A research on mechanical characteristics of the rape stalk

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Abstract

A research on the physical and mechanical characteristics of rape stalk has important significance for analyzing the lodging resistance capability and solving the problem of rape mechanization harvest. In this paper, by using the RGT computer-servo material testing system, the characteristics of compressing, cutting and bending of the elongating part of the Huaza No.10 in the harvest time had been researched. Tests results showed compression destruction stress of the elongating part of the stalk was 11.9MPa, the elasticity modulus of compression 172MPa, the maximum of cutting destruction stress 10.52MPa, the elasticity of flexure module 61MPa, and revealed the load-displacement curves of compressing, cutting and bending under certain operating mode respectively. The test results indicated that the rape stalk was heterogeneous, non-linear and anisotropic, and there was no yield in the destruction process; meanwhile, the main mechanical characteristic displayed in the outer wall of stalk, so the rape stalk can be simplified as a hollow pipe model in the research on the resistance loading capability and the mechanization harvest technology.

Key words: rape stalk; mechanical characteristics; Young's modulus; breaking stress

1. Introduction

The rape is one of the glorious ancient crops with long cultivation history, and one of the emerging crops developing rapidly. Since 1960s, the rape has become one of the four big oil-crops of the world. Nowadays in China, rape's sowing area and the ultimate output list the first in the world (Liu Lihou, 1997). At present, domestic and foreign researchers pay more attention to the research on rapeseed's high quality, high production breeding planter and so on(K.Papastamati & H.A. McCartney,2004; Klaus sieling,1997), but less on the rape stalk's research, which mainly concentrating on the stalk lodging performance research, such as to enhance the stalk lodging resistance capability through studying the measures of cultivation management; to build up the relations of the main stalk structure and lodging through observing different strain rape stalk epidermis, cerebral cortex, vascular bundle and marrow structure(Jiang Weimei & Zhang Dongqing,2001); to establish the adult rape plant's mechanics model through theoretical analysis, to infer the rape stalk resistance lodging parameter relations; to analysis and appraise the rape resistance lodging capacity, etc(Tian Baoming,2005). In terms of rape's mechanization harvest, the main research concentrated on the machines and tools design (Li Jiajun, 2005), but mechanics characteristics research on rape stalk which is the main object of harvest is basically blank. Launching research on the mechanics characteristics of rape stalk, obtaining the rape stalk's concrete mechanics characteristic parameters, its loading condition of distortion, and the destruction situation have important theory value and practical significance in analyzing the rape's lodging by providing quantification parameter values for the establishment of rape plant mechanics model, gaining the theoretic basis and the foundation technology parameters for determining the cutting strength, the cutting tool and the ways of cutting and designing mechanized harvester with low energy consumption and high efficiency. In this paper, tests had been carried out to study the compressing, cutting and bending characteristics, furthermore the experiment processes had been analyzed.

2. Materials and methods

2.1 Experimental materials

The rape stalks for tests were of Huazha No.10 in the Rape Experimental Base of Huazhong Agricultural University. Fig. 1 shows the rape caulis configuration. The tested rape stalks were gathered in 9: 00 AM on May 28, 2006 from the well grown plant, then the elongating part was intercepted which base diameter was between 5–25mm, and 200mm above the shrinking part, and be vertical without obvious defects and damage on epidermis. The sample was picked off from the elongating part according to requirements of the production test ban for testing, then the external was cleaned and polished, meanwhile the numbers were marked and the diameters recorded.

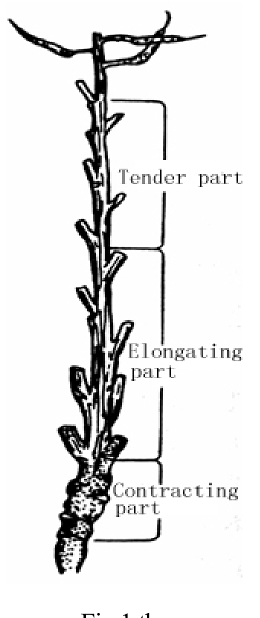

Fig 1 the rape caulis configuration

2.2 Experimental methods

The RGT computer-servo material testing system (Shenzhen Rreger Instrument Co., LTD., Guangdong. China) was used in the test, which type was RGT-10, specification 10KN;

precision of rank 0.5.The system was composed of main test hardware, RG control part and personal computer. The main test hardware can carry on various martial mechanical properties test like stretching, compressing, bending and shearing with different clamps. The states and results of test such as load value, deformation value, speed and stress, stress-strain curves can be shown during the testing. The tests were carried out according to "China's Standards about Testing Methods for Physical and Mechanical Properties of Bamboos" and "Testing Methods for Physical and Mechanical Properties of Woods". By testing, the density of the specimen was 0.77g/mm^3, wet rate 27.2~31%, test environment temperature 33 º C and air humidity 47%.

3. Results and discussion

3.1 Compressing test

Two neighboring test specimens with specification 20.0mm×d mm (rape stalk diameter) were intercepted from the gathered elongating sample. Fig 2 is the solid test specimen without removing the stalk marrow, while Fig 3 is the hollow test specimen with removing the stalk marrow. Both sides of the test specimen had been finished evenness. The test used the plane press board, showed as Fig 4, the test specimen was set to center position of the upside surface of spherical glide base, then loaded a 5*N* force in advance, while the load velocity was 10mm/min.

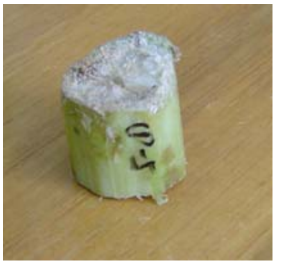

Fig 2 Solid test specimen

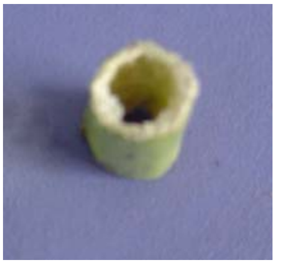

Fig 3 Hollow test specimen

Fig 4 Compressing test equip

Fig 5 Situations of the compression

Fig 5 shows the state after the hollow and solid test specimen s burst in compression process. The inside wall cell fascicules of the hollow test specimen lost the straight line balanced capacity during the compression gradually, because the cells wall were thick and diameters different, the cells wall gradually wrinkled folded or caved into the cavity during the process of increasing the load to the utmost resistant of compression, the stalk wall gradually squished to compress and burst. Meanwhile, because of the core marrow's function, the stalk cells wall didn't fold or cave in, but swelled the cracks to outside. Fig. 6 shows the load-displacement curves with good compressive condition provided by the computer control system. Mark "■" stands for load-displacement curves of the solid test specimen. The load - displacement curves revealed in the compression process before increasing the compression resistance to the utmost, load-displacement curves of the hollow and the solid test specimens were basically consistent, without obviously submitting stage and appearing non-linearity to some extent.

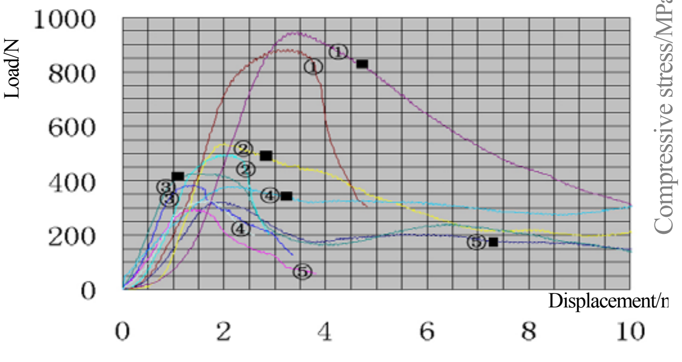

Fig 6 The load-displacement curves

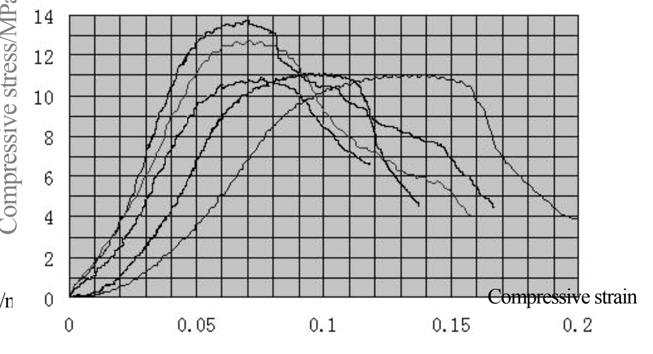

Fig7 Hollow stalk specimen's stress - strain curves

Tab.1 The maximum values of compression resistance

No.	Outer diameter (mm)	Wall thickness(mm)	Resistant to compression	
			solid specimen	solid specimen
①	22.48	3.12	945.71	881.70
②	14.93	2.04	538.57	484.96
③	12.17	1.80	427.14	385.14
④	10.68	1.21	377.14	325.29
⑤	7.80	1.09	320.00	293.85

The maximum values of compression resistance of solid and hollow test specimens are in correspondence with the curves shown in Table 1 from which we could know that the mechanical capability of the test samples mainly displayed on the outer wall of the stalk, the maximum values of compression resistance of solid specimen was approximately 10% higher than the hollow specimen, and became bigger and bigger along with the increase of the thickness of stalk wall. But after increasing the compression resistance to the utmost, the hollow sample burst, the compression resistance dropped rapidly. Meanwhile for the solid specimen, being compressed to a certain degree, the internal core marrow was pressed densely, and the compression resistance gradually tended to a fixed value. Therefore, the mechanical capabilities of the test specimens were mainly displayed on the outer wall of the stalk, the internal core only had compression resistance when compressed to a very large extent. Treating the hollow specimen as tubing, the load and the displacement may be transformed into the stress and the strain according to

$$\sigma = \frac{P}{\pi(r_1^2 - r_2^2)} \quad ; \quad \varepsilon = \frac{\Delta L}{L}$$

Where σ is compressive stress in *MPa*; *P* is the force loaded in the sample in *N*; r_1 and r_2 is exterior and inner radius in *mm*; ε is the compressing strain of sample; ΔL. *L* are the original length and the shorten length of sample and mm.

Fig 7 shows hollow stalk's stress-strain curves. The stress (0, 0.5), the strain (0, 0.01) sector is pre-compression stage; the stress (10, 14) sector is the biggest compression destruction stress sector. Table 2 is the maximum compressive strength of hollow specimen (compression destruction stress), the mean value of compression resistance is 11.902*MPa*, assuming σ_c = 11.9*MPa*.

Tab.2 the maximum compressive strength of hollow specimen

No	1	2	3	4	5	Average
Compressive strength(*MPa*)	11.01	11.12	10.84	13.76	12.78	11.90

When the load up to the maximum compression resistance, the test sample was destroyed, the stress dropped suddenly, accordingly the pre-compression stage to the destroy stage of the hollow sample drawn up in the curve by the computer was the stress-strain effective sector, in which the stress-strain curve presented certain non-linear characteristics. Select the effect sector of the stress-strain curve, using multinomial fitting method, a function expression of stress-strain curve could be gained. This process may further eliminate the measuring error caused by the uncertainty elements. The form of the fitted curve as:

$$S(x)=a_0\varphi_0(x)+a_1\varphi_1(x)+\cdots+a_n\varphi_n(x)$$

Where *S* is the stress, *x* is the strain of each data point, and the elasticity modulus may be expressed as:

$$E(x) = dS/dx$$

The multinomial number would affect the fitness, the highest multinomial number in the equation is 6, every curve was the best fitted after comparisons. Fitted curves are shown in Fig. 8, each fitted coefficient is shown in Table 3. The elasticity modulus of compression resistance of the hollow sample E_a =172.098*MPa*, assuming E_a=172*MPa*.

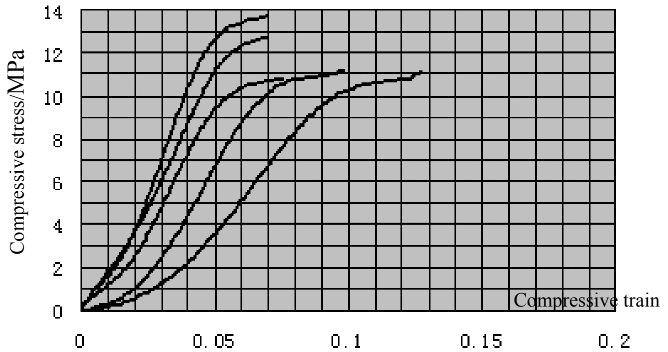

Fig8 Fitted curves of stress - strain curves of hollow specimen

Tab.3 The fitted coefficient of the multinomial curves

	x^6	x^5	x^4	x^3	x^2	x^1	x^0
1	-1e+09	4e+08	- 4e+07	2e+06	- 24676	279.79	0
2	-7e+08	2e+08	- 2e+07	975827	- 16345	202.18	0
3	3e+06	1e+07	- 3e+06	235227	- 3399.7	54.73	-0.09
4	3e+07	- 9e+06	669008	- 13460	1233	4.6339	0.001
	5e+08	- 7e+07	292498	174035	- 4018.5	193.02	0.097

2.2 Shearing test

The test specimen with specification 60.0mm×d mm (rape stalk diameter) were intercepted from the base of elongation sample shown in fig 9. The equipment of shearing was self made, which was composed of two steel disks, and material was made of $45^{\#}$ steel, the thickness was 7mm, shown in Fig. 10. Bores of different diameters were drilled in the corresponding positions of the two steel disks. The test specimens were inserted into the corresponding bores, and then loaded 5*N* force in advance, the load velocity was 10mm/min.


Fig 9 Shearing test specimen


Fig 10 Shearing test equip

Fig. 11 is the shearing load-displacement curves provided by the computer control system. At the preliminary stage of load increase, the steel disks compressed the stalk, when it was compressed to some extent, the test specimen was cut; while the load was increased to the biggest destruction level, the test specimen was broken, and load dropped rapidly until the test specimen was sheared. From the compressive test, the mechanical characteristics of the stalk were mainly displayed on the outer wall; therefore treating the stalk as tubing, and the limit of shearing intensity could be calculated by

$$\tau_{\max} = \frac{P_{\max}}{2\pi(r_1^2 - r_2^2)}$$

Where τ_{max} is the most shearing stress in *MPa*; P_{max} is force load in the sample in *N*; r_1 and r_2 is outer and inner radius in mm.

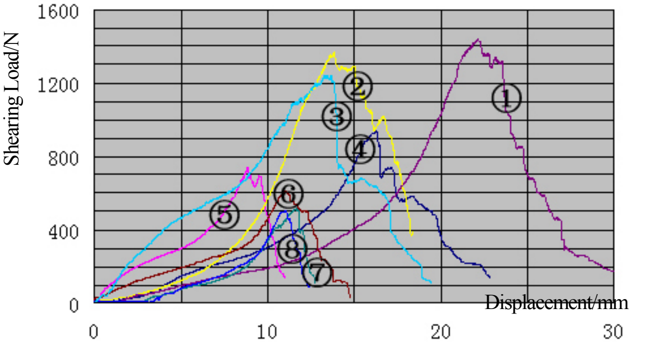

Fig. 11 the shearing load-displacement curves

The physical characteristic parameters of the various test specimens in the Fig. 10 are shown in Table 4. The load of the maximum shearing failure stress increased along with the increase of the thickness of the stalk wall, the biggest destruction stress didn't change obviously, its value was between 9*MPa* and 3.5*MPa*, the mean value was 10.52MPa.

Tab4. The physical characteristic parameters of various test specimens

No.	Outer diameter(mm)	Wall thickness(mm)	collapse resistance(N)	shearing failure stress(MPa)
①	19.82	2.76	1442.86	9.02
②	18.55	2.50	1364.29	10.04
③	17.27	2.54	1232.86	9.64
④	14.36	2.00	941.43	11.20
⑤	13.19	1.82	738.57	10.24
⑥	12.33	1.79	611.43	9.50
⑦	11.30	1.34	514.29	11.49
⑧	10.72	1.21	501.43	13.04

2.3 Bending test

The test specimen with specification 60.0mm×d mm (rape stalk diameter) were intercepted from the base of gathered elongation stalk samples, showed in Fig. 12.The experiment model was three-point bending, the equipment was shown in Fig.13. The experiment parameters: curving span 50mm, load 5*N* force in advance, and the load velocity 10mm/min.


Fig12 Shearing test specimen


Fig 13 bending test equipment

Fig. 14 is the bending load-displacement diagram provided by the computer control system. At the preliminary stage of load increase, the stalk was compressed, then curved, after achieving the maximum curving load, the outer wall of the sample broke; load value dropped rapidly. But to a certain degree, the load value tended to be steady, and it was discovered that the test specimen could not be broken off in all possible loads. Neglecting the function of the interior core marrow, taking the hollow specimen as tubing, the flexural module could be established by the following expression:

$$E_{弯}=\frac{PL^3}{12y\pi(r_1^4-r_2^4)}$$

Where E_B is the flexural module in *MPa*; *P* is force loaded on the specimen in *N*; r_1 and r_2 is the outer and inner radius in mm, *L* is the bending span; *y* is the bending deflection.

Fig. 15 is the flexure elasticity module chart of the test specimen, x-coordinate is the tension strain, y-coordinate is flexure elasticity module. In the chart, in the section of tension strain (0, 2), the stalk was under the compression condition the corresponding elastic module calculated was obviously wrong, therefore taking effective value in sector of tension strain (2, 8), the computation mean value was 61.38*MPa*, where the average flexure elasticity module of the specimen was E_B= 61*MPa*.

Conclusion

The parameters of physical and mechanical characteristics of the rape stalk's elongating part had been obtained through experiments. The value of compression resistance was 11.9*MPa*, the elasticity modulus in compression was 172*MPa*; the largest shearing failure stress was 10.52*MPa*; the elasticity of flexure module was 61*MPa*. These results indicated that the rape stalk is anisotropic material whose physics mechanical properties are different in all directions.

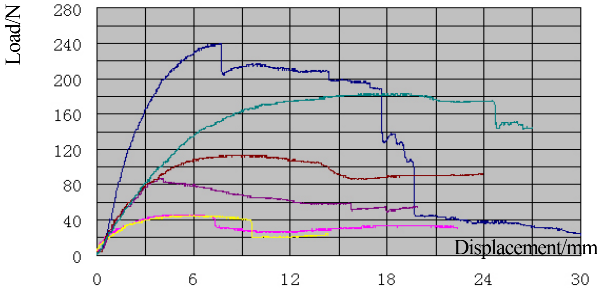

Fig 14.Bending load –displacement curves

The carrying capacities of the rape stalk mainly displayed on the outer wall of the stalk. And only when the biggest destruction load had been achieved, the core marrow was compressed to a certain degree, the carrying capacity then came forth. The results of the compressive tests indicated that carrying capacity of the rape stalk with core was approximately 10% higher than the hollow stalk; after the solid test specimen achieved the biggest destruction load, carrying capacity began to drop. When it dropped to a certain degree, the load value tended to be fixed. While the hollow test specimen achieved the biggest destruction load, carrying capacity dropped rapidly. Contrasting these compression tests, it could be drawn that the carrying capacity of rape stalk with core marrow was embodied by avoiding cell bursting resulting from tubular fiber of outer wall losing balance on the straight line in the compression process. Therefore in the processing of tentative data and the establishment of rape stalk model, the rape stalk may be simplified as hollow tubing.

The compression-displacement curve, the cut—displacement curve, and the curving load-displacement curve of the test specimen appeared non-linear characteristic; it proved that the rape stalk is non-isotropic and non-linear material. The rape stalk did not submit during the destruction process. In the bend test, when the load surpassed the biggest destruction stress, the test specimen destructed instantaneously (outer wall curving and breaking off), the result showed that the stalk was obviously of crispy. But in the later period, the test specimen entered the compressing stage, the load tended to be a fixed value, the stalk was very hardy to be completely broken off. In shearing test, the stalk was compressed firstly, then cut to break. Therefore, in the mechanization harvest of rape, we should take the double-holding cutting into consideration, because it could avoid shear leaking causing by stalk bending accompanying in non-holding cutting. Moreover, in order to reduce the power consumption for cutting core marrow, the cut should be carried out with high speed.

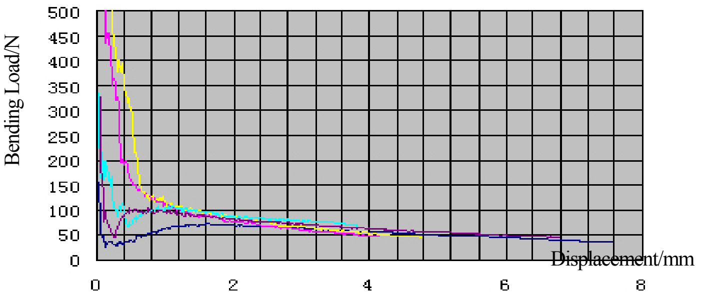

Fig 15 The flexure elasticity module

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