

Mechanical behaviour of Sugar palm (*Arenga pinnata*) fibres

P. Hrabě^{1,*}, Č. Mizera², D. Herák² and A. Kabutey²

¹Czech University of Life Sciences, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcká 129, CZ165 21 Prague, Czech Republic

²Czech University of Life Sciences, Faculty of Engineering, Department of Mechanical Engineering, Kamýcká 129, CZ165 21 Prague, Czech Republic

*Correspondence: hrabe@tf.czu.cz

Abstract. The tensile strength of Sugar palm (*Arenga pinnata*) fibres was examined. Fibre samples were prepared and tested up to the point of rupture with a deformation rate of 0.05 min⁻¹. The tensile device (Labortech, MPTest 5.050, Czech Republic) were used to determine the tensile force. The aim of the paper was to describe a mechanical behaviour of Sugar palm (*Arenga pinnata*) fibres. Measured values can be used as a basis for further research on the application of Sugar palm fibres.

Key words: tensile force, agriculture material, deformation energy.

INTRODUCTION

Environmental and economic concerns are stimulating research in the design of new materials for construction, furniture, packaging and automotive industries. Particularly attractive are the new materials in which a good part is based on natural renewable resources, preventing further stress on the environment. However, it is important to know that renewable resources depend on a balance, in which their harvests should be lower than its growth. Renewable, non-timber based materials could reduce the use of traditional materials such as wood, minerals and plastics for some applications (Leão et al., 1998). Vegetable fibres offer several advantages in comparison with synthetic fibres. They are biodegradable (crucial at the end of life of products), non-abrasive to processing equipment, are CO₂ neutral and can be used as acoustic and thermal insulators. Furthermore, they are an important source of income for agricultural societies (Alves et al., 2010).

Arenga pinnata (syn. *Arenga saccharifera*) is an economically important feather palm native to tropical Asia, from eastern India east to Malaysia, Indonesia, and the Philippines in the east. Common names include sugar palm, arenga palm, areng palm, black-fiber palm, gomuti palm, aren, enau, irok, and kaong.

Another important product of the sugar palm is its fibres. It has several names such as Aren, gomuti, and black and locally it is known as the ijuk fibres. The commercialization of sugar palm fibres can be tracked back as early as 1416 during the Malacca Sultanate era. Later in 1800, sugar palm was planted by British East India

Company in Penang to produce high durability rope made from its fibres (Othman & Haron, 1992). These multipurpose fibres can be used to make a number of products such as ropes, filters, brushers, brooms, mats, cushions and shelters for fish breeding (Mogea et al., 1991). Other than that, the preparation for sugar palm fibres is effortless as the fibres do not require any secondary processes such as water retting or mechanical decorticating process to yield the fibre. This is due to the fact that the fibres, originally wrapped around the sugar palm trunk from the bottom to the upper part of the tree, are in the form of natural woven fibre (Ishak et al., 2012; Ishak et al., 2013).

The tree begins to produce fibre before flowering approximately after five years of plantation. The fibre is black and its length is up to 1.19 m. Its diameter ranges between 94 and 370 μm and its density is 1.26 kg m^{-3} (Bachtiar et al., 2010). Bachtiar et al. (2010) reported the tensile strength, tensile modulus and elongation at break of sugar palm fibre to be 190.29 MPa, 3.69 GPa, and 19.6%, respectively.

Further characterisation of tensile properties of sugar palm fibres was conducted by Ishak (2011). The fibres were obtained from different heights of sugar palm tree (1, 3, 5, 7, 9, 11, 13, and 15 m) and tested for single fibre tensile test. The results showed that the fibres obtained from bottom part demonstrated inferior properties of tensile strength, modulus, elongation at break and toughness compared to fibres obtained in the area of a live palm frond.

This experiment aims to describe the mechanical behavior of Sugar palm (*Arenga pinnata*) fiber under tension loading.

MATERIALS AND METHODS

Sample

Samples of fibres produced from Sugar palm (*Arenga pinnata*), obtained from Balige, province of North Sumatra, Indonesia, were used for the experiment. The moisture content $M_c = 11.12 \pm 0.81\%$ (d.b.) of the samples was determined using standard oven method, ASAE method (ASAE S410.1 DEC97), (ASAE, 1998). Samples of 500 g mass from a batch of Sugar palm (*Arenga pinnata*) were randomly selected for the moisture content determination. The mass of each sample m_s (g) was determined using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany). For determining mechanical properties were produced five sets (set 1 – set 5) and each set was 5 fibres.

Tension test

To determine the relationship between tension force and deformation, a device (Labortech, MPTest 5.050, Czech Republic) was used to record the course of deformation function. The fibres of Sugar palm (Fig. 1) were glued into a paper to precisely fix gauge length $L_0 = 20$ mm (Fig. 1) and subsequently were inserted into grips of testing machines. The carrier paper was cut before starting the tensile test. The fibres were tested up to the rupture with a tension speed of $0.5 \text{ mm} \cdot \text{min}^{-1}$ under temperature of 20°C . The experiment was repeated five times with randomly selected fibres. The microscope (Zeiss Jenavert, Carl Zeiss, Jena, Germany) was used to measure of fibre diameter. The dimensions were determined in 5 places at gauge length for each fibre.

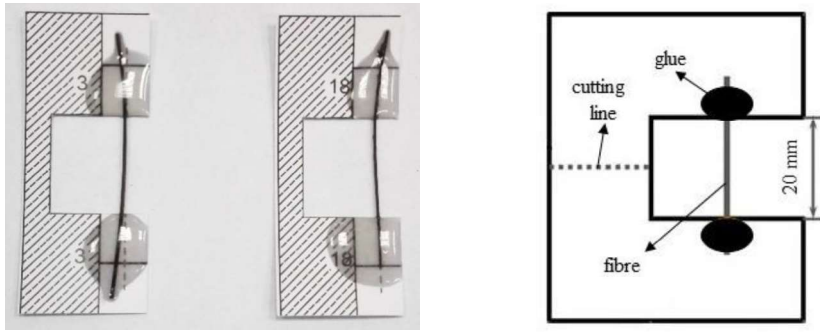


Figure 1. Method of fastening of the fibres to the tensile test.

The fibre cross-section area (S) was calculated by Eq. (1)

$$S = \frac{\pi D^2}{4} \quad (1)$$

where D (mm) is the outer diameter of fibre.

Stress–strain curve

Determined amounts of tension force were transformed into stress by Eq. (2) and the amounts of deformation were transformed into strain by Eq. (3)

$$\sigma = \frac{F}{S} \quad (2)$$

$$\varepsilon = \frac{x}{L_0} \quad (3)$$

where σ (MPa) is stress in fibre; F (N) is tension force; S (mm²) is appropriate cross section area of fibre; ε (-) is strain; x (mm) is the elongation of fibre, and L₀ (mm) is gauge length.

Volume energy

Volume energy is the area under the stress–strain curve from the zero strain to maximum strain and it was calculated by Eq. (4)

$$\lambda = \sum_{n=0}^{n=i-1} \left[\left(\frac{\sigma_{n+1} + \sigma_n}{2} \right) \cdot (\varepsilon_{n+1} - \varepsilon_n) \right] \quad (4)$$

where λ (J m⁻³) is the volume energy; i indicates the additional amount of strain in which the stress was determined (step of measurement was 0.001 mm); σ_n (MPa) is tension stress at appropriate strain; σ_{n+1} (MPa) is tension stress at the sequential strain. ε_n is strain, and ε_{n+1} is the sequential strain.

RESULTS AND DISCUSSION

For each of the five fibres the cross sectional area was determined by the equation Eq. 1 and its results are shown in Table 1 with additional information. The measurements show that all the specified geometrical properties of each fibre have similar properties throughout its length and it is given by the amount of variation coefficient less than 6%,

which is usually the quantity determined in biological materials (Mohsenin 1970; Stroschine 2000; Blahovec 2008; Mizera et al., 2016). The average values for each set are shown in Fig. 2 as the dependence between the tensile force and the elongation.

Table 1. Geometric and mechanical properties of Sugar palm (*Arenga pinnata*) fibres

Set	Tension force, N	Fibre diameter, μm	Tension stress, MPa	Deformation, mm	Deformation energy, J
I	29.43 ± 6.39	734.73 ± 41.37	31.20 ± 7.60	3.99 ± 0.98	70.99 ± 37.24
II	35.38 ± 8.25	813.93 ± 52.76	37.15 ± 6.37	4.25 ± 1.12	94.98 ± 55.00
III	32.26 ± 7.84	701.09 ± 39.54	28.43 ± 5.87	3.61 ± 0.89	41.19 ± 33.65
IV	31.20 ± 7.61	715.49 ± 40.23	35.26 ± 6.58	3.94 ± 0.95	57.09 ± 39.42
V	28.89 ± 6.27	722.69 ± 41.65	33.83 ± 7.56	4.19 ± 1.03	74.39 ± 42.54

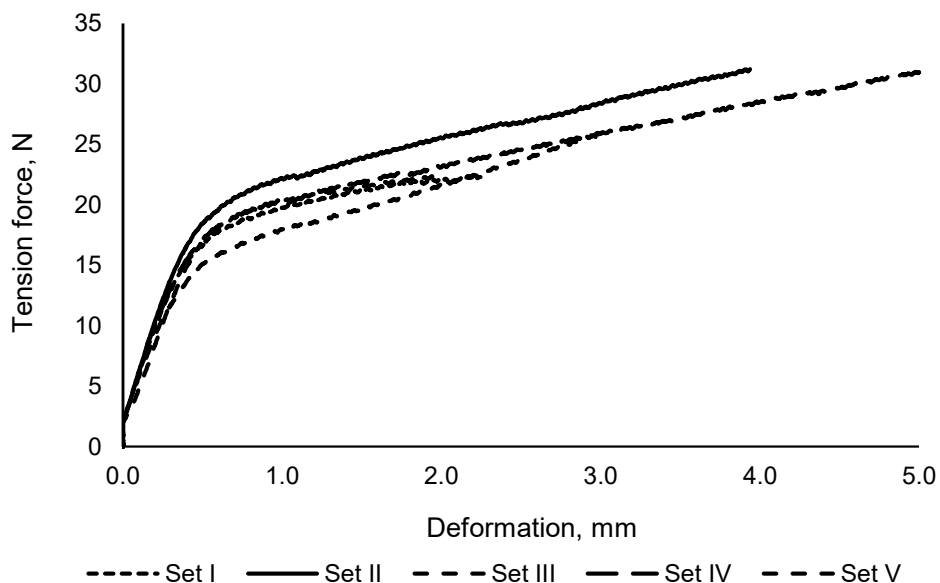


Figure 2. Dependency between tension force and deformation.

From already published studies is evident that Sugar palm fibre has very similar rupture stress as other fibres produced from other natural materials such as bamboo, vakka, coconut, banana, pineapple, hemp, abaca or sisal (Mogea et al., 1991; Bachtiar et al., 2010; Ishak et al., 2012).

Each measured relationship of tension force versus elongation was transformed using Eq. (2) and Eq. (3) into the stress–strain curve. For transformation, the individual cross-section areas (Table 1) were used.

Sahari, et al. (2012) studied tensile properties of Sugar palm (ijuk) fibre and compared it with fibres obtained from different parts of sugar palm tree namely the frond, trunk and bunch fibres. The results showed that the highest tensile properties (tensile strength, tensile modulus and elongation at break) were obtained at frond fibre followed by bunch fibre, ijuk fibre and lastly at trunk fibre. These results are in good agreement with their chemical compositions in the same study since the mechanical properties of

natural fibres are strongly influenced by their cellulose content (Habibi, et al., 2008) that provides strength and stability to the cell walls of fibres (Reddy & Yang, 2005).

From already published studies is evident that sugar palm fibre has very similar rupture stress as other fibres produced from other natural materials such as bamboo, vakka, coconut, banana, pineapple, hemp, abaca or sisal (Othman & Haron, 1992; Leão, et al., 1998; Reddy & Yang, 2005; Bachtiar, et al., 2010; Ishak, et al., 2011; Ishak, et al., 2012; Mizera, et al., 2016). In terms of elongation, the sisal and date show similar deformation properties as sugar palm.

From the point of view of classical construction materials, the mechanical behaviour of sugar palm fibre under tension loading can be also compared with standard materials such as aluminium or magnesium metal (Howard 2007). From the conducted study and previously published information about sugar palm (Alves, et al., 2010; Ishak, et al., 2011; Sahari et al., 2012), it follows that sugar palm fibre is environmentally friendly, biodegradable, and recyclable material and due to its mechanical behaviour under tension loading. In this study, the determined results of the mechanical behaviour could be applied as background for further research focused on the sugar palm fibre application.

CONCLUSIONS

The mechanical behaviour of Sugar palm fibre was determined. The fibre with its desirable properties, has great potential to be used. Not only is the fibre highly durable. On top of it, it is readily available in the form of woven fibres, making it easy to process. Since sugar palm remains largely unknown by many people and very little information is available about it, more research needs to be conducted to unveil its significance and to promote its usefulness for the benefits of the public.

From an analysis of determined mechanical and physical properties determined in this study, it follows that the fibre produced by sugar palm shows high strength, stiffness and exhibits exceptional structural properties. With regard to its biodegradability and recyclability as well as its mechanical behaviour, the fibre produced from sugar palm could be used as a construction material of the future.

ACKNOWLEDGEMENTS. This paper has been supported by Internal Grant Agency of Faculty of Engineering – Czech University of Life Sciences Prague – IGA 2018: Impact of technical and economic parameters of agricultural product drying in Indonesia with regard to quality of production and economic impact on local market.

REFERENCES

- Alves, C., Ferrão, P.M.C., Silva, A., Reis, L.G., Freitas, M., Rodrigues, L.B. & Alves, D.E. 2010. Ecodesign of automotive components making use of natural jute fiber composites. *Journal of Cleaner Production* **4**, 313–327.
- ASAE Standards 1998. *ASAE S410.1 DEC97 Moisture Measurement of Peanut* 45th Ed. American Society of Agricultural Engineers, St. Joseph.
- Bachtiar, D., Sapuan, S.M., Zainudin, E.S., Khalina, A. & Dahlan, K.Z.M. 2010. The tensile properties of single sugar palm (*Arenga pinnata*) fibre. *IOP Conference Series: Materials Science and Engineering* **11**, 12–18.

- Blahovec, J. 2008. *Agromaterials: Study guide*. Prague: Czech University of Life Sciences Prague, 102 pp.
- Habibi, Y., El-Zawawy, W., Ibrahim, M.M. & Dufresne, A. 2008. Processing and characterization of reinforced polyethylene composites made with lignocellulosic fibres from Egyptian agro-industrial residues. *Composite Science and Technology* **68**, 1877–1885.
- Howard, A.K. 2007. *Overview of mechanical properties and testing for design*. ASM Handbook. Mechanical Testing and Evaluation. Johnstown, PA: Concurrent Technologies, 959 pp.
- Ishak, M.R., Sapuan, S.M., Leman, Z., Rahman, M.Z.A. & Anwar, U.M.K. 2012. Characterization of sugar palm (*Arenga pinnata*) fibres: Tensile and thermal properties. *Journal of Thermal Analysis and Calorimetry* **109**, 981–989.
- Ishak, M.R., Sapuan, S.M., Leman, Z., Rahman, M.Z.A., Anwar, U.M.K. & Siregar, J.P. 2013. Sugar palm (*Arenga pinnata*): Its fibres, polymers and composites. *Carbohydrate Polymers* **91**, 699–710.
- Ishak, M.R., Leman, Z., Sapuan, S.M., Rahman, M.Z.A. & Anwar, U.M.K. 2011. Effects of impregnation pressure on physical and tensile properties of impregnated sugar palm (*Arenga pinnata*) fibres. *Key Engineering Materials*, pp. 471–472.
- Leão, A.L., Rowell, R. & Tavares, N. 1998. Applications of natural fibers in automotive industry in Brazil – thermoforming process. P.N. Prasad, *et al.* (Eds.), *Science and Technology of Polymers and Advanced Materials*, Plenum Press, New York, pp. 755–761.
- Mizera, C., Herak, D., Hrabe, P., Muller, M. & Kabutey, A. 2016. Mechanical Behavior of Ensete ventricosum Fiber Under Tension Loading. *Journal of Natural Fibers* **14**, 287–296.
- Mogea, J., Seibert, B. & Smits, W. 1991. Multipurpose palms: The sugar palm. *Agroforestry System* **13**, 111–129.
- Mohsenin, N.N. 1970. *Physical properties of plant and animal materials*. New York: Gordon and Breach, 891 pp.
- Othman, A.R. & Haron, N.H. 1992. In Nik, A.R. (Ed.), *Potensi industri kecil tanaman enau*. FRIM report No. 60. FRIM Press: Kepong, Malaysia. pp. 7–18 (in Indonesian).
- Reddy, N. & Yang, Y. 2005. Biofibres from agricultural by products for industrial applications. *Trends in Biotechnology* **23**, 22–27.
- Sahari, J., Sapuan, S.M., Ismarrubie, Z.N. & Rahman, M.Z.A. 2012. Physio-chemical properties of different parts of sugar palm fibre. *Fibers and Textile in Eastern Europe* **20**, 23–26.
- Stroshine, R.L. 2000. *Physical properties of agricultural materials and products*. West Lafayette: Purdue University, 296 pp.