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Parametric Research on the Mechanophysical Properties of Coconut Leaves

Zunxiang LI[ac], Xiaohong HUANG[ac], Jing JIAO[ac], Yi WU[b1], Xinpeng LIU[ac], Jihua DU [ac], Jing ZHENG [ac]
[a]*South Subtropical Crop Research Institute, China Academy of Tropical Agricultural Sciences(CATAS), No.1 Huxiu Road, Mazhang District, Zhanjiang, Guangdong, 524091, China;*
[b]*Coconut Research Institute, Chinese Academy of Tropical Agricultural Sciences, No.496 Wenqing Road, Wenchang, Hainan, 571339, China;*
[c]*Zhanjiang Tropical Crop Straw Efficient Recycling Engineering and Technology Research Center, No.1 Huxiu Road, Mazhang District, Zhanjiang, Guangdong, 524091, China*

Abstract. Research on the mechanophysical properties of naturally shedding coconut leaves has been carried out, which is expected to provide basic theoretical support for the design of key components of the coconut leaves harvester and the determination of operating parameters. The moisture content of "Hainan coconut" was determined to be 68.67 by using a DGF101-1ES electric blast drying oven; Using the weighing method, the density of "Hainan coconut" was measured as 0.8742g/cm^3; Through the UTM6503 electronic universal testing machine, three different loading speeds of 5mm/min, 10 mm/min, and 20 mm/min were used respectively, and the compression characteristic parameters of coconut leaves were tested and obtained. Supplemented by theoretical calculations, it was concluded that when the length of the sample was 20mm, the average axial compression modulus and compressive strength of coconut leaves increased with the increase of the loading speed; the average maximum force decreased first and then increased as the loading speed increased. When the length of the sample was 30mm, the average values of the axial compression modulus, compressive strength and maximum force of coconut leaves decreased first and then increased as the loading speed increased; when the loading speed reached 10mm/min, the minimum value of all three shown.

Keywords. Coconut leaves; mechanophysical properties; axial compression; compression characteristics

1. Introduction

As a typical economical woody oil crop, coconut is a monocotyledonous perennial evergreen tree of the palm family. Normally, coconut cultivation is distributed within 20° on both sides of the equator and between 20° and 23.5° north and south latitude, its main production areas are the Philippines, Indonesia, India, Malaysia and other countries[1-4]. Due to the growing demand for coconut products, the scale of coconut cultivation is

[1] Corresponding author: Y. WU, Coconut Research Institute, Chinese Academy of Tropical Agricultural Sciences, e-mail: wuyi-scuta@163.com

increasingle expanding[5]. The fruiting period of coconut trees is 50 years approximately. On average, each matured coconut tree has 22 leaves, and 12 new leaves germinate annually[6]. Every year, a large number of withered coconut leaves are cut down, discarded or burned by coconut farmers, resulting in pollution of the ecological environment and waste of a lot of resources[7], which is not conducive to the implementation of our country's sustainable development strategy. The rational use of coconut leaves shall bring certain socio-economic benefits. The research on the mechanophysical properties of coconut leaves is expected to provide a theoretical basis and design basis for the mechanized harvesting of coconut leaves, which is of great significance to improve the harvesting and utilization of coconut leaves.

Up to now, previous research on the material properties of coconut leaves has been conducted by relevant scholars[8-11]. Through the observation of the anatomical structure of different coconut leaves, Liu Rui explored the reasons for the weak growth potential of field cultivars in the early stage of tissue culture seedlings[12]. Based on the research on the anatomical characteristics of the fiber morphology, vascular bundle morphology and tissue ratio of different parts of the coconut leaves stalk by Zhu Sailing et al., it was found that the leaves stalk fiber is an excellent plant fiber raw material, which can be used to prepare high-quality packaging paper and functional packaging materials [13-14]. Through the study of the anatomical structure differences of coconut leaves under low temperature stress, Cao Hongxing and others found that the cold resistance of local high-species coconut in Hainan issuperior to that of Aromatica Green Dwarf coconut[15]. The above-mentioned literature revolves around the research on the material properties of coconut leaves as a fiber raw material and the cold resistance and growth ability of coconut leaves anatomy. However, the research on the mechanical properties of coconut leaves itself has not been involved in the literature.

In this research, the main stem of coconut leaves was taken as the research object, and the moisture content of coconut leaves was measured by drying method; the density of coconut leaves was obtained by weighing method; A microcomputer-controlled electronic universal testing machine was used to test and record the “maximum force-displacement” relationship curve of coconut leaves during the compression test. Other mechanical performance parameters were obtained through the theoretical methods of material mechanics and elastic mechanics. Thus, the required parameters of the material model were determined and analyzed accordingly so as to provide theoretical support for the development and optimization of coconut leaves pretreatment equipment.

2. Materials and Methods

2.1 Test material

In this test, “Hainan Coconut” was used as the test object, and the sample was taken from Haibin Park, Xiashan District, Zhanjiang City, Guangdong Province. Naturally shed coconut leaves were taken as test materials. The average width of coconut leaves was 300mm, with the average length 4000mm, and the weight of a single coconut leaves was 4267g approximately.

2.2 Test apparatus

The instruments used in this test mainly included a series of instruments, namely,

UTM6503 electronic universal testing machine, DGF101-1ES electric blast drying oven (temperature 0-250°C, voltage 220 V), electronic balance, Delixi digital vernier caliper, 8-inch woodworking table saw and cylindrical sampler, etc. The electronic universal testing machine rated load was 5kN, with an accuracy level of 0.5, a displacement resolution of 0.01mm, and a loading rate of 0.01-500 mm/min. The load-displacement relationship can be automatically recorded by the computer in the form of tracing points, and the coordinates and structural parameters of each point can be read out by the specified file [16].

2.3 Test method

2.3.1 Determination of moisture content of coconut leaves

10 ‘‘Hainan coconut” coconut leaves were taken and each coconut leaves was cut into small pieces with a cutting machine. With a drying box, the weighed coconut leaves were placed in a DGF101-1ES electric blast drying oven for drying, and the temperature was set at 105°C, dried to a constant quality, then the moisture content was measured, and finally the average value was taken.

2.3.2 Determination of coconut leaves density

Using the weighing method and an 8-inch woodworking table saw, the coconut leaves were cut radially. Then, sampling was carried out through a cylinder sampler, and a cylinder with an end face diameter of 12±1mm and a height of 20±1mm was obtained. The mass of the cylinder was measured with an electronic balance, and the mass was recorded as M; the diameter d and height h of the cylinder were measured by a digital vernier caliper. According to Eq. (1), the density of the cylinder was calculated. The determination of the density of 10 samples was repeated.

$$\rho = \frac{4m}{\pi d^2 h} \tag{1}$$

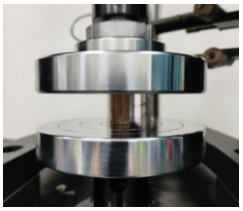
Where, m represents the mass of the cylinder, g; d represents the diameter of the end face of the cylinder, mm; h represents the height of the cylinder, mm; ρ represents the density of coconut leaves, g/cm^3.

2.3.3 Compression test method of coconut leaves

An 8-inch woodworking table saw was used to cut the coconut leaves to ensure that the end face of the sample was cut neatly and without breakage points nor cracks. Then, a cylindrical sampler was used to sample the axial direction of the coconut leaves, and the coconut leaves was made into 60 cylindrical samples with an end face diameter of 12±1 mm, a height of 20±1 mm, and a height of 30±1mm, as shown in Figure 1(a). During the test, firstly, the diameter and height of the end face of the coconut leaves sample were measured separately with a digital vernier caliper. The measured cylindrical sample was then placed in the fixture of the electronic universal testing machine, and compressed at three different loading speeds of 5 mm/min, 10mm/min, and 20mm/min until it was broken, as shown in Figure 1(b). The sample of the coconut leaves broken in the middle position was taken as an effective compressed sample. From the test data, 5 groups of

suitable axial compression data at three different loading speeds of 5mm/min, 10mm/min and 20mm/min were selected as the final data for analysis.

(a) Cylinder sample



(b) Compression process

Figure 1. Coconut leaves compression test

3. Results and Analysis

3.1 Moisture content of coconut leaves

Based on the test results, it can be inferred that the coconut leaves are dried at 105°C for about 20 h and the quality was constant. After calculation, it can be concluded that the moisture content of "Hainan coconut" was 68.67%. The data were shown in Table 1.

Table 1. Test data on moisture content of coconut leaves

S/N	M1/g	M2/g	MC/%
1	22.08	6.78	69.29
2	22.7	7.56	66.7
3	22.89	6.67	70.86
4	21.67	7.59	64.97
5	20.01	5.96	70.21
6	19.58	6.32	67.72
7	21.80	6.57	69.86
8	19.84	6.30	68.25
9	18.25	5.41	70.36
10	19.76	6.22	68.52
$\bar{x}$	20.86	6.54	68.67

Note: *M*1 represents the mass of coconut leaves before drying, *M*2 represents the mass of coconut leaves after drying, and $\bar{x}$ refers to the average value of the sample.

3.2 Coconut leaves density

The density of 10 coconut leaves samples was measured by weighing method. The test results were obtained according to the density calculation formula. After the test, the average value was taken, and the density of "Hainan coconut" could be calculated to be 0.8742g/cm^3. The data were shown in Table 2.

Table 2. Test data on density of coconut leaves

S/N	M/g	D/cm	H/cm	ρ /(g · cm-3)
1	2.16	1.2180	2.0880	0.8878
2	2.12	1.2220	2.0830	0.8678

3	1.97	1.1970	2.0030	0.8740
4	2.09	1.1980	2.0890	0.8876
5	1.97	1.1760	2.0650	0.8783
6	1.95	1.1790	2.0790	0.8591
7	2.07	1.2050	2.0820	0.8718
8	2.10	1.2090	2.0790	0.8799
9	2.14	1.2350	2.0750	0.8609
10	1.95	1.1740	2.0600	0.8745
$\overline{x}$	2.052	1.2013	2.0703	0.8742

Note: *M* represents the mass of the sample, *D* represents the diameter of the end face, *H* is the height of the sample, and $\overline{x}$ refers to the average value of the sample.

3.3 Coconut leaves compression test results and analysis

3.3.1 Compression test of samples with height of 20mm

The axial compression test of "Hainan coconut" with a moisture content of 68.67% and a density of 0.8742g/cm^3 was carried out at three different loading speeds of 5 mm/min, 10 mm/min, and 20 mm/min. The axial pressure-displacement curve of coconut leaves was illustrated in Figure 2, and the test data were shown in Table 3.

According to Figure 2, the pressure and displacement of coconut leaves in the initial stage of compression showed a linear trend, and there was no obvious yield point. Subsequently, due to the continuous increase in pressure, the coconut leaves reached the limit of compression resistance, and the coconut leaves were promptly crushed off, causing a sudden drop in pressure. During the compression process, the pressure fluctuated greatly with the increase of displacement, which was because the compression of coconut leaves was not completed in an instant, but gradually broke from the stress concentration.

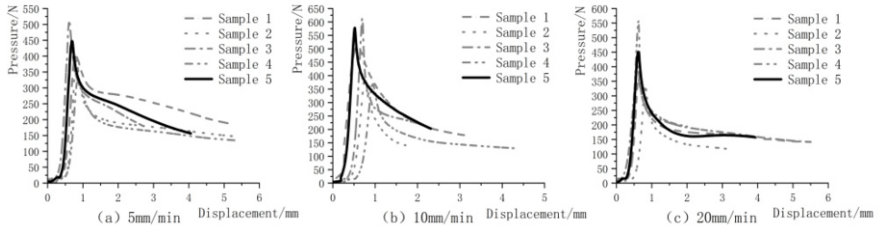


Figure 2. Axial compression test diagram of coconut leaves (samples with height of 20mm)

It can be concluded from Table 3 that when the axial loading speed of coconut leaves was 5 mm/min, the average compression modulus, compressive strength and maximum force were 308.21 MPa, 3.72 MPa and 421.62N, respectively; When the axial loading speed of coconut leaves was 10mm/min, the average compression modulus, compressive strength and maximum force were 346.37MPa, 3.77MPa and 416.65N respectively; When the axial loading speed of coconut leaves was 20mm/min, the average compression modulus, compressive strength and maximum force were 410.96MPa, 4.57MPa and 492.03N respectively.

Table 3. Axial compression test data of coconut leaves

S/N	5mm/min					10mm/min					20mm/min				
	d/mm	l/mm	E/MPa	P/MPa	F/N	d/mm	l/mm	E/MPa	P/MPa	F/N	d/mm	l/mm	E/MPa	P/MPa	F/N
1	12.06	20.76	362.18	3.95	450.87	12.03	20.79	305.67	3.50	397.86	12.09	20.79	497.56	5.04	578.03
2	11.98	20.89	356.30	3.20	361.12	11.66	20.65	360.75	3.73	397.85	11.68	20.72	343.50	4.77	511.10
3	11.79	20.79	162.15	3.09	336.89	11.91	20.77	415.43	4.59	511.55	11.67	20.78	288.76	3.63	388.50
4	12.05	20.82	244.00	3.54	403.22	12.06	20.86	369.11	3.92	447.48	11.45	20.71	319.53	3.58	368.61
5	12.12	20.89	416.42	4.82	555.98	11.59	20.54	280.88	3.11	328.53	11.60	20.63	605.44	5.81	613.91
$\overline{x}$	12.00	20.83	308.21	3.72	421.62	11.85	20.72	346.37	3.77	416.65	11.70	20.73	410.96	4.57	492.03

At three different loading speeds of 5mm/min, 10mm/min, and 20mm/min, the average change trend of the axial mechanical properties of coconut leaves was shown in Figure 3. According to Figure 3, the average values of the axial compression modulus and compressive strength of coconut leaves increased with the increase of the loading speed; the average value of the maximum force decreased first and then increased as the loading speed increased.

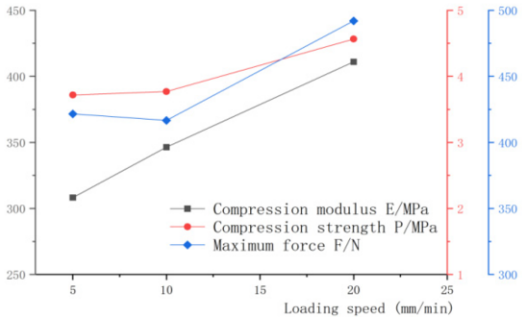


Figure 3. Trend chart of axial mechanical properties of coconut leaves

3.3.2 Compression test of samples with height of 30mm

The axial compression test of "Hainan coconut" with a moisture content of 68.67% and a density of 0.8742g/cm3 was carried out at three different loading speeds of 5 mm/min, 10 mm/min, and 20 mm/min. The axial pressure-displacement curve of coconut leaves was illustrated in Figure 4, and the test data were shown in Table 4.

According to Figure 4, the trend of pressure and displacement at a sampling height of 30mm for coconut leaves was similar to that of pressure and displacement at a sampling height of 20mm, which was because the coaxial pressure and displacement trends were slowly increasing first. When the coconut leaves reached the compression limit, it was promptly crushed off, resulting in a sudden drop in pressure.

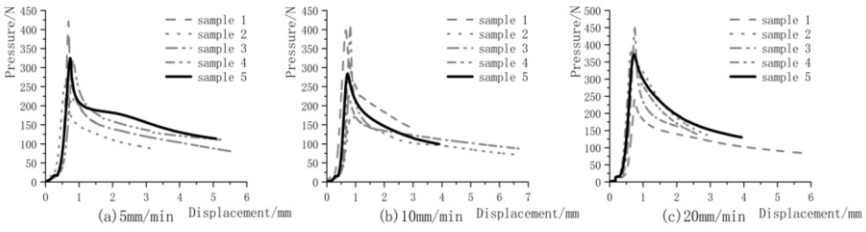


Figure 4. Axial compression test diagram of coconut leaves (sample with height of 30mm)

It can be concluded from Table 4 that when the axial loading speed of coconut leaves was 5 mm/min, the average compression modulus, compressive strength and maximum force were 363.37MPa, 2.82MPa and 308.75N, respectively; When the axial loading speed of coconut leaves was 10mm/min, the average compression modulus, compressive strength and maximum force were 340.58MPa, 2.74MPa and 297.32N respectively; When the axial loading speed of coconut leaves was 20mm/min, the average compression modulus, compressive strength and maximum force were386.65MPa, 3.24MPaand 364.91N respectively.

Table 4. Axial compression test data of coconut leaves (sample with height of 30mm)

S/N	5mm/min					10mm/min					20mm/min				
	d/mm	l/mm	E/MPa	P/MPa	F/N	d/mm	l/mm	E/MPa	P/MPa	F/N	d/mm	l/mm	E/MPa	P/MPa	F/N
1	11.93	30.81	564.10	3.77	421.05	11.76	30.66	378.52	3.67	398.17	11.78	30.41	297.24	2.20	239.99
2	11.66	30.74	291.89	2.36	251.93	11.96	30.81	176.21	1.54	172.63	12.09	30.73	389.96	3.24	371.75
3	11.81	30.61	343.65	2.97	325.07	11.65	30.82	333.97	2.12	225.95	12.14	30.69	336.94	3.28	379.79
4	12.07	30.52	267.45	2.00	228.81	11.74	30.89	456.60	3.75	405.99	12.02	30.84	507.41	3.96	449.12
5	11.58	30.73	349.74	3.01	316.88	11.75	30.59	357.60	2.62	283.83	11.75	30.91	401.70	3.54	383.90
$\overline{x}$	11.81	30.68	363.37	2.82	308.75	11.77	30.75	340.58	2.74	297.32	11.96	30.72	386.65	3.24	364.91

At three different loading speeds of 5mm/min, 10mm/min, and 20mm/min, the average change trend of the axial mechanical properties of coconut leaves was shown in Figure 5. According to Figure 5, the average values of the axial compression modulus, compressive strength and maximum force of coconut leaves decreased first and then increased as the loading speed increased; when the loading speed reached 10mm/min, the minimum value of all three shown.

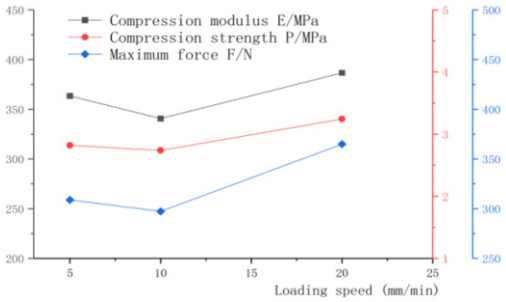


Figure 5. Trend chart of axial mechanical properties of coconut leaves

4. Conclusion

(1) Through tests, the moisture content of "Hainan coconut" was determined to be 68.67% and the density was 0.8742g/cm^3. The average width of coconut leaves was 300mm, the average length was 4000mm, and the weight of a single coconut leaf was approximately 4267g. The research conclusion is expected to provide a reference for the simulation and optimization of coconut leaves harvester.

(2) The sample was measured by an axial compression test. 1) When the loading speed was 5mm/min, the average compression modulus, compressive strength and maximum force of the sample with a length of 20mm were 308.21MPa, 3.72MPa and

421.62N respectively, and the average compression modulus, compressive strength and maximum force of the sample with a length of 30mm are 363.37MPa, 2.82MPa and 308.75N respectively; 2) When the loading speed was 10mm/min, the average compression modulus, compressive strength and maximum force of the sample with a length of 20mm were 346.37 MPa, 3.77 MPa and 416.65N, respectively, and the average compression modulus, compressive strength and maximum force of the sample with a length of 30mm were 340.58 MPa, 2.74 MPa and 297.32N; 3) When the loading speed was 20 mm/min, the compression modulus, compression strength and maximum force of the sample with a length of 20mm were 340.58 MPa, 2.74 MPa and 297.32N, respectively, and the average values of strength and maximum force were 410.96 MPa, 4.57 MPa and 492.03N, respectively, and the average values of compression modulus, compressive strength and maximum force of samples with a length of 30mm were 386.65 MPa, 3.24 MPa and 364.91N, respectively.

(3) Based on the results of compression tests of samples of different lengths of coconut leaves, it was concluded that when the loading speed was 5mm/min, 10mm/min, and 20 mm/min, the compression modulus, compressive strength, and maximum force of the sample length of 20mm were all higher than the average of the sample length of 30mm, which was consistent with the law that the shorter the length of the sample, the less likely it shall be compressed and broken.

Acknowledgments

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