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STRESS AND DEFORMATION OF WHEAT IN DIRECT SHEAR TEST

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Abstract. A method was developed and a device constructed to measure the force of internal friction of granular materials. The angle of internal friction of wheat grain was determined for two displacement speeds (0.5 and 5 mm/min) in the normal pressure range from 2.8 to 48 kPa. The angle of internal friction was found to decrease with an increase in normal pressure. Slip-stick behaviour was observed when the shearing speed equaled 0.5 mm/min. With an increase in displacement the deformation is localised in a shear zone. The thickness of the shear zone stabilised soon after the shear stress reached maximum value.

Keywords: wheat, friction, direct shear test

INTRODUCTION

The direct shear test has been frequently used to measure frictional properties of granular materials because of its simplicity and versatility. The direct shear test is usually performed by a pair of circular or square cells in which a particulate test sample is sheared to failure by the application of a lateral shear force. This test creates a shear zone within the sample by the relative movement of one cell with respect to the other. The angle of internal friction can be determined from this test. The commonly used shear cells were designed for soils and their dimensions are too small for measurements on large particles like grain. The coefficient of friction between a particulate material and a sliding surface can also be determined using a direct shear test for a condition in which the particulate material is allowed to shear over a fixed surface. Molenda *et al.* [3] used the direct shear method for estimating of the coefficient of friction of wheat grain against a corrugated steel surface.

A shear zone in granular material has recently gained the interest of researchers. Usually a shear zone forms along the wall in a rough wall silo with plug flow. Nedderman and Laohakul [1] examined shear zones in a model bin with glass ballotini, kale seed and mustard seed. They concluded that except for very smooth walls there is always a shear zone equal in width to a few particle diameters in which the velocity changes rapidly from that in the bulk to that at the wall. The shear region thickness was found to be independent of distance from the orifice, velocity or wall roughness but increased with bin width and particle diameter.

Munch-Andersen [4] suggested that when friction between wall and grains is higher than the internal friction of grain an effective rupture, zone called a boundary layer, forms along the wall in a bin with plug flow. The dilation in the boundary layer resulting from shearing during discharge gives rise to an overpressure. The overpressure was suggested to be constant

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causing a decrease in the relative overpressure with increased silo size. The thickness of the boundary layer was found to be dependent on the material. For barley it was about 20 mm, for wheat it was 5 mm. The presence of the boundary layer reduced the influence of local wall imperfections on the pressure distribution in the bin.

This paper is concerned with an experimental investigation of internal friction of wheat with special attention focused on the formation of the shear zone.

MATERIAL AND METHOD

A direct shear device was constructed to determine the angle of internal friction of agricultural granular materials like grains (Fig. 1). To account for relatively large sizes of grain the shearing area was set to 0.254 m wide and 0.61 m long. The sample tray was supported on six pairs of roller bearings, which allowed the test specimen tray to freely move in the longitudinal direction of the apparatus. The tray contained a set of vertical barriers to keep identical displacement of grain along the specimen tray. The height of the grain layer over the sample tray was equal to 7.6 cm. A vertical load on the grain was exerted by air pressure through a rubber diaphragm. Two end plates were attached horizontally to the front and back walls of the grain compartment. The role of the plates was to eliminate frictional contact in the regions of most nonuniform pressure resulting from the compaction of grain near the front wall and the dilation of grain near the back wall. Contrary to standard shear devices the shearing area did not change in the course of deformation. The sample tray was attached to a universal test machine which was used to measure the force required to pull the tray under pressurised grain mass. The angle of internal friction was calculated using the exposed area of the test surface, the normal pressure (air pressure), and the frictional drag force. Normal pressure in a range from 2.8 to 48 kPa was applied. Two tray speeds were tested 0.5 and 5 mm/min. To investigate the development of the shear zone a vertical column of stained grain 2.5 x 2.5 cm in cross section was formed in the sample during the filling of the test apparatus. After a prescribed displacement of the sample tray the test was completed and liquid paraffin wax was poured into the grain. After the wax solidified the sample was cut along the direction of displacement. Soft red winter wheat with a moisture content of 11.5% (w.b.) was used as the test material.

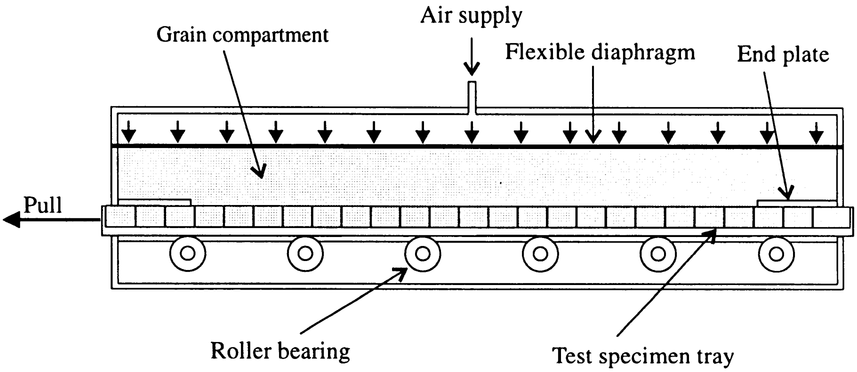

Fig. 1. Test apparatus for determining angle of internal friction of granular material.

RESULTS

A typical plot of frictional force - displacement curve obtained in the direct shear test is shown in Fig. 2. Maximum of the frictional force was obtained for displacement of the sample tray about 25 mm which corresponds to 6 diameters of an equivalent spherical grain. This displacement related to the grain sample height indicates that a critical

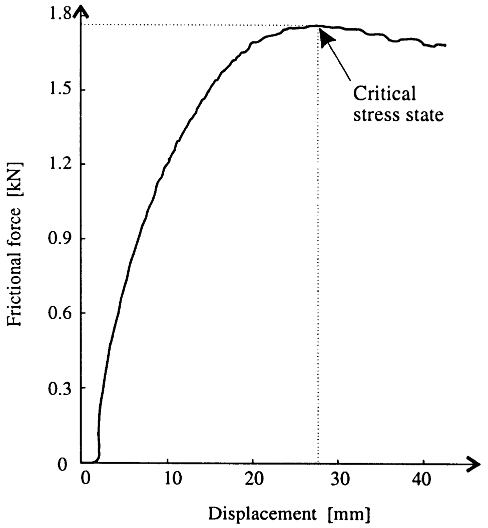

Fig. 2. Typical plot of frictional force - displacement curve.

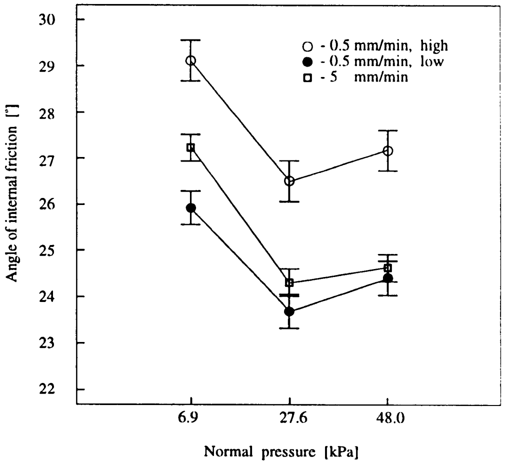

Fig. 3. Angle of internal friction of wheat as influenced by normal pressure.

stress state was obtained for relatively large shear strain. The angle of internal friction decreased as the normal pressure increased as shown in Fig. 3. Slip-stick behavior was observed when the shearing speed equaled 0.5 mm/min. Corresponding high and low values of the angle of internal friction were indicated in Fig. 3. Ratio of the high to low values of the angle of internal friction was 1.12. The majority of the angle of internal friction decrease was observed at a pressure below 27 kPa. Above this pressure changes in the angle of internal friction were not significant. The mechanical behaviour of grain at low pressure appears to be different than that observed for higher pressure. Thompson and Ross [5] examined the effects of excess pressure on the variation of bulk density of wheat. These authors observed the largest change in the bulk density at a pressure below 14 kPa. At this pressure range changes in bulk density resulted from the rearrangement of particles. At higher pressures bulk density increased more slowly being mainly a result of deformation of grains themselves. For wheat at a moisture content of 8 to 12% fifty percent of the total change in bulk density caused by the rearrangement of the grain particles occurs between 0 and 7 kPa with the remaining change in bulk density caused by the deformation of the particles themselves. This change in the mode of deformation is likely to be a reason for the decrease in the angle of internal friction at low pressures and its stabilization at higher pressure levels. The angle of internal friction for 48 kPa of vertical pressure was found to be 24.6°±0.3° which was close to 25°±0.8° obtained for the same grain and pressure in triaxial compression test [2]. Thus it may be stated that new direct shear method gives reliable results which are in good agreement with those determined in standard triaxial compression test.

In the first stage of the shear test deformation of the granular material is distributed uniformly along the sample height. With an increase in displacement the deformation is localised in the form of narrow shear zone. Thickness of the shear zone stabilised soon after the shear stress reached maximum value. The thickness of the shear zone was found to be about 13 mm for displacement of the tray equal to 25 mm and at a pressure equal to 48 kPa (Fig. 4). This type of shear zone forms along a rough or corrugated silo wall during plug flow. Zhang *et al.* [6] examined shear zones in wheat sliding against a corrugated steel surface. They estimated that the shear

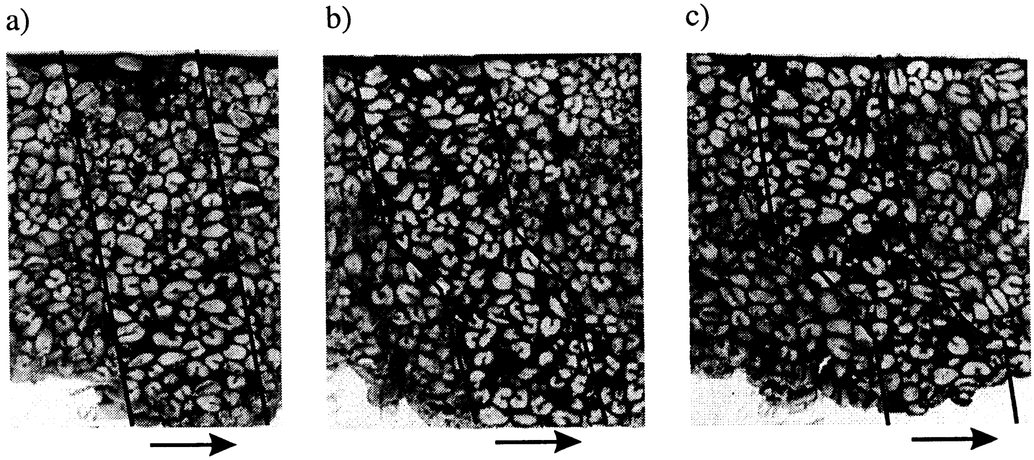

Fig. 4. Cross sections through deformed sample of wheat grain: uniform deformation (a), onset of formation of shear zone (b) and fully developed shear zone (c).

zone was 25 mm thick. The lower boundary of the shear zone was estimated 4.5 mm below corrugation peaks and the upper boundary was 18.5 mm above the corrugation peaks. They found that the location of the shear zone was not significantly affected by either grain moisture content or normal pressure.

CONCLUSIONS

1. The angle of internal friction decreased with increasing normal pressure in the range to 15 kPa. Above this range of normal pressure, changes in the angle of internal friction were not significant. The angle of internal friction for 48 kPa of vertical pressure was found to be 24.6°±0.3°, which was close to 25±0.8° obtained for the same grain in the triaxial compression test.

2. In the first stage of the shear test deformation the granular material is distributed uniformly along the sample height. When the shear stress reaches maximum value the deformation localise in the form of a shear zone. The thickness of the shear zone was found to be about 13 mm.

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