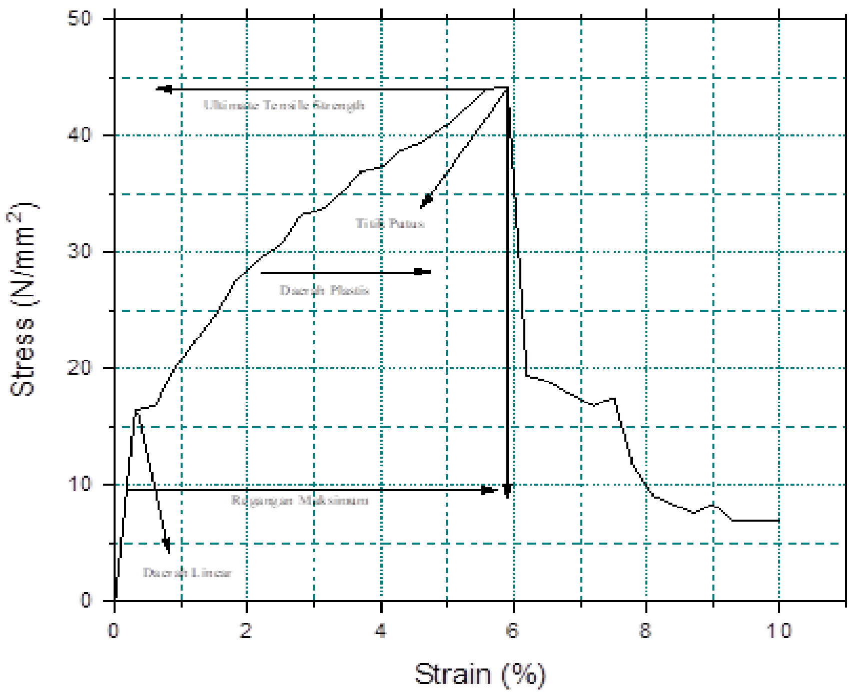


Figure 8. Stress strain curve of Spun Fiber (R3).

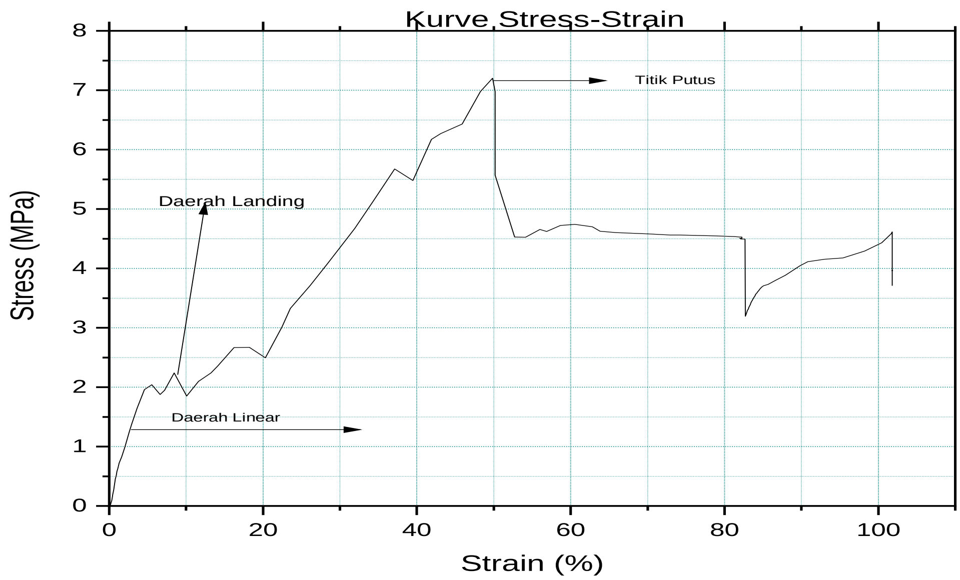


Figure 9. Correlation Curve Between Stress and Strain of Woven Fiber (N3).

The results of the characterization using a tensile testing machine on woven fibers with a diameter of 2.7 mm and an initial length of 182 mm showed cross-sectional area (A_0), tensile load F_m (N), stress (σ), strain (ϵ) and elongation (%). In the curve above experiencing plastic deformation, namely a change in shape that does not return to its original state. In **Fig. 9**, if the material is stretched beyond the proportional limit and reaches the landing area, it will experience plastic deformation. After loading, the stress produced on this woven fiber is 7.24 N.mm^{-2}.

Likewise, the strain is 95.39 mm^2 and the area of the woven fiber is 108 mm^2. The results of single, spun, and woven fiber testing can be seen in the **Table 2**.

Table 2. Tensile Test Results of Mechanical Properties of Single, Spun and Woven Fibers.

Type	Ultimate Tensile strength ($N\ mm^{-2}$)	Elongation at break (%)
Single fibre (T_1)	286.63	4.3
Spun/fibres Rope (R_3)	44.30	8.2
Woven ropes/Net (N_3)	7.24	48.4

The behavior of ropes and nets under viners loas are shown in **Figures 10**. The vertical and curved AP nets loaded with passion fruit (Passiflora edulis). The weight of passion fruit vines is balanced with the strength of the ropes and nets. With the ultimate strength of 44.30 $N.mm^{-2}$ the AP rope (with diameter of 2.7 mm or cross-sectional area of 5.72 mm^2) support loads as much as 25.8 kg or 253.5 N. The woven ropes or nets of 1 meter's width (composed of 10 ropes) with the ultimate strength of 7.24 Nmm^{-2} can support as much as 414 N or 42.3 kg. The AP nets with 1 meters wide could support vines loads as much as 42.3 kg.

Figure 10. The AP ropes and nets under viners load.

4. Conclusion

The ultimate strength of AP ropes and nets are 44 and 7 $N\ mm^{-2}$, the values are suitable to support the viners load of Passiflora fruits. The direct observations on the field also confirmed the suitability of the AP ropes and nets as supporting materials for agricultural purposes. The ropes and nets produced from AP fibres were used as agricultural materials such as green curtain (GC), green roof (GC) and erosion control blanket (ECB) in Gorontalo Province as well as in several location in Japan.

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