

Research Article

3D Solid Model Establishment and Finite Element Analysis of Corn Seed

^{1,2}Zhang Xin-Wei, ^{1,2}Yi Ke-Chuan, ¹Huang Min and ¹Liu Hong-Xia

¹College of Mechanical Engineering, Anhui Science and Technology University,

²Anhui Institute of Corn Breeding Engineering and Technology, Fengyang Anhui 233100, China

Abstract: In order to study the inner mechanical damage mechanism of corn seed, a new method of establishment of corn seed 3D solid model is proposed in this study: corn seed section images are collected; image cropping and size proportion restoration are finished by Photoshop; actual size of corn seed is reduced and outline of the different composition is extracted in AutoCAD; and the corn seed 3D solid model is established in Solidworks with the extracted outlines; then the 3D solid model is divided into solid meshes to establish finite element model; static load analysis is carried out on the finite element model and diagram of corn seed inner stress distribution is given.

Keywords: Corn seed, finite element, mechanical threshing, static load

INTRODUCTION

It is found in the study that corn threshing damage occurs mainly in the threshing process of feeding (Zhang and Gao, 2014; Zhang *et al.*, 2015), the initial stage. The damage mostly focus on seed's crown and the reason is threshing parts' impact on it (Srivastava *et al.*, 1976).

Many scholars have noticed this problem and study it respectively from aspects of temperature, pressure and drying of corn seed (Gustafson *et al.*, 1979; Muthukumarappan and Gunasekaran, 1994; Litchfield and Okos, 1988). Li *et al.* (2007) just mechanics analysis for corn grain, not analyze the micro mechanical properties under the action of load outside on the crown of corn seed (Li *et al.*, 2007).

At present, the analytical method of Finite Element Method (FEM) widely used on the project is not only analyzes micromechanics properties of corn seeds under the crown's external loads, but also directly observe the stress distribution and regularity of the seeds. Thus, FEM was used in this study for 3D Solid Model Establishment of corn seed and analyze its micromechanics properties during threshing process, which is helpful to study on the threshing damage mechanism, improving the principle, structure and threshing process of the thresher and providing theoretical basis to reduce the mechanical damage for maize seeds.

Solid model establishment of corn seeds:

The original data of the solid model: The structure size and shape of different corn seeds is different (Zhang, 2012; Li and Gao, 2007). In order to find the

structure size distribution of the seeds which are easy to be damaged by the thresher, take Shengtian 216 corn seeds as example. It can be found that the damaged seeds' length is between 6.5-8.4 mm, width 7.5-8.4 mm and thickness 5-7 mm after analyzing the seeds with mechanical damage. Therefore, seeds with suitable length, width and thickness at the rate are selected as the 3D model's prototype (Xu *et al.*, 2007).

Data collection of the solid model: The selected seeds are sliced and each piece's thickness is about 1 mm. If the seeds are with low moisture content, rigid material, leave the seeds into water and then slice them. In order to establish the seeds' model accurately in the software, the microscope is used to acquisition image of the seed slice and record the slice outline and dividing line of each part. In order to record the real slice size, the slice is calibrated before taking photos. A square about 10 mm on a side is drawn in a paper and the slice is put into the square and its image is acquired by the microscope. Then the image is imported into Photoshop for cut and only the square is saved. The square is shown in Fig. 1.

Save the image and the image is a square. The boundary among the seeds' embryo, horny endosperm and farinaceous albumen can be clearly seen and the line is clear too. A square about 10 mm on a side is drawn in AutoCAD and the image is inserted into AutoCAD in the form of raster. The base point is the lower left-hand point of the square (Fig. 2). It can be found that the image doesn't tally with the square. The raster image is adjusted to the seed's actual size and the spline is drawn along each part's edge by AutoCAD spline command and then saved as dwg file, as shown

Corresponding Author: Zhang Xin-Wei, College of Mechanical Engineering, Anhui Science and Technology University, Fengyang Anhui 233100, China

This work is licensed under a Creative Commons Attribution 4.0 International License (URL: <http://creativecommons.org/licenses/by/4.0/>).



Fig. 1: Adjusted picture

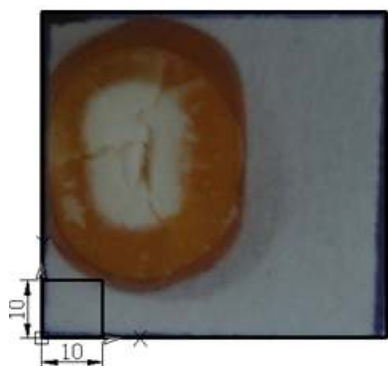


Fig. 2: Raster image in AutoCAD

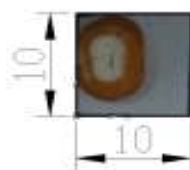


Fig. 3: The actual size picture



Fig. 4: The contour

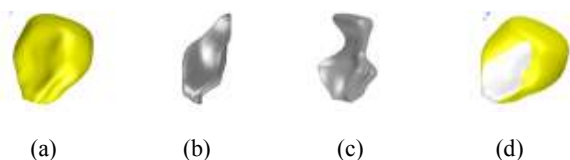


Fig. 5: Three-dimensional model of maize; (a): Single entity; (b): Embryo; (c): Softendosperm; (d): Maize

in Fig. 3. Repeat the above operation and the line features of all the seed slice are drawn and save them as dwg file.

Solid model establishment of the corn seed: A datum with equidistance 1 mm is established in Solidworks and the dwg file is inserted one by one into the corresponding datum. The sketch at different datum is aligned according to the neighboring sketch and the profile curve of all the dwg file is shown as Fig. 4. And then a whole model of the seed can be got by lofting the profile curve (Fig. 5a). That's a single entity with no embryo, horny endosperm and soft endosperm divided.

The surface is lofted based on embryo outline and single entity is got by surface lofting and then the 3D entity model of the seed can be got as Fig. 5b. 3D entity model of the soft endosperm can be got as Fig. 5c by lofting soft endosperm's outline. The single entity is done with the soft endosperm by boolean operation and the horny endosperm and soft endosperm can be got. Then combine the embryo, horny endosperm and soft endosperm and a full 3D entity model of corn seed can be got which conclude embryo, horny endosperm and soft endosperm as in Fig. 5c and d.

Finite element model establishment of the corn seeds: The entity model in Solidworks is just a geometrical model, which can't be used in finite element analysis and it must be discrete into finite number of units by make mesh generation on the geometrical model. The following assumptions are put forward when establishing the finite element model:

- Ignoring the influence of the seed coat and the seed is just made up by embryo, horny endosperm and soft endosperm.
- Embryo, horny endosperm and soft endosperm are all isotropic linear elastomers.
- Internal stress of the seed is zero before loading external load and the moisture content and the temperature in the loading process don't change.

It can be found in Shele that: deformation curve of the horny endosperm's force is similar to that of the seed's. When elastic model of the horny endosperm is taken as the whole seed's elastic model, this study finds that when the moisture content is 10% and the elastic model 5.5×10^9 Pa, Poisson's ratio of the seed is 0.4 (Li *et al.*, 2007; Zhao *et al.*, 1996; Cao and Cao, 1996).

Corn crown is exposed out of the corn before threshing and it is easy to be damaged in process of transportation. The visible corn is the most likely to be damaged by threshing machine and it is the easiest to produce mechanical crack by the statistical of damaged threshing corn. Therefore, this study mainly establish finite element model of the corn with load pressure.

The material properties of the corn are set in SolidWorks Simulation: the elastic model is 5.5×10^9 Pa; Poisson's ratio is 0.4; the corn hilum has fixed restrictions; the corn top is thrown with uniform load. According to the precious study (Li *et al.*, 2010; Zhang *et al.*, 2012), it is found that the corn crown is not flat and when there is mechanical action on it, only a small circle with radius of 1mm is formed. So the circle is chosen as shown in Fig. 6. The total load can be tested by experiment and it is 200 N (Zhang *et al.*, 2015).

In the entity model, Embryo, horny endosperm and soft endosperm are three independent entities. The thru among them are defined as contact face and no cracks

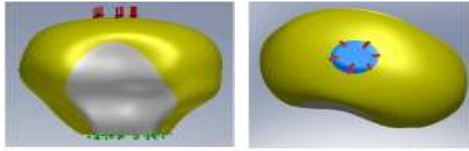


Fig. 6: Constraints and load region

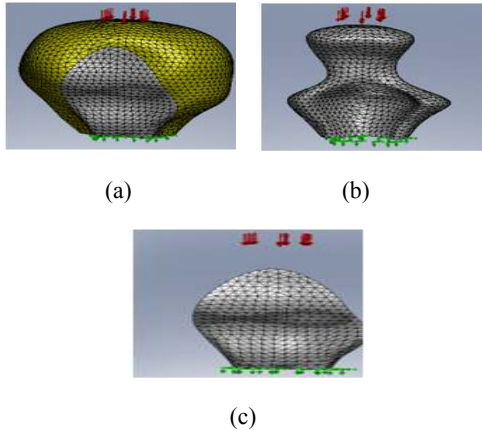


Fig. 7: The grain after grid division; (a): Grain; (b): Softendosperm; (c): Embryo

by application of contact/gap options, which means divide the corn with entity grid and the grid's overall size is 0.31 mm and the tolerance is 0.015 mm. The final effect is in Fig. 7. The finite element model is made up with 85812 nodes and 56067 units.

After grid division, the corn entity is changed into finite element model. The analysis of corn finite element can be got by running the example in Solidworks Simulation. Figure 8a illustrates corn's stress intensity after crown's static compression example and it can be seen that stress intensity on the mechanical action area and hilum is bigger. The biggest intensity is on the hilum and the smallest is on both sides of the corn. Stress intensity on internal corn can be observed in Solidworks Simulation and Fig. 8b and c illustrate stress intensity along with the grain width and thickness direction. It can be seen that the internal stress trend is crown's stress is smaller, then increasing gradually when down, then reducing gradually and it increases near to hilum and the biggest stress appears in a certain part of the both sides.

When the corn is under mechanical action, it can be easy to observe embryo damage because the embryo

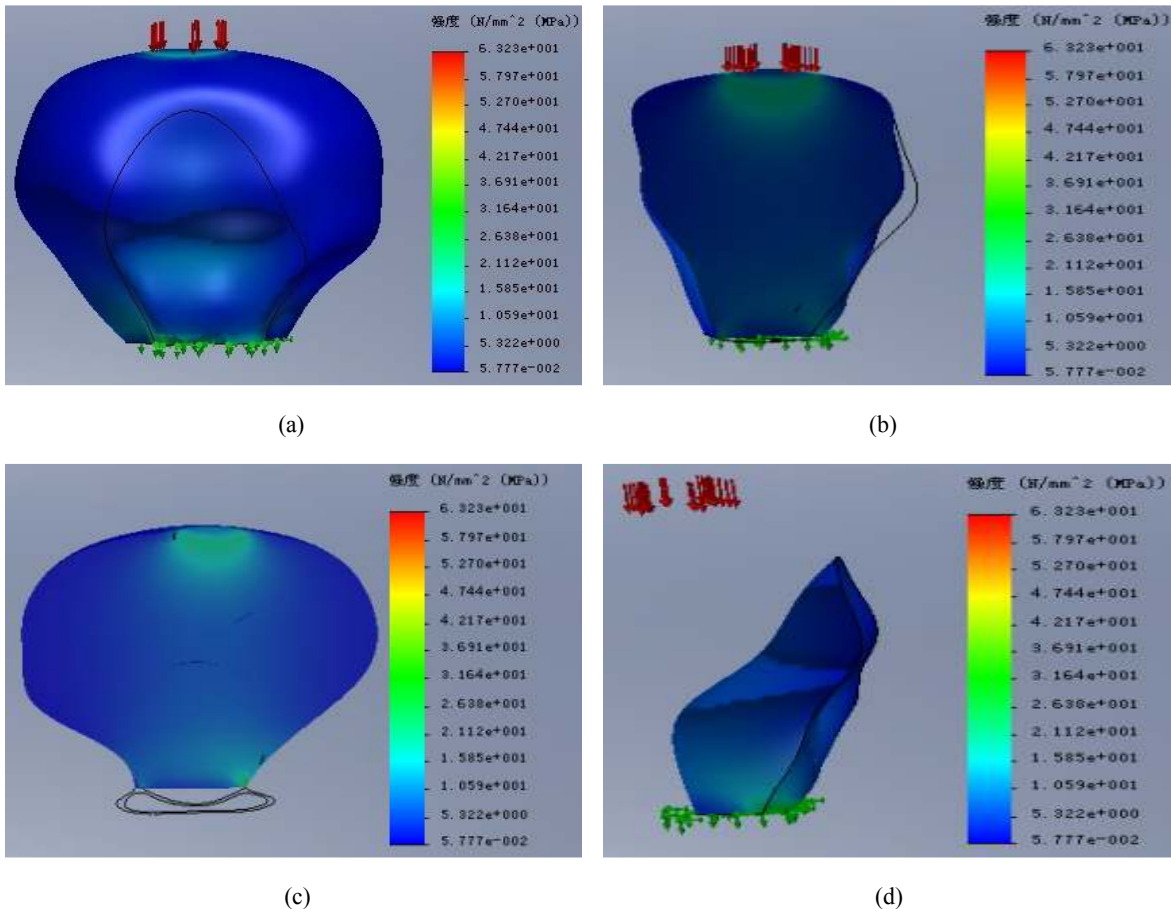


Fig. 8: Stress diagram of corn seed; (a): Grain; (b): Load at the width direction; (c): Load at the thickness direction; (d) : Stress diagram of embryo

skin is thicker and transmittance is worse. Finite element model can hide horny endosperm and soft endosperm and only observe stress diagram of the embryo (Fig. 8d). It is found in the figure that stress intensity of other parts is very small except the embryo bottom. From the corn structure, we find that hilum accounts for absolute proportion of the corn and horny endosperm and soft endosperm are very few and the rest is seed coat, which leads to the corn hilum is easy to fall off during the threshing process.

CONCLUSION

- The structure and size of corn with mechanical crack is analyzed because of the mechanical threshing characteristics and it is easy to get the size of damaged corn whose length, width and thickness are in 6.5-8.4, 7.5-8.4 and 5-7 mm, respectively. That provides basis to select 3D model of the corn.
- Slice the corn and calibrate the size and then acquire image. And 3D entity model of the corn concluding embryo, horny endosperm and soft endosperm is created by Photoshop, AutoCAD and Solidworks.
- Finite element model of the corn is established in SolidWorks Simulation and the model contains 85812 points and 56067 units.
- Analyze the finite element model of the corn and give stress distribution of the crown after putting static load on it. And it is found that stress intensity on the mechanical action area and hilum is bigger. The biggest intensity is on the hilum and the smallest is on both sides of the corn.

ACKNOWLEDGMENT

We were grateful for support funded the science and technology department of Anhui province (project NO: 1501031095).

REFERENCES

Cao, C. and C. Cao, 1996. Analysis of finite element method on internal stress of the corn seed during the drying process [J]. *Trans. Chinese Soc. Agric. Mach.*, 27(1): 57-62.

Gustafson, R.J., D.R. Thompson and S. Sokhansanj, 1979. Temperature and stress analysis of corn kernel-finite element analysis [J]. *T. ASAE*, 22(4): 955-960.

Li, X. and L. Gao, 2007. Experimental study on breaking mechanism of kernel stem of corn seed [J]. *Trans. Chinese Soc. Agric. Eng.*, 23(11): 47-51.

Li, X., L. Gao and F. Ma, 2007. Analysis of finite element method on mechanical properties of corn seed [J]. *Trans. Chinese Soc. Agric. Mach.*, 38(10): 64-72.

Li, X.F., X. Jie, Y.L. Zhang, F. Li and L.X. Gao, 2010. Detecting and research on characteristics and mechanism of inner mechanical cracks of corn seed kernels [J]. *Trans. Chinese Soc. Agric. Mach.*, 41(12): 143-147.

Litchfield, J.B. and M.R. Okos, 1988. Prediction of corn kernel stress and breakage induced by drying, tempering, and cooling [J]. *T. ASAE*, 31(2): 585-594.

Muthukumarappan, K. and S. Gunasekaran, 1994. Moisture diffusivity of corn kernel components during adsorption Part III: Soft and hard endosperms [J]. *T. ASAE*, 37(4): 1275-1280.

Srivastava, A.K., F.L. Herum and K.K. Stevens, 1976. Impact parameters related to physical damage to corn kernel [J]. *T. ASAE*, 19(8): 1147-1151.

Xu, P., S. Zhang and G. Wu, 2007. 3D finite element model of first mandibular molar by 3DSS, solid works and ALGOR [J]. *J. Clin. Stomatol.*, 23(10): 590-591.

Zhang, X., 2012. Research on characteristics and identification of inner mechanical cracks of corn seed kernels [D]. *Shenyang Agricultural University*.

Zhang, X. and L. Gao, 2014. Research of mechanical cracks extension process in corn seed [J]. *J. Chinese Agric. Mech.*, 35(2): 123-127.

Zhang, X., X. Li, D. Yang, D. Liu and L. Gao, 2012. Micromechanism of inner mechanical cracks generation and expansion of corn seed kernel [J]. *Trans. Chinese Soc. Agric. Mach.*, 43(12): 72-76.

Zhang, X., K. Yi and L. Gao, 2015. Contacting mechanics analysis during impact process between corn seeds and threshing component [J]. *Chinese Agric. Sci. Bull.*, 31(14): 285-290.

Zhao, X., Z. Ma and Y. Sun, 1996. The experiment research on the mechanical properties of the corn kernels [J]. *J. Jilin Univ., Technol.*, 21(1): 60-65.