MECHANICAL PROPERTIES
OF RAPESEED

E. Davison  
School of Engineering  
University of Guelph  
Guelph, Ontario

F.J. Middendorf  
School of Engineering  
University of Guelph  
Guelph, Ontario

W.K. Bilanski  
Member CSAE  
School of Engineering  
University of Guelph  
Guelph, Ontario

INTRODUCTION

Rapeseed has been described as Canada's "Cinderella" crop. Due to its excellent growth characteristics, it can be planted in areas where weather conditions are not favorable to other oilseed crops. It is also an excellent alternate crop for the wheat farmer because his existing machinery will handle rapeseed; hence, additional capital investment is not required. In 1971, some 54,000 farmers produced 95 million bushels of rapeseed valued at $206 million. Rapeseed oil is used for various purposes such as cooking oil, salad dressing and margarine. A further bonus exists in that the remains, after oil extraction, can be processed into nourishing meal for cattle, hogs and poultry. Whole rapeseed contains about 25% protein and 1,300 cal/kg, and oil-extracted rapeseed meal contains 35-38% protein and 850 cal/kg.

Removing the hulls from rapeseed reduces the undigestible fibre content of the meal by 10%. Development of an economically and technically feasible system for dehulling rapeseed would facilitate the substitution of rapeseed for soybeans. This would provide a principle source of protein in an inexpensive high-quality commercial feed.

Objectives

Very little is known about the mechanical behavior of rapeseed when it is subjected to an external load. Such information is necessary for the rational design of rapeseed milling or crushing machinery and the selection of roller surface material in particular. This investigation was directed towards the determination of the following properties:

(i) The maximum compressive strength of the rapeseeds at various moisture contents;
(ii) The apparent modulus of elasticity of rapeseeds at various moisture contents; and
(iii) The stress characteristics and Young's modulus of elasticity of the rapeseed shell.

EXPERIMENTAL PROCEDURES

Rapeseeds (Brassica campestra cv. Span) were studied at 7.2, 10.6, 13.6, and 17% moisture (WB). This was achieved by placing 2.5 kg of grain into each moisture-conditioning bottle and mixing by tumbling for 24 h. Moisture content of the rapeseed was determined before and after bottling in the moisture conditioning bottles, using the procedure recommended by the Association of Agricultural Chemists (2). The grain was then packed into 1-kg plastic bags, sealed and refrigerated at 4°C until used.

Compression Tests

Preliminary compression tests showed that seed orientation with the crease side down gave the most consistent results. To facilitate positioning and holding rapeseeds (avg diam, 1.4 mm), each rapeseed was cemented onto a 1 x 1 x 0.25-cm flat glass plate. Cementing prevented movement of the seed during testing. It also guaranteed consistency of position for each kernel and prevented deformation of the kernel, on the surface of the lower glass plate. Strain gauge cement was used because it is transparent and hardens quickly, thus minimizing changes in rapeseed moisture level before testing. In addition, the physical properties of this thin cement layer are such that its contribution to base deformation error is negligible. Glass was found most suitable as a base material because its transparency allowed specimen contact area to be measured, and also minimized contact stress deformation errors. To determine the contact area during compression, a thin layer of carbon was placed on the glass support plate by means of a candle. The area from which the carbon was removed by the compressed kernel represented contact area.

A random sample consisting of 15 kernels was taken at each moisture level.

The diameter of each kernel was measured along three axes, and the average diameter and standard deviation were calculated. The loading device (Instron, Model TM with automatic chart recording of load and deformation) was set at a speed of 0.05 cm/min to simulate a static load. Each individual kernel was compressed until failure, and the load deformation behavior during compression recorded automatically by the Instron (quoted machine accuracy less than 1% error).

Elasticity Tests

Elasticity and compression testing procedures differed in the method of loading. In the elasticity test, each kernel was loaded and unloaded between 0 and 3.0 N for a total of four cycles. This force did not fracture the kernel. Resultant deformation values from 20 kernels chosen randomly at each moisture level were averaged. These average values were used to plot the loading and unloading curves of Figure 3 where, for purposes of comparison, the unloading curves are shown superimposed onto the loading curves. Only unloading data were used to calculate the elastic modulus for each kernel since this represents more closely the elastic behavior. The elastic modulus values for 12 randomly chosen kernels at each moisture level for each of four cycles were then averaged. To check the extent and effect of possible backlash in the machine, actual deformation values of the kernels were also measured by a micrometer dial gauge for comparison with the automatically recorded values. This gauge was mounted in parallel with the load cell, so that deformation could be read directly. Deformation readings for each kernel were checked at 0.49 N and 2.45 N compression and load relaxation (unloading).

Rapeseed Shell in Tension

Narrow strips were cut from the shell of whole kernels of 7.2% moisture content and both ends of each strip were glued onto separate pieces of glass. After
the glue had hardened, this glass test fixture was mounted in specially designed jaws (Figure 1) and subjected to tensile loads in the Instron machine. The gauge length \( L \), consisting of the glue-free centre portion of the specimen, was checked by means of a feeler gauge. The fracture cross sectional area was measured using a microscope with micrometer eyepiece.

**RESULTS AND DISCUSSION**

**Rapeseed Load Deformation Characteristics**

Results of the rapeseed compression tests up to rupture load for four moisture levels are given in Figure 2. Observed rupture phenomena (bulging and bursting) suggest that the rapeseed kernel consists of a fairly strong shell and a soft fluid-like interior. It is postulated that during the compression test the internal pressure increased because of decreasing volume until the shell ruptured. An almost linear relationship existed between the load and the deformation. In every test, there was a sharp drop-off in the force after the breaking point was reached. Further deformation caused the force to increase again, but the load-deformation curve was no longer smooth. The curve beyond the rupture point was not considered an indication of the kernel's strength but rather of the force required to crush the seed after rupture was initiated and is not included in Figure 2. The load deformation curves varied slightly from one kernel to another; each point in Figure 2 represents the average of 15 tests.

**Apparent Modulus of Elasticity of Individual Rapeseed Kernels**

Stress analysis for a composite convex body, such as an intact rapeseed, is complex. Therefore, most information in the literature regarding such analysis is expressed in terms of force, deformation and time. The difficulty arises when attempts are made to express force-deformation data for the composite convex body in terms of stress-strain or other parameters which can then be used in subsequent mathematical treatment. The level of deformation has to be controlled so that the linear portion of the force-deformation or stress-strain curve is not exceeded.

Mohsenin (5) found that for wheat, loading and unloading for more than one cycle did not alter recovered and residual deformation. A typical wheat kernel exhibited no appreciable additional plastic deformation and its behavior approached that of an elastic body after the second loading cycle.

Hertz (3) proposed a solution for contact stresses in spherical elastic bodies. Mohsenin (5), Arnold and Roberts (1), and Kozma and Cunningham (4) reviewed Hertz' method and applied it to agricultural products, using the relationship

\[
E = \frac{0.338 k^{3/2} F (1 - \mu^2)}{D^{3/2}} \left( \frac{1}{R} - \frac{1}{R_1} \right)^{1/2}
\]

where:
- \( E \) is the modulus of elasticity
- \( k \) is the force constant
- \( F \) is the load
- \( D \) is the diameter of the body
- \( R \) and \( R_1 \) are the radii of the contacting bodies.
TABLE I  APPARENT MODULUS OF ELASTICITY AT FOUR MOISTURE LEVELS

<table>
<thead>
<tr>
<th>Moisture content (%)</th>
<th>Apparent modulus of elasticity (kN/cm²) mean (psi)</th>
<th>SD (kN/cm²)</th>
<th>Coefficient of variance (%)</th>
<th>95% confidence of apparent modulus of elasticity (kN/cm²)</th>
<th>Percentage error of apparent modulus of elasticity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6</td>
<td>38.540</td>
<td>5.58 x 10⁴</td>
<td>4.001</td>
<td>10.367</td>
<td>8.8826</td>
</tr>
<tr>
<td>13.6</td>
<td>32.469</td>
<td>4.7 x 10⁴</td>
<td>4.440</td>
<td>13.682</td>
<td>9.807</td>
</tr>
<tr>
<td>17.7</td>
<td>32.411</td>
<td>4.69 x 10⁴</td>
<td>3.114</td>
<td>9.510</td>
<td>6.865</td>
</tr>
</tbody>
</table>

Compression loading

De = elastic deformation

Dr = residual deformation

Dt = total deformation

Figure 3. Load cycling characteristics of rapeseed kernels at a moisture content level of 10.6 (elasticity tests).

where \( \mu \) can be assumed = 0.4 (7), approximately midway between steel (0.3) and soft rubber (0.49).

The following conditions must be met in order to use the above equation:
1. Contacting materials must be homogeneous, isotropic and elastic.
2. Loads must be static.
3. The contact stresses must vanish at the opposite ends of the contacting bodies.
4. Contacting surfaces must be smooth in order to eliminate tangential frictional forces.
5. Radii of curvature of the contacting bodies must be large compared with the radius of the contact surface boundary.
6. Hooke's law must hold.

Equation (1) was used to evaluate an apparent elastic modulus for the rapeseed kernel with the following considerations taken into account.

A typical loading-unloading curve (Figure 3) shows that part of the total deformation \( D_T \) is recovered and therefore is considered elastic deformation \( D_E \); part is residual and is termed residual deformation \( D_R \). Load cycling showed no significant change in the elastic deformation, whereas the value of the residual deformation gradually decreased, usually reaching a constant value in the third cycle. Subsequent to the second cycle, the rapeseed was considered to behave in a manner similar to a homogeneous and isotropic material. Loads applied at the very low velocity of 0.05 cm/min were considered to be essentially static loads. The contacting bodies (plate and rapeseed) were large with respect to the measured area of contact between rapeseed and flat steel plate. The localized contact stress at the bottom of the kernel was negligible compared to that at the top plate due to the increase in kernel contact area at the bottom plate. The contacting surfaces were considered sufficiently smooth, so that tangential frictional forces could be neglected.

Hertz (3) specified that the ratio of the radius of the circle of pressure to the radius of the spherical body being loaded be less than 1:10. That criterion did not hold in this research. Therefore, the revised theory of Mohsenin (5) was applied. Knowledge of Poisson's ratio is required to calculate the modulus of elasticity. This was not available for rapeseed. Poisson's ratio was found to be about 0.4 for dry shelled corn (7) and values between 0.38 and 0.4 for wheat were reported by Narayan (6). It was assumed that the value for rapeseed was about the same magnitude and was chosen to be 0.4. The modulus calculated according to equation (1) could, at best, be termed an "apparent modulus of elasticity of individual rapeseed kernels" since it is a property of a composite material. Elasticity values calculated from equation (1) decreased with increase in moisture content of the rapeseed (Figure 4). Table I shows the mean values of the calculated apparent modulus of elasticity and the related statistical data for the different moisture levels.

Rapeseed Shell Failure Under Tension

Results of the tension test of rapeseed shells are shown in Table II. The calculated modulus of elasticity in tension varied considerably. This could have been caused by such uncontrollable factors as damaged hull within the gauge...
TABLE II  APPROXIMATE MODULUS OF ELASTICITY FOR RAPESEED SHELL IN TENSION

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Area (mm²)</th>
<th>Load (N)</th>
<th>Stress (N/mm²)</th>
<th>Strain (mm/mm)</th>
<th>EShell (kN/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.350 x 10⁻³</td>
<td>0.555</td>
<td>59.33</td>
<td>4.84 x 10⁻²</td>
<td>122.6</td>
</tr>
<tr>
<td>2</td>
<td>10.177 x 10⁻³</td>
<td>0.431</td>
<td>42.76</td>
<td>2.26 x 10⁻²</td>
<td>187.3</td>
</tr>
<tr>
<td>3</td>
<td>18.535 x 10⁻³</td>
<td>0.853</td>
<td>46.29</td>
<td>1.15 x 10⁻²</td>
<td>402.1</td>
</tr>
<tr>
<td>4</td>
<td>15.030 x 10⁻³</td>
<td>0.686</td>
<td>45.7</td>
<td>1.67 x 10⁻²</td>
<td>277.53</td>
</tr>
<tr>
<td>5</td>
<td>13.36 x 10⁻³</td>
<td>0.785</td>
<td>58.84</td>
<td>2.62 x 10⁻²</td>
<td>217.7</td>
</tr>
<tr>
<td>6</td>
<td>9.14 x 10⁻³</td>
<td>0.574</td>
<td>62.76</td>
<td>6.71 x 10⁻²</td>
<td>94.1</td>
</tr>
<tr>
<td>7</td>
<td>19.29 x 10⁻³</td>
<td>0.588</td>
<td>36.5</td>
<td>1.00 x 10⁻²</td>
<td>305.0</td>
</tr>
<tr>
<td>8</td>
<td>30.60 x 10⁻³</td>
<td>1.423</td>
<td>46.48</td>
<td>3.40 x 10⁻²</td>
<td>136.3</td>
</tr>
<tr>
<td>Avg values</td>
<td></td>
<td></td>
<td>49.03</td>
<td>2.96 x 10⁻²</td>
<td>217.7</td>
</tr>
</tbody>
</table>

length $L$, presence of slight curvature of the sample in the horizontal or vertical direction, failure of the cement to hold the sample tightly, soft regions and other internal and external irregularities in the material. Therefore, the calculated value is an approximate modulus of elasticity in tension.

Brittle-type fracture of the shell is indicated by the straight line load extension plot up to the point of fracture (Figure 5). There is minimal indication of plastic deformation in Figure 5 and the scanning electron micrograph (Figure 6) tends to reinforce this observation.

The average value of all eight tests was calculated (Table II) and compared with known materials. It was found that the calculated tensile modulus of rapeseed shell (0.218 X 10⁶ N/cm²) does not reach that of glass fibre (7.58 X 10⁶ N/cm²) and wood (7.24 X 10⁶ N/cm²), whereas steel (20.68 X 10⁶ N/cm²) is approximately 100 times higher.

CONCLUSIONS

The following conclusions were drawn concerning the physical and mechanical properties of rapeseed:

1. Maximum compressive strength (Figure 2) of whole rapeseed kernels decreased with increasing moisture content. Average values of 13.73 N/kernel at 7.2% moisture (WB) to 9.81 N/kernel at 17% moisture (WB) were obtained. (Confidence intervals are given in Table I.)

2. The average rapeseed kernel deformed approximately 20% up to rupture of the shell when loaded at a rate of deformation of 0.05 cm/min (Figure 2).

3. Apparent modulus of elasticity of individual rapeseed kernels decreased with increasing moisture content,

4. Approximate modulus of elasticity for a rapeseed shell in tension was determined to be 2.18 X 10⁵ N/cm² (316 x 10⁵ psi).

SUMMARY

The apparent modulus of elasticity of individual rapeseed kernels, *Brassica campestra* cv. Span, was determined using Hertz' solution as modified by Mohsenin. This apparent modulus of elasticity decreased with increasing moisture content. Values of 70.1 x 10⁵ Newtons per square centimeter (10.18 x 10⁴ pounds per square inch) at 7.2% moisture (wet basis) to 32.4 x 10³ Newtons per square centimeter (4.7 x 10⁴ pounds per square inch) at 17% moisture (wet basis) were obtained.

The rupture strength of rapeseeds in compression was found to range from 13.73 Newtons per kernel at 7.2% moisture (wet basis) to 9.8 Newtons per kernel at 17% moisture (wet basis). The method of determination produced reproducible results and was convenient to use.

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REFERENCES


