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STUDY OF THE COMPRESSION BEHAVIOR OF SUNFLOWER SEEDS USING THE FINITE ELEMENT METHOD

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ABSTRACT

It is known that the phenomena that occur during compression of sunflower seeds are very complex. Comprehension of these phenomena is important for increasing the performance of the equipment in the vegetable oil industry, both for the cracking of shells and for the grinding of kernels. Also for the pressing of oilseed materials it is helpful to understand the compression behavior of sunflower seeds. The major objective of this work is to find an easy way of highlighting how the stresses and deformations propagate in sunflower seeds kernels and shells during the compression process, with the aim of optimizing the energy consumption required for the mechanical processing. Therefore, now days there is and we can use the finite element method. This method is the most advanced engineering tool for computing numerical and mathematical modeling of complex phenomena involving the propagation of stress and strain fields in continuous media. In this paper a two-dimensional FEM model for analyzing sunflower seeds subjected at compression by axial and lateral directions is presented. For experimental validation of FEM model we made uniaxial compression tests on sunflower seeds, using a Hounsfield/Tinius Olsen unit for mechanical tests, H1KS model. The models used in this work highlight that the orientation of the seeds is very important. There are situations when it is desirable that the stresses to be higher (at shelling, grinding, pressing, etc.) or situations when it is desirable that the stresses to be smaller (at transport, storage, etc.).

Keywords: *Finite Element Method, Sunflower seeds, Experimental validation, Oil industry.*

INTRODUCTION

Modeling of stresses and strains propagation of sunflower seeds in the compression process is very important because it allows estimating the energy consumption required to their decortication and pressing for oil extraction. To develop the mathematical models of seeds behavior at compression it is necessary to know the physical and mechanical characteristics for kernel and the shell, respectively Young's modulus and Poisson's ratio. Figure 1 presents the morphological structure of the one of the most known type of oilseed, i.e. the sunflower seed, composed of the outer shell (seed vessel or pericarp), a thin peel (seed coat or endocarp) and the kernel. In recent years, experimental studies and research were conducted to determine the physical-mechanical properties of seeds. Thus, in their works, Khodabakhshian et al. (2010) and Khodabakhshian (2012), have deducted the mean comparison of elastic modulus of sunflower seed and kernel considering the influence of variety, moisture content and loading rate. It was found that the elastic modulus of sunflower seeds and their kernels decreased with increasing moisture content from 3% to 14% dry basis, and also with increasing the loading rate from 2 to 10 mm/min, regardless seed varieties and size categories. Average Poisson's ratio values of seeds from 0.28 to 0.35, 0.31 to 0.38, 0.33 to 0.42, were obtained for moisture levels ranging from 3% to 14%, respectively. Poisson's ratio increased from 0.281 to 0.357, 0.314 to 0.387 and 0.346 to 0.42 at loading rates of 2 to 10 mm/min. The Poisson's ratio and elastic modulus of sunflower seed and its kernel also exhibit a positive correlation with the size for all studied varieties, moisture content and loading rates.

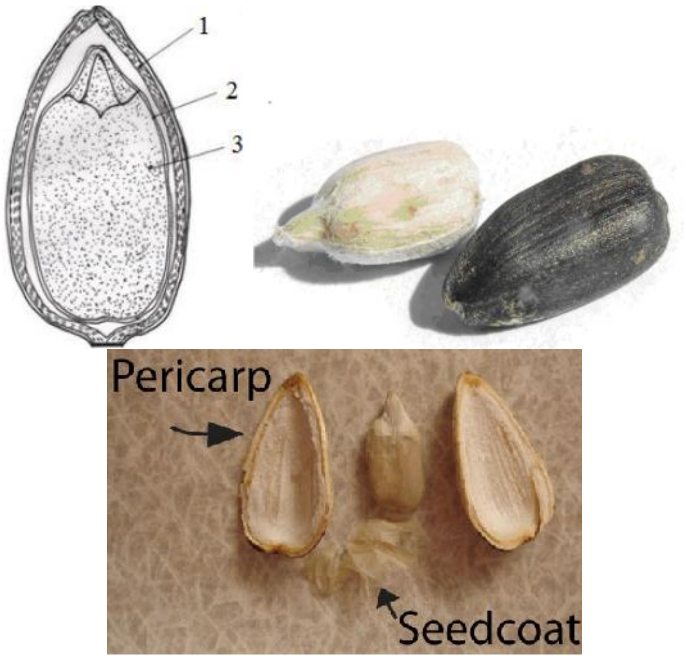

Fig. 1. Morphological structure of the sunflower seed
(1-pericarp; 2-endocarp; 3-kernel)

Gupta and Das (2000) studied the energy consumption for achieving the compression stress of sunflower seeds oriented vertically and horizontally. They concluded that the seeds loaded in a vertically absorbed more energy prior to breakage than those loaded in horizontally. Kernels loaded in vertically required less energy to breakage than those loaded in horizontally.
In their research, Jafari et al., (2010) present interesting experimental results, showing that the average compressive force required to cause seed breakage was 43.36 N for the vertical and 27.37 N for horizontal orientations of loading. Both the deformation and the energy absorbed at the breakage point of the seeds increased with increasing moisture content, regardless the orientation of loadings.
The major objective of this work is to discover and highlight the propagation of stresses and deformations in the kernel and shell of sunflower seeds during compression, aiming to optimize the energy consumption required for seed processing. The most advanced engineering tool for predicting the propagation of stresses and deformations is the Finite Element Method (FEM), widely used for computing numerical and mathematical modeling of complex phenomena involving the propagation of stress and deformation in continuous media.

MATERIAL AND METHODS

The mechanical properties of oilseeds can be determined using the uniaxial compression test. After their proper processing, the load-strain curves obtained by uniaxial compression test can provide important information regarding seed hardness, crushing strength, apparent modulus of elasticity, energy consumption for crushing, force and deformation at various compression moments etc. (ASAE Standards, 2000).
Table 1. presents the measured and calculated physical properties of the sunflower seeds used in this study.

Table 1. Physical properties of sunflower seeds

Dimensions, (mm)			Weight, m (g)	Volume, V (mm^3)	Average diameter, d_m (mm)	Coefficient of sphericity, ψ	Weight of 1000 seeds (g)
l	b	c					
10	6	3	0.06	100	6	0.55	58

Figure 2 shows the KS H1 Hounsfield/Tinius Olsen mechanical testing machine and the two orientations of seeds during compression tests. The characteristic force-displacement curves were obtained from these tests and the values of strain, force, energy consumption and slope to the breakage point of the shell were read at different moments during compression (Fig. 3).

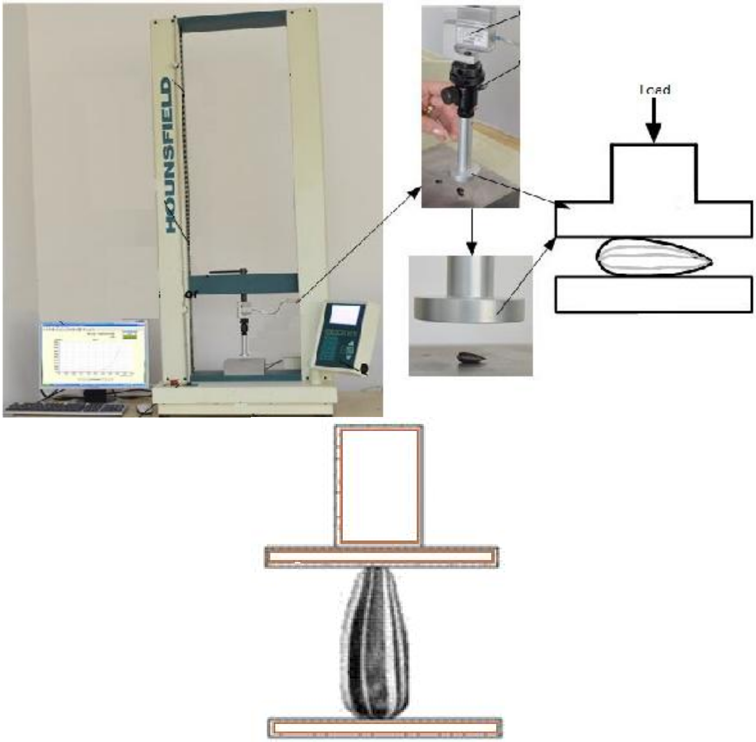

Fig. 2. The Hounsfield/Tinius Olsen mechanical testing machine, H1 KS model

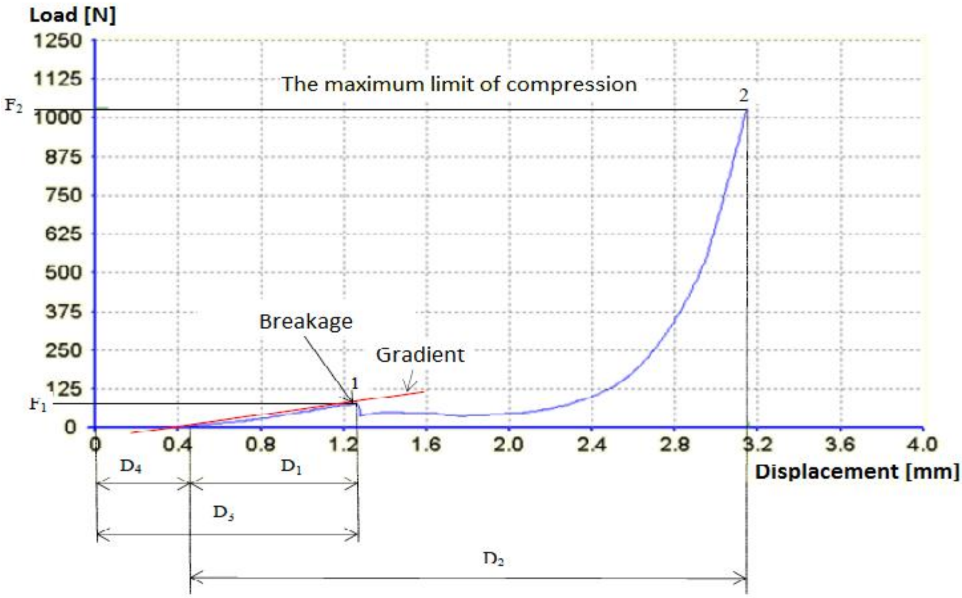

Fig. 3. Force-strain curve and its characteristic points

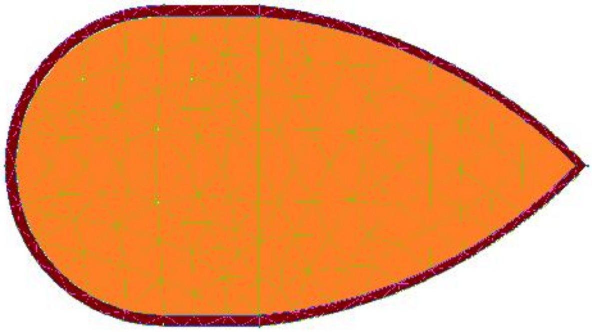

Fig. 4. Meshed model of sunflower seed

Seeds were placed and stabilized on the fixed plate of the machine and the speed of the movable plate was set at 1 mm/min. Force and strain values are given and saved by the software (Qmat) of the Hounsfield/Tinius Olse equipment. In point "1" on the force-strain curve (Fig. 3) occured the shell breakage and a sudden drop of the force can be observed. Beyond that point, the kernel further was subjected to compression, until reaching the maximum force of about 1030 N (in point "2") for 1 kN cell force. The results are used for the meshed model, which is required in the FEM modeling of the propagation of stresses and deformations in sunflower seeds. For numerical solving it was used the QuickField Finite Elements Analysis System, Release 6.0 software. Meshed model of the sunflower seed is shown in Figure 4. Young's modulus for shell had a value of 123 MPa, respectively 107 MPa for the kernel (Khodabakhshian, R., 2012). Poisson's ratio was 0.36 for the shell and 0.3 for the kernel (Khodabakhshian, R., 2012).

RESULTS AND DISCUSSION

Using the QuickField Finite Elements Analysis System, Release 6.0 software, were obtained the distributions of von Mises equivalent stresses and total displacements, for the analysed field of the complex model consisting of kernel and shell. The results obtained when placing the seed horizontally and vertically are presented in Figures 5, 6, and 7.

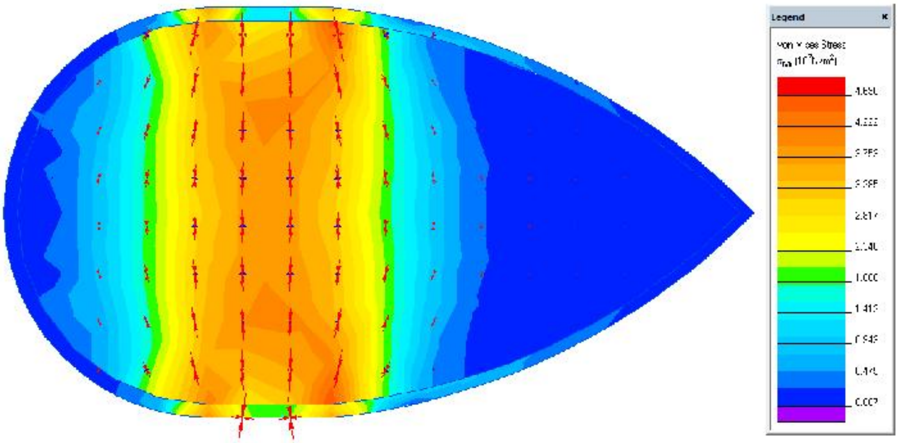

Fig. 5. Distribution of equivalent stresses in the sunflower seed oriented horizontally

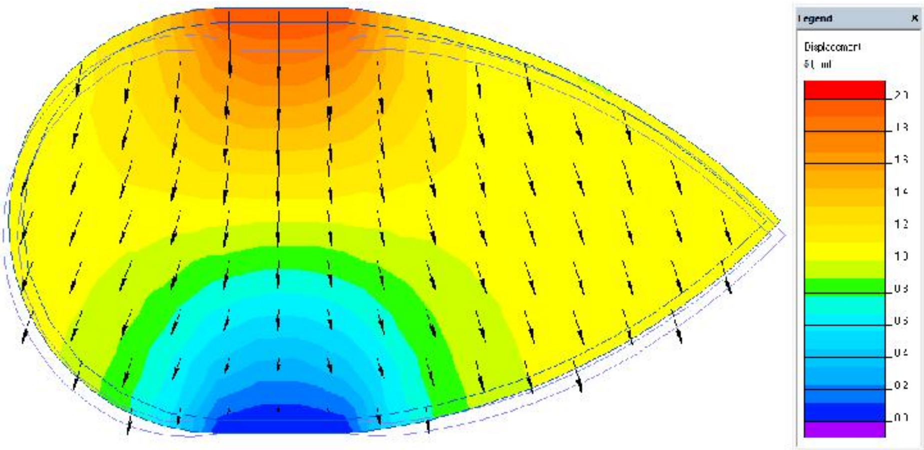

Fig. 6. Distribution of equivalent displacement in the sunflower seed oriented horizontally

In Figure 5. it can be noticed that the highest equivalent stress are found in the contact area between seeds and the plates of the testing machine. There, the maximum values are about 47 MPa. In the vertical-central area, the stress has values ranging between 20 MPa and 45 MPa. In this area, due to these stresses, are met the grinding conditions of seeds kernel. The surface of this area should be as high as possible. The stress in the shells is quite low (18-30 MPa).
Figure 6 shows the distribution of total displacements and how the seeds deform during loading. It can be observed that the highest displacements are found in the contact area between the mobile plane of the testing apparatus and they are oriented in vertical direction.

From Figure 7.. it can be seen that the highest equivalent stresses are found in the area near seed's top (100-123 MPa) which will thus favour seed breaking. It can also be observed that the highest displacements are oriented in vertical direction.

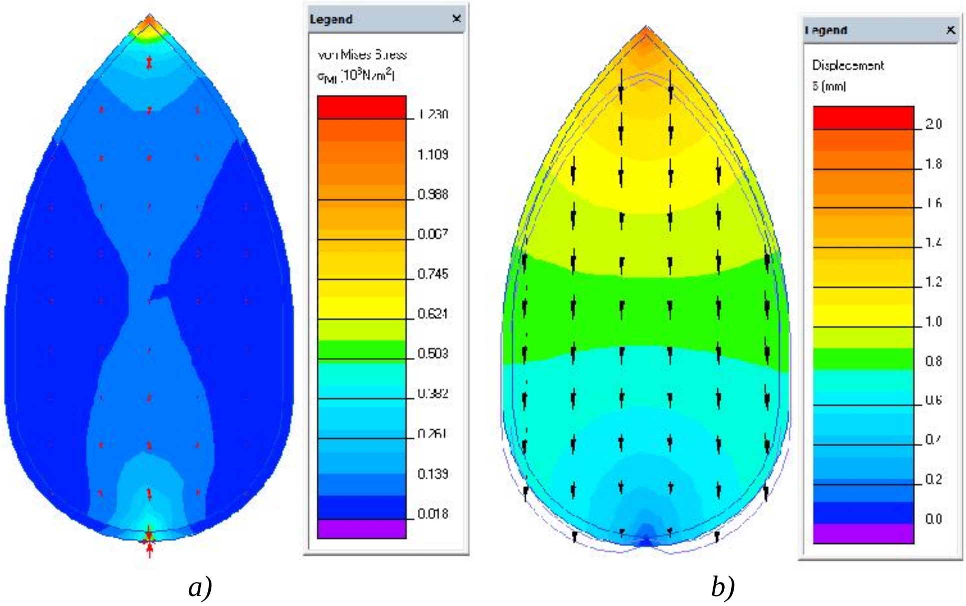

Fig. 7. Distribution of equivalent stresses (a) and displacements (b) when the sunflower seed is oriented vertically

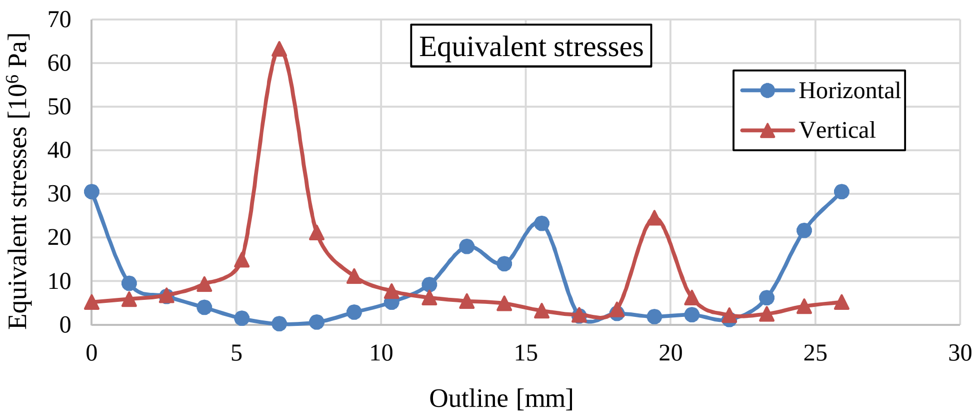

Fig. 8. Comparative analysis of equivalent stresses on the sunflower seed outline for both orientations

Figures 8 and 9 show the comparative analysis of equivalent stresses and total displacements on the sunflower seed outline for horizontal and vertical orientations. It is obvious that the stresses are more evenly distributed if the seed is placed horizontally. For vertical orientations, the highest equivalent stresses are concentrated on the top, respectively on the basis of the seed.

From Figure 8. it can be noticed that if the seed is placed horizontally, the distribution of stress is more uniform on its entire outline, favouring seeds transport and storage situations, but also a more uniform grinding of seed's kernel. Vertical orientation favours an easier breakage of seed shell (which is harder to achieve in practice).

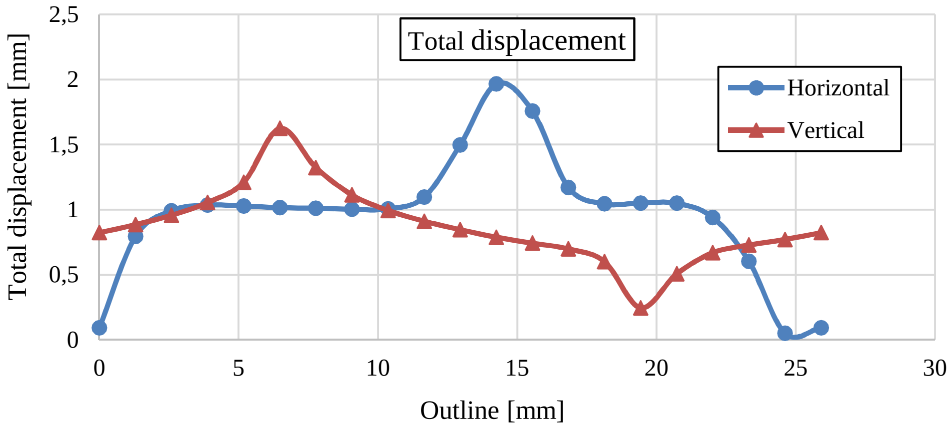

Fig. 9. Comparative analysis of total displacements on the sunflower seed outline for both orientations

CONCLUSIONS

The Finite Element Method is the most advanced engineering tool for computing numerical and mathematical modeling of complex phenomena involving the propagation of stress and displacement (strain) fields in continuous media. Thus, FEM can be an important tool for the modeling of stresses and strains propagation in the kernel and shell of sunflower seeds. The models used in this work highlight that the orientation of the seeds is very important. In some situations, it is desirable that the stresses are higher (at shelling, grinding, pressing, etc.) but there are also situations when the stresses should be smaller (during transport, storage, etc.). FEM models developed in this work facilitate the study of all situations to which the seeds are subjected in the technological processes.

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