Test and Analysis on Axial Compressive Mechanics of Ramie Stalk

Cheng Shen, Bin Zhang, Kun-Peng Tian, Xian-Wang Li, and Qiao-Min Chen

***Abstract*—With the application of elastic parameter test method of composite material mechanics, UTM6503 PC-controlled universal testing machine was adopted to study the characteristics of axial compressive mechanics on the xylem and the whole stalk in the paper. The test result showed that the average axial compressive elastic modulus of the ramie xylem of first crop of "Zhongzhu No.1" was 374.70 MPa and the average maximum compressive strength was 13.71 MPa, while the average axial compressive elastic modulus of whole stalk was 336.40 MPa, and its average maximum compressive strength was 13.19 MPa; there was no significant difference between the elastic modulus and the compressive strength of the ramie xylem and the whole stalk. In the stalk composition, xylem and phloem bond on the surface depending on their own adhesion strength which was not able to prevent the phloem slipping away along the surface of xylem. In the compressive test, it showed the load-bearing function of xylem more.**

***Index Terms*—Ramie, stalk, compression, mechanics.**

I. Introduction

Ramie, originating from China, is an ancient special economic crop in China with a long history of cultivation and fiber using [1]-[3]. Westerners name it as "Chinese grass" while Japanese call it "Nanking grass" [4]. Ramie has a high utilization value in fiber textile, mushroom substrate, forage, water and soil conservation and environmental governance [5]-[9] so that silk, cashmere and ramie fiber were praised as the three fiber treasure of China by foreigners. For a long time, China has been the world's largest producer of ramie whose planting area and production of ramie accounts for more than 90% of the total worldwide [10] and [11]. In recent years, some Chinese scientific research institutions have started the research and design of ramie harvester and ramie decortication machinery [12] and [13], however, their focus is mainly on the mechanical structure design and local optimization rather than research on mechanical characteristics of processed material, the ramie stalk, which leads to the result that the developed machines cannot reach the requirements of high-quality, high-effectiveness and low energy consumption [14].

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With reference to documents about research on mechanical characteristics of stalk crops, a large quantity of previous experimental research results [15]-[21] of stalk crops like sugar canes, bamboo reed, maize and so on indicate that through mechanical test methods like performing compression or stretching on crop's stalk, the test parameters of the stalk can be worked out and the elastic parameters and destruction forms of the stalk under different loading load of testing machines can be analyzed so as to have a clearer understanding towards crop's stalk and provide fundamental parameter for the research and production of crop machines.

Based on it, elastic parameter test method of composite material mechanics adopted in this paper performs research on the axial compression mechanics characteristics of ramie xylem and the whole stalk of the entire stalk to provide basic theoretical data for subsequent research and design of sample machines.

II. Materials and Methods

A. Materials and Samples for Tests

The first crop ramie of "Zhongzhu No.1" planted in Xianning Ramie Comprehensive Test Station of China Agriculture Research System for Bast and Leaf Fiber Crops was selected as the test material, and collected on May 31st, 2016. The collection site was located in Yangfan Village, Xian'an District, Xianning City, Hubei Province. The average moisture content was 70.15%. (rate of water content on the wet basis). The materials' geometry structure is a hollow circular tube consisting of xylem and phloem, shown as Fig. 1.

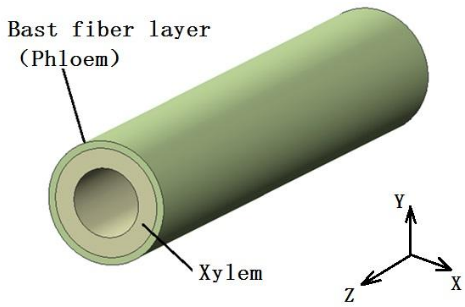

Fig. 1. The geometrical model of ramie stalk.

Materials within 30 cm of the bottom of the stalk or tested materials were selected to produce xylem samples and phloem samples. Xylem samples were produced through complete peel of phloem fiber layer of stalk materials, remaining the xylem parts that were cut into 14.5-15.5 mm in length. The cross sections of samples are cylindrical and their

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external and internal diameters are determined by the situations of stalk xylem of ramie samples. There should be separately 10 groups of two kinds of samples.

B. Test Equipment

UTM6503 PC-controlled universal testing machine was used as mechanical test equipment (Fig. 2). Using compression mechanics to tested the pressing block and the tested force was 5 kN. The accuracy of its force sensor and displacement transducer was within ±0.1%. In addition, other auxiliary tools include the tools like test fixture, vernier caliper and so on.

Fig. 2. UTM6503 PC-controlled universal testing machine.

C. Test Determination

Test time: Jun. 2nd, 2016; test site: Nanjing Research Institute for Agricultural Mechanization, Ministry of Agriculture (PRC). The test site was located in Xuanwu District, Nanjing Municipality, Jiangsu Province.

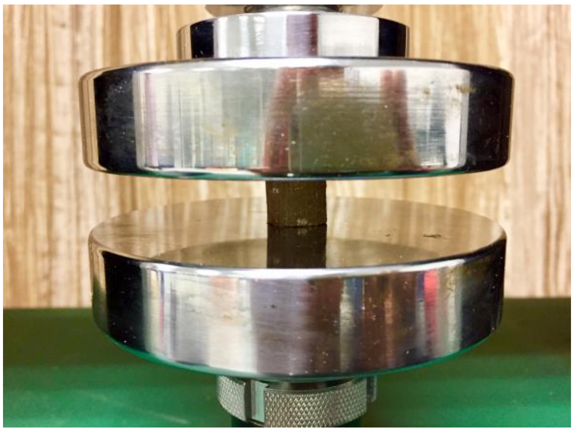

Fig. 3. Sample put between two pressing blocks.

Using vernier caliper to tested the geometry parameter (external diameter *D*, inner diameter *d*, Length *L*) of each sample and record; set universal testing machine movement and data collection schemes according to the test requirements; selected compression test standard on the panel as test standard. The test loading speed was 1 mm/min, and the user's parameter was the geometry parameter of tested materials in the practical test; selected strain-stress relation as the major figure and the main parameter was the maximum value; put samples between two pressing blocks (Fig. 3); turned on the universal testing machine for preload at preloading force <5 N, and after preloading collect systematical data and then zero setting; pressed the start button to perform the test; universal testing machine automatically collected test data to acquire strain-stress curve of the test; repeatedly performed the tests of xylem and phloem samples for ten times separately.

D. Data Statistics and Analysis

Performed data processing on large quantity of discrete points of strain-stress curve in each group of xylem and phloem test; using SPSS software to performed linear regression on the elastic deformation parts of curve initial linearity on the basis of principle of least square method and stress-strain relation formula of elastic modulus [22] (formula 1) to acquire the elastic modulus of data of each group; using material mechanics formula [23] (formula 2) to acquire the stiffness strength of data of each group.

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

where E is elastic modulus, MPa; σ is stress, MPa; ε is strain, mm/mm.

$$\sigma_p = \frac{F_{\max}}{A} \tag{2}$$

where σ_p is stiffness strength, MPa; F_{max} is maximum load in the loading process, N; A is area of cross section of samples, mm^2.

III. Results and Analysis

A. Results and Analysis of Xylem Tests

Axial compression test of the whole stalk should be performed on ten groups of xylem samples whose stress-strain curve is shown as Fig. 4. According to the results of tests, under the effect of stretching load, the stress-strain curve of xylem after the preloading period enters rather linear elastic deformation stage. When the loading value reaches the maximum value, the samples start to cracker and the curve declines.

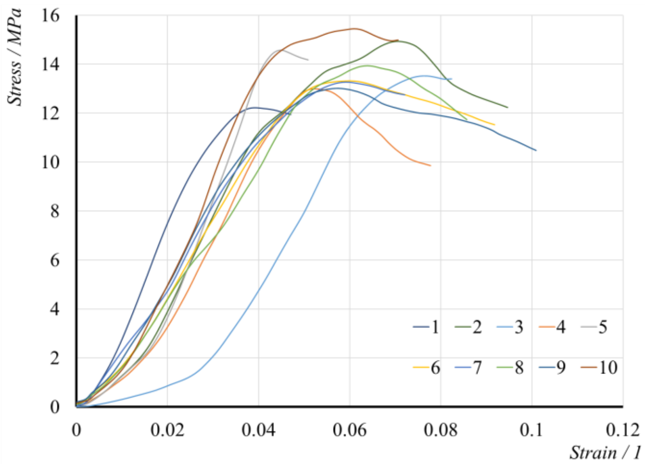

Fig. 4. Axial compressive stress-strain curve of xylem.

In accordance with calculation, the elastic modulus and stiffness strength of each group of xylem samples in axial compression tests are shown as the TABLE I. After statistics and calculation, the average value of elastic modulus E_{xl} was 374.70 MPa; standard deviation was 65.60 MPa; the maximum value E_{xlmax} was 501 MPa; the minimum value E_{xlmin} was 293 MPa; the average value of maximum compressive strength σ_{pxl} was 13.71 MPa; standard deviation was 0.95 MPa; the maximum value σ_{pxlmax} was 15.44 MPa; the minimum value σ_{pxlmin} was 12.21 MPa.

TABLE I: AXIAL COMPRESSIVE RESULT OF XYLEM

Test No.	Parameters				
	D / mm	*d* / mm	*L* / mm	σ_p / MPa	*E* / MPa
1	12.24	6.84	14.95	12.21	486
2	12.33	6.95	15.22	14.94	393
3	12.36	6.77	14.87	13.51	312
4	12.54	7.08	15.26	13.00	359
5	12.74	7.01	15.24	14.58	501
6	12.49	6.54	15.12	13.31	330
7	12.07	6.66	15.34	13.20	344
8	12.65	6.98	15.41	13.91	293
9	12.43	6.41	15.20	13.04	351
10	12.19	6.25	15.11	15.44	378
avg.	12.40	6.75	15.17	13.71	374.70
max.	12.74	7.08	15.41	15.44	501
min.	12.07	6.25	14.87	12.21	293
s. d.	0.20	0.26	0.16	0.95	65.60

Note: *D* is external diameter, *d* is inner diameter, *L* is Length, σ_p is compressive strength, *E* is elastic modulus, *avg.* is the the average value, *max. is* the maximum value, *min.* is the minimum value, *s. d.* is the standard deviation. The same for the follow-up table.

B. *Results and Analysis of Whole Stalk Tests*

Axial compression test of the whole stalk should be performed on ten groups of whole stalk samples whose stress-strain curve is shown as Fig. 5. According to the results of tests, under the effect of stretching load, the stress-strain curve of whole stalk after the preloading period enters rather linear elastic deformation stage. When the loading value reaches the maximum value, the samples start to cracker and the curve declines.

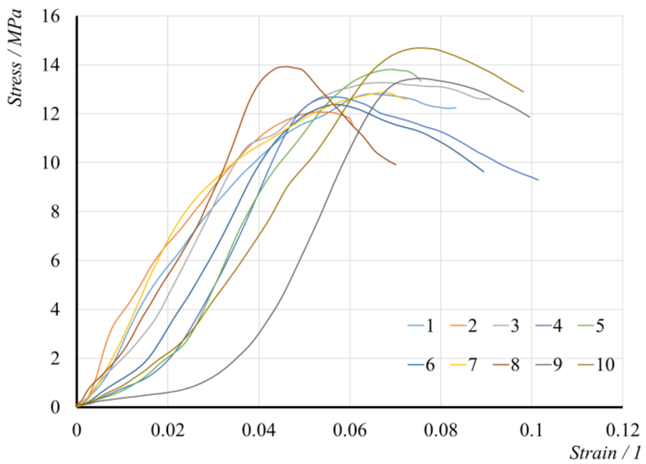

Fig. 5. Axial compressive stress-strain curve of whole stalk.

In accordance with calculation, the elastic modulus and stiffness strength of each group of whole stalk samples in axial compression tests are shown as the TABLE II. After statistics and calculation, the average value of elastic modulus E_{stk} was 336.40 MPa; standard deviation was 55.01 MPa; the maximum value E_{stkmax} was 424 MPa; the minimum value E_{stkmin} was 273 MPa; the average value of maximum compressive strength σ_{pstk} was 13.19 MPa; standard deviation was 0.76 MPa; the maximum value $\sigma_{pstkmax}$ was 14.68 MPa; the minimum value $\sigma_{pstkmin}$ was 12.02 MPa.

TABLE II: AXIAL COMPRESSIVE RESULT OF WHOLE STALK

Test No.	Parameters				
	D / mm	*d* / mm	*L* / mm	σ_p / MPa	*E* / MPa
1	14.56	7.02	15.02	12.81	276
2	14.37	6.58	15.03	12.02	288
3	14.33	6.95	15.14	13.27	361
4	14.69	6.88	14.89	12.69	312
5	14.27	7.16	15.37	13.81	392
6	14.65	7.24	15.26	12.36	307
7	14.39	6.38	14.97	12.86	419
8	14.54	6.47	14.84	13.92	312
9	14.62	6.94	15.66	13.45	424
10	14.33	6.32	15.23	14.68	273
avg.	14.48	6.79	15.14	13.19	336.40
max.	14.69	7.24	15.66	14.68	424
min.	14.27	6.32	14.84	12.02	273
s. d.	0.15	0.31	0.24	0.76	55.01

IV. DISCUSSION

Fig. 6 is the contrast diagram of compression elastic modulus between xylem and whole stalk. It can be indicated from the figure that the difference of elastic modulus between xylem and whole stalk is not obvious.

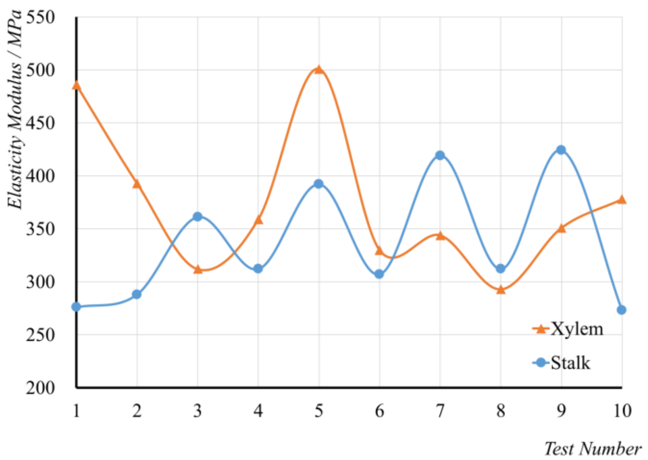

Fig. 6. Comparison of axial compressive elastic modulus of each part.

Fig. 7 is the contrast diagram of stiffness strength between xylem and whole stalk. It can be indicated from the figure that the difference of stiffness strength between xylem and whole stalk is not obvious. The phenome above illustrates that in the stalk composition, xylem and phloem bond on the surface depending on their own adhesion strength which was not able to prevent the phloem slipping away along the surface of xylem. In the compressive test, it showed the load-bearing function of xylem more. In addition, from the analysis results of tests, it can be discovered that the standard deviations of compression elastic modulus and stiffness strength of xylem and whole stalk were both large, reflecting that the differences of mechanical characteristics among different ramie stalks were rather large. As plants, ramie's mechanical characteristics are greatly influenced by factors like the selected parts, grade of maturity, rate of water content and so on. In subsequent research and application, while selecting ramie's mechanical characteristics parameter, expansion of value range on the basis of research in this paper should be considered.

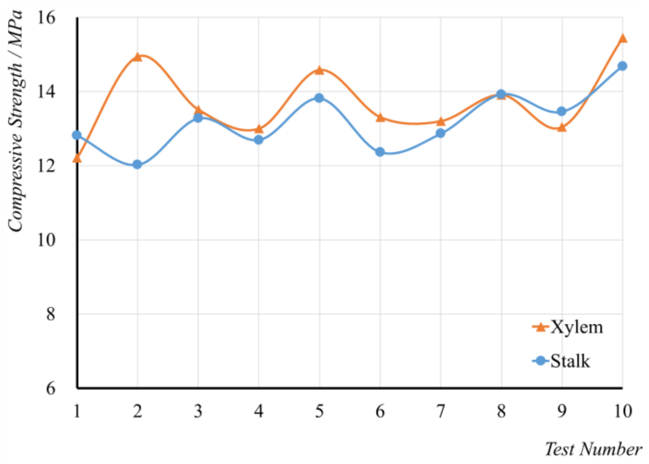

Fig. 7. Comparison of axial compressive strength of each part.

V. Conclusion

The average value of axial compression elastic modulus of the ramie xylem of first crop of "Zhongzhu No.1" was 374.70 MPa; the average value of the maximum compressive strength was 13.71 MPa; the average value of axial compression elastic modulus of the whole stalk was 336.40 MPa; the average value of the maximum stiffness strength was 13.19 MPa.

Both the average value of axial compression elastic modulus and the average value of the maximum compressive strength of the both xylem and whole stalk of first crop of "Zhongzhu No.1" were higher than the value of last (third) crop of "Zhongzhu No.1" [24].

The standard deviation of compression elastic modulus and stiffness strength of xylem and whole stalk were both large, jointly reflecting the large difference in mechanical characteristics among different ramie stalks.

In the stalk composition, xylem and phloem bond on the surface depending on their own adhesion strength which was not able to prevent the phloem slipping away along the surface of xylem. In the compressive test, it showed the load-bearing function of xylem more.

Focusing on mechanical research of ramie stalks, basic theoretical reference to ramie's mechanized harvesting technology, peeling and fiber extraction is provided in this paper.

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