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Experiment and Analysis on Properties of Castor's Rod Diameter

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***Abstract*—In order to study the cutting force of castor cutter, the cutting performance of castor stalk was improved. The influence factors of cutting mechanical properties were studied by microcomputer controlled electronic universal testing machine. In this paper, the position of castor stalk, moisture content, loading speed as the experimental factors, to study the extent of their impact on the elastic modulus, the result showed that the stalk position of the most significant impact on the elastic modulus, followed by the loading speed. Then, the growth trend of the outer diameter and wall thickness of the castor stalk at different heights from the ground and their effects on the elastic modulus were studied by multivariate design. Experiments showed that the outer diameter and cross-sectional area had great influence on the flexural modulus of stem, and the ratio of wall thickness and wall thickness to outer diameter had little effect on the flexural modulus of stem. This study provides a theoretical basis for later development of castor harvester.**

Keywords—Caster, Mechanical properties, Orthogonal test, Multivariate test

I. INTRODUCTION

Castor oil can be used as an important chemical raw material to produce hundreds of chemical products, such as lubricants, paints, activators, etc. It is widely used in national defense, aviation, chemical medicine and machinery industries, and it is called renewable "green stone" because of its renewability.

A lot of theoretical research and experimental research have been carried out on a series of problems such as the identification of mechanical properties and strength, and some preliminary results have been obtained. Pang Xiaoyuan et al [1] studied the variation of stem diameter with growth time and the change of compression, shear and tensile limit of rape seedlings with growth time, and established the stem stalk of rapeseed. In order to obtain the mechanical parameters of low-cutting cutting of cotton straw, Li Yudao et al [2] studied the shear mechanical properties of cotton. The shear strength and shear work of cotton straw at different time and different water content were tested experimentally. Zhao Chunhua et al [3]took perennial leguminous forage alfalfa, small crown of emerald and four gramineous forage varieties of Agropyron glabra and Bromus inermis at cutting stage as experimental objects. Zhang Kaifei et al[4] collected the bean stalks in the same season, used the vacuum drying oven to determine the moisture content of the bean straw, and obtained different parts under the same water content. Hu Lianglong et al [5]combined agricultural machinery with agronomy. Taking Ningzi No.1 and Ningzi No.2 as experimental objects, the changes of water content and shear strength of sweet potato vines during harvest were studied. And other people study on the cutting properties of the material[6-10].

II. MATERIALS AND EQUIPMENT

A. Test Materials

The test materials were obtained from the ramie stalks at the harvesting stage of the Tongliao Agricultural Science Research Institute in Inner Mongolia. It is shown in Figure 1. Immediately after the sampling is completed, it is stored in a sealed bag, and the water condition in its original state is maintained as much as possible to enhance the scientific and rationality of its subsequent tests.

Figure1. Experimental material

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1-transmission system 2-drive system 3-load simulation system 4-measurement control system 5-computer display system 6-data acquisition system

Figure2. Wdw-2 microcomputer controlled electronic universal testing machine

B. Test Equipment

The test equipment is WDW-2 type microcomputer controlled electronic universal testing machine, as shown in Figure 2. The universal testing machine can display load value, displacement value, deformation value, test speed and test curve in real time and dynamically, and carry on data processing and analysis. The measuring force of the universal testing machine ranges from 1 to 2000N, and the relative error of indication is within±1%.

III. ORTHOGONAL TEST FOR CASTOR'S ROD

A. Design Variables

In this paper, different parts of stems and multiple groups of castor stems with different water contents were selected for comparative experiments to explore the effects on the mechanical properties of castor stems. Loading speed is a key factor affecting the cutting force of stalks, and is also an important parameter for designing and optimizing related agricultural machinery.

B. Test Methods

When analyzing the bending mechanical properties of the stem, the experimental factors were selected as: stem part (A), water content (B) and loading speed (C). According to the actual measurement, 3 levels of A, B and C were selected, as shown in Table 1. The orthogonal scheme L9 (34) is selected to arrange the test scheme. Single factor single horizontal repeated test methods were used, and each set of experiments was repeated 3 times. In order to avoid large deviation of the test data, the speed during the test should not be too large.

TABLE 1 TABLE OF BENDING TEST FACTORS

Level	Stem parts(A)	Water content(B)/%	Loading speed(C)/mm·min^{-1}
1	Upper portion	30	30
2	middle portion	25	25
3	bottom	20	15

Therefore, the effect of the loading speed on the elastic modulus of the sample was only studied in the range of 15-30 mm/min. With the increase of load, when the fracture was not at both ends of the stem, it was recorded as a successful bending test, as shown in Figure3.

Figure3. Bending test

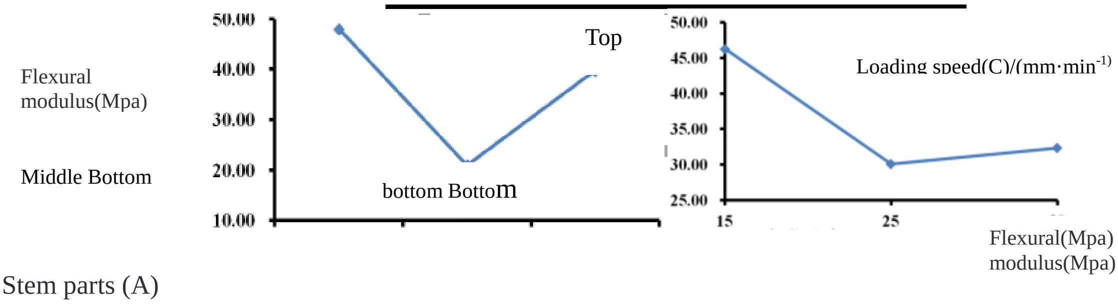
C. *Test results and Analysis*

In this study, the bending modulus of elasticity of castor stalk was selected as the characteristic factor to explore its bending mechanical properties. Orthogonal test was designed to analyze the influencing factors of bending mechanical properties.

In Table 2, k_1, k_2, and k_3 respectively represent the average value of the flexural modulus of the stem under various factors at each level, which can be used to reflect the influence of each level of the same factor on the test results. Use the data in Table 2 to plot the trend of each factor affecting the flexural modulus of elasticity, as shown in Fig.4.

TABLE 2 ORTHOGONAL TEST RESULTS OF ELASTIC MODULUS OF STEM BEND

Test number	1(A)	2(B)	3(C)	4	Elastic modulus (MPa)
1	1	1	1	1	40.1
2	1	2	2	2	40.8
3	1	3	3	3	38.4
4	2	1	2	3	11.1
5	2	2	3	1	37.7
6	2	3	1	2	14.2
7	3	1	3	2	62.7
8	3	2	1	3	42.7
9	3	3	2	1	38.5
K_1	119	114	97.0	116	
K_2	63.0	121	90.3	118	
K_3	144	91.1	139	92.3	
k_1	40.0	38.0	32.3	38.7	
k_2	21.0	40.4	30.1	39.2	
k_3	48.0	30.4	46.3	30.8	
Range R	27.0	10.0	16.1	8.45	



(a)factor influencing trend diagram (b)C factor influence trend chart

Figure 4. influence factors trend of bending test

The test results were subjected to range analysis, and the influence of the horizontal variation of each factor on the test results was compared by comparing the R values ($R=k_{imax}-k_{imin}$) under different influencing factors in the table. In Table 2, R1>R3>R2, so the order of influence of each factor on the flexural modulus is: stalk part, loading speed and water content.

Because the range analysis method can not completely estimate the error that must exist in the test and measurement process, the test results are analyzed by variance. The results are shown in Table 3.

TABLE 3 VARIANCE ANALYSIS OF ELASTIC MODULUS OF STEM BENDING

Soruces of variation	Sum of deviation square	DoF	Mean square	F value
Stem parts(A)	1146.52	2	573.258	8.47481
Water content(B)	163.703	2	81.8516	1.21006
Loading speed(C)	459.430	2	229.715	3.39601
Error	135.285	2	67.6426	

It can be seen from Table 3 that the three factors have a certain degree of influence on the flexural modulus of the stalk, and the stalk part has a greater influence on it. The following conclusions are drawn by combining with Fig.4: (i) The stem segment of the castor stem has strong bending resistance, and the flexural modulus can reach 47.96 *MPa*. (ii) In the lower speed range of 15-30 mm/min, the castor stem increases with the loading speed. The bending elastic modulus is about 30.11 *MPa* at about 25 mm/min. (iii) The flexural modulus of the castor stem increases first with the increase of water content. The downward trend can reach a maximum value of 40.39 *MPa* at a water content of about 25%.

IV. MULTIVARIATE TEST

A. Test method

In order to study the variation trend of the outer diameter and wall thickness of the test subjects at different growth heights, it provides a basis for the subsequent testing of the elastic modulus of the castor stems. The caliper stalks were used to measure the outer diameter and wall thickness of the parts from the stalks with the same water content (all 30%) of 60 mm, 120 mm, 180 mm and the upper and lower parts, respectively.

B. Test results and analysis

After the measurement, calculation and bending tests, the data obtained are organized as shown in Table 4.

(1) The growth trend of the outer diameter and wall thickness of castor stems with height

In order to make the data more intuitive, the distribution of outer diameter, wall thickness, wall thickness/outer diameter and cross-sectional area at different growth heights is drawn. The fitting curve is established.

(a) The outer diameter distribution of castor stems shows that the outer diameter of castor stems is different at different growth heights, and their numerical values are different. As can be seen from Fig.5, in the portion where the height of the castor stem is 60 mm from the ground, the outer diameter is mainly concentrated between 22.0 and 27.0 mm; in the portion near the ground height of 120 mm, the outer diameter Mainly concentrated between 27.0~30.0mm; in the part near the height of the ground 180mm, the outer diameter is mainly concentrated between 29.0~32.0mm.

The equation is fitted to determine the coefficient.The fitting equation is $y = 4.5788\ln(x) + 6.4826$,the determination coefficient is R^2=0.82.

TABLE 4 DATA STATISTICS TABLE OF MEASUREMENT AND CALCULATION OF EACH INDICATOR OF STALK

Height above the ground(mm)	External diameter(mm)	Wall thickness (mm)	Wall thickness /External diameter(%)	Cross sectional area(mm^2)	Flexural modulus (MPa)
50	20.9	7.1	34.0	308	47.1
50	21.2	7.1	33.5	315	47.3
50	22.7	7.4	32.6	356	47.9
60	24.8	8.0	32.3	422	50.1
60	26.5	8.9	33.6	492	51.8
60	26.8	8.8	32.8	498	51.6
110	23.1	3.6	15.6	205	10.2
110	22.6	3.4	15.0	221	13.5
110	25.6	4.7	18.4	289	19.4
120	27.8	4.8	17.3	274	18.2
120	27.3	4.4	16.1	317	21.0
120	27.0	4.4	16.3	347	22.2
130	29.7	4.4	14.8	282	18.8
130	29.5	3.6	12.2	300	20.0
130	27.3	3.7	13.6	312	19.9
130	28.9	3.8	13.1	350	22.6
130	30.8	3.9	12.7	369	23.8
130	28.5	3.6	12.6	433	24.7
140	32.5	3.9	12.0	350	23.2
170	24.2	3.1	12.8	205	12.3
180	30.2	3.0	9.93	256	18.2
180	32.3	3.9	12.1	348	22.7
190	26.2	2.7	10.3	199	11.6
190	25.9	3.2	12.4	228	14.8

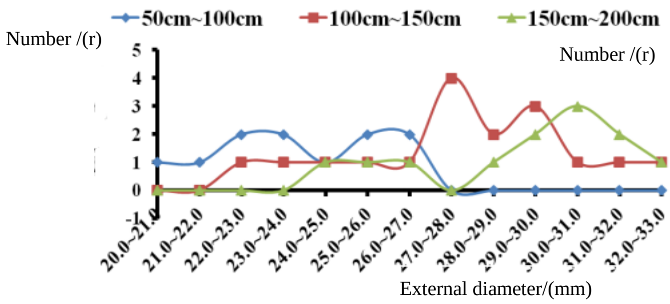


Figure5. Distribution pattern of outer diameter

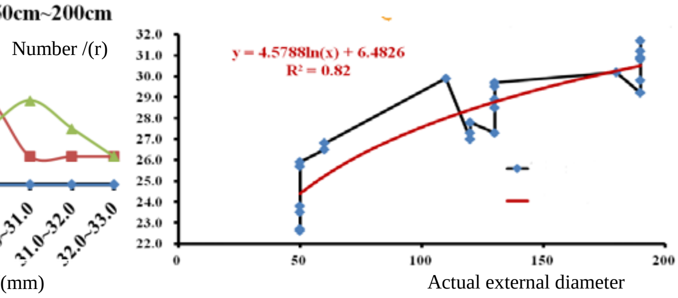


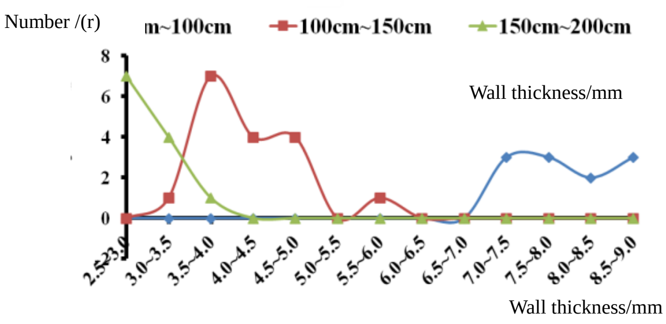
Figure6. Fitting curve of outer diameter and height above ground

(b) The wall thickness distribution diagram of castor stems shows that the wall thickness of castor stems is different at different growth heights, and their numerical values are different. It can be seen from Fig. 7 that the wall thickness is mainly concentrated between 7.0 and 8.5 mm in the part where the height of the castor stem is 60 mm from the ground; the wall thickness is 120 mm in the vicinity of the ground. Mainly concentrated between 3.5~5.0mm; in the part near the height of the ground 180mm, the wall thickness is mainly concentrated between 2.5~3.5mm.

The reduction of stem wall thickness is roughly in a polynomial relationship with the growth height. The fitting equation is

$$y = -6\times10^{-11}x^{6} + 5\times10^{-8}x^{5} - 2\times10^{-5}x^{4} + 0.0025x^{3} - 0.2143x^{2} + 9.4362x - 154.93 \;,$$

the determination coefficient is R^2=0.969.



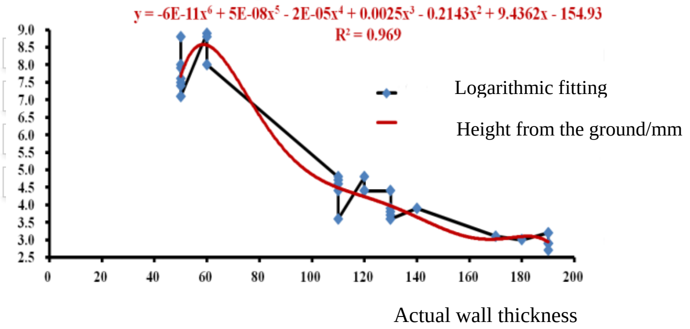


Figure7. distribution pattern of wall thickness

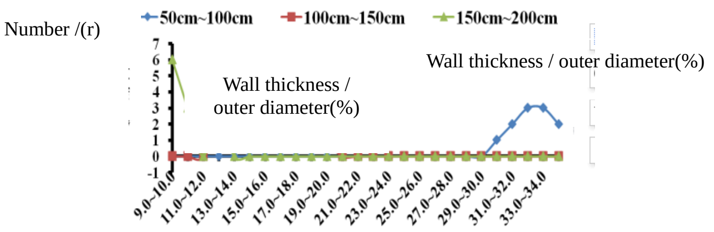
Figure8. Fitting curves of wall thickness and height above the ground

(c) The wall thickness/outer diameter distribution of castor stalks shows that the size of the castor stalks is different at different growth heights. As can be seen from Fig.9, in the part where the height of the castor stem is 60 mm from the ground, the ratio is mainly concentrated between 30.0 and 34.0 mm; in the part near the height of the ground 120 mm, the ratio is mainly concentrated. Between 12.0 and 19.0 mm; in the vicinity of the height of the ground is 180mm, the ratio is mainly concentrated between 9.0 and 13.0mm.

Using the data from the above interval, a scatter plot with straight lines and data marks is drawn, and the ratio of the wall thickness to the outer diameter of the stem is fitted to the growth height curve, as shown in Fig. 10. The fitting equation is

$y=-5\times10^{-7}x^4+0.0002x^3-0.0386x^2+2.393x-15.455$,

coefficient of determination is R^2=0.983.



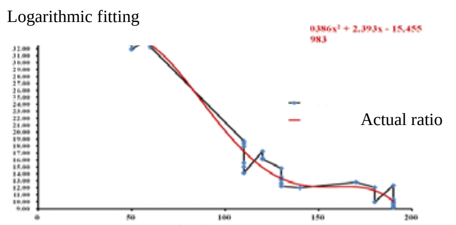
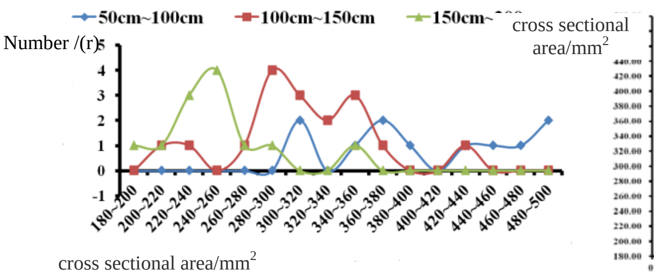


Figure9. Distribution pattern of wall thickness/outside diameter Figure10. Fitting curve of the wall thickness/outside diameter to the height above the ground

(d) The cross-sectional area distribution of the castor stems shows that the cross-sectional area of the castor rods is different at different growth heights, and their numerical values are different. As can be seen from Fig.11, in the part where the height of the castor stem is 60 mm from the ground, the cross-sectional area is mainly concentrated between 300 and 400 mm.

Using the above-mentioned interval data, a scatter plot with lines and data marks is drawn, and the cross-sectional area is fitted to its growth height curve, as shown in Fig.12. The fitting equation is y=-2×10-5x4+0.0076x3-1.3085x2+91.941x-1798.4, the coefficient of determination is R2=0.7465.



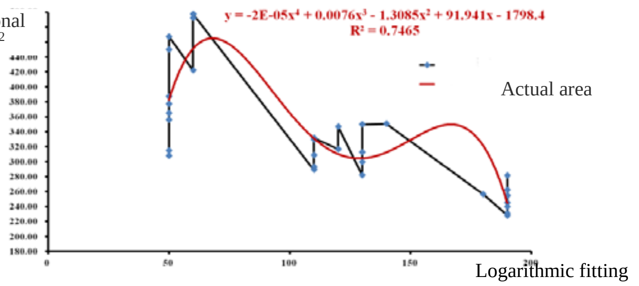


Figure11. Distribution pattern of sectional area

Figure12. Height from the ground/mm

V. Conclusion

The mechanical properties of crops considered in the stage of agricultural mechanization design are conducive to determining the working conditions of the implements, The main conclusions are as follows:

(1) The experiment showed that the structure of castor stalk had a significant effect on its mechanical properties. Under bending force, the bending elastic modulus of the stem at the bottom of the stem is 47.96 MPa, and the shear elastic modulus of the stem at the middle of the stem is 45.37 MPa. Therefore, in the redevelopment of agricultural products and the optimization of related machinery should be combined with its structural performance to put forward a more reasonable and effective program.

(2) The flexural modulus of castor stems increases first and then decreases with the increase of water content. When the water content is about 25%, the maximum value can reach 40.39 MPa, which can be combined with the relationship between water content and planting time. Research to further obtain the best period of harvesting of castor.

(3) The bending elastic modulus changes with the growth height of the castor stems first and then slightly increases. The initial flexural modulus rapidly decreased from 51.83 MPa to 13.47 MPa because the cross-sectional area rapidly decreased from 497.63 mm^2 to 289.03 mm^2 .

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