Experimental research on physical and mechanical parameters of matured bottom stalk of the reed

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Abstract: The compressing, stretching, bending, and shearing stress of reed stalk growing in the Yangtze River region were investigated by using a computer-controlled electronic universal testing machine. The results were as follows: the average maximum values of the stress resistance intensity, pulling resistance intensity, the average of maximum bending resistance intensity, and shearing resistance intensity were 22 MPa, 152 MPa, 118 MPa and 26 MPa respectively, whereas the equivalent values of the modulus of elasticity were 45 MPa, 321 MPa, 77 MPa and 286 MPa respectively. The stalk of reed is a kind of anisotropic material and it is different from Arundo donax L., ramie and wheat. Thus, the traditional agricultural machine for cutting and processing is found to be inconvenient to use in reed harvesting. The data of the experiments provided an important foundation for determining the structural parameters of reed cutter.

Keywords: reed, stalk, modulus, mechanical properties

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1 Introduction

Reed, also called LuWei or LuSun, belongs to Gramineae family, which is a kind of aquatic plants, tends to grow in shallow water or low wetlands. Because of its fine texture, low price and easy processing, it is considered as a good raw material for papermaking[1]. Besides, it can be used as a light material in manufacturing an artificial silk and rayon; it is also used as feed, woven mats and curtains, etc. The leaves, flowers, sterns, rhizomes and asparagus of reed can be made into medicine with a high practical value[2]. According to the field tests, the plant characteristics for the reed, which grow on the both sides of the Yangtze River region, are 4-5 m height, 15 mm stern diameter, and 19 per square meter growth density. The entangled winding reed stalks comprise a complexity in mechanical harvesting, especially due to the composite stress and strain generated during the process of the stalk cutting, which affects directly the quality of cuttings and efficiency[3-5]. Studying the physical and mechanical properties of mature stems at the bottom edge of the reed stalk to find out the basic parameters such as the maximum destruction stress and elastic modulus, was very essential in analyzing the stress-strain distribution during the process of cutting the reed stem and yet designing and manufacturing of a high-efficiency and low power reed cutters[6]. In this paper, the compressing, stretching, bending, shearing destruction stress and elastic modulus were tested, and the acquired data were analyzed.

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2 Materials and methods

2.1 Sample collection and production

The reed stalks used in the experiments were collected from Wuhan Zhuankou reed farm and Jiayu reed farm on November 27 in 2009 and November 24 in 2010 from well grown plants. Samples were chopped off at 10 mm above the ground with different diameters ranging between 10-30 mm and length of 600 mm, as shown in Figure 1. The selected samples were grown vertically without an obvious defects and damage on epidermis[7]. According to the production requirements the leaves were totally removed while the external part was cleaned and polished. The samples were then randomly labeled and grouped for the accuracy of the results.

Figure 1 Acting position sketch of the reed stalks

2.2 Test equipment and methods

A Chinese made computer-controlled electronic universal testing machine designed by Shenzhen Rreger Instrument Co., LTD., Guangdong, model No. RG-M3005, having the specifications of 5 KN power and 0.5 of accuracy, was used for testing the samples. The system was equipped with a main test hardware, RG control part and personal computer. Some physical and mechanical properties such as stretching, compressing, bending and shearing stress were then investigated and the results expressed in load value, deformation value, speed and stress were obtained.

The experiments were carried out on the basis of the Chinese Standards according to the Testing Methods of Physical and Mechanical Properties for both of Bamboos[8] and Woods[9]. The average density of the specimen was found to be 0.963 g/mm^3, wet rate 68%, test environment temperature 19℃ and air humidity 70%. The whole measurement system is illustrated in Figure 2.

Figure 2 Structure diagram of the measurement system

3 Results and Analysis

3.1 Compression test and analysis

The production specifications of the compressed sample were: 20.0 × d × t (H×OD×stem wall thickness). Both sides of the tested specimen were equally cut. A plane press board with the upside surface of a spherical glide base was used in the test. The tested specimen was positioned in the center of the upside surface of spherical glide base, the stalk was treated as a hollow tubing. The compression-displacement test control procedures was then selected and adjusted to the horizon, subsequently a load of 10 N under velocity of 5 mm/min was applied.

According to the load and deformation data provided by the computer control system, the stress-strain curve of the compression test was obtained as shown in Figure 3. The deformation occurred to the reed stems under the compression loads was an elastic deformation, at first, then it was changed to the plastic deformation. After increasing the compression resistance to the highest value, the sample started to crack, and the stress started to decline sharply. Because the reed stems were hollow reed pipe structure, their failure process starts as crackle first and the stress revealed in a form of twist. The results of the reed stem compression projected in Table 1, indicated that the average maximum compressive resistance pressure of reed stem was 26 MPa.

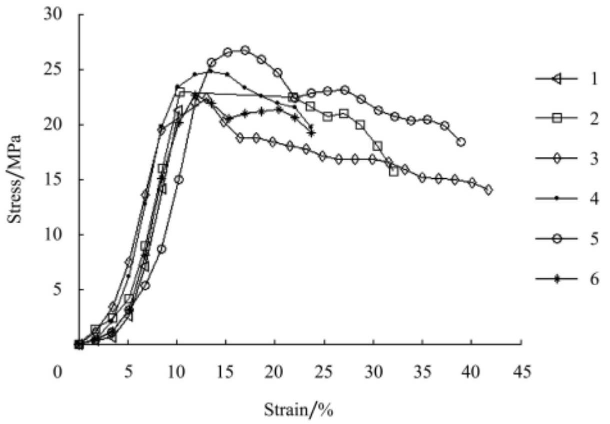

Figure 3 Reed compressing stress-strain curve

Table 1 Compressing experiment results of reed stalk

Sample number	Maximum load /N	Compressive strength /MPa	Yield strength /MPa
1	2355.714	24.995	23.979
2	3058.572	28.635	7.436
3	2642.857	24.743	9.442
4	1732.860	22.980	21.180
5	2370.000	26.943	10.946
6	3052.857	28.581	28.568
Average	2535.480	26.150	16.930

The curves of the effective range of the stress-strain parameter for the reed stem compression mapped by the computer demonstrate the beginning of the loading stage until the occurrence of the stem damage. The stress-strain curves showed some nonlinear characteristics. In order to eliminate the uncertainty caused by measurement error, the Matlab software was used for the polynomial fitting. By determination of coefficient's R-square analysis, the best five fit polynomials were obtained. The form of the fitted curve was as follows:

$$S(x)=a_0+a_1x+a_2x^2+a_3x^3+a_4x^4+a_5x^5$$

Where, S is the stress, x is the strain of each point, α_i is the coefficient of polynomial

The polynomial fitting compression stress-strain curves of the reed stems are illustrated in Figure 4. A similar straight line section called the linear elastic region was monitored in the initial stage of stress-strain curves. In this section, the stress and strain was directly proportional to a constant ratio. The slope of the line represents the modulus of elasticity (Young's modulus)[10] expressed as E which obtained from the most optimized fitting equation, i.e.: $E(x)=dS/dx$, then using the SPSS software, a linear regression analysis[11] was done. The linear equation is expressed as $Y=a+bX$. Regression analysis results are shown in Table 2. After acquiring the average of the slope for each linear, the elasticity modulus of compression resistance of the reed stem was calculated as E = 286 MPa.

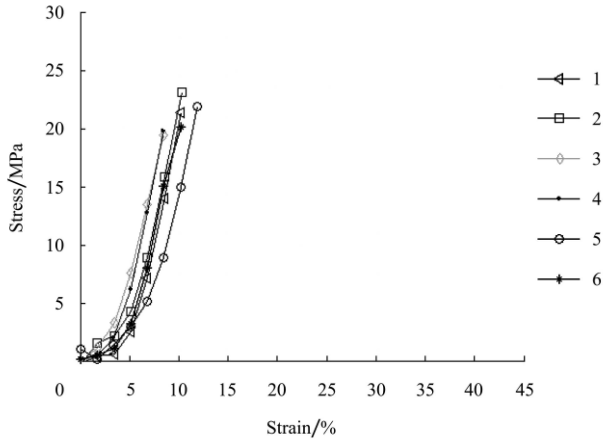

Figure 4 Reed compressed stress-strain multinomial drafted curve

Table 2 Regression analysis of reed compressing stress-strain curve

Sample number	Intercept	Regression coefficient	Coefficient of determination
1	-8.867	3.225	0.994
2	-15.141	3.493	0.988
3	-1.066	2.017	0.983
4	-10.184	2.918	0.997
5	-11.056	2.648	0.999
6	-8.902	2.849	0.995

3.2 Stretching test and analysis

The production specifications of stretching sample were 160.0×10.0× t (for stem length × width × thickness respectively). The sample was treated as a metal sheet. The compression-displacement test control procedures was then selected and adjusted and a load of 10 N under velocity of 5 mm/min was applied.

Figure 5 showed the stress-strain curve of stretching according to the load and deformation data provided by the computer control system. When plastic deformation of reed stalks reached the extreme point, and tensile load reached the maximum value, the sample starts to crack, and the stress started to decline sharply. The data obtained from the reed stem stretching were tabulated in

Table 3. The results indicated that the average maximum stretching resistance pressure of reed stem was 118 MPa.

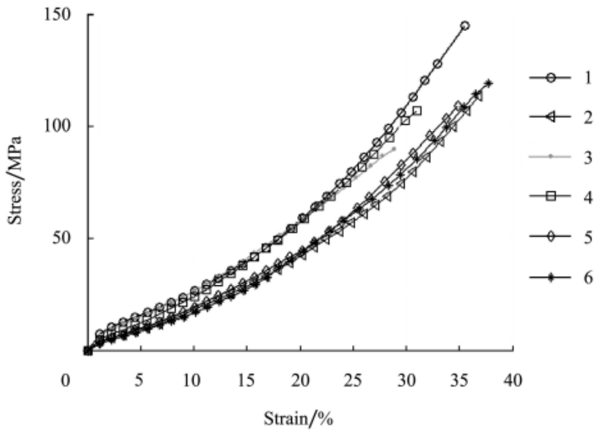

Figure 5 Reed stretched stress-strain curve

Table 3 Stretching experiment results of reed stalk

Sample number	Maximum load /N	Tensile strength /MPa	Yield strength /MPa
1	2671.428	148.413	40.833
2	2701.428	128.640	41.905
3	1794.286	89.714	18.071
4	2030.000	106.842	23.534
5	2014.286	111.905	23.571
6	2470.000	123.500	26.930
Average	2280.240	118.170	29.140

Similar to the data management followed in the compression test, the stretching stress-strain curves were fitted, and a stretching stress-strain reed polynomial fitting curve was obtained as shown in Figure 6. From a linear regression analysis, the results were obtained and exposed in Table 4, then the stretching elastic modulus of the reed stem was calculated as E=321 MPa.

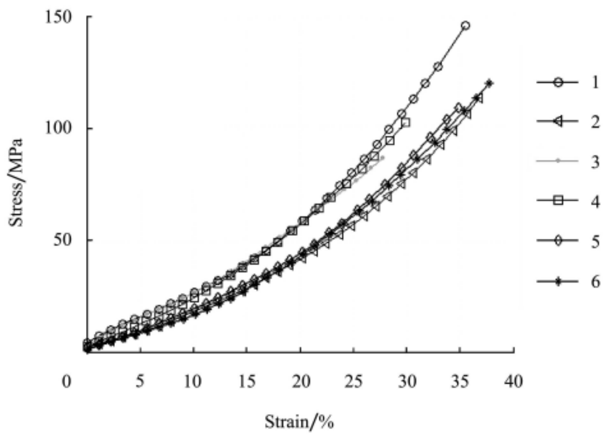

Figure 6 Reed stretching stress-strain multinomial drafted curve

Table 4 Regression analysis of reed stretching stress-strain curve

Sample number	Intercept	Regression coefficient	Coefficient of determination
1	-14.399	3.709	0.983
2	-10.287	2.643	0.992
3	-9.254	3.378	0.997
4	-15.202	3.683	0.993
5	-11.682	2.874	0.987
6	-16.024	3.002	0.989

3.3 Bending test and analysis

The production specifications of the bending specimen were: L×d×t (for stem length × diameter ×stem wall thickness respectively), the whole length L was to be greater than 60 mm. An experimental device called three-point bending[12] was used in the test , the sample was treated as a pipe materials. Following the bending-displacement test control procedures, the compression-displacement test control procedures were selected and adjusted, and a load of 10 N under velocity of 5 mm/min was applied.

Figure 7 illustrated the stress-strain curve of bending test according to the load and deformation data provided by the computer control system. After increasing the bending resistance to the extreme limit, the sample started to crack, and the stress started to decline sharply. The stress-strain curve looked to be oscillating in some points because some samples were jagged before destroying. The results of the reed stem bending were projected in Table 5 which showed that the average maximum bending resistance pressure of reed stem was 152 MPa.

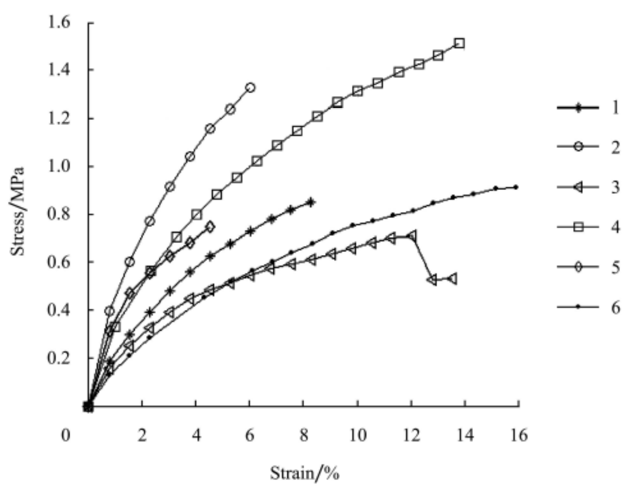

Figure 7 Reed bended stress-strain curve

Table 5 Bending experiment results of reed stalk

Sample number	Maximum load /N	Bending strength /MPa	Breaking strength /MPa
1	126.071	154.098	147.55
2	160.500	383.166	373.446
3	192.071	85.558	82.567
4	137.500	97.261	96.605
5	136.857	96.807	94.230
6	138.000	97.620	97.510
Average	148.5	152.420	148.650

Based on the same method of the data management in the compression test, the bending stress-strain curves were fitted, and the bending stress-strain reed polynomial fitting curve was obtained as demonstrated in Figure 8. From a linear regression analysis, the results were obtained and exposed in Table 6, then the stretching elastic modulus of the reed stem was calculated as E = 77 MPa.

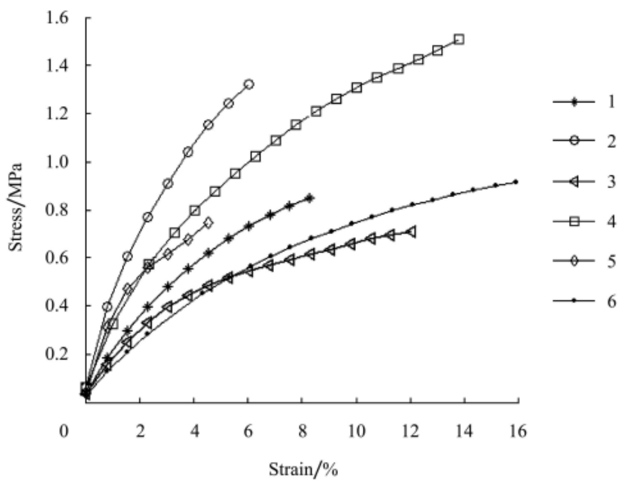

Figure 8 Reed bending stress-strain multinomial drafted curve

Table 6 Regression analysis of reed bended stress-strain curve

Sample number	Intercept	Regression coefficient	Coefficient of determination
1	0.32	0.091	0.979
2	0.434	0.099	0.961
3	0.235	0.069	0.974
4	0.173	0.067	0.983
5	0.261	0.083	0.988
6	0.291	0.054	0.940

3.4 Shearing test and analysis

L×d×t (for length× diameter ×stem wall thickness respectively) represent the production specifications of the sheared specimen. A self made device was used for shearing stress determination; the sample was treated as a pipe material. Thereafter a compression-displacement test control procedures were selected and adjusted, and a load of 10 N under velocity of 5 mm/min was applied.

Figure 9 revealed the stress-strain curve of shearing test according to the load and deformation data provided by the computer control system. Due to the irregular cracks of reed stalks and the stress of slight scattering, the stress-strain curve for some samples appeared to be fluctuated before destroying. After increasing the bending resistance to the utmost, the sample was completely destroyed, and the stress started to decline sharply. The results of the reed stem shearing were shown in Table 7 which revealed that the average maximum shearing resistance pressure of reed stem was 22 MPa.

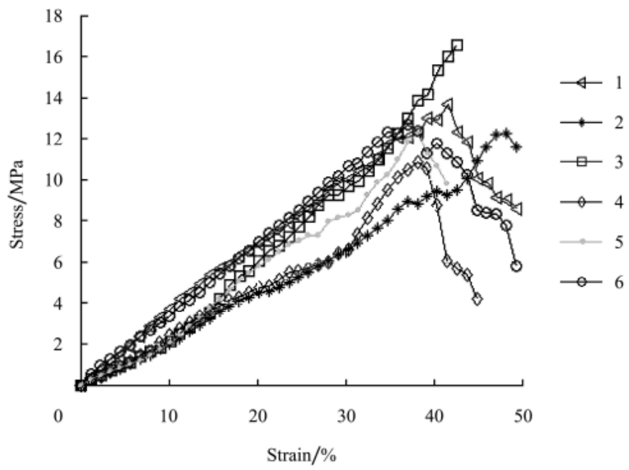

Figure 9 Reed sheared stress-strain curve

Table 7 Shearing experiment results of reed stalk

Sample number	Maximum load /N	Shearing strength /MPa	Yield strength /MPa
1	2538.572	19.589	4.617
2	1878.571	22.999	5.404
3	1664.286	18.920	3.833
4	1938.571	22.038	4.434
5	2417.143	27.479	5.652
6	2207.140	23.420	8.550
Average	2107.380	22.410	5.420

Adopting the same method of data management in the compression test, the sheared stress-strain curves for the reed were fitted. The polynomial fitting curve was obtained as projected in Figure 10; the fitting coefficients were shown in Table 8. Then the linear regression analysis was conducted and the results obtained were illustrated in Table 8. The sheared elastic modulus of the reed stem was calculated as, E= 45 MPa.

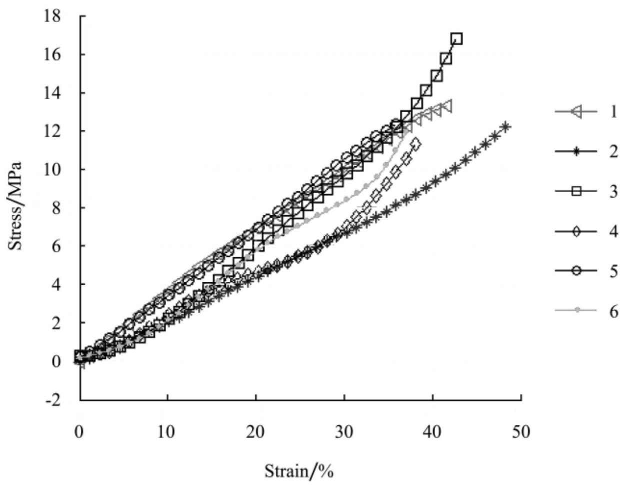

Figure 10 Reed sheared stress-strain multinomial drafted curve

Table 8 Regression analysis of reed sheared stress-strain curve

Sample number	Intercept	Regression coefficient	Coefficient of determination
1	0.432	0.369	1.000
2	0.580	0.490	0.996
3	0.254	0.358	0.999
4	1.682	0.408	0.989
5	-1.018	0.467	0.995
6	-0.159	0.601	0.999

4 Conclusions

1) Mature reed stalks growing in the Yangtze River region were used in the experiments. The results obtained were as follows: the average of maximum stress resistance intensity, pulling resistance intensity, bending resistance intensity, shearing resistance intensity were 26 MPa, 118 MPa, 152 MPa and 22 MPa respectively, whereas, the equivalent values for modulus of elasticity were 286 MPa, 321 MPa, 77 MPa and 45 MPa respectively.

2) Stretching modulus of elasticity was obviously greater than the bending modulus, however, stretching resistance intensity and bending resistance intensity were non-significantly different, which indicated that the horizontal and vertical mechanical properties of reed stems were significantly different. Stretching elastic modulus and stretching resistance intensity were greater than the maximum compression elastic modulus and maximum compressive strength, and both were greater than the maximum shearing modulus and shearing strength. The results showed that the reed stem material was significantly anisotropy and non-linear, which indicated that the anisotropy constitutive relationship should be adopted when establishing the reed mechanical models.

3) The physical and mechanical properties of reed were different from that of Arundo donax L. (Arundo donax L. having a maximum stretching resistance intensity of 123 MPa, stretching elastic modulus of 1 260 MPa, maximum compressive resistance intensity of 52 MPa, compressive elastic modulus of 595 MPa, maximum bending resistance intensity of 125 MPa, bending elastic modulus of 1 715 MPa[13]), and ramie (having the values of maximum stretching resistance intensity of 32.25 MPa, stretching elastic modulus of 177.26 MPa, the maximum bending resistance intensity of 40.77 MPa, bending elastic modulus of 7 358.69 MPa[14]), as well as for wheat which have a stretching intensity of 21-32 MPa[15]. Thus, the traditional agricultural machine for cutting and processing the above mentioned crops are inconvenient for reed harvesting. Accordingly, a new cutting for harvesting technology should be adopted to meet the physical and mechanical properties of reed.

Acknowledgements

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