

Finite element analysis of cotton ginning state based on ANSYS

Xiaochuan Chen¹, Di Wang¹, Yiping Qiu², Jun Wang^{2,3}, Yong Li⁴ and Bin Li¹

Abstract

To analyze the stress state of seed cotton in the process of cotton ginning and to improve the quality of lint, a new model for cotton, the laminated cotton model, is presented based on the idea of a composite laminate. The model assumes the cotton mass is made up of a certain number of cotton fibers, each of which has a different arrangement angle. Based on this model, the ginning process is simulated using finite element analysis. The mechanical properties of a single cotton fiber that is either machine- or hand-picked are obtained. The working condition of the ginning process is described successfully. By analyzing the influence of different working conditions on the serration cotton ginning process, the simulation results show the model prediction is reasonably consistent with existing experiments. For example, to improve the productivity and quality of lint, it is important to guarantee the saw teeth are sharp and smooth, with none being crooked or inverted, and missing teeth on each saw blade should not exceed the specified value.

Keywords

finite element model, ANSYS, cotton gin, breaking strength

Cotton is one of the oldest and most industrialized economic crops in China. Cotton ginning is an indispensable transitional processing industry for providing the raw cotton used in textile industry. Serrated ginning is an important part of cotton processing and refers to the separation of long fibers from cottonseed to form lint.¹ Mechanical damage in cotton fiber processing shifts the fiber length distribution and alters its shape.² It is a dynamic process. Because cotton fibers are intertwined with each other, forming a complicated structure, the force and condition of the cotton fiber itself are very difficult, if not impossible, to measure under the action of the saw blade rotation. However, the finite element theory provides us with a feasible way. It is relatively convenient and effective to study the ginning process using ANSYS software to simulate the stress state of cotton fiber under serration.

For a further study of cotton, a reasonable cotton model is indispensable. Smith and Robert assume that cotton fibers consist of a series of spherical units connected by massless rigid rods;³ Yamamoto and Matsuoka take both the rigid and flexible properties of the fibers into account and establish a round bar with a number of small balls at the same radius;⁴

Kong and Flatfoot consider the cotton fiber as a flexible chain model that connects the dispersed nodes with no mass, which reflects the plasticity of the fibers;⁵ in China, Zhu and Lin have comprehensively analyzed the forces of fiber in the air flow field and established a particle fiber model;⁶ Zeng regards cotton fiber as a fiber chain composed of n balls and $n-1$ non-mass elastic rods, which reflects the elasticity and plasticity of the fibers, but ignores the frictional properties of the fibers;⁷ and Zheng and others put forward a double-layer multi-section elongated rod-type fiber structure model that can reflect the mechanical

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properties such as tension, bending, twisting, plasticity, friction and so on.⁸

Because of the complexity of the structure of cotton, little research on it has been carried out. The reported studies are limited to the mechanical model of a single cotton fiber. In the finite element software ANSYS, no model can be directly used to analyze fibers in a cotton flower. Therefore, this paper proposes a new finite element method for modeling cotton fiber in a cotton flower during ginning to improve the quality of the lint. In recent years, due to a rapid increase in labor costs, cotton picking has been gradually automated using cotton-picking machines in China. However, this could lead to a fiber length and trash content change as reported in recent literature.^{9,10} In this study, we also compared the ginning process of cotton with hand and machine picking.

Establishing a cotton model

The rough shape of a cotton ball in a cotton flower is an irregular ellipsoid. Inside the cotton ball, the cotton fibers are randomly intertwined and all angles are present in a three-dimensional (3D) space. To analyze and simulate the cotton fiber arrangement, a simplified scheme is proposed. Firstly, a layer of cotton fibers is aligned at a particular angle in a two-dimensional (2D) plane, then the second layer of cotton fibers is placed on the first at a different angle. The subsequent layers of fibers are placed on top of each other with somewhat different angles for each layer until the layers form the whole ball. The ANSYS software provides a layered composite element, which has different cross-sections and simulates the delamination of cotton fibers by defining the angles of each section, thus forming a model of the cotton laminate. In addition, the Burgers model can be used to describe the viscoelastic properties of cotton fibers and characterize the material properties of the units.¹¹ The current model may not be perfect because it uses a 2D laminated structure to describe a 3D distribution of the cotton fibers in a cotton ball. Nevertheless, because we are simulating the behavior of a cotton ball in tension, the overall tensile stress-strain behavior may not be too different when comparing the 2D laminated model and a real 3D model. A real difference could exist if the cotton ball is subjected to bending, which could be influenced by interlaminar shear properties when a 2D model is used. However, in a ginning process, bending is not a major deformation for the cotton ball. For the simplicity of analysis with the accuracy acceptable in engineering applications, it might be reasonable to use the current 2D model. We may develop a more accurate 3D model in our future work.

Once the model is set up, it needs to be simplified. Some unnecessary geometric irregularities could be ignored to avoid prolonged computation time. The cotton ball shape is simplified as a polyhedron composed of two hexagonal tables. Because the saw is only in contact with the cotton near the serration, a single serration is created in the model and the circular motion at the large scale of the serration is taken as a rectilinear motion along the tangent of the outer tangent at the small scale.

The layered structure of the laminated cotton ball needs to be defined. The direction of the layer is determined by the direction of the fiber. In the ANSYS, the layered structure is constructed from bottom to top. The SOLID186 unit, which can be set as a layered structure, is selected and the direction of laying is 0 degrees, -45 degrees, 90 degrees and 45 degrees. The repeating cycles of four fiber layers fill the whole cotton ball. Parts of the layers are shown in Figure 1. After setting up the layered structure, the whole model of cotton with single serration is established by defining the coordinates and the mesh is divided as shown in Figure 2. In addition, as the various saw blades are installed in parallel on the drum in the ginning working box, some cotton balls may be in contact with two saw blades simultaneously. From a force point of view, the conditions for more than two saw blades are similar to those for two. Upon observation of the actual distribution of the saw blades in a real ginning machine, a finite element model for the simultaneous contact of a single cotton ball with two serrations was established, as shown in Figure 3.

Finite element simulation of serrated ginning

Finite element simulation

The material properties of each unit should be defined with the same parameters as the design of each material. The SOLID185 unit is used in the serration and SOLID186 unit is used in the cotton. The elastic modulus of serration is 2.07×10^5 MPa. Poisson's ratio is 0.29 and the density is 7850 kg/m^3 . The elastic modulus of cotton is 2.4×10^3 MPa. Poisson's ratio is 0.4 and the density is 400 kg/m^3 . The viscoelasticity of the cotton is described by the Prony series, $t1 = 3.53$, $a1 = 0.123$, $t2 = 924.09$, $a2 = 0.877$, which are input into the corresponding program. To consider the influence of friction factors, face-to-face contact is built into the model. The rigid serration surface is the target and the element type is TARGE170. The surface of a flexible cotton ball is the contact and the element type is CONTA174.¹² The unit option was set such that the serration surface is not separated from the cotton ball surface but allows

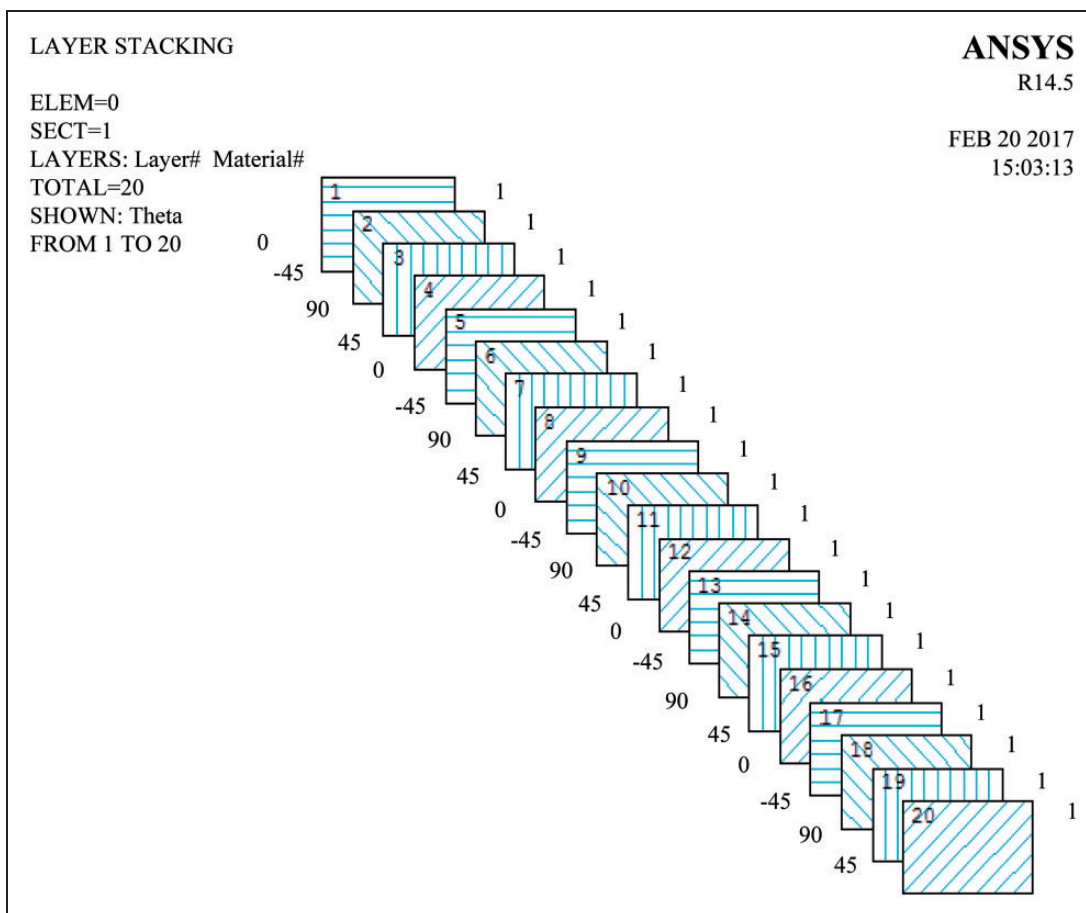


Figure 1. Partial layer structure.

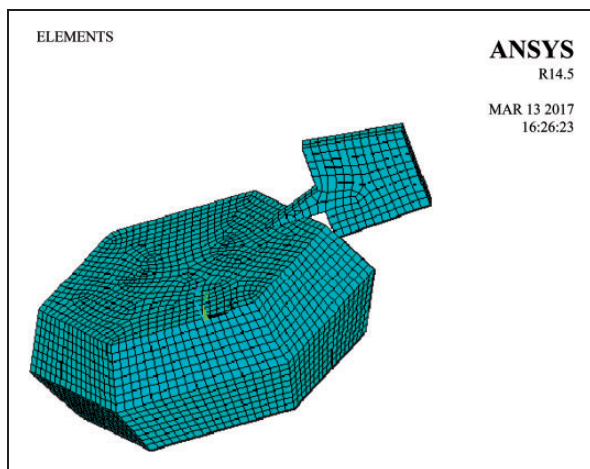


Figure 2. Cotton and single serration finite element model.

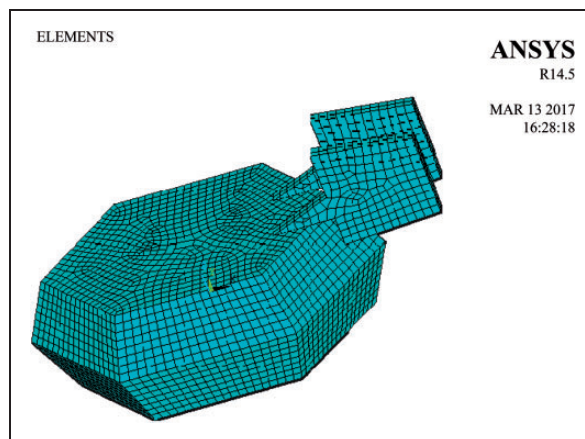


Figure 3. Cotton and two serrations finite element model.

relative sliding. The cotton ball and serration are restrained by control nodes.¹³ To reduce the computational overhead for the cotton, the internal cottonseeds were not included independently during the modeling

process, but rather they were represented in setting the boundary conditions. The central part of the cotton node was used to represent a cottonseed. Because the cottonseed movement is restricted by the gin rib, the nodes in the center of the cotton can only rotate

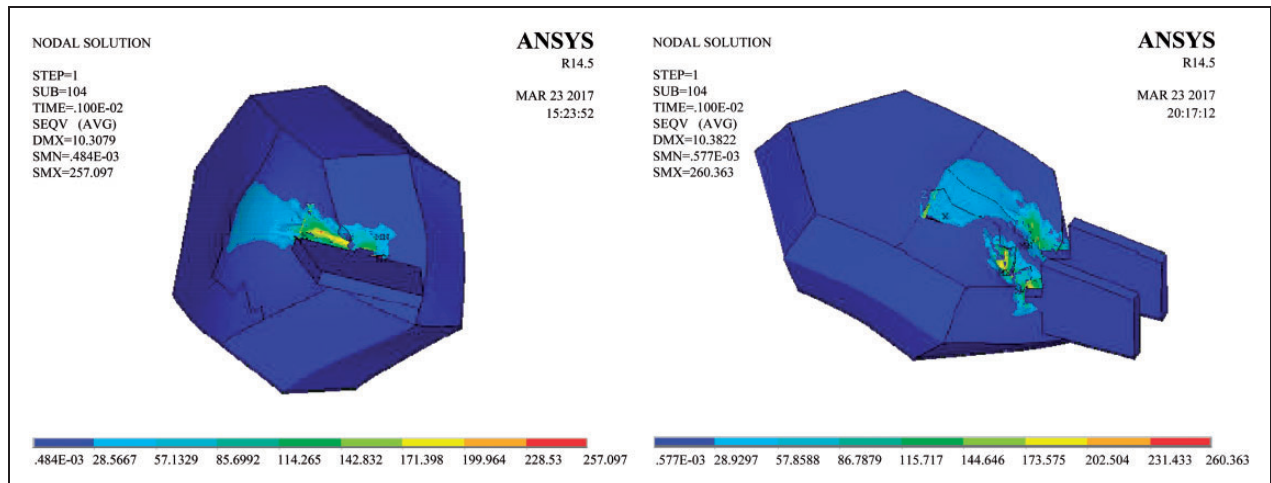


Figure 4. Stress nephogram of model.

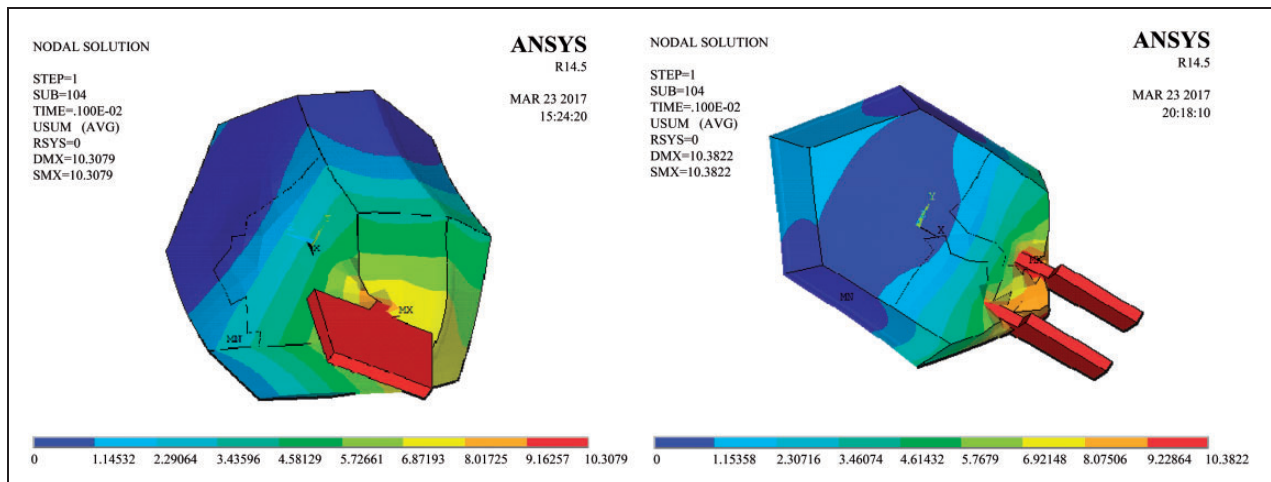


Figure 5. Displacement nephogram of model.

along the x -axis and the y -axis and move along the z -axis. Seed density was 400 kg/m^3 , the rotary speed of the blade was 435 r/min , the solution time was $1.4 \times 10^{-3} \text{ s}$ and the sub step was 100. The specified analysis type was transient. The solution method was complete and the large deformation option was opened to start solving. Finally, the actual solution step was 104 steps. Figure 4 shows the stress nephogram of the final step model. Figure 5 shows the displacement nephogram of the final step model. To see the relation of stress and displacement with time, a point was selected on the contact surface of the model.

Figure 6 shows the increase of the stress and displacement of the cotton fibers with time and reach the maximum at the last (104th) step. It reflects the process that the serration hooks the cotton fibers and gradually

takes them away. The stress and displacement distribution on the cotton flower can be seen from the nephogram of the final step model. The figure on the right side of Figure 6 is a plot of displacement versus time. The positive direction of the coordinate system is opposite to the displacement direction, so the displacement actually increases with time. We have changed the label of the vertical axis to stress and displacement to make the figure easier to understand. The stress distribution on the cotton was directly related to the serration and the stress in the contact area between the cotton and serration was the largest. In the stress nephogram, the stresses in the green, yellow and red areas were above 114 MPa , but the volume was smaller than the whole volume of the cotton ball. Most of the other areas of the cotton are in dark and light blue, and

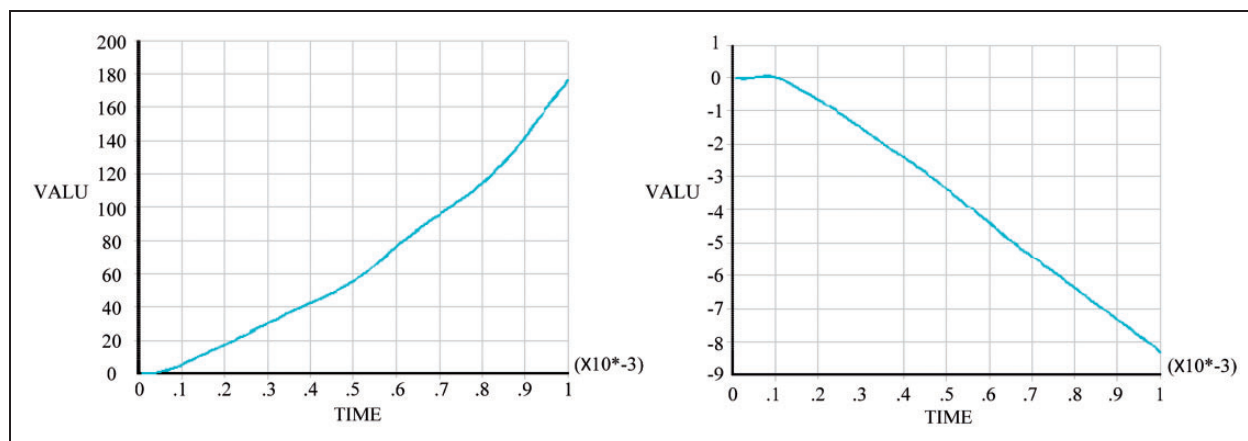


Figure 6. Nodal stress (left) and displacement (right) curves.

the stress was below 114 MPa. In addition, higher stresses occurred at the center of cotton ball, the root of the fiber and the surface of the cottonseed compared with those in the surrounding areas, although these were lower than the contact part with the serration. From the displacement nephogram, the serration hooks the cotton fiber to make a larger deformation of the cotton. The side displacement is larger than the other side due to the effects of the serration, and the displacement value varies gradually from side to side.

In addition, comparing the results of the double- and single-serration models, it is known that the effects of the two serrations on cotton are similar. In the case of actual ginning, the installation distance of the saw blade is limited, and it is difficult for a cotton ball to have contact with three or more saw blades at the same time. Therefore, the simulation results of the above two models basically cover all the cotton.

Statistics of mechanical properties of cotton fiber

There are two critical forces applied to the cotton fiber associated with the ginning process: one is the bonding force (strength) between the cotton fiber and cottonseed, and the other is the breaking force (strength) of the cotton fiber. The fiber breaking strength has to be greater than the bonding strength to pull the cotton fiber from the cottonseed without breaking the fiber.¹⁴ The cotton flowers are either picked by machine or by hand. Based on the methods of experimental and statistical analysis, the mechanical properties of single fibers in machine- and hand-picked cotton are studied, which provided the basis for the analysis of cotton ginning.

The experiment was carried out on an XQ-2 fiber strength tester, and the cotton same species, Xinluzhong 37, of machine- and hand-picked cotton

from the field in Alar, Xinjiang, China was used as the experimental material. The gauge length was 10 mm and the stretching speed was set at 10 mm/min. The pre-tension value was 0.25 cN under the standard textile testing condition of 20°C and 65% relative humidity. In total, 200 sets of data were obtained for both machine- and hand-picked cotton. The data were collated and grouped from small to large values that were divided into 12 groups with a group interval of 0.5 cN. The first group of breaking strength in hand-picked cotton is from 2.00 to 2.50 cN and the breaking strength in machine-picked cotton is from 1.50 to 2.00 cN. The count and frequency of each group were calculated and shown in Tables 1 and 2 and the corresponding distribution histograms were shown in Figures 7 and 8.

As shown in Figures 7 and 8, the highest frequency of the hand-picked cotton is 22.5% in the range of 5–5.5 cN followed by 20.5% in the range of 5.5–6.0 cN. The highest frequency of the machine-picked cotton is 21% in the range of 5–5.5 cN followed by 20.5% in the range of 4.5–5.0 cN. The distribution of breaking strength in cotton fibers was close to the normal, but it had the right deviation.

As mentioned earlier, the breaking strength of single cotton fibers directly affects the subsequent ginning process. The mean and the median of the single fiber breaking strengths for hand-picked cotton were 5.13 and 5.26 cN, respectively, whereas those for the machine-picked cotton were 4.65 and 4.75 cN, respectively. The average and median values of the breaking strength of machine-picked cotton are less than those of hand-picked cotton, indicating that the breaking strength of machine-picked cotton is lower than that of the hand-picked cotton.¹⁰ According to the national standard GB1103-2007 “cotton/fine cotton”, machine-picked cotton is a different grade; hand-picked cotton is

Table 1. Breaking strength distribution of single fiber in hand-picked cotton

Group number	Range (cN)	Count	Cumulative count	Frequency (%)	Cumulative frequency (%)
1	(2.00,2.50)	1	1	0.5	0.5
2	(2.50,3.00)	3	4	1.5	2
3	(3.00,3.50)	4	8	2	4
4	(3.50,4.00)	16	24	8	12
5	(4.00,4.50)	23	47	11.5	23.5
6	(4.50,5.00)	33	80	16.5	40
7	(5.00,5.50)	45	125	22.5	62.5
8	(5.50,6.00)	41	166	20.5	83
9	(6.00,6.50)	29	195	14.5	97.5
10	(6.50,7.00)	2	197	1	98.5
11	(7.00,7.50)	2	199	1	99.5
12	(7.50,8.00)	1	200	0.5	100

Table 2. Breaking strength distribution of single fiber in machine-picked cotton

Group number	Range (cN)	Count	Cumulative count	Frequency (%)	Cumulative frequency (%)
1	(1.50,2.00)	2	2	1	1
2	(2.00,2.50)	2	4	1	2
3	(2.50,3.00)	8	12	4	6
4	(3.00,3.50)	12	24	6	12
5	(3.50,4.00)	22	46	11	23
6	(4.00,4.50)	35	81	17.5	40.5
7	(4.50,5.00)	41	122	20.5	61
8	(5.00,5.50)	42	164	21	82
9	(5.50,6.00)	23	187	11.5	93.5
10	(6.00,6.50)	10	197	5	98.5
11	(6.50,7.00)	1	198	0.5	99
12	(7.00,7.50)	2	200	1	100

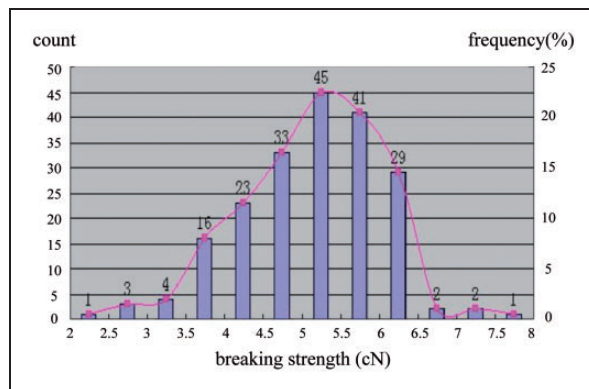
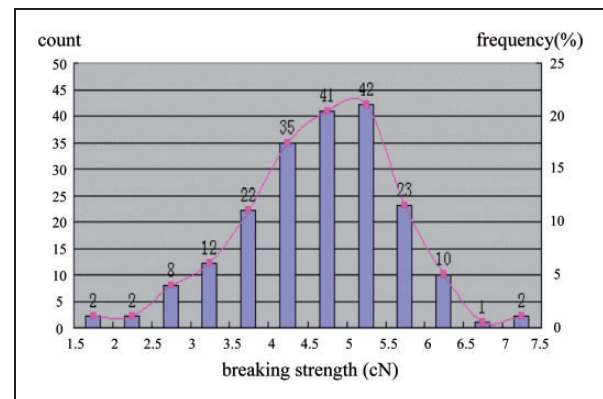
**Figure 7.** Frequency histogram of single fiber breaking strength in hand-picked cotton.**Figure 8.** Frequency histogram of single fiber breaking strength in machine-picked cotton.

Table 3. Conversion value of mechanical properties of cotton fiber

Cotton type	Breaking strength (MPa)			Connection force (MPa)
	Average value	Median value	10th percentile	
Hand-picked cotton	163.4	167.5	123.9	78.0
Machine-picked cotton	148.1	151.3	104.1	

middle grade and the strength of it is higher than machine-picked cotton.¹⁵ In addition, the 10th percentile of hand-picked cotton was 3.89 cN and that of machine-picked cotton was 3.27 cN.

Analysis of cotton fiber ginning

Through the experiment, the value of the connection force was determined as 2.45 cN. The experiment was performed by measuring the force to pull off the cotton fibers. The connecting force or the average force acting on each individual fiber was determined by dividing the measured force by the number of broken fibers manually counted in the experiment. Based on an average cotton fiber diameter of 20 μm , the values of the breaking strength and connection force were converted into stresses to compare them with the simulated results. Table 3 shows the conversion value of the mechanical properties of cotton fiber at 7.5% moisture regain, which is combined with Figure 4. The result is shown in Figure 9.

In Figure 9, with the increase of stress, the bonding force value of the cotton fiber to seeds was reached first. In the stress nephogram of cotton, the stress in many areas far away from the serration is lower than that of the cotton fiber. This part of the stress was smaller so that the cotton fibers were not snapped in a single hook. At this point, the cotton ball rolled together with the cottonseed to leave the row of ginning ribs and wait for the next hook. The stress in the part of the cotton near the serration was generally higher than the average bonding strength to cottonseeds. The cotton fibers in this area were rolled down and removed by the serration and the lint was formed after brushing the cotton. However, the stress has not reached the 10th percentile of the single fiber breaking strength. The single cotton fiber with small breaking strength could be broken into two pieces, but the quantity is less than 10%. As the stress continued to increase, the cotton fibers were affected by the impact of the saw bit, leading to more and more cotton fiber breakage, resulting in the formation of short fibers.

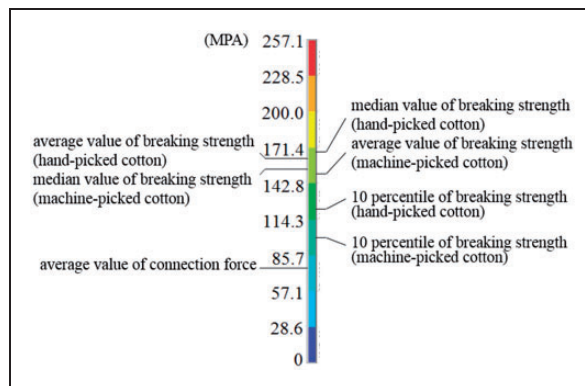
**Figure 9.** Comparison of mechanical properties and stress nephogram of cotton fiber.

Figure 4 shows that using the set of the simulation parameters (7.5% moisture regain and density 400 kg/m^3), the area in which the stress reached above the 10th percentile of cotton fiber breaking strength was very small and there were not enough cotton fibers to be rolled. Thus, it can be considered that the short fiber rate of lint was not high. As the performance index of the lint is affected by the stress during ginning, the force on the cotton must be controlled for an acceptable quality of cotton lint. It is important to reduce the range of large stress areas in the nephogram. By controlling some parameters during ginning, such as seed roll density, moisture regain, and saw blade speed, the large stress area could be reduced as much as possible. It can also be seen that the breaking strength of the machine-picked cotton was lower than that of the hand-picked cotton under the same ginning conditions and the quality of the lint was also lower.

Analysis of the impact of working conditions on the serration cotton process

Analysis of the change of density of seed coiled cotton

The density of seed cotton roll varies when the gin machine is working. Through the analysis of the working efficiency of the gin machine, we have determined that the density of 400 kg/m^3 was taken as the middle to retrieve the values from both sides. The foregoing finite element analysis was carried out at 250, 350, 450, 500, and 600 kg/m^3 , respectively, and Table 4 is obtained.

Table 4 showed that the stress and displacement on the cotton were also increased with the increase of the density of the cottonseed. This indicates the impact of serration on cotton was enhanced with the increase of

cottonseed density. When the seed cotton roll tightens, the stress increases and forces the cotton fibers into the notch between the teeth so that the saw can carry it away more smoothly. At the same time, the quantity of cotton fibers on a single serration also increased, as did the efficiency of ginning. If the density is insufficient, the seed cotton roll is not compact. Without sufficient contact between single seed cotton, the friction force and the resultant force cannot be exerted. The torque generated by the saw blade is difficult to pass, and the whole motion cannot be formed in the ginning machine.

However, the density of seed cotton roll was still low. As the impact of the serration increases, more and more cotton fibers will be snapped. In Table 4, when the density of seed cotton reached 600 kg/m^3 , the maximum stress on the cotton reached 386.1 MPa . This is much greater than the average strength of the hand- and machine-picked cotton (the data are shown in Figure 9). Although it is known from the stress nephogram that the region with a stress of more than 171.6 MPa at a density of 600 kg/m^3 (other than blue)

is not large, the values of the breaking strength of the cotton fibers in Table 3 are below 170 MPa . It is inferred that a lot of cotton fibers are shocked and broken. The amount of short fibers increases so it is difficult for the lint obtained after ginning to meet the quality requirements for rolling.

Therefore, the feeding speed should be controlled and the density of the seed cotton roll should be adjusted according to the working conditions in ginning production. According to the above analysis, it can be seen that the stress at 250 kg/m^3 is insufficient and the ginning efficiency is not high. The quality of the lint obtained at the density of 600 kg/m^3 is poor. According to the working conditions, the actual density of the seed cotton roll can be selected between 350 and 500 kg/m^3 .

Analysis of the influence of serration state change

Three models of serration are established: normal, wear (serration becomes blunt, the contact area of cotton is bigger) and defective (the contact surface of cotton has a gap). On this basis, the aforementioned finite element analysis was carried out. The model is shown in Figure 10, and the stress nephogram and displacement nephogram are shown in Figures 11 and 12.

Figures 11 (a) and 12 (a) show the stress and displacement of cotton under wear serration. When the serration is worn out due to improper maintenance, the stress and displacement on the cotton decreases. The maximum stress decreases from 257.1 to 200.8 MPa , due to the area of the cotton fiber surface being enlarged by the serration after the abrasion. The pressure on the unit area decreases and the stress of the cotton becomes smaller when the pressure is the same. This makes the friction between the fiber and the serration smaller, which was not conducive to serrated

Table 4. Relationship between density of seed cotton and stress displacement of cotton

Density of seed cotton (kg/m^3)	Maximum stress (MPa)	Maximum displacement (mm)
250	191.4	10.08
350	222.0	10.17
400	257.1	10.31
450	296.0	10.48
500	329.0	10.64
600	386.1	10.74

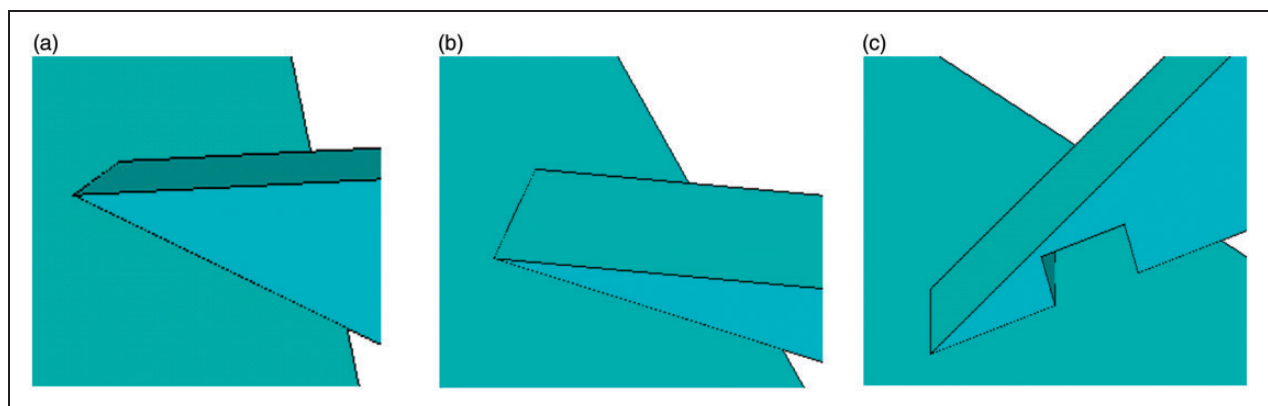


Figure 10. Modeling of three types of serration.

- (a) Normal serration
- (b) Wear serration
- (c) Defective serration

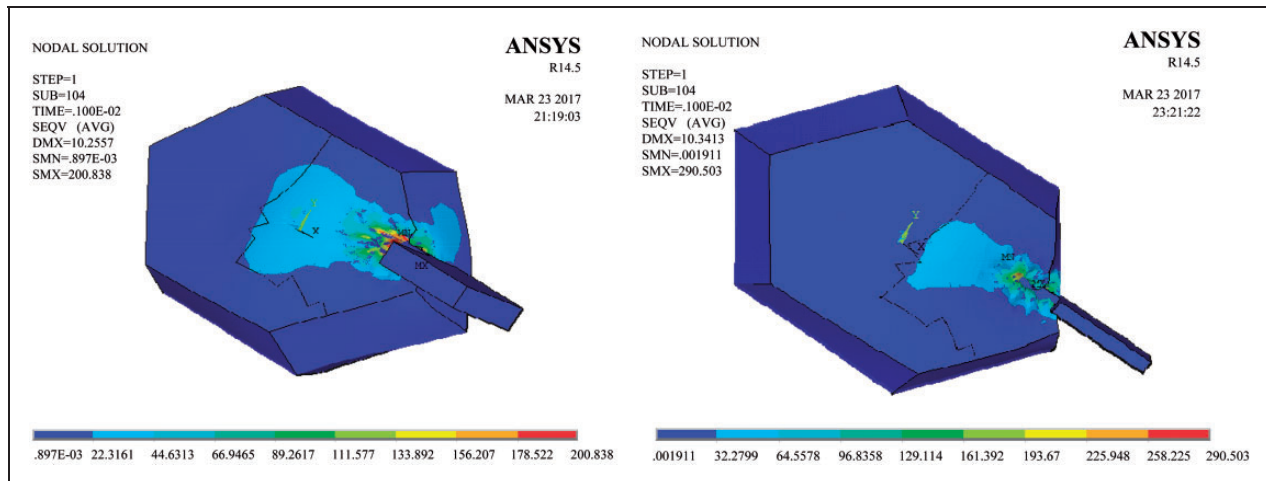


Figure 11. Stress nephogram of different serration models.

- (a) Wear serration
(b) Defective serration

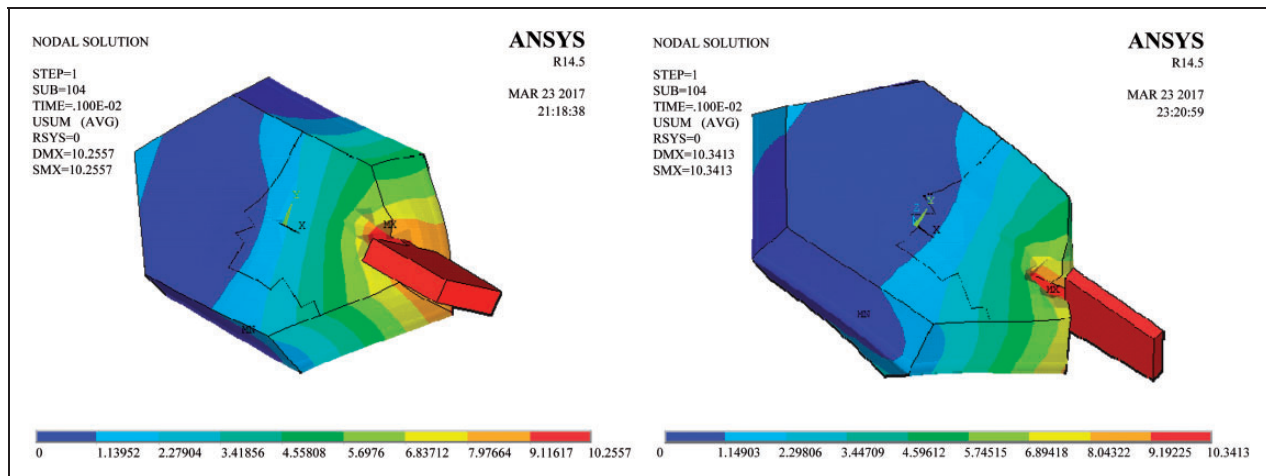


Figure 12. Displacement nephogram of different serration models.

- (a) Wear serration
(b) Defective serration

fiber. From the stress nephogram, the areas of red, yellow, green and light blue were enlarged. It reflects that the concentration of stress was decreased and the impact of the serration was reduced. Therefore, the occurrence of abrasion wear on the serration has the greatest effect on ginning efficiency. If the serration is sharp and the surface smoothness is high, the puncture effect on the cotton fiber is stronger and the work efficiency could be high. After the cotton fiber is taken away, brushing the cotton will become easier.

Figures 11 (b) and 12 (b) show the stress displacement of cotton under defective serration. When the serration is damaged, the surface of serration becomes irregular and the roughness is higher. As can be seen from the diagram, the stress and displacement of the cotton increase and the stress is more concentrated. The stress in the concentrated area corresponds to the defect of the serration. The maximum stress of the damaged serration model is 290.5 MPa. Therefore, a defect of the serration will lead to a stronger impact and the resulting edge will

damage the cotton fiber, which increases the amount of short fibers and reduces the quality of the lint. In general, a new saw blade has many jagged edges, cracks, and a poor finish, which is similar to the defective serration. This problem can be solved by polishing the saw blade to meet requirements before processing.

In summary, the state of serration has an important effect on the ginning process. To improve productivity and the quality of lint, it is important to guarantee that the saw teeth are sharp and smooth, not crooked or inverted, and the number of missing teeth on each saw blade does not exceed the specified value. To achieve the above requirements, it is necessary to ensure the use of the right saw blades. Production needs to operate strictly according to the regulations and the machines should be maintained and repaired at the right time.

Conclusions

Through the above analysis, the following conclusions can be drawn:

1. The finite element simulation of the laminated cotton model successfully describes the working state of cotton gin and achieves reasonable results. In view of the influence of different working conditions on the serration ginning process, the results are consistent with previous experience and verify the rationality of the model.
2. To improve the quality of ginned cotton, the results of finite element simulation have a certain reference value to determine the working conditions in the actual production of cotton and selection of parameters.
3. In addition, experimentally determined statistics of cotton fiber mechanical properties have found that the mechanical properties of machine-picked cotton are lower than those of hand-picked cotton under the condition of cotton planting. Machine picking cotton is the trend of the cotton industry in China. Improving the processing technology of machine-picked cotton is of great significance to ensure the quality of processed cotton lint.

Declaration of conflicting interests

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References

1. Anthony, WS and Mayfield, WD. *Cotton Ginners Handbook*, (No. 503). Washington, DC, USA: United States Department of Agriculture, 1994.
2. Krifa M. Cotton fiber length distribution modality alteration in ginning and mill processing. *Journal of the Textile Institute* 2013; 104(7): 731–744.
3. Smith AC and Roberts WW. Straightening of crimped and hooked fibers in converging transport ducts: Computational modeling. *Textile Research Journal* 1994; 64(6): 335–344.
4. Yamamoto S and Matsuoka T. A method for dynamic simulation of rigid and flexible fibers in slow field. *The Journal of Chemical Physics* 1993; 98(1): 644–650.
5. Kong LX and Praftoot RA. Two-dimensional simulation of air flow in the transfer channel of open-end rotor spinning machines. *Textile Research Journal* 1996; 66(10): 641–650.
6. Zefei Z and Jianzhong L. *Fiber particle suspension flow dynamics analysis*. Shanghai: Chinese Textile University Press, 2000.
7. Yongchun Z. *Study on the Movement of Fiber in the High-speed Flow Field of Nozzle*. Shanghai: Donghua University, 2003, pp.63–72.
8. Lingchen Z, Hongli C, Xiaoming L, et al. Mechanics model of double-layer multi-section slender rod cotton fiber. *Light Industry Machinery* 2015; 10: 25–28, 33.
9. Tian J, Zhang X, Zhang W, et al. Leaf adhesiveness affects damage to fiber strength during seed cotton cleaning of machine-harvested cotton. *Industrial Crops and Products* 2017; 107: 211–216.
10. Tian J, Zhang X, Yang X, et al. How to reduce cotton fiber damage in the Xinjiang China. *Industrial Crops and Products* 2017; 109: 803–811.
11. Huiqing Z and Badumu. Cotton fiber microstructure of the formation process and the fiber performance. *China Fiber Inspection* 2008; 6: 52–55.
12. Guilong L and Zaiyang S. *ANSYS structure and material application handbook*. Beijing: Tsinghua University Press, 2013.
13. Xiaohua L. Analysis of the influence of cotton processing on the primary quality of cotton fiber. *China Cotton Processing* 2013; 4: 27–28.
14. Hong X and Xiaohong S. *Cotton inspection and processing*. Beijing: China Textile Press, 2006.
15. Xu H and Xia X. Property comparison between machine picked cotton and hand-picked cotton. *Journal Textile Research* 2009; 30(9): 5–10.

Appendix

The experiment of cotton ginning

As in the actual process of separating cotton, the ginning box is closed. It is equivalent to a black box and it is difficult to observe the internal work directly from outside. The ginning itself is a dynamic process. The stress and displacement on the serration and the

laps change from time to time and it is difficult to extract information from the moving object. Therefore, to be able to research the process of ginning, in accordance with the research on the actual structure of the ginning box, this paper designs a device. The device can simulate the ginning process, but the structure is much simpler than the actual ginning machine. The purpose of the experiment is to measure how much force the seed cotton will bear when the cotton fiber is pulled off from the cottonseed and taken away by the saw blade.

The following are some of the relevant parameters of the small ginning machine used in this paper: the space of two ribs at the work points was 2.8–3.2 mm; the outside diameter of saw blade was 320 mm; drum diameter and inside diameter of saw blade was 64 mm; the center distance of two saw blades was 19.4 mm; and the quantity of seed cotton processing was 300 kilograms per hour.

According to the actual parameters, the experimental device is designed by changing the ginning part of a single saw blade and a small amount of seed cotton in the form of action to simulate the work inside the ginning box. The overall experimental setup is shown in Figure 13. Number 1 is the steel saw blade, which has 303 teeth and is mounted on the axis (2). It is positioned through the shaft (3). The shaft is mounted on the bracket by a rolling bearing (4). The other end of the bracket is placed on a cylinder (6) and cotton is arranged in the cylinder to be rolled. The cylinder and the bearing have the right installation distance to ensure the relative position of the saw blade and the seed cotton. The middle of the cylinder has a 3 mm gap to simulate that between the rows of the embossed ribs

so the saw blade can be inserted into the gap with the seed cotton. The width of the gap is slightly smaller than the size of the cotton seed to make sure the cottonseed does not fall. A hook is attached to the edge of the saw blade, near the lower part of the cylinder for hanging weights.

Before starting the experiment, seed cotton with a density of 400 kg/m^3 at 7.5% moisture regain is put into the cylinder. The saw blade is rotated into the serration in full contact with the seed cotton, before being inserted into the slot just above the hook. At the beginning of the experiment, the weights are hung on the hook; a smaller weight is selected when the bolt is hung for the first time and the contact between the saw blade and the cotton fiber in the cylinder is observed. The weight directly provides the pulling force for the saw blade and acts on the cotton flower. When the weight is gradually increased, the force acting on the cotton flower also increases. The final force is increased to pull the cotton fiber from the cottonseed and the cotton fiber is taken away by the rotating saw blade. The cottonseed is left inside the cylinder because it is larger than the gap size.

When the cotton fiber is pulled by the saw blade, the weight is the final force on the cotton and the force is recorded as the result of the experiment. To reduce the error caused by chance, five experiments were carried out and the average taken. After each experiment, the cotton fiber on the serration is brushed off. The seed cotton in the cylinder needs to be removed and new seed cotton re-installed into the cylinder. It should also be noted that a single serration should only hook a cotton fiber on a cotton to match the subsequent finite element model. Because a single serration is

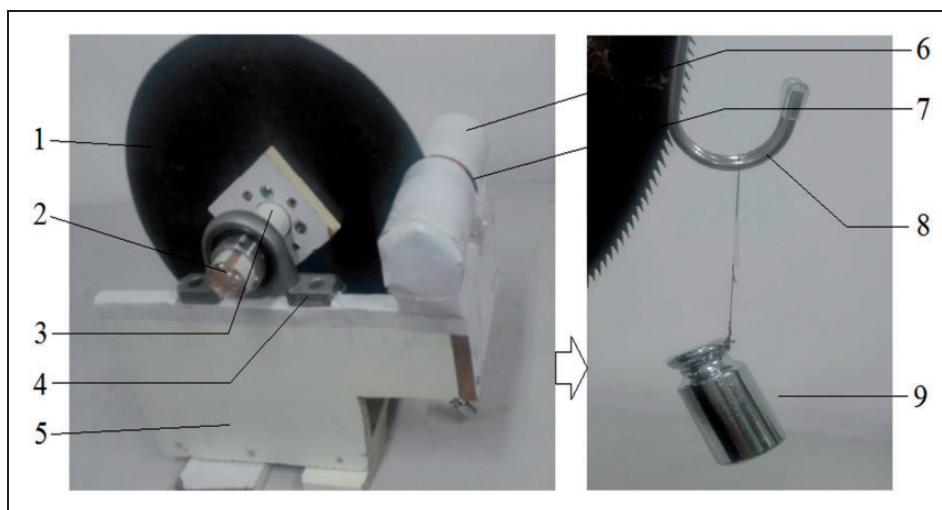


Figure 13. Ginning experiment device.

1: saw blade, 2: shaft, 3: axle sleeve, 4: roller bearing, 5: bracket, 6: cylinder, 7: cylinder gap, 8: hook, 9: weight



Figure 14. The cotton fibers are rolled on the serration.



Figure 15. A cottonseed rolled off some fibers.

much smaller than a single cotton flower, the condition is easy to meet. Figure 14 shows the cotton that is rolled down on the serration, and Figure 15 shows a cottonseed that has been rolled out of some fibers.

Table 5. The relationship between the density of seed cotton and the force of cotton

The density of cottonseed (kg/m^3)	Cotton force (N)
250	0.6
350	0.8
400	0.9
450	1.0
500	1.1
600	1.3

It is experimentally determined that the force on a single cotton at one time is 0.9 N when the seed cotton has a density of 400 kg/m^3 at 7.5% moisture regain. The experiments are carried out with density of 250 kg/m^3 , 350 kg/m^3 , 450 kg/m^3 , 500 kg/m^3 , and 600 kg/m^3 . A different amount of seed cotton is put into the cylinder to achieve the above density values. Although the other conditions remain the same, different weights are attached to the hooks. With the increase of the density of seed cotton, the cotton fibers that are hooked by a single serration increase and the force required to pull the cotton fiber from the cottonseed also increases. The density of each group is averaged over five experiments, and finally the one-to-one correspondence between the density of seed cotton and the force of cotton and cotton is achieved. It is shown in Table 5.