Shearing Characteristics of Corn Stalk Pith for Separation

Zhengguang Chen, * and Ge Qu

The rind of corn stalk (*Zea mays* L.) contains a high content of lignin, which is difficult for ruminants to digest. So, the separation of the pith and rind is the basis for the effective use of corn stalk. The shearing characteristics of pith are important parameters in the process of the separation of rind and pith for corn stalk. In this study, both the shearing strength and shearing energy were determined for the pith of cornstalk. The shearing force was measured at three moisture content levels (10 w.b.%, 40 w.b.%, and 70 w.b.%), different sample heights (lower, middle, and upper), and three different shearing speed levels (2 mm·min^{-1}, 20 mm·min^{-1}, and 50 mm·min^{-1}). The shearing strength and the shearing energy were calculated from this data. The shearing energy was calculated by using the area under the shearing force *versus* the displacement curve. The results showed that the maximum shearing strength and the shearing energy increased as the moisture content increased. The maximum shearing strength and shearing energy were found to be 0.8452 MPa and 0.6446 J, respectively. Both the shearing strength and the shearing energy were found to be higher in the lower region of the stalk due to structural heterogeneity.

Keywords: Corn stalk; Shearing strength; Shearing energy; Pith rind separation

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INTRODUCTION

Crop stalk is the richest regenerative resource in the world. In China, plenty of straw resources form annually, and corn stover production is as much as 220 million tons per year, which makes up approximately 28.6% of the total output of crop residues (Lv *et al.* 2013). However, rich corn stalk resources have not yet been effectively utilized. Plenty of them are vainly burned off in farmland, and not only are the resources wasted, but the fires also leave the natural environment damaged.

Corn stalk mainly consists of rind, pith, leaf, *etc.*, and the chemical components of the different parts vary greatly. In corn stalk, the rind contains rich lignin and fiber and is the perfect raw material in artificial plate and papermaking (Lee *et al.* 2005; He *et al.* 2016). The pith and leaf contain rich coarse albumen and sugar, which are an excellent type of fodder for ruminants (Yan *et al.* 2006). The rind of corn stalk is difficult to digest for the animals (Huo *et al.* 2011), and if pith were used in papermaking and plate manufacturing, the paper and plate would be apt to absorb water in the air and their quality would be reduced. Therefore, for the most effective utilization of the different parts of corn stover resources, each part of corn stalk requires effective separation. Meanwhile, research on the mechanical properties of corn stalk pith can provide a basis for the design and parameter optimization of a mechanism that can separate the pith from the rind of corn stalk effectively.

Current studies on the mechanical properties of crop stalk focus mainly on the test and analysis on such mechanical characteristics, such as the tension, bending, and compressive performances of the complete corn stalk. Here the bending strength, tensile strength, shearing strength (İnce *et al.* 2005; Galedar *et al.* 2008; Esehaghbeygi *et al.* 2009; Igathinathane *et al.* 2009; Hoseinzadeh and Shirneshan 2012; Yu *et al.* 2012), compressive properties (Mani *et al.* 2006), and moisture content were measured at different positions on the stalk. The main purpose of measuring these mechanical properties is to study the correlation between the mechanical properties and the resistance to lodging (meaning unintended bending or flattening after storms) of corn stalk; or the correlation between these mechanical properties and straw briquette properties (Mani *et al.* 2006) and straw chopping (Igathinathane *et al.* 2011); or the correlation between the mechanical properties of stalk and chemical constituents, *etc*. The mechanical properties of the rind of corn stalk were studied by Chen *et al*. 2012, whose purpose was to maintain the rind integrity during the separation of corn stalk rind and pith.

In this paper, a shearing test was conducted for corn stalk pith to determine the shearing strength and shearing energy as a function of height regions, moisture content, and shearing speed. The purpose is to provide a scientific basis for designing a corn stalk rind and pith separator with high efficiency and low power consumption.

EXPERIMENTAL

Materials

Corn, variety DN255 (Developed by the Northeast Agricultural University(NEAU), China,) was used as the test material. Although this is not a common corn variety, the crop was visually similar, and stalks had similar dimensions to common varieties used in our other studies (Chen *et al*. 2012; Chen and Wang 2017). The corn was planted on May 10, 2015, ear harvested on October 25, 2015, and stalk harvested on December 17, 2015 from the plots (location: 45.720098°N, 126.802909°E) of Experiment Station, NEAU, Haerbin. The collected corn stover was stored indoors until experiments.

The leaves and sheaths were removed to expose the stalk. The stalks with a straight stem, free from pests and disease, without insect bites, without apparent defects on the surface of the stems, and with uniform color were selected. The mean length of the corn stalks was 2100 mm, the pith of corn stalk was taken artificially and made into a column shape for use as a test specimen with a cross-section of 10 mm by10 mm and a length of 100~150 mm(Fig. 1).

Fig. 1. The Pith Specimens of Corn Stalk

To determine the average moisture content of the stalk stem on the test date, the specimens gathered from the field were weighed and dried at 105 °C for 24 h, according to

ASABE S358.3 (2012) in the oven (Model WH-71, TAISITE, Tianjin, China) and reweighed. The experiments were conducted at a moisture content of 10 w.b.%, 40 w.b.%, and 70 w.b.% The diameter of the stalk stem decreases towards the top of the plant. That means that it shows different physico-mechanical properties at different heights due to cross-sectional heterogeneity. Therefore, it was divided equally into three height regions as the upper, middle, and lower (Fig. 2). The average outside diameter of the stems in the upper, middle, and lower regions varied between 12.53 mm to 13.28 mm, 18.71 mm to 21.11 mm, and 22.22 mm to 25.38 mm, respectively.

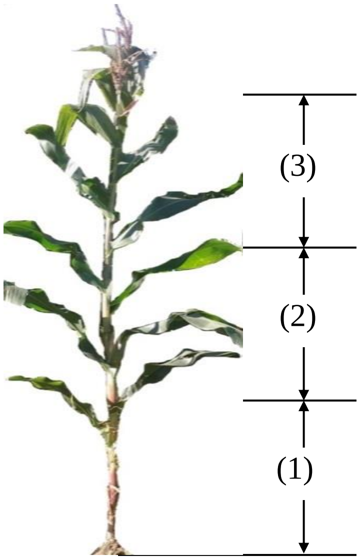


Fig. 2. The Corn Stalk regions evaluated in shearing test:(1) lower region;(2) middle region; (3) upper region

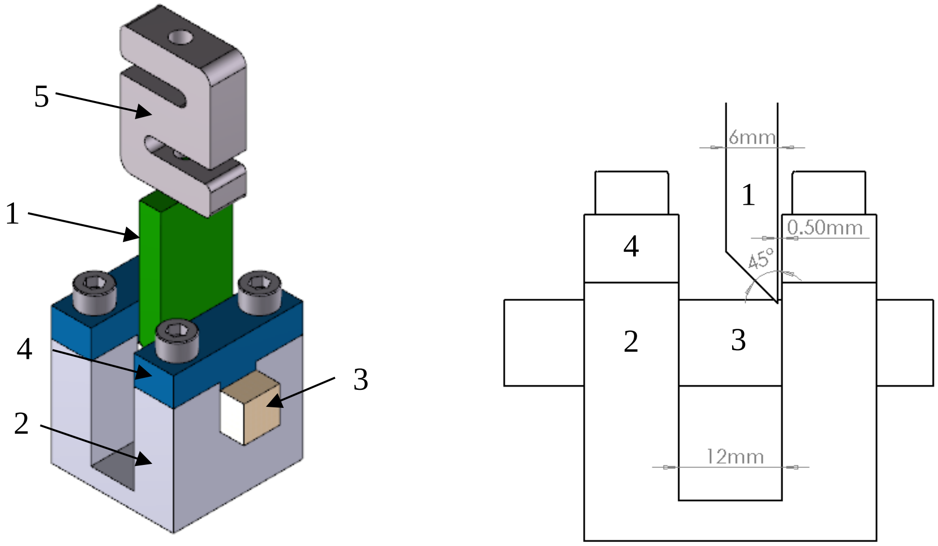
Equipment

A standard universal testing machine (UTM) (Jinan Shijin Group, Jinan, China; Model: WD-500, load cell capacity 500 N) was utilized in this study. A central control system operated the UTM and saved the load-displacement characteristics data. The system's frequency of recording data was three times per second. An electronic digital caliper with an LCD screen and measuring range of 0 mm to 150 mm was used to measure the section area of the test specimens. A DHG-9053A air-blow drying oven (Yiheng Scientific Instruments Co., Ltd., Shanghai, China) was applied to dry the pith specimen. A Sartorius BSA3202S lab balance (Weight Capacity: 3200 g, readability: 0.01g, Sartorius Corporation, Goettingen, Germany) was used to measure the specimens' weight.

Methods

Shearing test

To determine the shearing force of the pith of corn stalk, an experimental shearing apparatus was used (Fig. 3a). A test specimen was placed on the pith support and was secured by a fixed clamp. The shearing strength was measured by a strain-gage load cell, beneath which a knife plate could slide freely in a close sliding fit. The gaps between the knife and the sample support was not more than 1 mm (Fig. 3b). Shearing force was applied to the stalk pith specimens by mounting the load cell in the UTM, the sliding knife plate was loaded at different speeds, and as for the shearing test, a force-displacement curve was recorded up to the failure of the specimen.



a b

Fig. 3. Shearing schematic diagram of corn stalk pith; a. Axonometric diagram, b. Partial front view, (1) Knife, (2) Pith support, (3) Specimen, (4) Fixed clamp, and (5) S-type load cell

Experimental design

To realize the research objectives, three factors including the sampling height (A), moisture content of the stalk pith (B), and shearing speed (C) were selected as the factors used for the shearing test. Three levels were arranged for each factor. The values of independent variables discussed in this study are detailed in Table 1. Tests were conducted on all combinations of variables, *i.e.*, full factorial design, such that a total of 27(=3^3) groups of tests were conducted. Each test group was repeated until getting 5 test results whose coefficient of variation(CV) was no less than 15%, their mean value, for the purpose of reducing the random error, was applied as the final test result. So at least 135 shearing tests would be completed in this experiment.

This study is based on the existing separating machine for rind and pith of corn stalk. The knifes, mounted on a rotating roller, mill corn stalk, cut and opened along the axis, to achieve the goal of separating the pith from rind. This research emphasis is on influence of the machine's operating parameters and stalk moisture state of corn stalk on operating efficiency, rather than the blade angle, knife sharpness, although they are some factors which will affect physical properties of the stalk (Kushaha *et al*. 1983), which might be one of the main points for our future studies.

Table 1. Dependent and independent variables studied in this research

Dependent variables	Independent variables	Values
Shearing Strength Shearing Energy	Moisture content (w.b.%)	10, 40, 70
	Sample Height(mm)	500, 1000, 1500
	Shearing Speed (mm/min^{-1})	2,20,50

In order to compare the impact of each factor on dependent variables on the same level, each independent was encoded by a level -1,0, and +1. The values and levels of each test factor are shown in Table 2. The three height regions: lower, middle, and, upper are depicted by the values 1, 2, and 3, respectively.

The response surface method was adopted to perform data processing *via* Design Expert software (V8.0.6, Stat-Ease, Minneapolis, USA), to obtain the influence of the law of experimental factors on the evaluation indexes.

Table 2. Independent Variable Levels of Shearing Test

Experimental Factors	Levels		
	-1	0	1
Sampling Height (*A*) (500 mm)	1	2	3
Moisture Content (*B*) (w.b.%)	10	40	70
Shearing Speed (*C*) (mm/min^{-1})	2	26	50

Process of shearing specimen

Fig. shows examples of the force recorded during shearing tests with the distance covered by the movable knife as a function of displacement. As shown in the graph, the shearing process of the stalk pith can be generally divided into two stages: extrusion deformation and shear slip. The corn stalk stem is a fibrous material, and shearing the fibers is achieved by compression, which causes these fibrous tubes to become denser before severing the fibers. In other words, it shows the properties of solid cut after compression. When the shearing force of the movable knife is less than the shearing strength of the stalk pith, the stalk pith is compressed and its deformation is elastic and plastic (AB segment in Fig. 4), which is referred to as the extruding deformation stage.

The resistance of the partially pressed deformation of stalk pith reaches equilibrium with the shearing force, and at the moment the shearing process is in the critical state, shifting from extrusion deformation to shear slip (point B in Fig. 4). This is when the shearing force of the stalk pith reaches its maximum value. When the shearing force of the movable knife is larger than the shear capacity of the stalk pith itself, the shear plane slips, and is followed by the shear slip stage (BC segment in Fig. 4). With the gradual reduction of the shearing plane, the shearing force correspondingly decreases quickly, until the entire section of the stalk pith is sheared off. The mechanical criteria considered during this process were the failure criteria (maximum force, maximum stress, and energy required for failure).

As we can see from Fig. 4, when the moisture content is relative high (40%, black line), the displacement(11mm) of the knife is a little bigger than the specimen's size (10×10mm); by contrast, when the moisture content is relatively low (10%, red line), the displacement of the knife is approximately equal to the specimen's size. This is because the specimen has more plastic deformation being sheared when its moisture content is high.

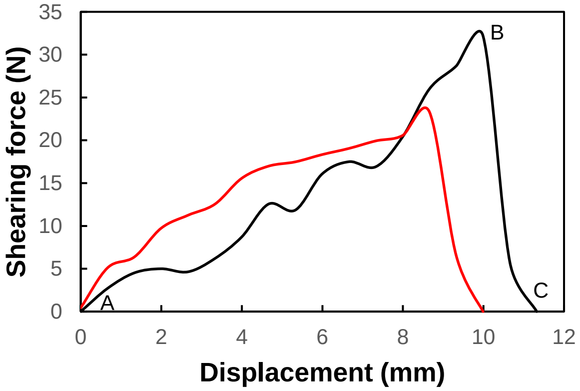


Fig. 4. Shearing force *versus* displacement for corn stalk pith. Moisture content 40%(black line) and 10%(red line)

Calculation of shearing energy

Suppose that the function corresponding to the shearing force-displacement curve attained in the shearing process is *f(x)*, then the shearing energy required for shearing off the stalk pith is calculated using Eq. 1,

$$W = \int_0^d f(x)dx \tag{1}$$

where *W* is the shearing energy required for shearing off the stalk pith (J), *d* is the displacement covered by the movable knife from initial stalk pith contact to shearing off the stalk, and *f(x)* is the function of the shearing force-displacement curve.

Because of the difficulty of acquiring *f(x)*, the trapezoidal integral formula can calculate the shearing energy as follows,

$$W = \sum_{i=0}^{n-1} \frac{F_i + F_{i+1}}{2} \Delta x_i \tag{2}$$

where F_i is the shearing force recorded by the computer in the *i*-th time (N), Δx_i is the displacement recorded in the *i*-th time (mm), and *n* is the total number quantity of the recorded data points.

Calculation of shearing strength

After recording the maximum shearing force in the shearing process (the force at the critical point B in Fig.) and measuring the cross-section area of the pith, the shearing strength of the specimen is calculated using Eq. 3,

$$\tau = \frac{F_{\max}}{S} \tag{3}$$

where F_{max} is the maximum shear force (N), *S* is the cross-section area of the test specimen of stalk pith (mm^2), and τ is the shearing strength (MPa).

RESULTS AND DISCUSSION

Table 3 gives the test results on the mean and standard deviation of shearing strength, and the mean and standard deviation of shearing energy of the pith specimens. According to Table 3, the maximum mean shearing strength was 0.87 MPa, which appeared at the lower part of the corn stalk and when the moisture content was relatively high. As shown in Table 3, the variation range of the shearing energy of corn stalk pith lies in 0.070 J to 1.068 J, with a mean value of 0.281 J. The test results of the shearing energy are in the same order of magnitude as that of wheat (Li *et al.* 2012).

By utilizing the data in Table 3, a 2FI (Two-Factor Interaction) fitting model on the shearing strength of corn stalk pith was attained, as shown in Eq. 4. According to the ANOVA analysis in Table 4, the *p*-value of the model was less than 0.0001, which indicated that the model was highly significant. The determination coefficient R^2 of this model (0.9283) indicated that this model had a favorable fitting degree. As a result, the model could be used to evaluate the influence of the law of various experimental factors on the shearing strength of stalk pith.

Table 3. Results of Shearing Energy and Shearing Strength of Pith

No.	Sampling Height (500mm)	Shearing Speed (mm·min^{-1})	Moisture Content (w.b.%)	Mean Shearing Energy (J)	SD of Shearing Energy (J)	Mean Shearing Strength (MPa)	SD of Shearing Strength (MPa)
1	1	2	10	0.193	0.023	0.191	0.024
2	1	2	40	0.303	0.038	0.445	0.054
3	1	2	70	0.556	0.064	0.870	0.077
4	1	20	10	0.186	0.013	0.149	0.007
5	1	20	40	0.301	0.039	0.351	0.043
6	1	20	70	0.815	0.101	0.820	0.121
7	1	50	10	0.225	0.013	0.150	0.010
8	1	50	40	0.254	0.034	0.242	0.027
9	1	50	70	0.621	0.075	0.733	0.092
10	2	2	10	0.178	0.021	0.224	0.018
11	2	2	40	0.204	0.025	0.563	0.074
12	2	2	70	0.390	0.010	0.738	0.05
13	2	20	10	0.167	0.016	0.193	0.005
14	2	20	40	0.201	0.023	0.420	0.054
15	2	20	70	0.451	0.061	0.703	0.016
16	2	50	10	0.201	0.014	0.164	0.010
17	2	50	40	0.291	0.025	0.268	0.036
18	2	50	70	0.494	0.009	0.644	0.083
19	3	2	10	0.222	0.004	0.272	0.018
20	3	2	40	0.264	0.036	0.609	0.055
21	3	2	70	0.306	0.038	0.633	0.088
22	3	20	10	0.202	0.028	0.245	0.011
23	3	20	40	0.214	0.027	0.473	0.067
24	3	20	70	0.245	0.017	0.482	0.042
25	3	50	10	0.164	0.012	0.196	0.017
26	3	50	40	0.242	0.023	0.354	0.024
27	3	50	70	0.348	0.038	0.453	0.054

Among the items in the model, the shearing speed (C), the moisture content of stalk pith (B), and the interactive item of moisture content and sampling height (AB) were all significant and had noticeable influences on the shearing strength.

Table 4. ANOVA of Regression Model for Shearing Strength

Source	Coefficient	Mean Square	*F*-value	*p*-value
Model	0.4230**	0.20	43.18	<0.0001
A	-0.014	3.42E-003	0.72	0.4054
B	0.2368**	1.00	211.30	<0.0001
C	-0.0727**	0.097	20.51	0.0002
AB	-0.0897**	0.097	20.42	0.0002
AC	-0.0098	1.17E-003	0.25	0.6244
BC	-0.0189	4.38E-003	0.93	0.3474
Residual		4.73E-003		

Notes: **Parameter coefficient significant at 99% confidence level; *Parameter coefficient significant at 95% confidence level

The impacts of the sampling height (*A*) on the shearing strength were not significant.

$$\tau = 0.42 - 0.014A + 0.24B - 0.073C - 0.09AB - 0.0098AC - 0.019BC \qquad (4)$$

With the shearing energy as a dependent variable, and the sampling height (*A*), moisture content (*B*), and shearing speed (*C*) as independent variables, a surface fitting was performed from the results of the shearing test (data from Table 3) by the user-defined response surface method. The corresponding regression model is shown as Eq. 5,

$$W = 0.24 - 0.069A + 0.14B + 0.012C - 0.090AB - 2.422E - 3AC + 0.15BC + 0.28A^2 + 0.079B^2 - 9.719E - 3C^2 \qquad (5)$$

According to the ANOVA analysis (Table 5), the *p*-value of the model was less than 0.0001, which indicated that the model was extremely significant. The determination coefficient R^2 of this model was 0.8883, which meant that the model had a favorable fitting degree. Of all the model items, sampling height (*A*), moisture content (*B*), interactive item (*AB*), and the quadratic item (B^2) were all found to be significant and had great influences on the shearing energy. The SNR (Signal-to-Noise Ratio) of the model was 12.56 (> 4), which showed that the model had enough useful signal. The model was feasible within the test parameters range. As a result, the model could be used to determine the assessment of the law of effect caused by various test factors on the shearing energy.

Table 5. ANOVA of Regression Model for Shearing Energy

Source	Coefficient Estimate	Mean Square	*F*-value	*p*-value
Model	0.240**	0.064	15.02	<0.0001
A	-0.069**	0.086	20.23	0.0003
B	0.140**	0.35	81.51	<0.0001
C	0.012	2.788E-3	0.66	0.4293
AB	-0.090**	0.097	22.73	0.0002
AC	-2.422E-3	7.185E-5	0.017	0.8981
BC	0.015	2.714E-3	0.64	0.4353
A^2	0.028	4.760E-3	1.12	0.3048
B^2	0.079**	0.037	8.73	0.0089
C^2	-9.719E-3	4.879E-4	0.11	0.7389

Note: **Parameter coefficient significant at 99% confidence level; *Parameter coefficient significant at 95% confidence level

Effect of Single Factor on Shearing Strength

From the regressive model in Eq. 4, by setting two of the three factors at the 0 level, the model on the law of effect caused by the third factor on the shearing strength was attained. This is expressed as Eq. 6,

$$\begin{aligned} \tau_A &= 0.42 - 0.014A \\ \tau_B &= 0.42 + 0.24B \\ \tau_C &= 0.42 - 0.073C \end{aligned} \qquad (6)$$

The influence law curve of various single factors on the shearing strength is shown in Fig.. The moisture content is known to have an important effect on the properties of materials. With the factors increasing from levels of -1 to +1, the moisture content curve had the greatest range among the three factors, so the moisture content had the most significant effect on the shearing strength, which was consistent with the data shown in

Table 4 (the item B, the *p*-value was less than 0.0001). Following the moisture content was the shearing speed (p = 0.0002), while the effect of the sampling height on the shearing strength of stalk pith was not significant (p = 0.4054). With an increase of the moisture content of stalk pith from level -1 to +1, the shearing strength quickly rose from 0.18 MPa to 0.66 MPa, which was consistent with previous studies (İnce *et al*. 2005; Nazari Galedar *et al.* 2008; Tavakoli *et al.* 2009). This was because when the moisture content increased, the toughness of the stalk pith became high, and the plastic deformation of stalk pith was dominant in the shearing process.

The shearing strength gradually decreased with increased shearing speed. This effect of shearing speed was also reported by Zhang *et al.* (2016) in the study on mechanical properties of soybean straw. This phenomenon might be due to the less lignification of the pith resulting in the reduction of maximum shear stress when the loading speed was high. That is to say, high shearing speed is more conducive for scraping the pith from pith. In practice, the pith was separating from the corn stalk (cut and opened along its axis) by the rotating blades (knifes), which mounted around a rotary roller. So, in the process of separating the rind and pith, it was more favorable for the separating process to increase the rotational speed of the scrapers

The change of the sampling height showed no significant effect on the shearing strength, which had total variation of only 0.028 MPa, and the absolute value of slope of the sampling height line in Fig. 5 was smallest among the three lines, so the change of sampling height amount little change in shearing strength.

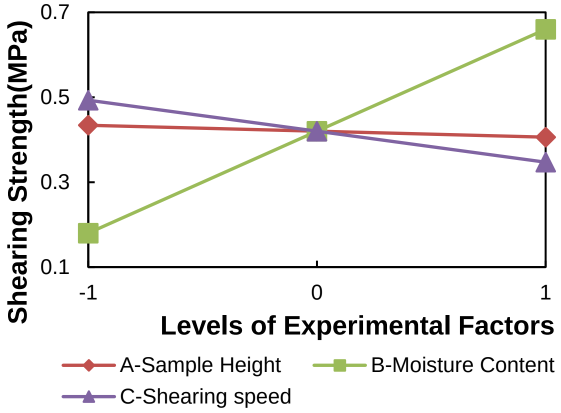


Fig. 5. Shearing strength diagram of pith of corn stalk

Response Surface Analysis for Influence of Experimental Factors on Shearing Strength

To analyze the interactions among all of the influence factors, response surfaces were drawn to perform an intuitive analysis. By setting the levels of the different factors at 0, respectively, interaction surfaces and contour maps could be obtained for another two factors.

According to the ANOVA analysis in Table 4, the interactive item (*AB*) of the sampling height and moisture content significantly affected the shearing strength of the stalk pith (p = 0.0002). The effects of the other interactive items were not significant; this result was similar to the results attained by Chen *et al.* (2016) in a shearing test on corn stalk. Figure 6 shows the response surface on the effect caused by the sampling height and moisture content on the shearing strength of corn stalk pith. Because there was not a quadratic item in the shearing model of stalk pith (see Eq. 4), the response surface actually seemed to be an inclined plane without bending. When the sampling height changed from upper to lower, the shearing strength of the stalk pith gradually rose with the increased moisture content, *i.e.*, when the moisture content was relatively high, the maximum shearing strength appeared at the lower part of the stalk. The maximum shearing strength calculated on basis of model was 0.8452 MPa. When the moisture content of stalk pith was relatively low, the shearing strength was overall low. In this condition, the shearing strength changed little with the change in sampling height. This was possible because when the moisture content was low, the brittle deformation was dominant in the shearing process.

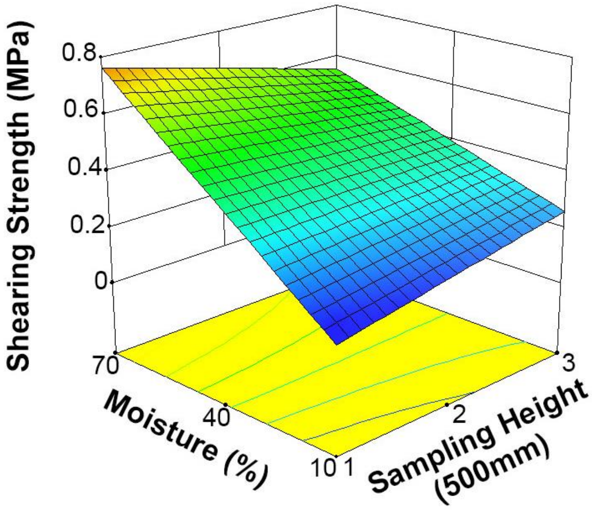


Fig. 6. Effect of sampling height and moisture content on shearing strength of pith

Effect of Single Factor on Shearing Energy

By setting two of the three factors in Eq. 5 at the 0 level, the model on the law of effect caused by the third factor on the shearing energy was attained. This is expressed as Eq. 7,

$$\begin{aligned} W_A &= 0.24 - 0.069A + 0.028A^2 \\ W_B &= 0.24 + 0.14B + 0.079B^2 \qquad (7) \\ W_C &= 0.24 + 0.012C + 0.0097C^2 \end{aligned}$$

Figure 7 illustrates that the shearing energy showed a continuous increase with increased moisture content from the level -1 to +1. The higher the moisture content in the pith was the tougher the stalk pith was, and the plastic deformation of the stalk pith was dominant. As a result, the maximum shearing force and the displacement in the stage of extrusion deformation increased, which led to an increase in the shearing energy. Therefore, from the view of saving energy, the stalk with low moisture content was more favorable for the rind-pith separation in the production practice.

The shearing energy increased with the decreasing level of the sampling height of the stalk pith, *i.e.*, the energy consumed in shearing off the lower corn stalk pith was higher than that consumed in shearing off the upper corn stalk pith. Such result may have been caused by a higher lignin content in the lower corn stalk in comparison with that in the upper stalk (Nazari Galedar *et al*. 2008). A higher lignin content in the rind increased its shearing resistance capacity.

The shearing speed showed no significant effect on shearing energy, which was consistent with the conclusion drawn in the reference (Li *et al.* 2012) on the shear test for wheat stalk.

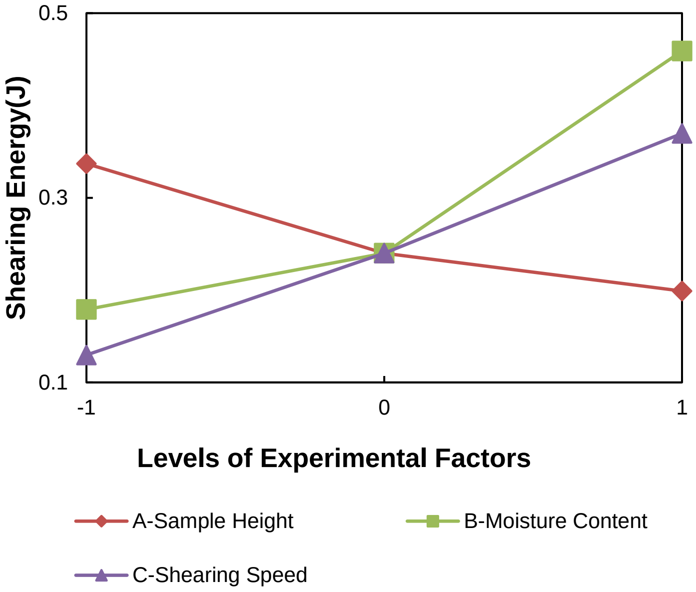


Fig. 7. Shearing energy diagram of pith of corn stalk

Response Surface Analysis for Influence of Experimental Factors on Shearing Energy

According to the ANOVA analysis (Table 5), the interactive item (*AB*) of the sampling height and moisture content significantly (p = 0.0002) affected the shearing energy of corn stalk pith, and the effects of the other interactive items were not significant. Figure 8 shows the response surface on the interactive effect caused by the sampling height and moisture content on the shearing energy of corn stalk pith. When a sampling height changed from upper to lower, the shearing energy of the stalk pith gradually rose with the increase in moisture content, *i.e.*, when the moisture content reached its maximum value, the shearing energy consumed for shearing off the pith taken from the bottom of the corn stalk reached its maximum value, which was 0.6446 J.

It can be calculated from Eq. 5 that if the shearing speed was fixed at the 0 level (26 mm/min) and the moisture content was 10%w.b., the difference of the shearing energy of corn stalk pith with different sampling heights was 0.048 J; when the moisture content was 40 w.b.%, the difference of the shearing energy with different sampling heights was 0.13 J; when the moisture content was 70 w.b.%, the difference was 0.32 J. Thus, it can be seen that when the moisture content of the corn stalk pith was low (10%w.b. or lower), the effect of the sampling height on the shearing energy was little. In contrast, when the moisture content was high (40%w.b. or more), the effect of the sampling height on the shearing energy was great, *i.e.*, the shearing energy quickly rose with the increase in moisture content and decrease in the sampling height.

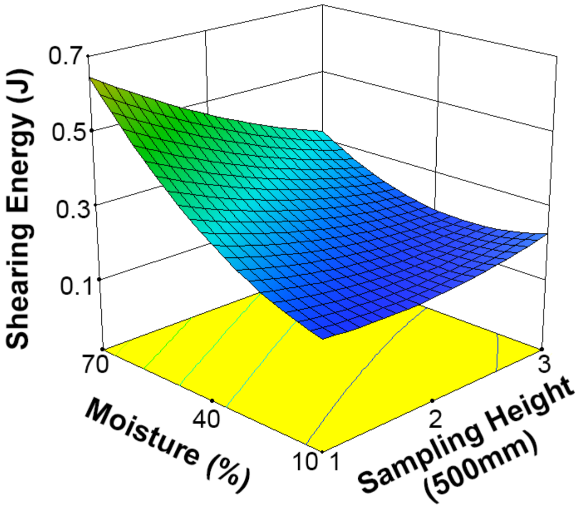


Fig. 8. Interactive effect of moisture content and sampling height on shearing energy

CONCLUSIONS

1. From the influence of the law of single factor, increased shearing speed could lower the shearing strength of stalk pith to some extent. The effect of the sampling height on the shearing strength was not significant. The moisture content greatly affected the shearing strength and shearing energy of corn stalk pith.
2. From the influence of the law of double factors, the interaction term of sampling height and moisture content greatly affected the shearing strength and shearing energy, which showed a continuous increase with increasing levels of moisture content and decreasing sampling height.
3. When the moisture content of stalk pith was low, its shearing strength and shearing energy were at low levels. In addition, they were rarely affected by the sampling height and shearing speed. In contrast, when the moisture content of stalk pith was high, its shearing strength and shearing energy quickly increased. The shearing strength and shearing energy reached their highest points when the moisture content was high and the pith was taken from the bottom of the corn stalk. The low moisture content was beneficial to saving energy during the process of separating the rind and the pith of corn stalk.

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