

COMPUTER ASSISTED SIMULATION OF FORAGE CHOPPING PROCESS

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Abstract. Nowadays choppers are equipped with knives that are inclined toward the drum generator for progressive cutting. Optimal inclination depends on the nature of the chopping material. This paper presents a method for simulation and analysis of the cutting process of forage from a drum chopper. Initial equipment parameters were entered into an analysis program to calculate stress distribution on the knife and material over time. The knife and shredding material were designed in Solidworks. Simplified models for both knife and shredding material were opted for simulation. These simplified models were imported into Ansys 18.0 in order to simulate the forage cutting process. To simulate the cutting, forage maize has been chosen as the material to be cut. The Explicit Dynamics module present in Ansys was used for simulation. For the straight knife the maximum stresses appear, as expected, on the tip of the knife and have a relatively uniform distribution along the edge of the knife. Also for the straight knife tensions grow relatively quickly, reach the maximum, then after the knife has penetrated the material, tensions begin to gradually decrease. The maximum stresses on the inclined knife appear first on the corner that first penetrates the material, then spread along the knife as it penetrates the material. Unlike the straight cut, here the maximum stresses are lower, but they stretch over a longer period of time and then start to decrease. Of the all inclined knives simulated the knife inclined at 15° showed the lowest stress value and the smallest stretch of maximum stress over time.

Keywords: finite element method, simulation, CAD.

Introduction

In the technological process of the forage harvester, the most important working tool is the chopper, which performs the fragmentation of the feed to the required size and throws it to the exhaust system of the combine. Nowadays choppers are equipped with knives that are inclined toward the drum generator for progressive cutting. Optimal inclination depends on the nature of the chopping material. M. J. O'Dogherty concluded that researches show that blades used in forage chopping should have a rake angle of 10-20° [1].

Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of the design, improve communications through documentation, and to create a database for manufacturing [2].

FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm [3].

This paper presents a method for simulation and analysis using FEA software of the cutting process of forage from a drum chopper in order to determine the optimal inclination of the knife for cutting forage maize.

Materials and methods

The knives from drum choppers are inclined to the drum generators at an angle $\tau = 12...30^\circ$ for progressive cutting of the material (Fig. 1). They have a sharp angle at $i_c = 16...37^\circ$ [4].

The equations of the knife path are: [4]

$$x = v_p \cdot t + t \cdot \cos\omega t, \quad y = R \cdot \sin\omega t, \quad (1)$$

where R – radius of the drum;
 ω – angular velocity of the drum;
 v_p – feed speed.

The component equations of the knife speed [4]:

$$v_x = v_p - \omega \cdot R \cdot \sin\omega t, \quad v_y = \omega \cdot R \cdot \cos\omega t. \quad (2)$$

The cutting speed is [4]:

$$v_r = \sqrt{v_p^2 + \omega^2 \cdot R^2 - 2 \cdot \omega \cdot R \cdot v_p \cdot \sin\omega t} \tag{3}$$

For simulation, the knife was assigned only a vertical velocity, the horizontal one was neglected:

$$v_p = \omega \cdot R \tag{4}$$

Also, friction was neglected for simulation purposes.

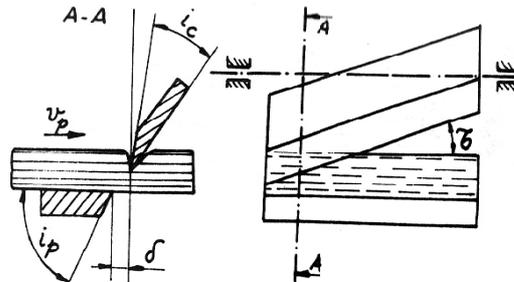


Fig. 1. Inclination of knife [4]

The knife and shredding material were designed in Solidworks (Fig. 3-5). Simplified models for both the knife and shredding material were opted for simulation.

The forage material was reduced to a parallelepiped having the dimensions 30x30x50 mm.

The simplified knife has a length of 35 mm, a thickness of 4 mm and is sharpened at 15°.

These simplified models were imported into Ansys 18.0 in order to simulate the forage cutting process. To simulate cutting, forage maize has been chosen as the material to be cut. The mechanical properties for the selected maize are presented in Table 1.

Table 1

Mechanical properties for maize [5;6]

Material	Density, kg·m ⁻³	Elasticity modulus, MPa	Shear strength, MPa
Forage Maize	320	210000	100

The knife was attributed the mechanical properties of steel, presented in Table 2

Table 2

Mechanical properties for steel

Material	Density, kg·m ⁻³	Elasticity modulus, MPa	Shear strength, MPa
Steel	7800	210000	220.59

These mechanical properties have been introduced in Ansys in order to simulate the chopping process as accurately as possible.

The Explicit Dynamics module present in Ansys was used for simulation.

The discretization of the knife was finer in the area of contact between the knife and the material.

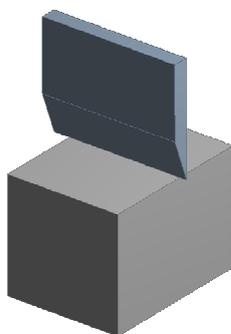


Fig. 3. Simplified parametric model for straight cutting

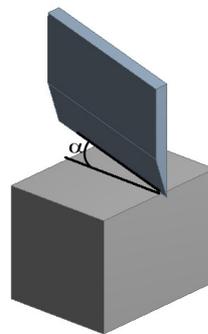


Fig. 4. Simplified parametric model for inclined cutting: α – inclination of the knife

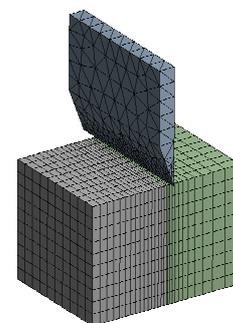


Fig. 5. Discretization of parts

The peripheral speed attributed to the knife is $20 \text{ m}\cdot\text{s}^{-1}$, the speed corresponding to a chopper with the radius $R = 200 \text{ mm}$ and the speed $n = 960 \text{ rpm}$.

Results and discussion

Fig. 6 shows the stress distribution on the straight knife. It can be noticed that the maximum stresses appear, as expected, on the tip of the knife and that they have a relatively uniform distribution along the edge of the knife. Fig. 7 shows the stress distribution on the cut material.

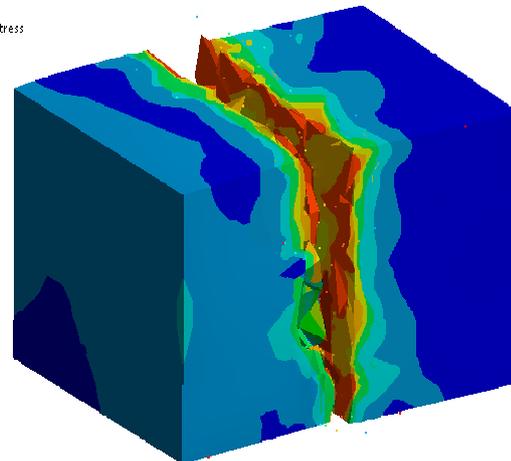
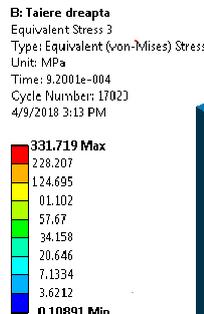
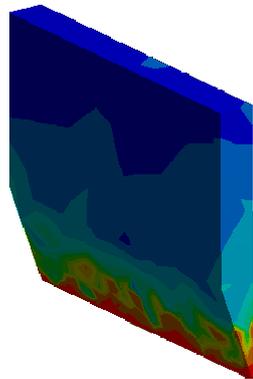
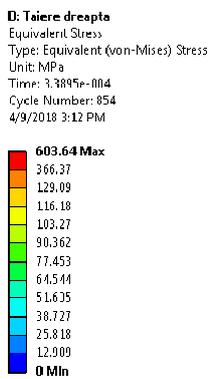


Fig. 6. Stress on straight knife

Fig. 7. Stress in cut material

Fig. 8 shows the graph of stress distribution on the straight knife in time. It is noticeable that at first the tensions grow relatively quickly, reach the maximum, then, after the knife has penetrated the material, tensions begin to gradually decrease.

Fig. 9 shows the stress distribution on the knife inclined at 15° . It is noticed that the maximum stresses appear first on the corner that first penetrates the material, then spread along the knife as it penetrates the material.

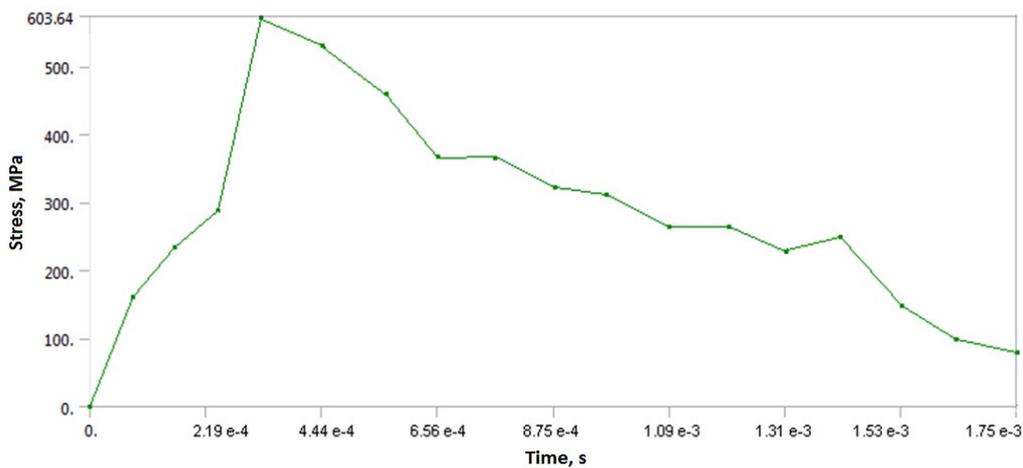


Fig. 8. Stress distribution on straight knife in time

Fig. 10 shows the graph of the stress distribution on the inclined knife in time. Unlike the straight cut, here the maximum stresses are lower, but they stretch over a longer period of time and then start to decrease.

Fig. 11 compares the distribution of stresses over time at different inclinations of the knife. It is noted that the results are similar, but the knife inclined at 15° shows the lowest stress value and also the smallest stretch of maximum stress over time.

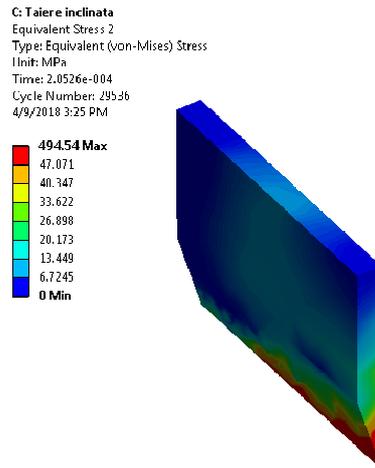


Fig. 9. Stress on inclined knife

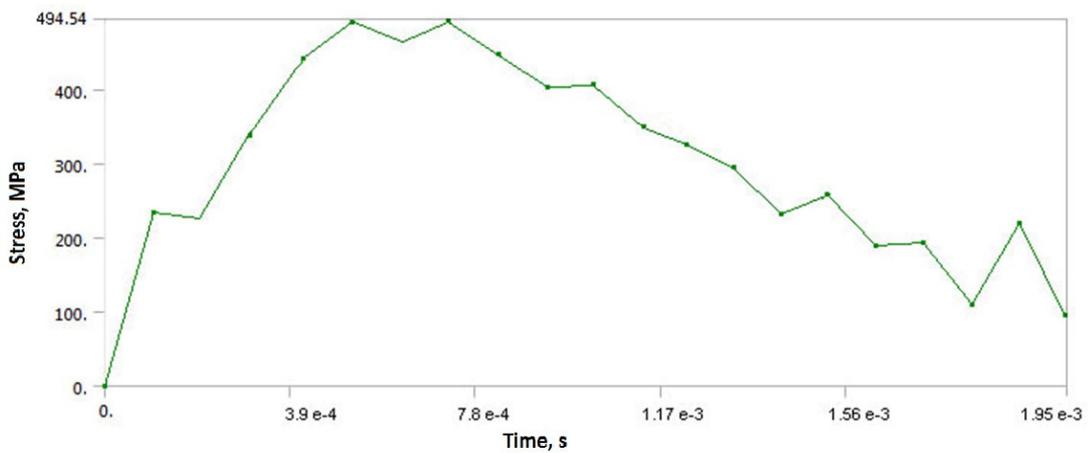


Fig. 10. Stress distribution on inclined knife in time

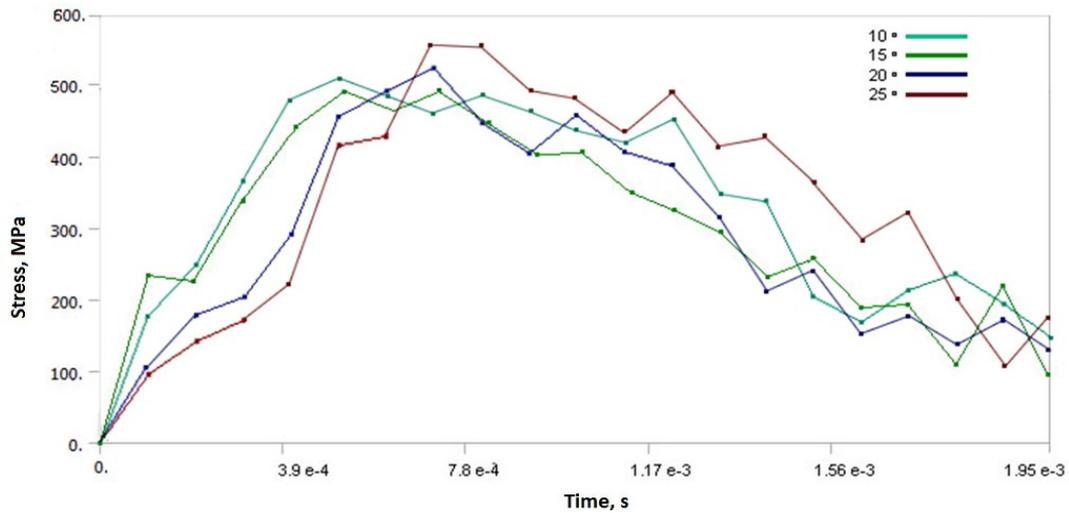


Fig. 11. Distribution of stresses over time at different inclinations of knife

Conclusions

This work used FEA to simulate the cutting process of vegetal material and to perform stress analysis of the cutting knife and the cut material. The stress distribution along the cutting knife and the cut material was evaluated using the ANSYS software.

Inclined cutting simulation showed a lower maximum stress than the straight cutting.

Of the all inclined knives simulated, the knife inclined at 15° showed the lowest stress value and the smallest stretch of maximum stress over time.

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