

FINITE ELEMENT MODELING SIMULATION IN THE STRAW PELLET COLD COMPRESSING MOLDING PROCESS

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According to the character of straw pellet fuel cold molding technology, the compressing process was modeled by Finite Element Modeling (FEM) structure analysis tools. This indicated the variation laws between the stress and the strain, and the influence of the structure parameters of the die on the stress and the strain. It's concluded from the work that when the length-to-diameter ratio of the die was 5.2 and the conicity of the die was 45°, the compress molding showed better degree of bonding and finish. This provided theoretical evidence for the study of the molding mechanism of the straw pellet and the selection of the structure parameters of the die.

Keywords: Straw; Compress molding; Finite Element Modeling; Length-to-diameter ratio of the die; Conicity of the die

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INTRODUCTION

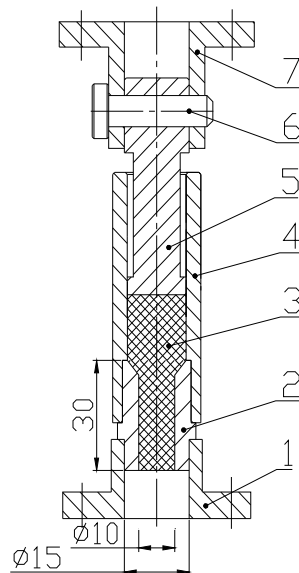
Straw cold compress molding technology is an important means of biomass utilization. It's also the basis of other biomass using technologies. Previous studies have focused on closed compressing, especially briquette molding and hot compressing molding. Previous research has been important for the development of the molding technology (see Smith et al. 1997; Beker 1997; Naidu 1995; O'Dogherty et al. 1982; Orth and Lowre 1977; Butler 1985). Nevertheless, closed compress molding has some limitations, for the straw is in an open mode during real compressing. So the study of open mode compressing has practical importance. In this article, aiming at straw cold molding equipment, the finite element modeling (FEM) method was used to study the changing law of the strain and stress and the influence of die structure.

Straw is a viscoelastic material that has not only elasticity but also plasticity. The cold molding process belongs to a class of nonlinear structural problems due to change of status. So it has to be studied by a nonlinear FEM method (Morl and Osakada 1987). The ANSYS software is designed to use an FEM method, using a structural nonlinear analysis module to simulate the interaction between different kinds of physical media. So in the research reported here, ANSYS was used to simulate the cold molding compressing process. The straw in the compressing stage was treated as a continuous medium. The FEM model was set up from the front to end to do face-to-face contact analysis. The strain and stress chart, flow change chart, and equivalent plastic strain chart in the

molding process were simulated. The law of influences of the structure and parameters of the die was studied in detail.

EQUIPMENT

To fulfill the need for straw cold compressing molding, special open equipment was designed, which consisted of a sleeve, die, pressure lever, and pin. The outer diameter of the die is 15 mm, the inner diameter is 10 mm, and the height of the die is 30 mm. The height of the straw is about 300 mm and filled three times into the die. The die was made of alloy steel. An illustration is given in Fig. 1:



1. bottom 2. die 3. material 4. sleeve 5. pressure lever 6. pin 7. fixture

Fig. 1. Illustration of open straw pellet molding equipment

The equipment was regarded as the simulating target. The simulating results will be contrasted with those obtained from the experimental equipment.

ANSYS ANALYSIS

The squeezing stage in the cold molding process was chosen as the target for analysis. The contact analysis belongs to a face-to-face and rigid body as well as flexible body problem. For the contact surface, one in them was regarded as a rigid body, and the other contacted to it was regarded as a flexible body. In this article, the die was regarded as the objective surface, simulating by TARGE169 element. And the straw, which was a flexible body, was regarded as a contact surface, simulating by CONTA172 element.

Set-up of the Model

In the compressing process, the straw was first crushed, then it was filled into the die. Under pressure, the interspace between the straw became progressively smaller and eventually became stuck together.

As the primary goal of the work was to study the influence of the die structure, the equipment was simplified in setting up the model. The tapered part of the die was the key object of the study. The model consisted of the raw material and the die. The later was equipped with the body of the pellet, so its Degrees of Freedom (DOF) in every direction was zero.

Definition of the Material Property

As there's friction between the die and the straw in the molding process, three kinds of material models were defined, the straw material, the die, and the contact pair, which was a virtual model. The properties of the three parts of the model are given in Table 1 (Dong et al. 2005):

Table 1. Properties of Three Kinds of Materials

No.	Part	Item	Value
1	Straw Material	Density ($\rho/g\cdot mm^{-3}$)	0.33×10^{-3}
		Inner friction angle (rad)	0.5467
		Cohesion (kPa)	0.02462
		shear modulus (G/GPa)	8
		Poisson's Ratio (μ)	0.35
2	Die	Elastic modulus (E/GPa)	210
		Poisson's Ratio (μ)	0.28
3	Contact pair	friction coefficient (μ_s)	0.2

Definition of the Element and Meshing

The plane82 element was chosen on the basis of its high simulating accuracy and shift coordinating performance, such as plasticity, wriggle, rigid hardening, and large strain (Tang et al. 2006). To define the width real constant, keyopt(3) was set equal to 3. To define the element key option, keyopt(2) was set as the contact algorithm, keyopt(6) was set as a rigid array, and keyopt(7) was set as the time step control.

The model was first set up. Then it was meshed by the scanning tool, using quadrilateral free gridding (Liu and Hu 2002). At last, an FEM model was generated with nodes and elements.

Set-up of Contact Pair

The contact pair was set up by face-to-face contact elements. A new contact pair was added with a linear contact type and a rigid target type. The target face and contact face were selected, the contact properties were set, and the seeping range was set to 0. To use a constant friction method, keyopt(6) was set equal to 1 (Tang et al. 2006). To eliminate initial seeping, keyopt(9) was set equal to 1. For a reasonable step forecast keyopt(7) was set equal to 2.

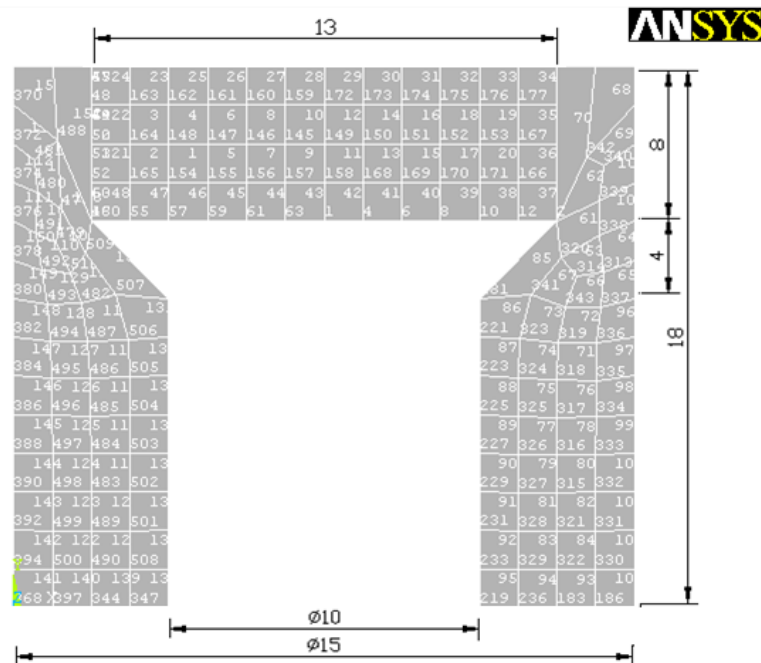


Fig. 2. Chart of finite element model

Definitions of the Constraint and Loading

The DOF (degrees of freedom) included plane X-shift and Y-shift. The die belonged to a fixed constraint as it is connected to the mill body. So the load was pressure was induced from the lever in front of the straw and its shift.

To avoid an excessively slow convergence of the model, a modified rigid array was adopted. The Newton-Raphson option was set to full. Reasonable iterations were selected in the approximate range of 25 to 50. To avoid un-stable phenomena, a linear search was adopted. Large displacement was set to static. Large deformation effects were set in analysis option. The load step time was set to 250, sub steps were set to 150, maximum sub steps to 10000, and minimum sub steps to 10 (Dong et al. 2005). The problem was then solved.

RESULTS AND ANALYSIS

As the FEM model was a rotational symmetry one, only one side was analyzed. The specific results were as follows:

Stress Analysis

As the X-axis stress has similar variation laws with the Y-axis, only the Y-axis stress was analyzed. 20MPa

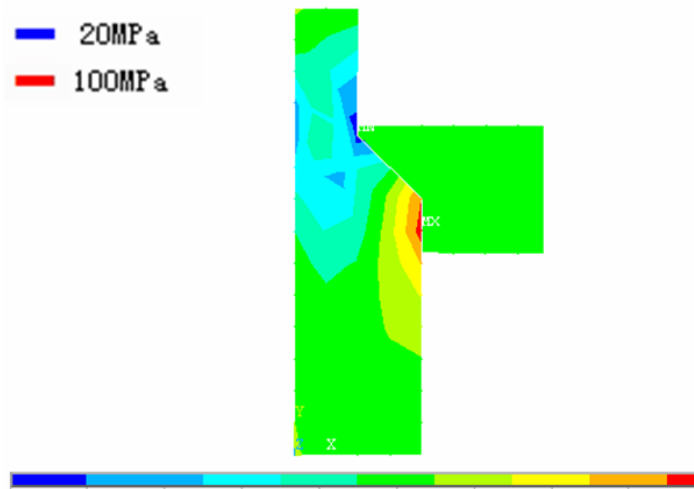


Fig. 3. Chart of Y axis stress distribution

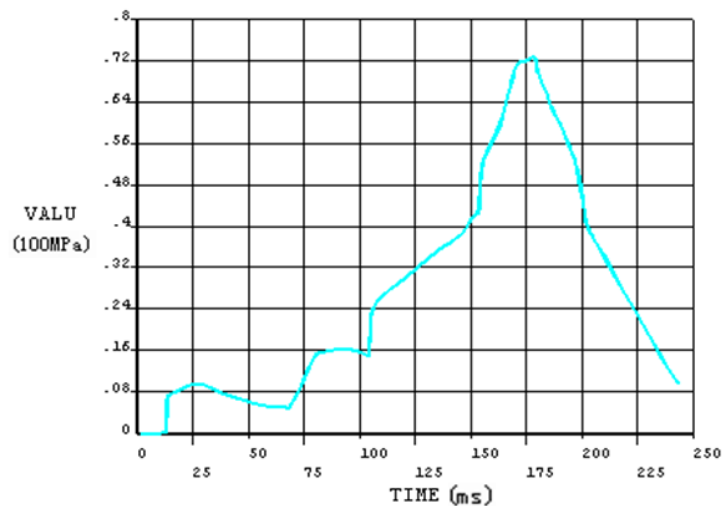


Fig. 4. Change curve with Y axis stress vs. time

As shown in Fig. 3, the maximum Y-axis stress occurred at the connecting place between the tapered part and straight part of the die. It's deduced that here the friction force was the largest, and the wear and tear here were also the most serious. As is evident from Fig. 4, the stress remained at a low level in the feeding stage, and it increased gradually in the compressing stage. The stress reached its highest level during the molding stage, after which it decreased quickly.

Strain Analysis

For the strain distribution chart of X-axis and Y-axis see Fig. 5 and Fig. 6:

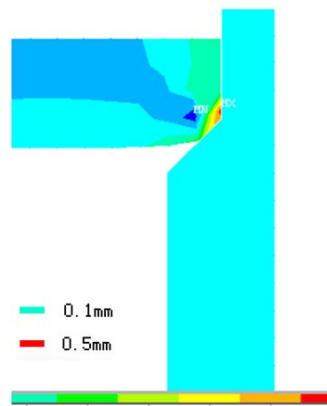


Fig. 5. Chart of X axis strain distribution

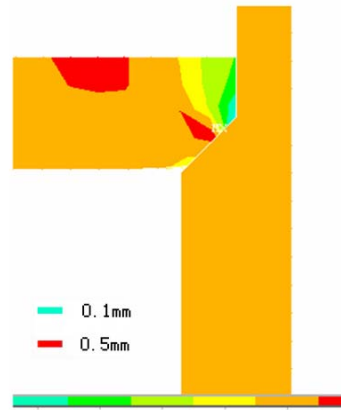


Fig. 6. Chart of Y axis strain distribution

As shown in Fig. 5, the strain in the tapered part of the die was the largest. The strain in the central part of the straw was the smallest, as it probably was affected by the shearing stress. When the straw material went through the tapered part of the die, large shearing stress and strain occurred, which made the material in the contact face move to the central part. Therefore the strain here was the largest.

From Fig. 6, the maximum strain of Y-axis focused on the central part of the straw. And the minimum strain focused on the tapered part of the die. This was the united impact of the friction force and the taper. The strain of the straw near the taper fell behind others, which was mainly plastic deformation. The central part flowed the most quickly, which was mainly elastic deformation (Hu 2008).

Flow Chart in the Molding Process

The flow chart can describe the change through the molding process. For Fig. 7, the distribution of its mesh shows the flow status in terms of pressure. Only the taper part was studied in detail, as it's the key point in this article. Here the 'T' indicated the elapsed time during the whole process.

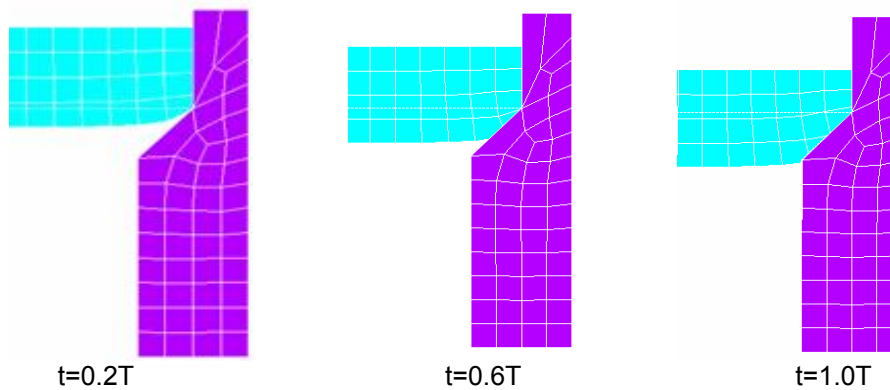


Fig. 7. Flow chart of the straw in compressing process

From Fig. 7, for the straw material, the mesh of the X-axis and Y-axis all changed prominently, especially in the tapered part of the die. This was because the outer part fell behind the inner part due to the friction force between the straw and the die in the flowing

process. As the compressing process proceeded, the central part of the mesh tended to remain stable, whereas the deformation of the contact part continued to increase.

In addition, the mesh changed from a foursquare form to a parallelogram pattern. These results indicated that there's a shearing stress and strain in addition to the pulling stress and strain in the molding process. At the beginning of the process, as the pressure was small, the friction force between the straw and the die was also small, so the shearing stress and strain were at a low level. As the process boosting forward, the friction increased quickly, so the shearing stress and strain also increased obviously at this time.

The Influence of the Length-Diameter Ratio of the Die

The length-diameter ratio was the ratio between the length and the diameter of the die. In this article, only the diameter was changed to obtain various ratios with constant length. The taper part was still chosen as the object of the study. Figure 8 shows the flow charts when the length-diameter ratio was 4.16, 5.2, 6.24 separately, and at 0.6T.

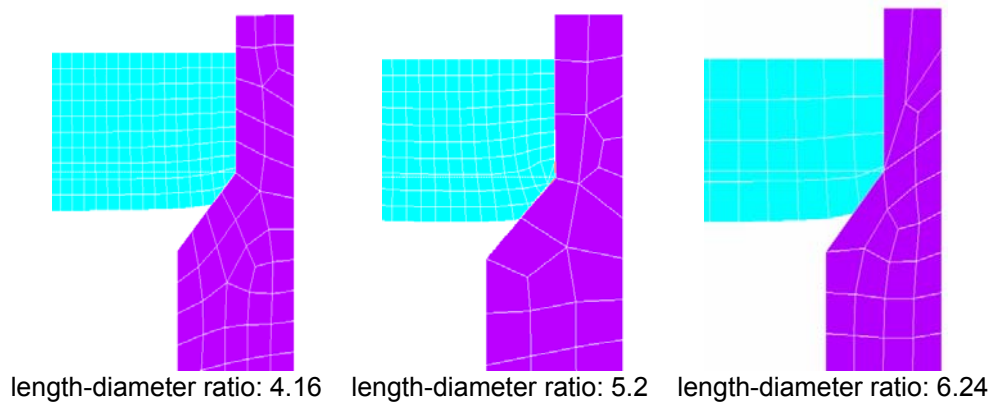


Fig.8. Flow charts of the straw with different length-diameter ratio of the die

From the figures above, there existed the same changing law, although the length-diameter ratios were different. The mesh in the central part remained nearly straight. However, in the taper part, the mesh changed greatly.

Also, it's indicated that, for different length-diameter ratio, the change of the mesh was different, correspondingly. When the ratio was 4.16 or 6.24, the mesh changed sharply. Especially, when it was 4.16, the mesh slipped downward. When it was 6.24, the mesh slipped upward. When it was 5.2, the mesh kept still in the taper of the die, which indicated that at this time the pressure stress was very small. The pressure stress was mainly to push the straw downward to become a pellet. This was beneficial to molding.

It is deduced that the behavior was the result of pressure stress and shearing stress, in which the former was useful for molding and the latter was harmful for molding. When the length-diameter ratio increased, the diameter decreased, and the pressure stress on the straw increased correspondingly. However, at the same time as the shearing stress was applied, the straw near the taper of the die slipped to the central part which became squeezed seriously. This easily led to cracking. So when the ratio was in the medium range, for example 5.2, the deformation of the straw flowing downward exceeded the slipping of the straw from the taper to the central part. At this time, the

straw was squeezed out quickly with good effect. However, if the ratio continued to increase, the straw was more likely to slip to the center and crack.

The Influence of Taper Angle to Molding

Figure 9 presents the flow charts under different taper angles of 30° , 45° , and 60° (Here $t=0.2T$).

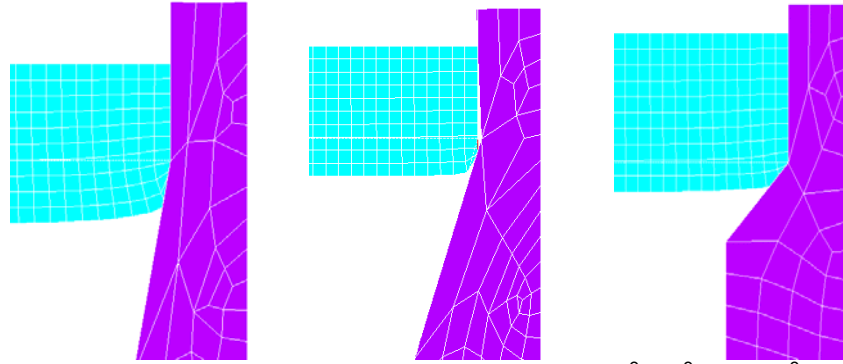


Fig. 9. Flow chart of the straw with taper angle 30° , 45° , and 60°

From the figures above, the taper angle had great influence on molding. For different angles, the changing trend was the same. The change of the central part was small. However, the change of the taper was great, especially on the front of the taper.

In addition, there's a difference for different taper angles. It's embodied between the stress and strain of the straw. When it's 30° , the pressure stress was focused on the taper part of the die. The slip of the straw to the central part was non-obvious, which was likely to lead to inharmonious interactions between the two. The density would be not uniform, which would influence the quality of the pellet. When it was 60° , the shearing stress increased, which made the straw slip to the central part. This would enhance the density of the pellet. However, as the shearing stress, the straw was easy to crack in the lateral dimension. When it was 45° , the reversed effects can both be taken into account. The molding result was optimal.

Equivalent Plastic Strain

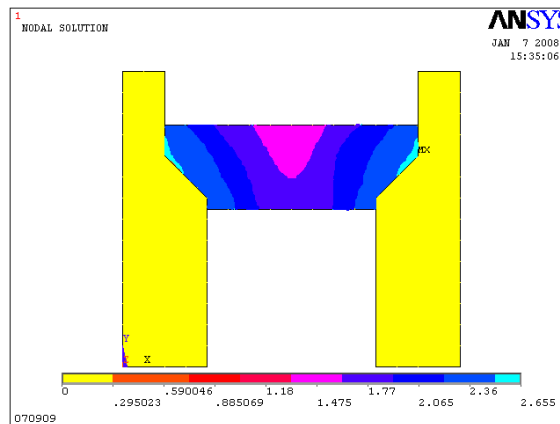


Fig. 10. Chart of equivalent plastic strain (by millimeter)

The equivalent plastic strain could reflect the plastic deformation. Figure 10 is a chart of equivalent plastic strain in the molding process. From the figure, in the X-axis direction, the plastic deformation was the smallest in the central part of the straw. The closer to the taper part of the die, the larger of the plastic deformation. In the Y-axis, the plastic deformation was the lowest on the top of the straw and the largest on the bottom. The reason was that in the X-axis direction, the pressure stress was focused at the contact face, which led to plastic deformation. In the Y-axis direction, in the presence of a shearing stress, lateral displacement occurred and diffused to the central part. This led to plastic deformation as the material was pressed to an increasing degree.

CONCLUSIONS

1. When simulating the straw compressing molding by ANSYS software, the compressing stage can be treated as a system of continuous media. The material model of it approximates an elastic-plastic model. The problem can be solved using a rigid-soft body contact method.
2. In the molding process, as the effects of the friction force were expressed in the tapered part of the die, the plastic deformation of the straw near the taper part fell behind that near other parts. The straw in the central part flowed quickly, which was mainly attributable to elastic deformation.
3. When the length-diameter ratio changed from 4.16 to 5.2, the increase of the straw flowing speed was larger than that of the straw seeping speed to the central part. The capacity of the die increased, and the molding effect was sound. When it changed from 5.2 to 6.24, the speed of flowing was smaller than that of seeping. The capacity decreased. So the best ratio was 5.2.
4. When the open taper angle was 30° , the pressing stress focused on the taper part of the die. However, in the central part the deformation was not obvious. Then the density of the pellet would be nonuniform, which influenced the quality of the pellet. When the open taper angle was 60° , the shearing stress increased. Then the density of the pellet would be enhanced. However, cracking was likely to happen. When it was 45° , the two influencing factors can be both taken into account. A comprehensive pelleting effect was optimal under this condition.

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