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STRENGTH OF SHELL IN COMPRESSION TEST OF RAPESEED*

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Abstract. A sphere surrounded by a shell is deformed on both sides and assumes the shape of a barrel when compressed between two parallel plates. Further cotyledons deformation causes shell filling, leads to increase of the shell stress till its disruption. The approximated stress of the shell surrounded the compressed rapeseed can be calculated from the Lamé equation. A rapid increase of surface area for deformation of seed over value $l=0.3$ correctly reflects damage of wet rapeseeds in the range of large deformation. The above method enabled the interpretation of the force-deformation curve for large deformation of non-elastic wet rapeseeds, where mechanical strength is mainly connected with the resistance of seed shell to tension. The modulus of elasticity determined in compression tests of whole seeds achieved value in the range 125-131 MPa (for the moisture level of 17 %). and 174-180 MPa (for the moisture level of 14 %).

Keywords: rapessed, strength of shell, compresion test

INTRODUCTION

The influence of moisture content and thermal properties of seed [7,10,13,15] and shell [6,8,9,12] were evaluated by many researches. With the increase of moisture content rapeseed become very plastic and even slight forces, which do not produce negative biological results, may cause considerable deformations of shape. Davison *et al.* [1] elaborated a theoretical stress model of rapeseed, which based on some simplifying assumptions. Using the above model and previously reported experimental work [2], a value for the isothermal compressibility coefficient of the cotyledons was obtained. This value compared with that for water and vegetable oil tends to support the validity of the model and the assumption that the cotyledons act mainly as a liquid within the seed shell. This results suggested that the compressibility of cotyledon in relation to the large shape deformation is low and in geometrical calculations can be ignored.

ASSUMPTIONS

The description of the shape deformations of the rapeseed compressed between parallel plates accomplishment requires the application of some simplifying assumptions:

- the rapeseed is a sphere surrounded by elastic shell;
- the compressibility of the rapeseed cotyledon is small and it can be assumed that the volume is constant;
- in geometrical calculations the shell thickness in relation to the seed diameter is small and can be ignored;
- the rapeseed compressed between parallel plates assumes the circular shape of barrel.

Using the assumption of constant volume, make it possible to determine the changes of surface area describing the spherical body being compressed between parallel plates. When the deformations are slight the sphere does not lose its shape and hence it was assumed that the lateral surface of the barrel

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created by compressing opposite cups of sphere will also be spherical in its shape [4,5,12,14,15]. In previous reports, the description of shape deformations as the main aim of rapeseed model compressed between parallel plates was elaborated [4,5].

METHODS

A sphere surrounded by a shell imitating a rapeseed is deformed on both sides and change the shape into a barrel when compressed between parallel plates. When the deformation is slight the sphere does not lose its shape and hence it was assumed that lateral surface of barrel created by compressing the opposite cups of sphere will also be spherical in its shape. In initial phase of compression of moist rapeseed only a shape deformation of viscoelastic seed cotyledon was observed. Further cotyledons deformation causes shell filling, leads to the shell tensions till its disruption.

Because of the way compression was applied between two parallel plates the highest level of stress that tension the shell appeared at the longest barrel circumference. The shell strain can be estimated by calculating the increase of diameter D of barrel during seed compression.

$$\varepsilon_c = \frac{\Delta D}{D}. \qquad (1)$$

The problem consist in determining the diameter of barrel which will be formed on compressing the sphere between two parallel plates and which will be deformed by the value of l. The barrel surface area is created by rotation of a curve described by the equation of circle (Eq. (2)) with radius R and the coordinates of circumcentre $(0, s')$ (Fig. 1):

$$y = R^2 - x^2 + s'. \qquad (2)$$

The barrel diameter can be determined using the assumption of constant volume of low compressibility spherical body deformed its shape into a barrel:

$$\frac{1}{6}\pi d^3 = \frac{1}{12}\pi (d-l)(2D^2 + a^2) \qquad (3)$$

Transforming the following formula was obtained:

$$D = \left(\frac{d^3}{d-l} - ld - \frac{1}{6}l^2\right)^{1/2}. \qquad (4)$$

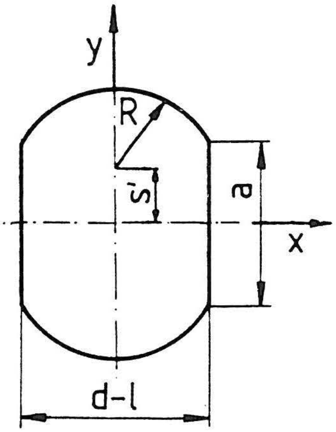

Fig. 1. Barrel shape in cross section.

The approximated value of stress of the shell surrounded compressed barrel can be calculated from the Lamé equation concerning circumference stress σc, radial stress σr, and radial strain Δr of a pipe subjected to the influence of inner and outer pressure p_i and p_o (Fig. 2). Unsubstantial thickness g of shell and no outer pressure allow to reduce the Lamé equation into the following form:

$$\sigma_c = \frac{p_i(2r^2 + 2rg + g^2)}{2rg + g^2} \qquad (5)$$

$$\sigma_r = -p_i \qquad (6)$$

$$\Delta r = \frac{r\Delta p_i}{E}\left(\frac{(r+g)^2 + r^2}{(r+g)^2 - r^2} + \nu\right). \qquad (7)$$

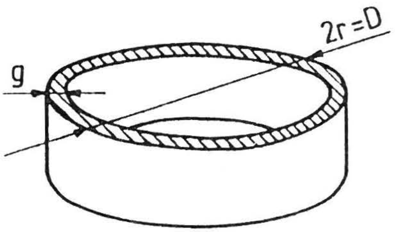

Fig. 2. A pipe subjected to inner and outer pressure p_i and p_o.

Substituting $r=0.5\,D$ into Eq. (7) we can calculate the modulus of elasticity E_L of the rapeseed shell:

$$E_L = \frac{2D\Delta p_i}{\Delta D}\left(\frac{(0.5\,D+g)^2+(0.5\,D\,)^2}{(0.5\,D+g)^2-(0.5\,D)^2}+\nu\right) \tag{8}$$

However, the value of inner pressure increment p_i and the limits of the barrel diameter increase ΔD are not known. In initial phase of moist rapeseed, compressed between parallel plates, only a shape deformation of viscoelastic seed cotyledon was observed. This process has been illustrated in Fig. 3.

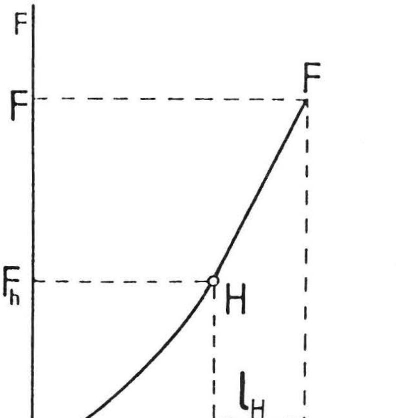

Fig. 3. Characteristic sections and values of the force-deformation curve.

Further cotyledons deformation causes shell filling, and when this process completed, an increase of the inner pressure which, in turn, leads to the shell tensions from the point H till its disruption, see point F in Fig. 3.

Assuming that during seed shell tensions the pressure necessary for shape deformation is constant, the increase of pressure resulting in the shell disruption can be determined from a simple relation:

$$\Delta p_w = \left(\frac{F}{A} - p_p\right) - \left(\frac{F_h}{A_h} - p_p\right) \tag{9}$$

that takes the following form:

$$\Delta p_w = \frac{4}{\pi}\left(\frac{F}{a^2} - \frac{F_h}{a_h^2}\right). \tag{10}$$

The increase of diameter D in the Eq. (8) should be substituted by the values from the range of shell tensions, i.e., the increase of deformation $\Delta l = l_H$.

Hence, the increase of the barrel diameter is:

$$\Delta D = D - D_h \tag{11}$$

where D has been calculated for total deformation l up to shell disruption, and D_h calculated for deformation l_h for point of initial tension of a shell.

Hence using Eqs (8), (10) and (11) we can calculate the modulus of elasticity of the shell E_L from the following equation:

$$E_L = \frac{4D_h}{\pi\,(D-D_h)}\left(\frac{F}{a^2} - \frac{F_h}{a_h^2}\right)\cdot \left[\frac{(0.5D_h+g)^2+(0.5D_h)^2}{(0.5D_h+g)^2-(0.5D_h)^2}+\nu\right] \tag{12}$$

Substituting characteristic values l, l_h, F and F_h, taken form the force-deformation curve obtained in compression tests of rapeseeds and the values: a, a_h - the diameters of contact area as so values D and D_h calculated using Eq. (4), it is possible to determine the modulus of elasticity of seed shell E_L.

The above method enabled the interpretation of the force-deformation curve for large deformation of non-elastic wet rapeseeds where mechanical strength is mainly connected with the resistance of seed shell to tensions.

Because we used some simplifying assumptions to determine modulus of elasticity of rapeseed shell we decided to check it in another way.

In the previous papers [3,5] a method of measuring the resistance to tension of seed shell at various moisture contents was elaborated. The method applied a tension test, which can be interpreted according to the Hook's equation. The test requires cutting a sample with a constant section area. This original method used in the determinations of rapeseed shell resistance allows for avoiding the problem of sample fixing in the holders. It is possible thanks to the way of the sample stripe cutting from the shell for the tension test. Cutting the seed with two parallel blades we get a disk; after two halves of the seed leaves are taken out we obtain a stripe of the shell in the shape of a band.

The sample section area was determined as the area set out by the stripe width (1 mm) equal to the distance between the cutting blades and the shell thickness were determined for all of the studied moisture levels. The band was disrupt by means of two parallel cylinders (Fig. 4) in order to obtain a sample consisting of two parallel stripes of the shell. The initial length of the sample was recorded.

Determination all of above mentioned values allows for calculating tension stress and the modulus of elasticity of seed shell on the basis of the Hooke's equation.

The tension tests were also performed on the INSTRON machine. The sample was placed on two parallel steel hooks with the diameters of 0.6 mm. The deformation velocity was 5 mm/min, and the force-displacement curve was obtained for each sample. The characteristic parameters were read and modulus of elasticity was calculated.

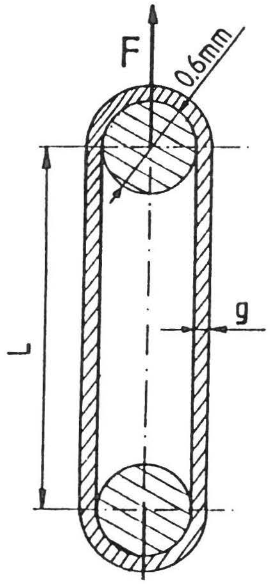

Fig. 4. Rapeseed shell in tension test.

RESULTS

Compression tests of rapeseeds

Compression tests of seeds and also seed shell tensions tests were conducted on Jupiter, Ceres and Jantar rape varieties according to both of the elaborated methods.

From the force-displacement curve it is possible to read and determine many values connected to mechanical properties. Using some of geometrical dependencies of compressed seed and values reads from force-displacement curve the rapeseed shell modulus of elasticity was calculated. The values necessary to calculate modulus of elasticity of rapeseed shell are showed in Table 1.

For moisture content lower than 14 % there was no stress in the shell caused slight

Table 1. Values necessary to calculate the modulus of elasticity of rapeseed shell (Jupiter, Jantar)

Value [unit]	Varieties			
	Jupiter		Jantar	
	Moisture content (%)			
	14	17	14	17
F [N]	10.71	9.49	11.02	9.82
Fh [N]	4.12	3.43	4.28	3.82
l [mm]	0.77	0.82	0.77	0.83
lh [mm]	0.39	0.50	0.41	0.45
a_2 [mm^2]	2.97	2.99	2.99	3.21
a_h [mm^2]	1.47	1.90	1.55	1.69
D [mm]	2.04	2.09	2.05	2.10
D_h [mm]	1.86	1.72	1.84	1.86
E_L[MPa]	171.21	125.71	180.76	130.69

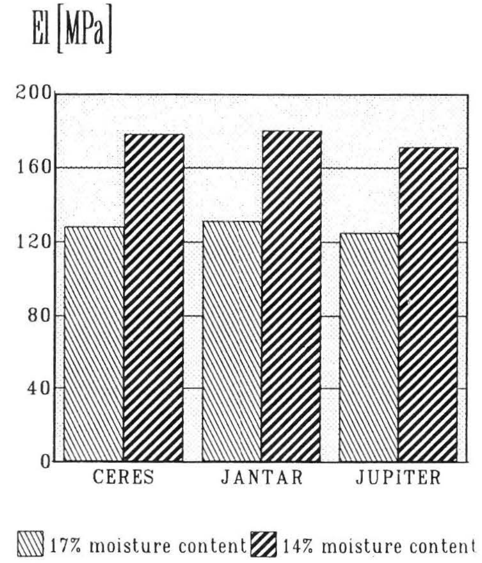

Fig. 5. Modulus of elasticity of rapeseed shell in compression tests.

changes in the shape of compressed seed. Than it was possible to calculate modulus of elasticity of shell for 14 % and 17 % moisture content only. Similar values for another varieties were observed.

Tension tests of rapeseed shell

The method used allows for registering the force-displacement curve while tension a double shell stripe till it break. The maximum values of the forces observed during shell rupture and modulus of elasticity in the full range was presented in previous paper [4]. The modulus of elasticity was only correctly determined for the range of elastic deformations (Fig. 6). It allowed for observing a definitely negative influence of the moisture contents on the values of the modulus of elasticity that decreased from 298 MPa to 167 MPa for Ceres variety, from 344 MPa to 171 MPa for Jantar variety and from 256 MPa to 163 MPa for Jupiter variety. It was also noticed that the rapeseed shell of the Jantar variety was the strongest among the studied varieties.

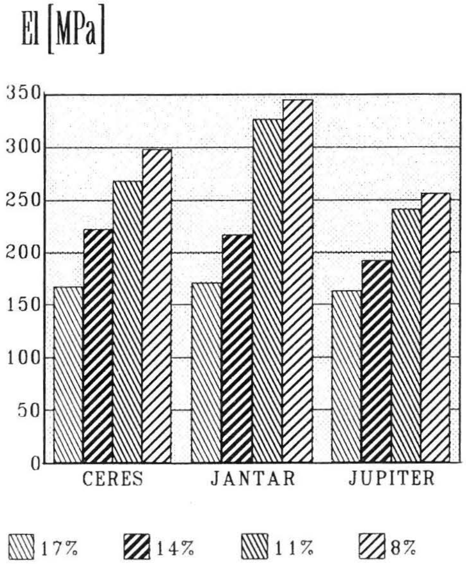

Fig. 6. Modulus of elasticity of rapeseed shell in tension tests.

Using the theoretical model, the Lamé equation and some characteristic value reads from the force-displacement curve of compressed seed, a modulus of elasticity of rapeseed shell achieved higher values then determined in tension tests.

Using some simplifying assumptions explain a higher value of rapeseed shell modulus of elasticity reached in compression tests, but the same decreasing tendency observed for all varieties with increase of moisture content expected that the elaborated method proof influence of the shell strength on mechanical resistance of whole rapeseed compressed for large deformation.

CONCLUSIONS

1. Cotyledons deformation caused shell filling and increase of shell tension up to its disruption.

2. Using a simple model describing geometrical relations of the spherical body surrounded by an elastic shell and Lamé equation, made it possible to determine tension strength, stress and modulus of elasticity of the rapeseed shell in compression tests of whole seed.

3. The above method enabled the interpretation of the force-deformation curve for large deformation of non-elastic wet rapeseeds, where mechanical strength is mainly connected with the resistance of seed shell to tensions.

4. The modulus of elasticity determined in compression tests of whole seeds higher than in tension tests achieved value in the range 125-131 MPa (for the moisture level of 17 %) and 174-180 MPa (for the moisture level of 14 %).

5. The modulus of elasticity achieved in tension tests decreases with the increase of moisture contents in the range from 256-344 MPa (for the moisture level of 8 %) to 163-171 MPa (for the moisture level of 17 %).

6. The elaborated method of measuring the seed shell modulus of elasticity allows for the application of the tension tests in which the sample does not have to be fixed in the holders.

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