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Study of damping force between corn kernels and cobs based on DEM

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Abstract. To analyse the damping force between the kernel and the cob using DEM, the threshing properties were tested under quasi-static loading. And the effect of type of loading, variety of corn and moisture content was considered. The test results show that the type of loading and moisture content exerted a significant influence on the mechanical properties and the variety of corn had less significant effects. Under the same moisture content, the transverse compression and transverse tension damping force were significantly higher than the damping force by other two types of loading. And the damping force reached the minimum value at the moisture contents of 16.26% , and increased with increasing moisture content. According to the above test results, the corn threshing process was simulated and analyzed. The feasibility and effectiveness of the study on the damping force and coefficient are validated.

1. Introduction

Corn is the world's largest food crop and one of the most important raw materials and feed for production. Given the complexity of the threshing process, the discrete element method (DEM) [1] has been used to analyse the corn-threshing process, which can effectively analyze the contact between the part of the thresher and the ear of corn, as well as the movement process of the ear, the core and the seed population of corn. However, how to establish the mechanical connection model between corn kernels and corn cobs is a key problem, which has a great influence on the threshing process. Therefore, the mechanical properties of the corn kernel and corn cob during threshing must be studied in depth.

To date, scholars have studied the properties of corn kernel stalk. Threshing forces of seed corn kernel stalk have been tested [2], [3], [4] and [5], and the effects of factors were all considered. But the researches remains qualitative through experiments, the connection mechanism model has not been established. Our research group has made some new explorations on the mechanical properties of corn kernel stalk and preliminarily established the mechanical model of connection between corn kernels and corn cobs [6], but the research on the damping properties of the model is not deep enough.

Xiong and Liu pointed out in their review of material damping that materials have damping properties, and because of the existence of damping properties, materials have energy loss in mechanical vibration. Correspondingly, the corn kernel stalk has damping properties and energy loss during repeated loading. Therefore, taking the damping properties between the corn kernels and corn cobs as the research object, the repeated loading test was carried out on the corn kernel stalk, the corn kernel stalk force and displacement curve were obtained, and the damping force between corn kernels

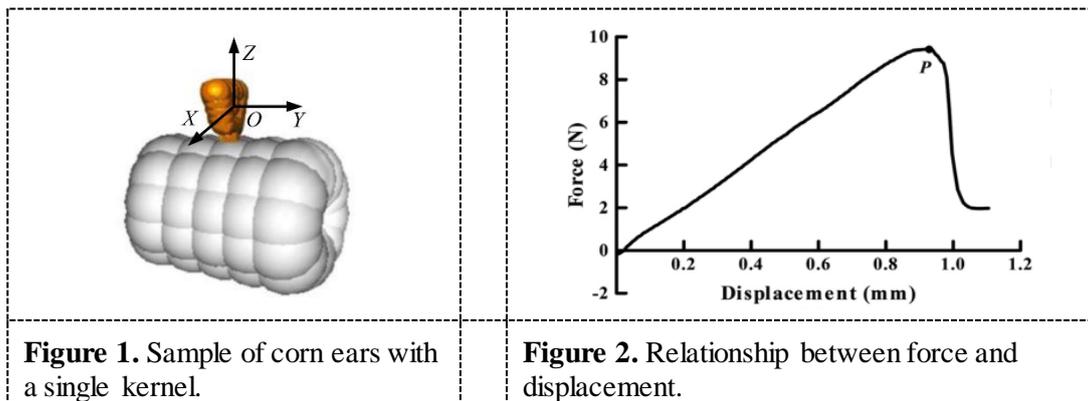


and corn cobs was calculated, and the effect of moisture content, corn variety and type of loading were all considered. In order to provide theoretical basis and the necessary input parameters when analyzing the corn threshing process using the discrete element method.

2. Models and methods

2.1. Connection model and parameter

In order to establish the connection model between corn kernels and cobs, the mechanical properties of corn kernel stalk were preliminarily tested. The ear sample of corn is shown in Figure 1, and the relation curve of connection force and displacement obtained through testing is shown in Figure 2.



According to the experimental study, the connection force between corn kernels and corn cobs is approximately linear [7]. Therefore, in the DEM software developed independently, the linear viscoelastic mechanical model is adopted to calculate the connection force between corn kernels and corn cobs.

The connecting force between the kernel and the cob along the X-, Y-, and Z-axes:

$$\begin{cases} F_x^{(t)} = F_{xK}^{(t)} + F_{xD}^{(t)} \\ F_y^{(t)} = F_{yK}^{(t)} + F_{yD}^{(t)} \\ F_z^{(t)} = F_{zK}^{(t)} + F_{zD}^{(t)} \end{cases} \quad (1)$$

where $F_i^{(t)}$ ($i = X, Y, Z$) represent the connection force between the kernel and the cob along the X, Y, and Z-axes at time t . The elastic connection force and connecting damping force along the X, Y, and Z-axes are given by:

$$F_{x(y,z)K}^{(t)} = F_{x(y,z)K}^{(t-\Delta t)} + K_{x(y,z)} \Delta u_{x(y,z)} \quad (2)$$

$$F_{x(y,z)D}^{(t)} = C_{x(y,z)} \Delta u_{x(y,z)} / \Delta t \quad (3)$$

where $F_{iK}^{(t-\Delta t)}$, $F_{iD}^{(t-\Delta t)}$, K_i , C_i , and Δu_i ($i = X, Y, Z$) represent the connecting elastic force and the connecting damping force at time $t - \Delta t$, the connection stiffness coefficient which is the slope of the approximate straight line segment OP, the connecting damping coefficient, and the translational displacement increments between the kernel and the cob along the X, Y, and Z-axes respectively.

The connection parameters in the model mainly includes the connection stiffness coefficient and damping coefficient, the stiffness coefficients K is equal of the slope of the fitting line, but due to the influence of moisture content, corn variety, type of loading, and many other factors, the determination method of damping coefficient C and damping force are complicated, and needs to be further studied.

2.2. Test principle and method

2.2.1. Test principle

In order to study the damping properties between corn kernels and corn cobs, the test was carried out to simulate the actual threshing process, and the kernel was loaded and unloaded several times, and finally loaded until they threshed, to obtain the threshing force and threshing displacement as shown in Figure 3. And the test was divided into four parts according to the direction of application of force: transverse tensile direction (Z-axis in Figure 1), transverse compression direction, longitudinal direction (Y-axis in Figure 1), and tangential direction (X-axis in Figure 1).

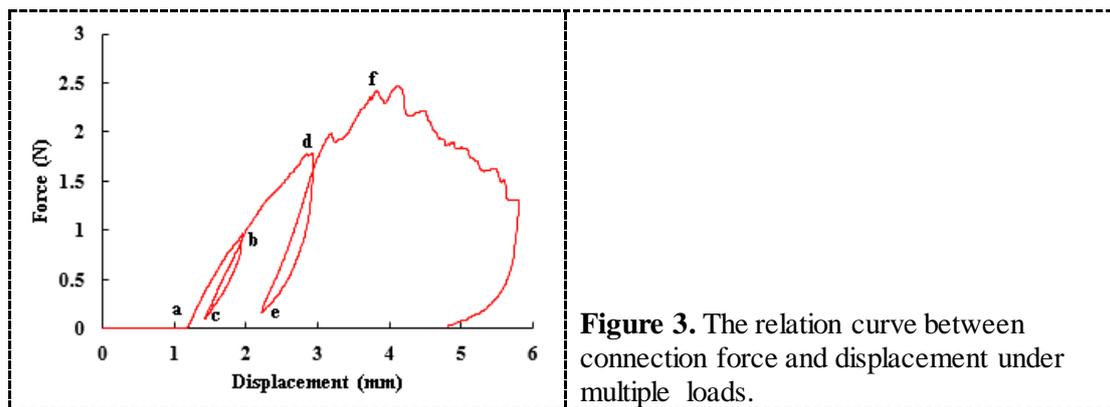


Figure 3. The relation curve between connection force and displacement under multiple loads.

As shown in Figure 3, AB, BC, CD, DE and EF segment were the first loading, the first unloading, the second loading, the second unloading and the third loading curve. During the first loading and the first unloading curves, the relationship between force and displacement was non-linear and the two curves do not coincide. And a closed loop region was formed between the loading and the first unloading curves, indicating that there is work done by damping force during the process.

2.2.2. Data processing method

It can be seen from Figure 3, due to the existence of damping force, a closed loop region was formed between the loading and unloading curves. Therefore, the area of the loop region is equal to the energy loss in the process of loading and unloading, which is equal to the work done by the damping force. The curve fitting process is as follows: the data of the first loop region and the second loop region are processed respectively, and the loading and unloading curves are fitted by the least square method. The data of the first loop region is shown in Figure 4, and the data of the second loop region is shown in Figure 5.

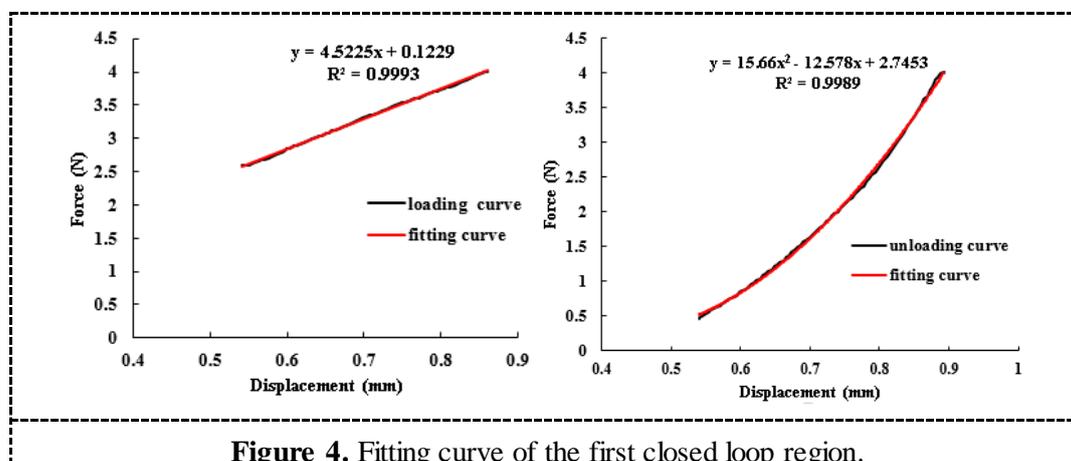


Figure 4. Fitting curve of the first closed loop region.

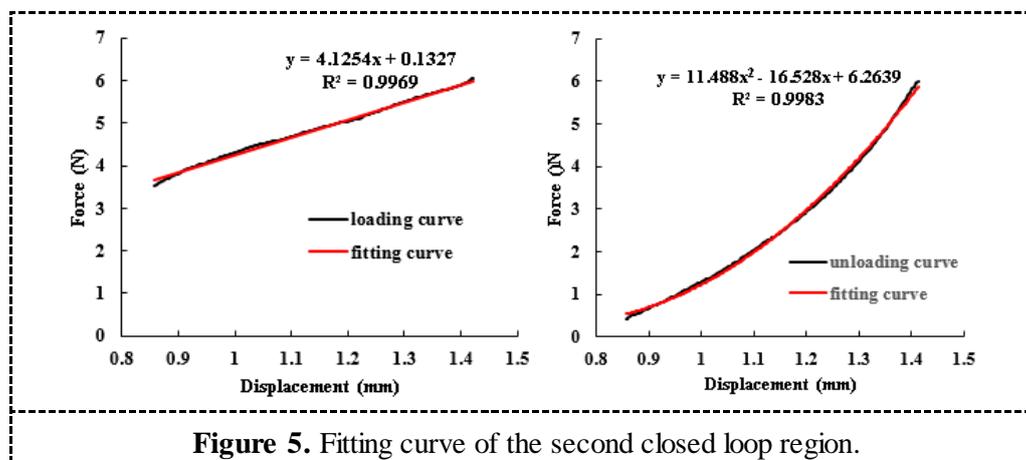


Figure 5. Fitting curve of the second closed loop region.

On this basis, the area of two closed loop areas was calculated using integral method, and the damping forces during loading and unloading are calculated. The integral area of the first loop region is

$$\int_{0.527}^{0.893} (4.523x + 0.123) dx - \int_{0.527}^{0.893} (15.66x^2 - 12.58x + 2.75) dx = 0.224077$$

The damping force is calculated as 0.1692N.

The integral area of the second loop region is

$$\int_{0.893}^{1.434} (4.13x + 0.1327) dx - \int_{0.893}^{1.434} (11.49x^2 - 16.53x + 6.26) dx = 0.774364$$

The damping force is calculated as 0.245437N.

3. Results and discussion

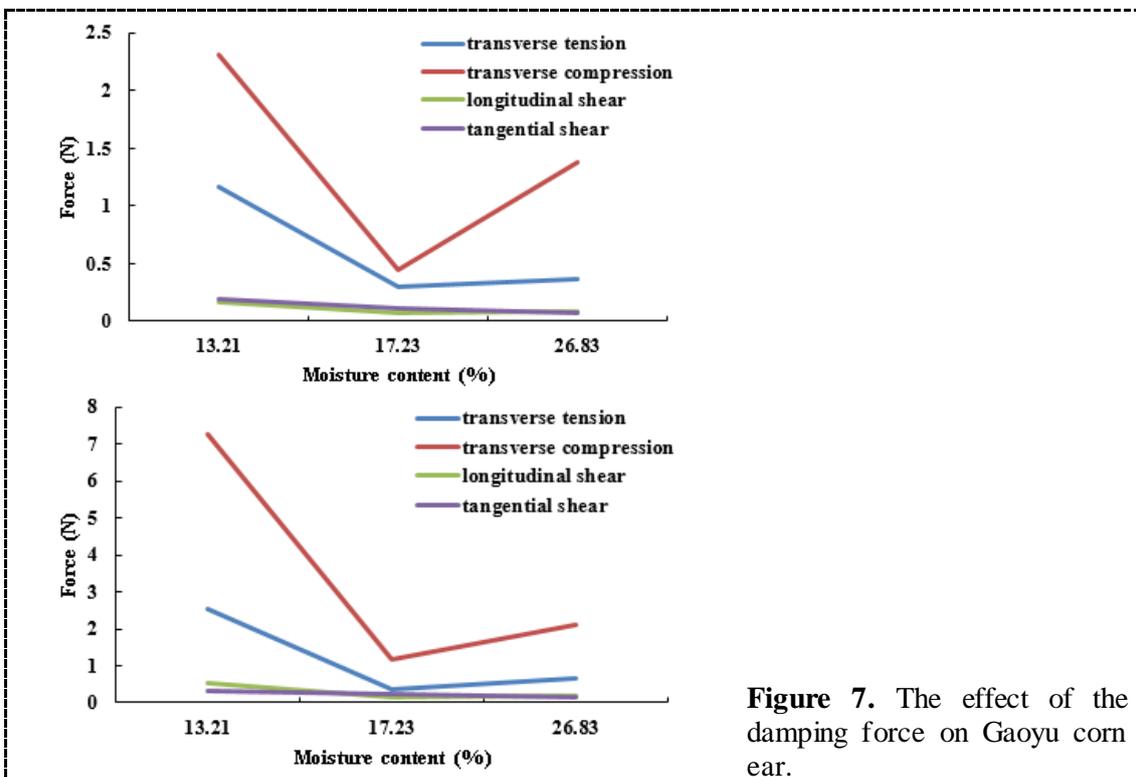
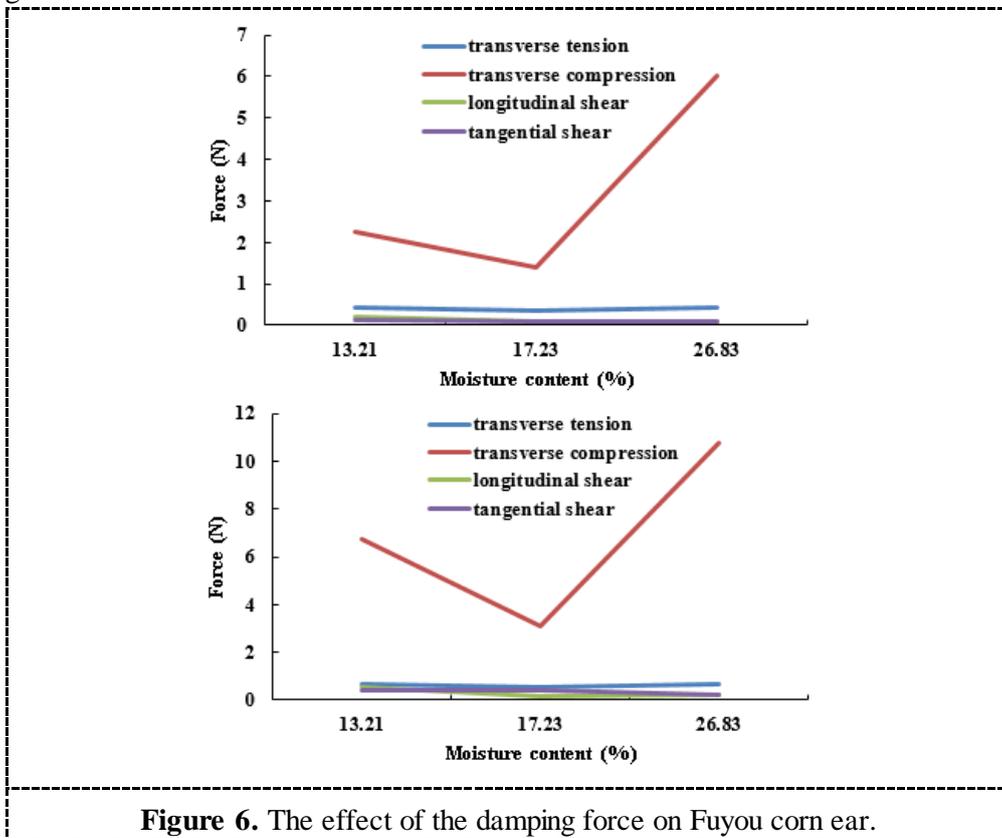
The effects of types of loading, kernel moisture content and corn variety on damping force and damping stiffness were considered. Each test was repeated 25 times, and outliers were removed leaving averaged values as experimental results. The factors, and levels, of the test are summarised in Table 1. The effects of the types of loading and moisture content on Gaoyu and Fuyou varieties of corn are shown in Figs. 6 and 7, respectively.

Table 1. Factor and level of mechanical test of corn kernel stalk.

Type of loading	Corn variety	Moisture content (%)	
		Gaoyu	Fuyou
1 Transverse compression	Fuyou	11.54	10.22
2 Transverse tension	Gaoyu	16.26	14.40
3 Longitudinal shear		18.14	18.55
4 Tangential shear		29.98	30.94

The effect of the type of loading on the damping force on Fuyou corn ear in the first loop region was shown in the Figure 6 (a). The figure shows that under the same moisture content, transverse compression damping force of kernel stalk was maximum, and was significantly higher than the damping force by other types of loading. And the transverse compression damping force reached the minimum value at the moisture contents of 16.26%, and increased with increasing moisture content after that of 16.26%. And the damping force by other types of loading remained unchanged with the increasing moisture content. The effect of the type of loading on the damping force of the corn kernel stalk in the second loop region was shown in the Figure 6 (b). And the damping forces of transverse

compression, transverse tension, longitudinal shear and tangential shear had the same trends with the increasing moisture content.



The effect of the type of loading on the damping force on Gaoyu corn ear in the first loop region was shown in the Figure 7 (a). Under the same moisture content, the damping force of transverse compression and transverse tension were significantly higher than the other two types of loading. And the damping force of longitudinal shear and tangential shear had little difference. The effect of the type of loading on the damping force of the corn kernel stalk in the second loop region was shown in the Figure 7 (b). And the damping forces of transverse compression, transverse tension, longitudinal shear and tangential shear had the same trends with the increasing moisture content. Through comparison the type of loading and moisture content exerted a significant influence on the mechanical properties and the variety of corn had less significant effects.

4. Simulation analysis of the threshing process

According to the above test results, the corn threshing process was simulated and analyzed. The dynamic simulation of the corn-threshing process is shown in Figure 8: from the beginning, ears of corn entered the threshing area (this continued until the end of the threshing process), due to the contact effects between the ears of corn and thresher parts such as the threshing drum, its spike-teeth and concave plate, kernels were gradually threshed from the cobs, and there were some undischarged ears of corn left in the threshing area with some un-threshed kernels remaining thereon. It could be seen that there were obvious differences in the number of separated kernels produced over the drum length and those collected under the concave plate. These phenomena were basically consistent with the conditions of the actual bench test.

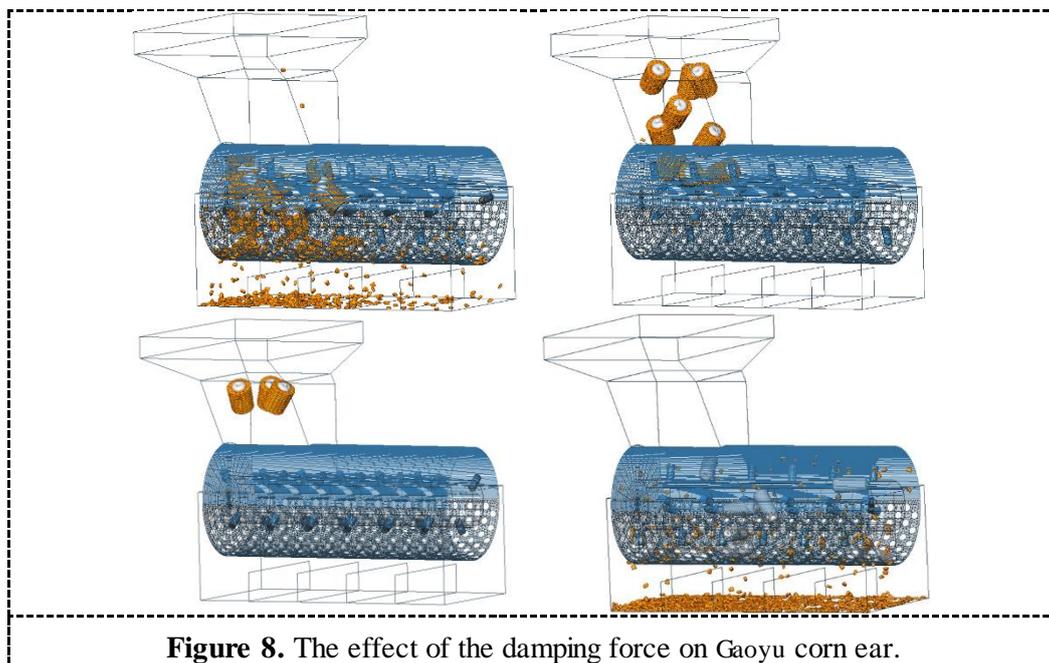


Figure 8. The effect of the damping force on Gaoyu corn ear.

5. Conclusions

To analyze the damping force between the kernel and the cob, the threshing properties were tested under quasi-static loading. And the effect of type of loading, variety of corn and moisture content was considered. The type of loading and moisture content exerted a significant influence on the mechanical properties and the variety of corn had less significant effects.

According to the above test results, the corn threshing process was simulated and analyzed. The feasibility and effectiveness of the study on the damping force and coefficient are validated.

In the future, this method will be used to carry out the simulation analysis and experimental study of the threshing process on different structure corn thresher with multiple factors and levels. This work

can also provide a reference to the simulation of the threshing process in other grain crops using a three-dimensional discrete element method.

Acknowledgement

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