Krzysztof KUKIEŁKA, Radosław PATYK, Leon KUKIEŁKA, Łukasz BOHDAL, Przemysław BARTOSIK
Koszalin University of Technology, Mechanical Engineering Faculty
ul. Racławicka 15-17, 75-620 Koszalin, Poland
e-mail: krzysztof.kukielka@tu.koszalin.pl, radoslaw.patyk@tu.koszalin.pl, leon.kukielka@tu.koszalin.pl, lukasz.bohdal@tu.koszalin.pl, bartosikprzemyslaw@o2.pl

NUMERICAL DETERMINATION OF MATERIALS CHARACTERISTICS FOR THE NEEDS OF SIMULATION AND ANALYSIS OF STALK CUTTING PROCESSES

Summary

The aim of this work is to develop a numerical application to determine the materials characteristics and to simulate the phenomena of cutting process by a single stalks and a few stalks as well as to present the possibilities of its application for simulation of the cutting process under real conditions - occurring in cutting assemblies of typical agricultural machinery. An example of use of this application to the modelling of cutting process of stalks in the cutting system of the harvester Bizon is presented. The next stage will be to develop a methodology to enable better design of the knife units used in a variety of agricultural and forestry machinery and their optimization.
Key words: *plants, stalks, stems, cutting, simulation, analysis*

NUMERYCZNE WYZNACZANIE CHARAKTERYSTYKI MATERIAŁOWEJ NA POTRZEBY SYMULACJI I ANALIZY PROCESU CIĘCIA MATERIAŁÓW ŹDŹBŁOWYCH I ŁODYGOWYCH

Streszczenie

Celem niniejszej pracy jest opracowanie aplikacji numerycznej do wyznaczania mechanicznych charakterystyk materiałowych i symulacji zjawisk podczas procesu cięcia pojedynczego źdźbła oraz kilku źdźbeł oraz przedstawienie możliwości jej zastosowania do symulacji procesu cięcia w warunkach rzeczywistych – występujących w zespołach tnących typowych maszyn rolniczych. Podano przykład zastosowania tej aplikacji do modelowania procesu cięcia źdźbła w nożycowy zespole tnącym kombajnu zbożowego Bizon. Dalszym etapem będzie opracowanie metodyki umożliwiającej lepsze projektowanie zespołów tnących stosowanych w różnych maszynach rolniczych i leśnych oraz ich optymalizacja.
Słowa kluczowe: *rośliny, źdźbła, łodygi, cięcie, symulacja, analiza*

1. Introduction

The common tendency of multi-criteria optimization of modern agricultural machinery assemblies necessitates a thorough knowledge of the physical phenomena occurring during operations such as plowing, soil seasoning, cutting of stalk material, squeezing, comminution, etc. From modern machines usually require that the resulting product was on the highest quality, but the cost of its production as low as possible. The difficulty in solving the task as the optimization two-criterion is that physical phenomena are geometrically, physically and sometimes heat and nonlinear boundary conditions in the areas of contact of working with the material are unknown. One of the fundamental processes occurring in many agricultural machinery (combines, mowers, cane harvesting machines, machines for harvesting willow, etc.) is the process of cutting stalk materials. The theoretical analysis [6] distinguishes between the following possibilities of cutting stalks: transverse, oblique, oblique sloped diagonal slanted at an angle to the plane of the stem longitudinal, longitudinal - oblique, longitudinal - axial. It is known that the process of cutting stalk material in two stages (squeezing and cutting) [1, 2, 6]. However, the practical measurement of physical phenomena occurring in the real process of cutting stalks is difficult (or impossible) due to the impossibility of measuring such as the distribution of pressure and friction between the blade of a knife blade and liners, lack of knowledge of the mechanical characteristics of the material being cut stalks, etc. Therefore, it is impossible to analytical solution of the basic problem of such term displacement and deformation states at any time during the process of cutting stalks. Consequently, it is impossible to determine the optimum geometry of the blade and the liners in various machines. For example, in a combine harvester different companies use different geometries of blades and finger liner. Currently the development of techniques and methods of modelling and simulation makes the design process of cereal cutting technology may be significantly expanded and improved. Contemporary using different modelling methods such as physics, physical, mathematical, computer and consequently, statistical and modelling using artificial intelligence. Each of these methods has advantages of modelling how defects. In physical modelling, statistical and using the artificial intelligence is necessary to build a material object and carrying out experiments but does not require knowledge of the physical phenomena occurring in the process. This approach requires a significant effort (time and money) to perform the model and conduct experiments. An alternative to these methods of modelling can be: physical modelling, mathematical and computer [7], but it requires knowledge of the physics of the process, but significantly can reduce spending on the development of an adequate model of the test object. The aim of this work is to develop a numerical application to simulate the phenomena of a single stalks the cutting process and a few stalks and present the possibilities of its application to the simulation of the cutting process under real conditions - occurring in group cutting typical agricultural machinery, for example, use of this application to the modelling of cutting stalks by the cutting scissor in the harvester

Bizon. The next stage is to develop a methodology, which enable better design knife assemblies used for a various of agricultural and forestry tractors and as a result their optimization. Due to the strong nonlinearity of the cutting process using finite element method uses an updated Lagrangian formulation and explicit and implicit integration algorithms derived the equations of motion. It involves replacing the continuous discrete object model with separate sub-volumes, and/or sub-areas resting on nodes [3, 5]. In this paper a model of the physical process of constituting the set phenomena assumptions and simplifications, mathematical model, which includes differential and algebraic equations and inequalities and functions conditional on the basis of which one can predict the course of physical phenomena in the modelled process. Validation of the accuracy of developed mathematical models and numerical algorithms and applications in the system ANSYS was made by comparing the simulation results of a single stalks the cutting process with the results of experimental measurements.

2. Determination of the characteristics of the stalks material

Transverse cutting stalks process were tested, the stand for investigation is shown in figure 1, which allows to obtain stalks for the test the force-displacement of the blade. Cutting stalks made using a flat blade with a width of 1 mm. It allows the registration of the variation of the force F as a function of displacement Δl (fig. 1b), which in turn permits the design of stalks the mechanical characteristics of $\sigma = f(\varepsilon)$, with the selected properties of a material (type, humidity, etc.) once the technological parameters of the process (the speed of cutting, friction conditions, etc.).

a) b)

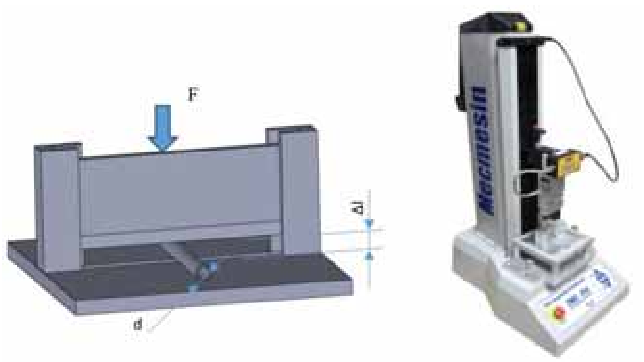

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Fig. 1. Scheme of the tests (a) and testing machine Mecmesin (b)
Rys. 1. Schemat wykonywania badań (a), maszyna wytrzymałościowa Mecmesin (b)

When cutting stalks confirmed literature data [1, 2] the existence of two phases, that is, squeezing and cutting appropriate. In order to develop the characteristics of $\sigma = f(\varepsilon)$ or the test material is required beyond the knowledge of the characteristics of $F = f(\Delta l)$ measure cross-cut fields. View of the samples after cutting for selected transverse cutting speeds are shown in figure 2.

a) b) c)

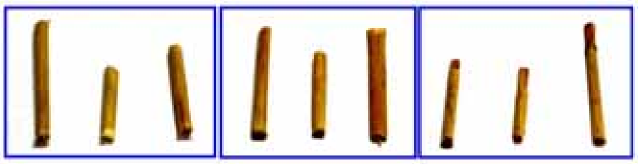

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Fig. 2. Samples after cutting for cutting angle 0°: a) 100 mm·min^{-1}, b) 300 mm·min^{-1}, c) 500 mm·min^{-1}
Rys. 2. Próbki po przecięciu dla kąta cięcia 0°: a) 100 mm·min^{-1}, b) 300 mm·min^{-1}, c) 500 mm·min^{-1}

Measurement of a cross-sampling was done on the machine Werth (fig. 3). The idea developed a methodology to determine material parameters based on the use of modelling and numerical simulation and optimization procedures.

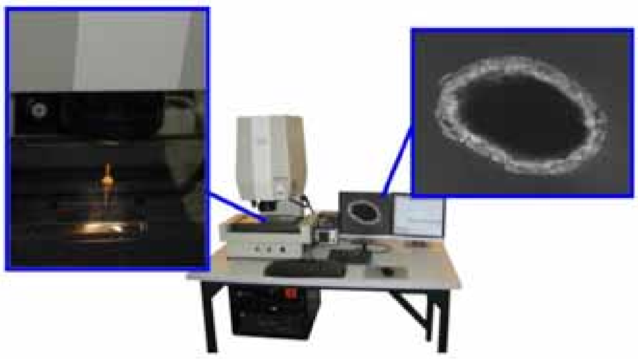

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Fig. 3. Measurement of cross-sectional area on the optical measuring machine Werth
Rys. 3. Pomiar powierzchni przekroju poprzecznego na optycznej maszynie pomiarowej Werth

The numerical simulation assumed that the stalks material is homogeneous and isotropic, and its destruction after crossing the limit of the normal or tangential stress. The real geometry of the stalks was replaced by a thin-walled pipe of circular cross-section, with a diameter d without elbows. The wall thickness was equal to the average thickness of the test stalk [8, 9]. Based on the above assumptions, the model is adopted to simplify the elastic-plastic material with material failure criterion for the maximum values of normal (σ_{Nmax}) and tangential (σ_{Smax}) stresses. In the developed numerical model mapped the process of cutting rye stalks consistent with experimental experience. As design variables in the optimization process adopted values of material parameters, and appropriate limitations were took [4]:

$$\begin{aligned} E &= x_1 \cup x_1 \in \langle 0{,}5\ ,\ 1{,}1 \rangle\ [\mathrm{GPa}], \\ v &= x_2 \cup x_2 \in \langle 0{,}01\ ,\ 0{,}15 \rangle\ [-], \\ \sigma_{N\max} &= x_3 \cup x_3 \in \langle 49{,}5\ ,\ 60 \rangle\ [\mathrm{MPa}], \\ \sigma_{S\max} &= x_4 \cup x_4 \in \langle 49{,}5\ ,\ 60 \rangle\ [\mathrm{MPa}]. \end{aligned} \tag{1}$$

The idea of the optimization process is the adjustment of material parameters (design variables), with the numerical model faithfully reproduces the behaviour of the biological material during the cutting process. As the optimization criterion was the value of the maximum compressive force occurring during the simulation process F_{Smax} cutting stalks. While, the objective function is defined as the absolute value of the difference of the maximum force experienced during the cutting process by empirical studies F_{Dmax}, and simulation:

$$F_{destination} = \left|F_{S\max} - F_{D\max}\right| \rightarrow \min. \qquad (2)$$

Numerical analyzes were performed using ANSYS. Stalk rye has been modelling as an object 3D, in which there is 3D state of stress and 3D state of strain. Stalk has been cut a single blade (fig. 4a). Figure 4d shows the characteristics of the resultant force to the displacement of the test stalks rye. It is consistent with the results available in the literature (fig. 4c) [1, 2]. Was followed by the optimization process, which resulted in optimal (due to the criterion) values design variables. In the case of the selection of material parameters for the stalks rye amounted to, respectively, the Young's modulus $E = 587$ MPa, Poisson's ratio $\nu = 0{,}072$, material failure criterion for the maximum value of normal stress $\sigma_{N\max} = 58{,}52$ MPa and tangent $\sigma_{S\max} = 59{,}24$ MPa.

In figure 4d shows the characteristics of the force to move the blade to the numerical model with the optimal values design variables. Developed material data (fig. 4b) have been implemented to simulate the cutting process in real conditions.

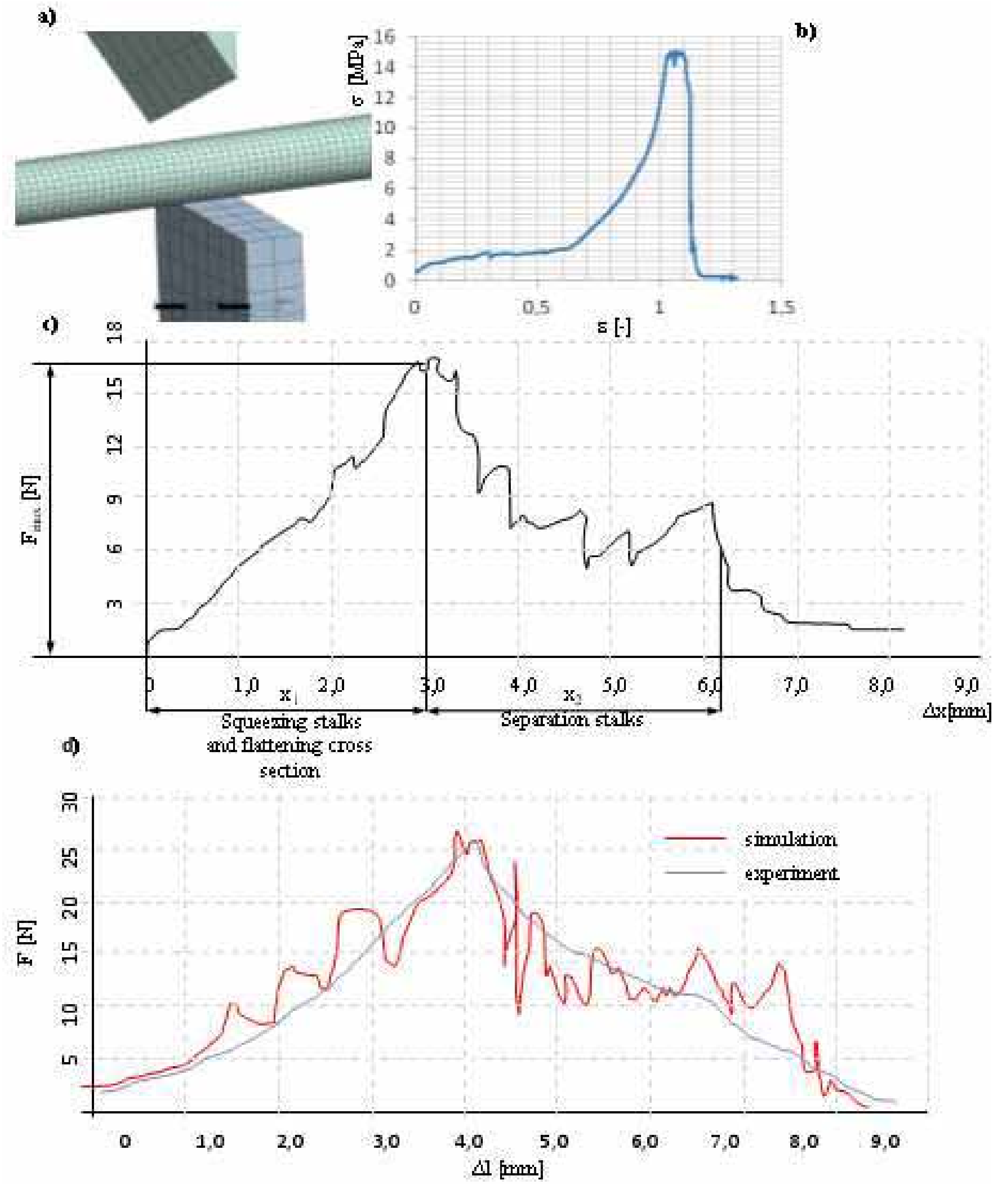

Fig. 4. View of the discreet numerical model (a), a graph $\sigma = f(\varepsilon)$ of the cutting stalks process, along with the phases [2] (c) cutting force change as a function of movement of the blade determined numerically and experimentally (d)

Rys. 4. Widok dyskretnego modelu numerycznego (a), opracowany wykres $\sigma = f(\varepsilon)$ przebieg procesu cięcia źdźbła, wraz z jego fazami [2] (c), zmiana sił cięcia w funkcji przemieszczenia noża wyznaczona numerycznie i eksperymentalnie (d)

3. Application of the cutting process under real conditions

Sample calculations were performed for knife assembly of the harvester Bizon for the solid model was developed based on the geometry shown in figure 5.

In computer simulations assumed that the knife and bayonet the finger liner is made of a ideally rigid material, and the blade has a material elasto/visco-plastic with hardening the Cowper-Symonds model:

$$\sigma_Y = [1 + (\dot{\varepsilon}_i^{(P)}/C)]^m (\sigma_{Y0} + \beta \cdot E_p \cdot \varepsilon_i^{(P)}) \qquad (3)$$

where β is the plastic strain hardening parameter, σ_{Y0} is the initial, static yield point, $\dot{\varepsilon}_i^{(P)}$ is the plastic strain rate intensity, C is the material parameter defining the effect of the plastic strain rate intensity, $m = 1/n$ is a material constant defining its sensitivity to the plastic strain rate, $\varepsilon_i^{(P)}$ is the plastic strain intensity and $E_p = E_T \cdot E/(E - E_T)$ is the material parameter depending on the modulus of plastic strain hardening $E_T = \partial\sigma_Y/\partial\varepsilon_i^{(P)}$ and Young's modulus E. A discrete cracking approach was selected to model ductile fracture and element deletion method was adopted to simulate crack propagation. A strain based material separation criterion available with ANSYS for this material model was used in the simulations. According to this criterion, material separation occurs when the strain value of the leading node is greater than or equal to a limiting value. The limiting strain was taken as $\varepsilon_f = 0{,}80$ based on experimental investigations. When an element of matrix material reached the limiting strain value, the corresponding element would be deleted. The values of the constants for the stalk are taken as follows in this study: $C = 40\ \mathrm{s}^{-1}$ and $n = 5$, while $\rho = 800$ kg·m^{-3}, $\sigma_{Y0} = 8$ MPa, $E = 587$ MPa, $\nu = 0{,}072$, $E_T = 6$ MPa, and $\beta = 1$. Disregard effects of thermal phenomena. Discretize geometric model for the tetragonal 65180 finite elements and 99150 nodes. On the basis of analytical calculations cutting assembly combine, set boundary and initial conditions on the object of study, it is bayonet with finger liner were fixed taking away translational and rotational degrees of freedom, and the knife was assumed linear velocity $V = 25$ m·s^{-1}. At this stage speed resulting from the omission of the operating speed of the combine. Calculated states equivalent stresses and displacements of the axis states UZ shown in figure 6.

a) b)

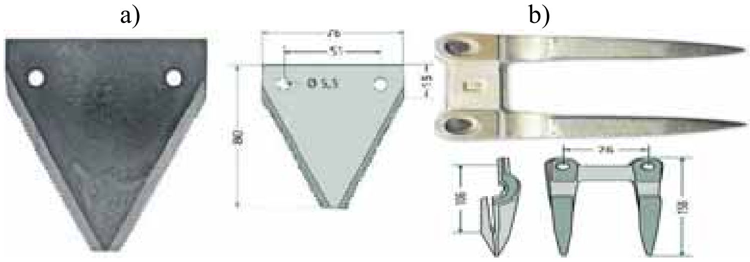

Fig. 5. Parts of the cutting assembly of harvester Bizon: a) knife, b) bayonet with finger liner [10, 11]
Rys. 5. Części zespołu tnącego kombajnu Bizon: a) nóż, b) bagnet ze stalką [10, 11]

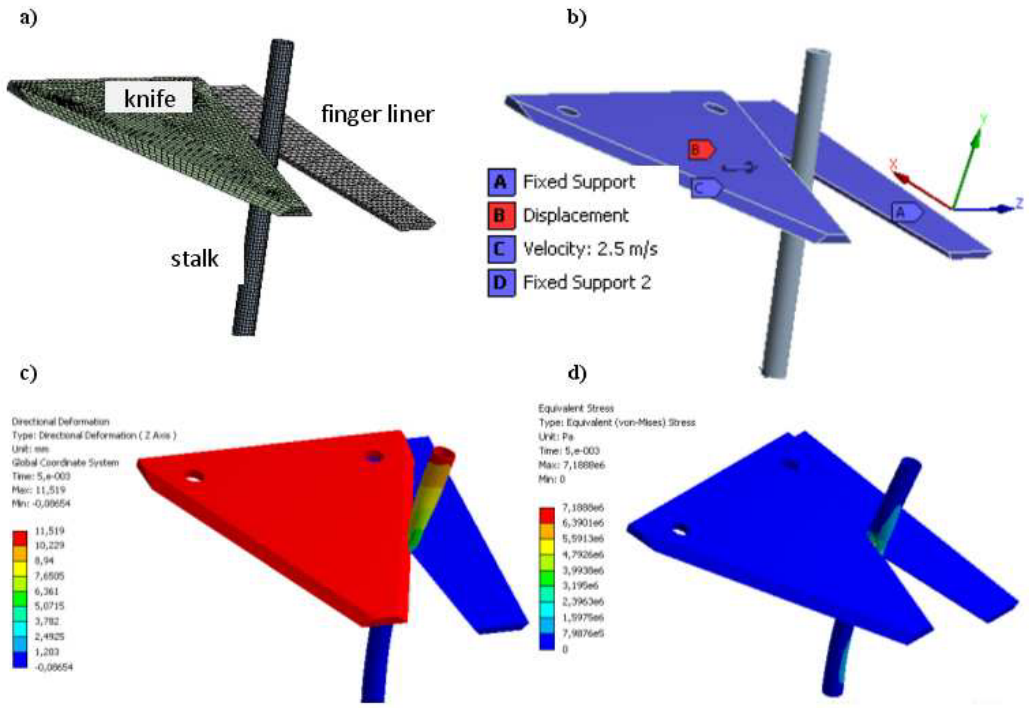

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Fig. 6. The computer model of cutting assembly (knife and finger liner) in harvester Bizon: a) discretization, b) boundary-initial conditions, c) the state of displacement by axis UZ, d) the equivalent stresses
Rys. 6. Model komputerowy zespołu tnącego (nóż i stalka) kombajnu zbożowego Bizon: a) dyskretyzacja, b) warunki brzegowo-początkowe, c) stan przemieszczeń po osi UZ, d) stan naprężeń zredukowanych

Numerical application allows the examination of the displacements, strains, stresses, pressures in the contact zone and the forces involved in the process. The developed application can take into account the motion of the machine, therefore, take into account the real conditions of the process. This approach enables the explanation of physical phenomena for different cases of cut. In further studies, it will be possible to optimize the process for the different boundary conditions for different agricultural and forestry machinery.

4. Conclusions

1. It was shown that it is possible numerical calculation of the mechanical characteristics of the stalk material. Methodology based on multi-criteria optimization showed that the process of cutting stalks designated numerically coincides with the course set experimentally and are consistent with the literature.
2. Application developed to simulate the process of cutting stalks on the machine Mecmesin allows to determine the mechanical characteristics of different materials for different ways to stalk cutting.
3. Developed application of ANSYS system allows for analysis of time physical phenomena occurring in the process of cutting stalks. It is possible: to present the modelled properties of materials as a complex, as a function of strain and strain rate, modelling the interactions contact between the knife and cut material, to examine by changing the input data and model boundary conditions, the qualitative and quantitative impact of these interactions on the cut process. The simulation results can be used to design cutting tools optimized cereals.

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