Modeling and verification of corn straw based on no-tillage cutting process in Conservation Agriculture

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Introduction

Straw mulching as a component of conservation tillage has an important role in reducing wind and water erosion, increasing soil moisture, improving soil structure and increasing crop yield. The performance of stubble cutting devices becomes the key factor that affects the anti-blocking performance and operating performance of the no-tillage machine because of the corn straw is difficult to cut off . Based on the study of mechanical and physical properties of corn straw, this article uses the Hertz-Mindlin with Bonding Model in the discrete element software EDEM to establish a mechanical model of transversely isotropic oval corn straw, the contact and bond parameters of straw were calibrated by mechanical test. Finally, the shear force and deformation of corn straw in physics were used to verify the validity of the straw model, so as to provide theoretical support for the optimization and improvement of the stubble device and the no-tillage equipment anti-blocking performance research.

Materials and methods

Due to the differences in the physical and mechanical properties and the differences in load and destruction form of the straw rind and inner pith during the shearing process of the cutter, chose to establish discrete element model and perform parameter calibration according to the stress and deformation of the straw rind and inner pith. The discrete element model of corn straw was shown in Fig.1, Among them, the straw rind was formed by two kinds of 264 longitudinal fibers bonded along elliptical coordinates, and each fiber was bonded by 222 particles with a radius of 0.225 mm along a straight line, a total of 58608 particles. The inner pith was made up of 1090 particles of the same type at equal intervals, and the radius of particle was 1.05mm. The dimensions of the long and short axis of the discrete element model for straw were 23 and 18 mm respectively, and the length was 100 mm.

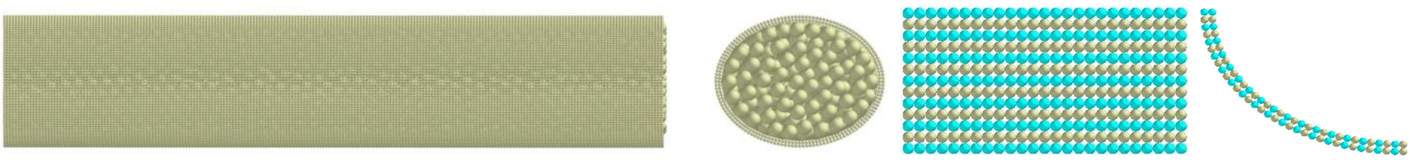

Figure 1. Discrete element model of corn straw

The straw rind includeed epidermis and tube bundle tissue mainly. The epidermis was composed of tough and smooth cells, the tube bundle tissue composed of 2-4 layers of fibroblasts and catheter arranged along the rind longitudinally. The corn straw was hypothesized as a model of transverse isotropy formed by multi-layer of longitudinal cellulose bonded to each other. According to the arrangement direction and connection mode of cellulose, the discrete element model of cellulose was established. In order to accelerate the simulation speed, two layers of particles with a radius of 0.225 mm were used to establish the rind model. Different colors in the picture represented different types of particles, the two particles were alternately arranged to isolate the same kind of particles. In the simulation, the stress of bonds between the same kinds of particles were used to simulate the internal stress of rind fiber, the force of the bonds between different kinds of particles simulates the force between rind fiber.

The straw inner pith was loose and porous, the elasticity was large, which played an important role in the stability of the straw. Based on the structure of the inner pith and the stress characteristics of the shearing process, a discrete element model of the corn stalk inner pith was established as shown in Fig.1. The model was composed of 3264 particles with a radius of 1.05mm, and the porosity of the discrete element model was 40%. The cross section of the model was elliptical, the dimensions of the long axis and short axis were 21.2, 16.2mm, and the total length was 100mm.

In the verification test, used the shear force measuring device to get the vertical force acting on the disk during the shearing progress and compared it with the force of the straw acted on the disc model in the simulation test. At the same time, the high speed camera was used to record the shear deformation process of corn straw on No 45 steel plate The shooting direction of the high-speed camera was parallel to the side of the disk, 40° to the plane of the conveyor belt, and the Shutter speeds was 1/1000 second.

Conclusion

Table 1. The bonding parameters of corn straw

Bonding parameters	Rind		Inner pith
	Longitudinal direction	Transverse direction	
Normal stress stiffness per unit area, N/m^3	2.86×10^{10}	8.84×10^{9}	4.15×10^{8}
Shear stress stiffness per unit area, N/m^3	1.11×10^{10}	1.23×10^{9}	5.00×10^{6}
Critical normal stress, N/m^2	1.42×10^{8}	2.00×10^{6}	1.32×10^{6}
Critical shear stress, N/m^2	1.2×10^{7}	1.54×10^{6}	4.42×10^{6}
Bonded disk radius, mm	0.6	0.6	1.2

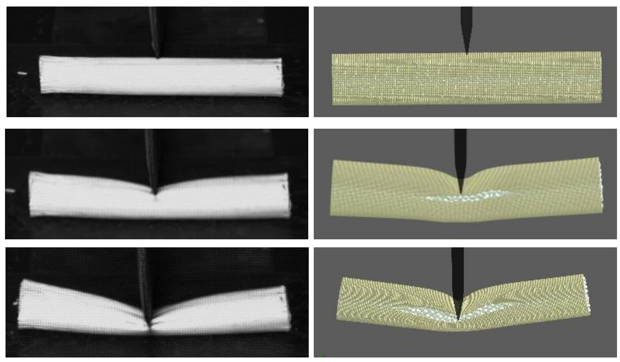

Figure 2. Comparison of corn stalk deformation

A transverse-isotropic model of corn straw was development using the Hertz-Mindlin with Bonding mode of EDEM, the model was able to simulate the cutting progress of no-tillage stubble cutting device. The bonding parameters of corn straw were demarcated by the mechanical test of straw rind and inner pith shown in table 1. The verification test results showed that and the shear work of cutting device deviation was 2.2%, when the straw reached the maximum shear force the deviation of cutter displacement in physical and simulation test was 2.6mm and the maximum shear force deviation was 6.8%. The deformation and damage of the straw mechanical model in the shearing process were identical, which was of great significance to the study of the interaction mechanism of the stubble cutting device and the design and optimization of the stubble cutting device. The modeling and calibration methods of corn straw, provided a method for modeling transversely isotropic materials from structural analysis, parameter measurement to numerical simulation.