SHEAR STRENGTH OF WHEAT STRAW

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This study was undertaken to determine the shear strength of wheat straw. A shearing apparatus used for soil shear tests had been modified to determine the shear strength of straw at different moisture levels and at different shearing speeds. Two blade edges, a 90° straight edge and a 30° bevel edge were used to shear the wheat straw.

INTRODUCTION

Minimum and zero tillage practices are being adopted by farmers in the Prairie region of Canada. The main problem associated with proper seed placement under these tillage practices is the density and toughness of crop residue. In order to place the seed at a proper depth, the crop residue must be cut by coulters and furrow openers. Tests by the Prairie Agricultural Machinery Institute of no-till drills (PAMI 1979a,b) have indicated that under heavy crop residue, the disc openers were unable to cut through the surface residue resulting in seed being placed either on the residue or on the soil surface. In lighter crop residue and in softer soil, the straw was pushed to the bottom of the furrow without being cut.

Literature studies reveal that no work has been reported on cutting resistance of crop residue or the shear strength of straw which is an important parameter in designing seeding machines for minimum and zero tillage practices. Researchers have concentrated their work on improvement of the design of the cutting edge to chop forage crops or to determine its energy requirements. A study was, therefore, undertaken to determine the shear strength of wheat straw as affected by its moisture content.

LITERATURE REVIEW

Considerable work has been reported on the power requirements of machines that cut or chop forage crops. However, these do not relate to the shear strength of straw but provide information on the effect of various test parameters such as loading speed, moisture content of stalk and sharpness of the blade on the power requirement.

Chancellor (1958) studied the effect of blade angle, blade sharpness, moisture content of forage crops, and impact on energy requirement. He concluded that the force and energy values increased with the blade dullness and only after the blade angle exceeded 30°. If the blades were suitably beveled and sharpened, the most significant mechanical factor was the aggregate thickness of the material being cut. Lilijedhal et al. (1961) concluded that the moisture content had very little effect on shear energy with a sharp blade. As the blade became dull, the effect of the moisture was more pronounced.

Halyk and Hurlburt (1968) computed the ultimate tensile strength of alfalfa stems on the basis of the maximum load carried by the test piece taken from different sections of the single plant. Test results showed a considerable variation in the ultimate tensile strength of the test specimens. Both the ultimate tensile strength and ultimate shear strength were found to be inversely proportional to moisture content and directly proportional to dry matter density.

McRandal and McNulty (1978) while studying the process of impact cutting for optimum design of rotary mowers, concluded that the minimum blade velocity for satisfactory impact cutting was independent of blade type and was approximately 20 m/sec for both grass and oat straws. Energy required in cutting grass and oat straw decreased by approximately 25% as blade velocity was increased from 20 to 60 m/sec.

McRandal and McNulty (1980) emphasized shear properties of various grasses because of their importance to the cutting operation in forage crop harvesting. The influence of shear velocity and the blade bevel angle were also investigated. The results indicated that the resistance to penetration was dependent on blade bevel angle for both leaf and stem, and all mechanical properties were independent of shear velocity except the stem resistance to penetration.

Prince et al. (1958) reported that the energy requirement for cutting forage crops decreased more rapidly than the decrease in cross-sectional area. This effect they considered as a measure of decrease in toughness of fiber along the length of stem. The energy required to cut the individual stalk increased both with stalk diameter and thickness of leading knife edge.

Since the practice of minimum tillage has increased in recent years, little work has been reported from the engineering viewpoint. The above references do not deal directly with the shear resistance of straw; however, the following may be concluded from the review of these papers:

(1) There is little or no effect of speed on the energy required to cut the forage crops.
(2) At very high moisture content ultimate tensile strength and ultimate shear strength are inversely proportional to the moisture content and directly proportional to the dry matter density.
(3) Energy required to cut forage crops was found to be inversely proportional to the sharpness of blade.

EXPERIMENTAL APPARATUS AND PROCEDURE

Shear Apparatus

A soil shear apparatus with modifications made to the shear box was used in this experiment to measure the shear strength of wheat straw (Fig. 1). The shear box had two rectangular metal pieces sitting one above the other. The piece at the bottom was movable whereas the top one was stationary. The bottom piece was driven to and fro by the screw fixed to the rear end of the box. Different speeds of shear box were obtained by changing the gear ratios. A strain gauge load cell from Interface, Inc. (Model SSM-250) was used to measure the force required to shear the straw.

Experimental Procedure

The straw pieces were held against the cutting edge by another small rectangular metal piece. The metal piece was tight-
Shear strength and moisture content relationship

Tables I and II show the shear strength of straw at different moisture contents for a 90° and for a 30° blade. The maximum shear strength values obtained with a 90° blade for two, five and ten straws were 29.57 MPa at 27.0% moisture content, 23.04 MPa at 27.0% moisture content and 16.40 MPa at 21.5% moisture content, respectively. The maximum shear strength values obtained with the 30° bevel blade for two, five and ten straws were 16.22...
TABLE I. SHEAR STRENGTH OF STRAW WITH THE 90° BLADE (MPa)

<table>
<thead>
<tr>
<th>Moisture content % (WB)</th>
<th>Number of straws</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td></td>
<td>7.02</td>
<td>7.19</td>
<td>6.95</td>
<td>7.04</td>
</tr>
<tr>
<td>10.8</td>
<td></td>
<td>13.51</td>
<td>11.81</td>
<td>9.62</td>
<td>11.65</td>
</tr>
<tr>
<td>13.7</td>
<td></td>
<td>22.29</td>
<td>17.34</td>
<td>14.52</td>
<td>18.05</td>
</tr>
<tr>
<td>17.8</td>
<td></td>
<td>25.09</td>
<td>20.07</td>
<td>16.01</td>
<td>20.39</td>
</tr>
<tr>
<td>21.5</td>
<td></td>
<td>28.32</td>
<td>22.55</td>
<td>16.40</td>
<td>22.42</td>
</tr>
<tr>
<td>27.0</td>
<td></td>
<td>29.57</td>
<td>23.04</td>
<td>15.89</td>
<td>22.83</td>
</tr>
</tbody>
</table>

TABLE II. SHEAR STRENGTH OF STRAW WITH THE 30° BEVEL BLADE (MPa)

<table>
<thead>
<tr>
<th>Moisture content % (WB)</th>
<th>Number of straws</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>8.8</td>
<td></td>
<td>10.22</td>
<td>8.59</td>
<td>6.97</td>
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<td>10.75</td>
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<td></td>
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<td>11.61</td>
<td>9.82</td>
<td>11.75</td>
</tr>
<tr>
<td>16.9</td>
<td></td>
<td>16.22</td>
<td>13.21</td>
<td>12.41</td>
<td>13.95</td>
</tr>
<tr>
<td>17.0</td>
<td></td>
<td>15.89</td>
<td>10.60</td>
<td>12.51</td>
<td>12.97</td>
</tr>
<tr>
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<td></td>
<td>12.76</td>
<td>12.95</td>
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</tr>
<tr>
<td>23.6</td>
<td></td>
<td>16.01</td>
<td>13.01</td>
<td>12.35</td>
<td>13.79</td>
</tr>
</tbody>
</table>

The basic factor contributing to the variation in shear strength of the straw was the unequal cross-sectional area of individual straw pieces. The variation in the frictional area between blade and straws, which was more significant with the 90° blade may have contributed a little to the variation in shear strength. If the number of straws were increased further the shear strength per unit area basis would not vary to a greater extent. A random variation will occur because on a large number of samples the effect of the above-mentioned variables would be minimum.

Test data, when plotted on semi-log paper, resulted in bilinear phases of a straight line. This relationship is shown in Fig. 3 for the 90° and the 30° blades. In a first phase, the shear strength increased with moisture content and in a latter phase shear strength remained constant. For the first phase a least square regression analysis was carried out on the combined data to determine a relationship between moisture content and shear strength values. For a second phase, an average of the shear strength values was taken as a constant term.

The 90° Angle Blade

Figure 3 represents a plot of combined data between moisture content and shear strength on semi-log paper. Since no significant difference was found in the equations for two, five and ten straws, a general equation of combined data for each phase was obtained for the 90° blade.

For the increasing phase of shear strength the equation is:

\[ Y = e^{0.444 + 0.96X} \]  

(index of determination = 0.941)

where \( Y \) = shear strength of straw in MPa. 
\( X \) = moisture content in percent on wet basis.

MPa at 16.92%, 13.21 MPa at 16.9% and 12.51 MPa at 17.0%, respectively.

From Tables I and II it was seen that the shear strength increased more rapidly with moisture content up to approximately 15% then remained nearly constant for higher moisture values. This phenomenon was observed because the straw is brittle and less viscoelastic at lower moisture content and thus easier to break. At higher moisture contents there is an increase in viscoelastic properties of straw. Therefore, the straw failed at lower shear force but was difficult to cut into separate pieces. The optimum moisture content for cutting the straw into pieces was found to be in the range of 8–10% and the shear strength values were in the range of 7–11 MPa.

The behavior of the shear strength in the cases of two, five and ten straws was nearly the same. The shear strength values were expected to be equal on a per-unit area basis in all three cases. However, there was a variation in shear strength values from two straws to five and ten straws. The shear strength values with two straws were higher but there was no significant difference among the values obtained with five and ten straws. The variation in the cross-sectional area contributed more to the variation in the shear strength values. The average cross-sectional area of wheat straw as found to be 2.32 mm². The minimum cross-sectional area of a straw piece was 0.16 mm² whereas the maximum was 8.23 mm² with a coefficient of variation of 0.54. It was observed that the total cross-sectional area of straw pieces was not a multiple of the number of straws, for example, the cross-sectional area of five straws was not 2.5 times that of two straws.

The 30° Angle Blade

Figure 3 represents a plot of combined data between moisture content and shear strength on semi-log paper. Since no significant difference was found in the equations for two, five and ten straws, a general equation of combined data for each phase was obtained for the 30° blade.

For the increasing phase of shear strength the equation is:

\[ Y = e^{3.127 + 0.95X} \]  

(index of determination = 0.941)

where \( Y \) = shear strength of straw in MPa. 
\( X \) = moisture content in percent on wet basis.

MPa at 16.92%, 13.21 MPa at 16.9% and 12.51 MPa at 17.0%, respectively.
For the constant phase of shear strength the equation is:

\[ Y = e^{2.462} = 13.50 \]

From these equations, the upper limit of moisture level for increasing phase of shear strength was found to be 17.5%.

**The 30° Bevel Blade**

Figure 3 represents a plot between moisture content and shear strength on semi-log paper similar to the 90° blade. Individual plots of two, five and ten straws did not show a significant difference. Therefore, a general equation of combined data for each phase was obtained for a 30° bevel blade as follows.

For the increasing phase of shear strength the equation is:

\[ Y = e^{1.297 + 0.101 X} \]

(index of determination = 0.808)

For the constant phase of shear strength the equation is:

\[ Y = e^{2.085} = 21.87 \]

From these equations, the upper limit of moisture level for increasing phase of shear strength was found to be 13.0%.

In the case of the 90° blade, the upper limit for the increasing phase was 17.5%, while in the case of 30° blade the upper limit was 13.0%. The shear strength values obtained with the 30° blade were less in magnitude in comparison with the 90° blade. This indicates that the cutting energy requirement of the 30° blade would be less than that of the 90° blade.

**Effect of Shear Velocity**

The velocity at which the straws were sheared was 0.020 mm/sec. Some tests were conducted at speeds of 0.005 mm/sec, 0.007 mm/sec, 0.010 mm/sec and 0.015 mm/sec to observe the effect of velocity on shear strength. It was found that the shear strength was independent of shear velocity for the range of velocities tested. Chancellor (1958) also reported little difference in cutting energy (for alfalfa, foxtail and timothy) as shear velocity increased from 1.75 m/sec to 5.2 m/sec. McRandal and McNulty (1980) reported that shear velocity had no effect on shear energy in case of forage crops. The tests were carried out between 0.25 and 0.68 mm/sec shear velocity.

Although barley and oat straws were not tested, it is expected that the shear resistance of these straws would follow the same pattern as that of the wheat straw with some difference in the magnitude of cutting force.

**CONCLUSIONS**

Shear tests on wheat straw using a modified soil shear apparatus resulted in the following conclusions.

1. At lower moisture levels straw was found to be brittle and less and viscoelastic and thus easier to shear. The optimum value of moisture content was found to be between 8% and 10% for efficient shearing of straw. The corresponding shear strength values were found to be minimum and were in the range of 7-11 MPa.

2. There was a nonlinear relation between the shear strength and the moisture content of straw. This nonlinear relationship occurred in two phases, first the increasing phase, where shear strength increased with the increase in the moisture content of straw and the second, the constant phase, where shear strength remained constant with the increase in the moisture content.

3. The shear strength increased to a moisture level of 17.5% with the 90° blade and to 13.0% with the 30° blade. The magnitude of the shear strength with the 30° blade was lower than that of the 90° blade indicating lower cutting energy requirement with increased sharpness of the blade.

4. The variations in shear velocity did not have any affect on the shear strength of straw.

These conclusions indicate that for minimum and zero-till seeding, the coulter cutting edge should be sharp. The crop residue moisture must be below 17%. However, the interaction with soil has to be taken into account for efficient cutting of the crop residue for proper seed placement.

**ACKNOWLEDGMENT**

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**REFERENCES**


