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Agriculture and Agricultural Science Procedia 2 (2014) 370 – 374

Agriculture and Agricultural Science Procedia

"ST26943", 2nd International Conference on Agricultural and Food Engineering, CAFEi2014"

Physical and Mechanical Properties of Kenaf Stems at Varying Moisture Contents

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Abstract

Physical and mechanical properties of kenaf stem Malaysian variety V 36 were studied. The physical properties revealed maximum plant height was 310 cm and the lowest was 150 cm. Maximum stem diameter was 30 mm and the smallest was 14 mm. The mechanical properties revealed the maximum cutting force and shearing energy were 1584.55 N and 8.75 J, respectively for 35% moisture content. While 694.86 N and 3.50 J were recorded for 72% moisture content. The Young's modulus ranged between 67.59 MPa to 234.24 MPa. The greater shearing energy was obtained at the lower levels in the stem.

Peer-review under responsibility of the Scientific Committee of CAFEi2014

Keywords: cutting energy; cutting force; kenaf stems; moisture content

1. Introduction

Kenaf (*Hibiscus cannabinus*) is an annual crop which is high in fiber yield (Bakhtiari et al., 2011; Mazumder et al., 2005). Kenaf's ability to fix CO_2 has expanded its global consciousness as a natural source of cellulose fiber (Hossain et al., 2011; Lam et al., 2003). Its carbon dioxide assimilation capability, water purification ability and fast growing characteristics have invigorated several nations to consider kenaf as an alternative source of natural fiber (Kobayashi et al., 2003; Dauda, et al., 2013). Scordia et al., (2013) reported recent studies from Italy and Greece that even though kenaf is less efficient in using CO_2, water, solar radiation, and nitrogen than other carbon fixation (C_4)

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Peer-review under responsibility of the Scientific Committee of CAFEi2014
doi:10.1016/j.aaspro.2014.11.051

crops, but its assimilation rates are high. Thus, the utilization of kenaf as an alternative raw material choice to wood will aid in reducing deforestation, and subsequently increasing environmental stabilities.

During cutting, the plant stem bending strength may be important. For instance, some devices in the absence of counter shear can cut plant stem, the stem below the cutting plane behaves as a cantilever beam. In some cases, they may be loaded as a simple supported beam. In whichever case, the loading direction is radial i.e. perpendicular to the longitudinal axis of the plant stem.

Knowledge of the plant physical and mechanical properties is important for understanding the plant material reaction to cutting forces and deformation. It will also make it easier to find logical solution to improved cutting devise design (Persson, 1987). Cutting is often accomplished by shearing the plant material between a stationary counter shear and a moving knife. In developing a machine to cut plant materials, the aims are to achieve and maintain the quality of the harvested material at the same time minimizing the energy and force required to complete the task. Therefore it is necessary to determine the physico-mechanical properties such as shearing and bending stress and energy requirements in order to design suitable kenaf stems cutting devices and enhance operational parameters. In this regard, this study was carried out to determine the physical and mechanical properties of Malaysian kenaf stem variety V 36.

2. Materials and methods

2.1. Physical properties determination

The following properties of kenaf plant Malaysian variety V 36 were determined; length, diameter, and stubble height of the kenaf stem. The stem diameter was measured with vernier calliper while a tape rule was used to measure the length of the stems. Stem moisture content was determined by oven dry method at a temperature of 104 °C for 24 hours all measurements were taken in the laboratory at a room temperature of 28 °C (ASABE, 2012; ASABE, 2008b).

2.2. Mechanical properties determination

Kenaf stem Malaysian variety V 36 randomly selected and cut from INTROP/TPU research field located at 2^{o}58.844'N, 101^{o}42.722'E, Universiti Putra Malaysia was used for the experiment. The freshly harvested kenaf stems were manually sampled on 18^{th} March, 2014 while others were kept in the cold room of the biomaterial processing laboratory of the Department of Biological and Agricultural Engineering Universiti Putra Malaysia to monitor the moisture contents. The stems were cut close to the ground leaving about 10 cm stubble heights. The cut stems were divided into three samples. The samples were tested when the target moisture contents were reached. Moisture content (Mc) and diameter (D) of the stems were recorded. The diameter was measured using Mitutoyo absolute digimatic vernier calliper (precision 0.010). The moisture contents (Mc) were determined by oven dry method at 104 °C for 24 hours (ASABE, 2008a; ASABE, 2012). The kenaf stems diameter decreased towards the top of the plant. Hence it was equally divided into three major parts; as upper, middle and lower (Ghahraei et al., 2011, Nazari et al., 2008).

To determine the maximum cutting force (N), compressive stress (MPa), Young's modulus (MPa), maximum energy (J) and stem area (mm^2), blade with 25^{o} edge angle was fixed on the Universal Instron Testing Machine cross head at the Machine Design Laboratory, Department of Agricultural and Biological Engineering, Universiti Putra, Malaysia. The stem was positioned on the counter shear support and was cut at a speed of 500 mm/min. The data was transmitted to the Instron computer system. Three readings were taken each for moisture contents at 72%, 55% and 35% in order to verify the effects of moisture content on the cutting properties. A simple mean was evaluated for the data.

3. Results and discussion

3.1. Physical properties

The results obtained from the measurement of several randomly selected samples within the test plots (100 samples) of each kenaf stem showed that the maximum value of stem length was 3.10 m while the minimum height recorded was 1.5 m. The maximum diameter recorded was 30 mm and the minimum was 14 mm. The average values of the results obtained are hereby presented in Table 1.

Table 1. Kenaf stems Malaysian variety v 36 physical properties average values.

Stem Property	Range	Average
Stem Length (m)	1.5 - 3.10	2.81
Stem Diameter (mm)	14 - 30	22.98
Stubble Height (cm)	10 - 18	15
Moisture Content (%)	74	74

3.2. Mechanical properties

The experiments were conducted at three moisture content levels of 35%, 55% and 72% w.b. and at three levels up the stem. At the different moisture contents studied, the values of the compressive stress were within the ranges of 3.06–9.14 MPa, 4.11–10.06 MPa, and 2.10-8.52 MPa for the upper, middle and lower levels in the stem respectively. The maximum cutting force and shearing energy were 1584.55 N and 8.75 J, respectively for 35% moisture content, while it was 694.86 N and 3.50 J for 72% moisture content. The Young's modulus ranged from 67.59 MPa to 234.24 MPa. The greater shearing energy was obtained at the lower levels in the stem; this could be as a result of the accumulation of more mature fibres at the lower part of the stem as a result of the oldest part of the plant at lower region of the kenaf plant which has relatively highest content of lignin. Lignification makes the cell wall thicker which increases their rigidity (Nazari et. al., 2008). It was also observed that at higher moisture content of stem, the force required to cut the stems was lower at an average of 518.74 N which increased with a decrease in moisture content to an average of 1430.75 N, this might be attributed to the decrease in density difference between the stem levels at lower moisture contents.

The maximum cutting force and cutting energy varied with crossectional area as could be seen in Tables 2, 3 and 4 indicating the significance of crossectional area on the parameters studied. This is similar to results reported by Prasad and Gupta (1975), Choi and Erbach (1986), Ghahraei et al., (2011), and Nazari et al., (2008). The results similarly indicated that increase in moisture content of stalk led to a decrease in the Young's modulus, shearing force and the shearing energy. The shearing energy also decreased with decrease in stem diameter along the stem towards the upper regions, this is similar to results obtained from studies conducted by Galedar et al., (2008) and Galedar et al., (2009) on alfalfa stems. This may be due to the viscous damping effect of moisture as reported by Persson (1987).

Table 2. Some kenaf cutting properties at 72% moisture content.

SN.	Stem diameter (mm)	Maximum force (N)	Compressive stress (MPa)	Young's modulus (MPa)	Maximum energy (J)	Stem area (mm^2)
1	14.98	539.83	3.06	43.14	3.05	176.24
2	14.68	694.86	4.11	122.23	3.50	169.26
3	14.54	349.40	2.10	37.41	1.54	166.04
Mean	17.73	528.03	3.09	67.59	2.70	179.09

Table 3. Some kenaf cutting properties at 55% moisture content.

SN.	Stem diameter (mm)	Maximum force (N)	Compressive stress (MPa)	Young's modulus (MPa)	Maximum energy (J)	Stem area (mm^2)
1	12.41	189.52		48.47	0.64	120.96
2	13.81	1194.95	7.98	228.48	6.37	149.79
3	11.52	171.74	1.65	31.42	0.93	104.23
Mean	12.58	518.74	4.82	102.79	2.65	124.99

Table 4. Some kenaf cutting properties at 35% moisture content.

SN.	Stem diameter (mm)	Maximum force (N)	Compressive stress (MPa)	Young's modulus (MPa)	Maximum energy (J)	Stem area (mm^2)
1	14.86	1584.55	9.14	369.64	7.25	173.43
2	13.69	1480.79	10.06	225.46	8.75	147.20
3	13.54	1226.92	8.52	107.63	7.56	143.99
Mean	14.03	1430.75	9.24	234.24	7.85	154.87

4. Conclusions

The physical properties of kenaf stem variety V 36 revealed the maximum plant height recorded was 310 cm and the lowest was 150 cm. Maximum stem diameter was 30 mm and the smallest was 14 mm. The moisture contents determined ranged between 73-75% (wet basis).

The cutting characteristics of kenaf stems at three different moisture content levels of 35%, 55% and 72% revealed that the maximum cutting force and shearing energy were 1584.55 N and 8.75 J, respectively for 35% moisture content. While 694.86 N and 3.50 J were recorded for 72% moisture content. The Young's modulus ranged between 67.59 MPa to 234.24 MPa.

Acknowledgements

The authors acknowledge the support of UNIDO (United Nations Industrial Development Organization), CFC (Common Fund for Commodities), IJSG (International Jute Study Group), Institute of Tropical Forestry and Forests Products (INTROP), UPM and MNKTB (Malaysian National Kenaf and Tobacco Board).

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Accepted for oral presentation in CAFEi2014 (December 1-3, 2014 – Kuala Lumpur, Malaysia) as paper 220.