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https://doi.org/10.5109/23771

出版情報：九州大学大学院農学研究院紀要. 27 (3/4), pp.179-188, 1983-02. Kyushu University

J. Fac. Agr., Kyushu Univ., 27 (3・4), 179-188 (1983)

Internal and Material-Surface Coefficients and Repose Angle of Selected Grains and Soybeans

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(Received October 14, 1982)

The principle of a shear box was applied for the determination of the internal and surface coefficient of friction of selected grains and soybeans at different moisture contents. The repose angle of the materials was also investigated using a flow box. The poured angle was determined by two methods and at the same time the drained angle and the flowability was measured. The coefficient as well as the repose angle were found to increase with increase in moisture content of the materials. The flowability was found to be linearly related to the drained angle and hence it can be used to measure the repose angle of the materials as it is easier to apply than the other methods.

INTRODUCTION

A proper design for a stock-pile facility for grains will require reliable data on the internal angle of friction and the angle of friction of the material on the wall surface of the facility. Such data are required as input parameters on the calculation of wall pressures exerted by the grain on the wall of the structure. Moreover, the design of conveying machinery such as elevators, conveyors and unloaders will require the knowledge of the kinetic friction coefficient of the material to be conveyed. In self emptying bins, the repose angle of the material is equally important.

So far many contradicting results have been reported on these friction coefficients by many researchers to the extent that one would wonder on which results to believe. The contradictory results have risen due to the absence of standard experimental equipments as well as the variation of the coefficients with varieties. In some cases, some researchers have assumed the internal angle of friction to be equal to the repose angle in the calculation of the structure wall pressures arising from the grain. Such assumptions have lead to contradictory wall pressure results.

The priniciple of determining the internal coefficient of friction for almost all materials has been based on a shear box. While a standard apparatus has been established for soils, still one is to be established for agricultural materials. Therefore development of such an apparatus is of utmost importance. This study was therefore carried in order to obtain reliable and accurate data that would be used for the design and construction of stock-pile facility as stated earlier, Chuma ***et al.*** (1981) using a shear box that was constructed by the authors. In the investigation the main factor on the friction was assumed to be moisture content as well as nature of the surface of the wall material.

LITERATURE REVIEW

Stewart (1968) suggested that the internal friction of grains is caused by interlocking, rolling resistance as well as sliding resistance. However the author reported the major factor to be placed on the grain size, shape, moisture content and specific weight of the material. The same author reported a difference between repose and internal angle of friction to be significant.

Friction coefficients for wheat on steel, hardwood, plywood and glass panel have been investigated by Zoerb (1972). The coefficients were reported to increase with increase in moisture content. However, the increase in steel and hardwood was not consistent. The effect of moisture content on material friction on wall surfaces was also reported by Seno ***et al. (1976)*** to increase linearly with increase in moisture content of the materials. The authors further reported a linear increase in the internal angle of friction and repose angle of rough rice to increase with increase in moisture content. For milo, the authors reported a decrease in repose angle with increase in moisture content, while for corn a linear increase was reported.

In contrast to the linear increase in the coefficient of friction with increase in moisture content, Lawton and Marchant (1980) reported the internal friction for wheat, barley, tick beans and oats to increase gradually between about 10 % and about 15 % moisture contents followed by a rapid increase when the moisture content increased from about 15% to about 22 % and finally increased gradually once more when the moisture content increased from about 22 % to about 30 %.

As far as the design of the shear box is concerned, Brubaker and Pos (1965) found the coefficient of friction for wheat, soybeans and nylon spheres to be affected by the size of the shear box. Shear boxes of internal diameter of 203, 304 and 406 mm did not significantly affect the coefficient of friction, while a shear box of internal diameter of 101.6 mm influenced significantly the coefficient. Furthermore, the authors reported the coefficient not to be affected by the rate of shear force, normal load and time. However, these results are in contrast to those observed by Bickert and Buelow (1965).

Snyder ***et al.*** (1967) reported a greater coefficient of kinetic friction for wheat on metal surfaces with smoother surfaces in the range of 4–45 micron inches roughness.

EXPERIMENTAL MATERIALS AND METHODS

The properties of the materials are as elsewhere, Chuma et al. (1981).

Internal and surface friction

The experimental apparatus for the determination of the internal and surface friction is shown in Fig. 1. Two plastic cylinders each of internal diameter of 204mm and 80 mm deep lined with teflon were used as the shear box. The lower cylinder was fixed while the upper cylinder was moveable and was separated from the lower cylinder by ball bearings to a distance of 2 mm. The sliding movement of the upper cylinder over the lower cylinder was achieved through a pivot arm which could be pressed down by a 50 kg load cell attached to a universal testing machine, MODEL TOM 10000X manufactured by Shinkoh. One end of the pivot arm was depressed down by the load cell and the shear force was transmitted to the moveable upper cylinder through a horizontal shaft. The shear resistance force on the upper cylinder was then calculated by taking moments on the fulcrum of the pivot arm.

The material to be tested was filled into the cylinders and a normal load was applied on top of the material at intervals of 5 kg from 10 kg to 35 kg. A shear force was then applied by the universal testing machine and the shear force was registered by the load cell and recorded on an X-Y recorder. The maximum shear force on the shear force-displacement curve was taken as the shear force for any given normal load. However, in wheat and soybeans at high moisture contents, the maximum shear force was hardly obtained and in such a case the shear force was estimated from the curve between 10 and 15 mm displacements which was established to be the displacement necessary to obtain the maximum shear force for internal angle of friction.

Disk plates were made from plastic, plywood, steel and concrete for the determination of the surface-material friction. In this investigation the material was filled only to the bottom cylinder. The disks were then placed on top of the material and the test was carried as before.

Repose angle

On letting a material to flow through a slit at a given height, a pile whose shape is characteristic of the material is formed. The angle formed by the

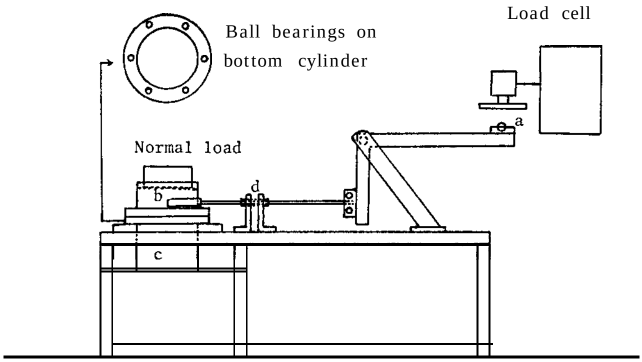

Fig. 1. Schematic diagram for internal and material-surface coefficient of friction measurements. a, shear force; b, moveable cylinder; c, bottom cylinder; d, slide bearing.

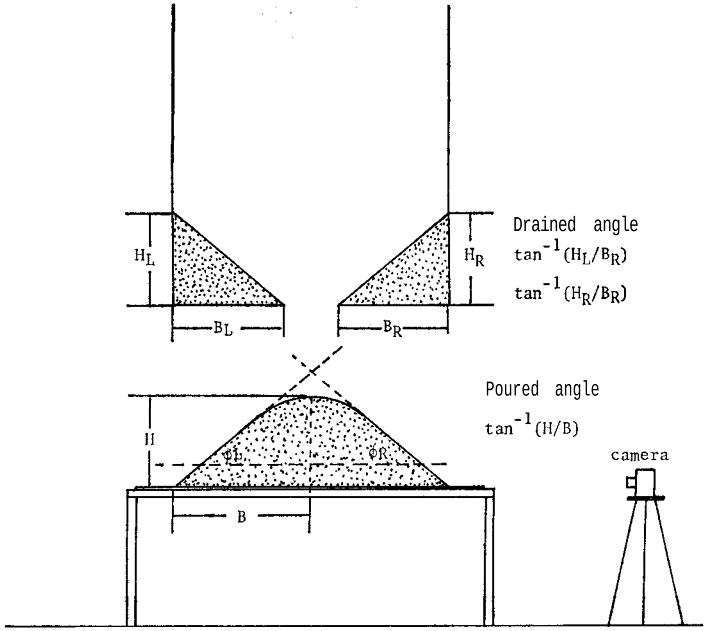

Fig. 2. Experimental apparatus for measurement of repose angle by camera (ϕ_L and ϕ_R), poured angle and drained angle.

side of the pile with a horizontal surface is called a repose angle. The repose angle for the materials was determined using a plastic rectangular box which was open at the bottom through which the material was allowed to flow. The box was 207 mm long, 322 mm high and 30 mm broad for rough rice, milled rice and wheat tests, while for soybeans and corn the size of the box was 400mm long, 600 mm high and 42 mm broad. The size of the slit was varied to 10 mm, 20 mm and 30 mm for rough rice, milled rice and wheat tests and for soybeans and corn the slit was varied to 30 mm, 40 mm and 50mm. The height of drop of the material was also investigated at three different heights (150 mm, 200 mm and 250mm).

The samples were filled into the boxes and allowed to flow through the slits on to a spread sheet of paper below as shown in Fig. 2. The boundary of the pile on the paper was marked so as to determine the surface area of spread. From this area and height of the pile the repose angle was calculated. In addition to this the side of the pile was photographed at four positions 45” apart and the average repose angle was calculated from these pictures.

Due to the size of the box and the small size of the slit, not all the materials could flow out of the box. The drained angle formed by the trapped materials was measured by determining the height and the bottom lengths of the material at the corners of the box.

As the material was flowing out of the box, the time needed for all the flowable material to flow out was also measured. The volume of the material flowing through a unit cross section area of the slit per unit time was assumed to represent the flowability of the material.

In all the tests, different moisture contents of the material were investigated and each test was repeated five times.

RESULTS AND DISCUSSION

An example of the shear force-displacement curve on the X-Y recorder is shown in Fig. 3. The shear force could be observed to increase rapidly with less displacement of the upper cylinder at the initial stage of shear force application. The displacement then increases gradually as the shear force increases to a point where the shear forces ceases to increase that is the shear force reaches a maximum value. Beyond this point, although the shear

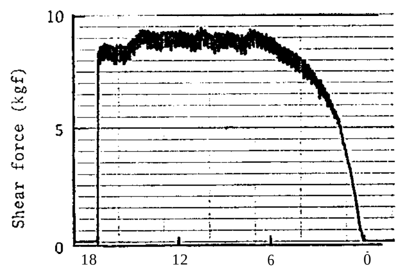

Fig. 3. Typical shear force displacement curve for soybeans.

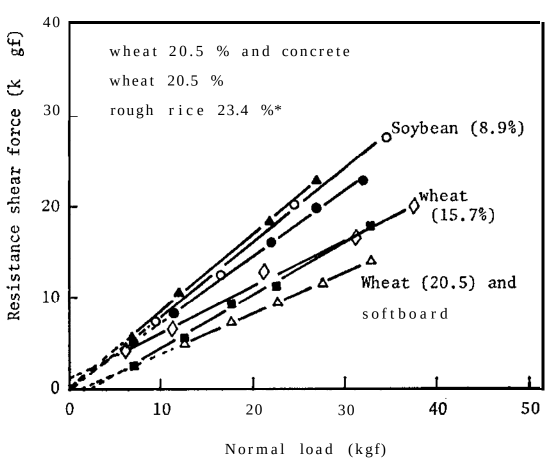

Fig. 4. Relationship between shear fore and normal load in a shear box.
*: Moisture content % w.b.

force does not increase and in most cases it even decreases the displacement continues to increase. The displacement at which the maximum shear force was obtained was in most of the tests lying between 8 and 15 mm. In some of the material-surface friction tests, the displacements were as small as 5 mm.

The maximum shear force was plotted against its respective normal load as shown in Fig. 4. The normal load-shear force relationship was found to have high correlation coefficients (0.949-o. 999). From this linear relationship, the coefficient of friction was calculated using Coulomb's equation (Terzaghi, 1951),

$$s = c + \sigma \tan\phi ,$$

where,

s : shear force (kgf),
σ : normal load (kgf),
c : shear force when ϕ is zero,
$\tan\phi$: coefficient of friction.

The constant c would indicate cohesion forces of the material. In some of the tests existance of cohesive forces were observed but they were low enough to be neglected. The existance of cohesive forces was also reported by Stewart (1968) and Seno *et al.* (1976) on sorghum and rough rice, respectively.

The internal and surface coefficients of friction are shown in Table 1. From the results, the coefficient is moisture and nature of the surface dependent. The general trend was the coefficient to increase with increase in moisture content, especially on wheat and soybean. However, as few moisture content levels were investigated, concrete conclusion could not be drawn. The

Table 1. Internal coefficient of friction and material-surface friction coefficients of selected grains.

Material	M. C.[1)]	Self	Concrete	Steel	Plywood	Plastic
Soybean	8.8	0.659	0.291	0.158	0.431	0.250
	36.2	0.801	0.454	0.458	0.638	0.370
Milled rice	12.0		0.316	0.237	0.293	0.273
	18.4	0.514	0.301	0.214	0.255	
	27.5	0.431	0.429	0.318	0.492	
Rough rice	7.5		0.435	0.226	0.401	0.280
	11.8	0.755	0.451	0,262	0.549	0.285
	23:4	0.775	0: 501	0.199	0.462	
Wheat	10.0	0.548	0.382	0.294	0.412	
	20.5	0.670	0.385	0.294	0.415	
Corn	22.0	0.386				
	25.4	0.939				
			0.475	0.450	0.501	

[1)]: Moisture content in % wet basis.

Table 2. Repose angle of selected grains obtained by different methods and at different moisture contents.

Material	M. C. (% w. b.)	Drained angle	Angle by camera	Angle by area and height
Rough rice	16.5 18.9 26. 1	**38.8** 40.8 44. 3	**36.8** 37.9 41.1	**30.2** 32.6 34. 1
Milled rice	14.2 14.9 19.7	36.8 34.4 35.2	34.5 34.0 32.3	26. 4 29.5 29.5
Wheat	13.6 17.9 20.7	29.9 33.3 39.3	28. 1 29.6 36.9	22. 1 27.3 31.8
Soybean	12.8 16.2 21.6	35.5 29.2 33.9	30.8 27.7 30.8	29.1 25.6 28.4
Corn	9. 7 [illegible]	28.3 28.4 31.4	26.3 27.2 29.8	23. 2 26.6 27.[illegible]

increase in the coefficient with increase in moisture content is in consistence to the results reported by Zoerb (1972) on wheat. The order of the internal coefficient of friction was observed to be from corn, milled rice, wheat, soybean to rough rice in ascending order, respectively. As for the material-surface friction, the lowest coefficient was found to he on steel followed by plastic in all the materials at any given moisture content. The highest material-surface friction coefficient was either on plywood or on concrete depending on the material or moisture content.

Repose angle

Table 2 shows the repose angle of the materials obtained by different methods. In all the methods, as the moisture content increased, the repose angle for wheat, corn and rough rice also increased. In contrast to the other methods, the camera method indicated an increase in the repose angle of milled rice. With all the methods, the repose angle for soybeans was found to be minimum at 16.2 % moisture content. At the normal storage moisture contents of the materials at room temperature, the least drained angle was observed in corn followed by wheat, soybeans, milled rice and rough rice in ascending order, respectively. With the exception of milled rice, this order is comparable to that in the internal angle of friction.

The relationship between the three methods was investigated. The highest correlation coefficient was found to be between the camera and the poured angle by area and height methods (0.970), while that between the drained angle and area and height method was 0.830.

Fig. 5 shows the variation of the repose angle with moisture content. The angle was observed to increase linearly with increase in moisture content in rough rice with a correlation coefficient of 0.943. These results are in agreement to those reported by Seno et *al.* (1976). However, the repose angle for wheat, corn and soybeans increased curvilinearly as the moisture content increased. That for wheat reached a peak at 34.6 % after which it decreased up to 43. 6 % moisture content. For soybeans a gradual increase was observed

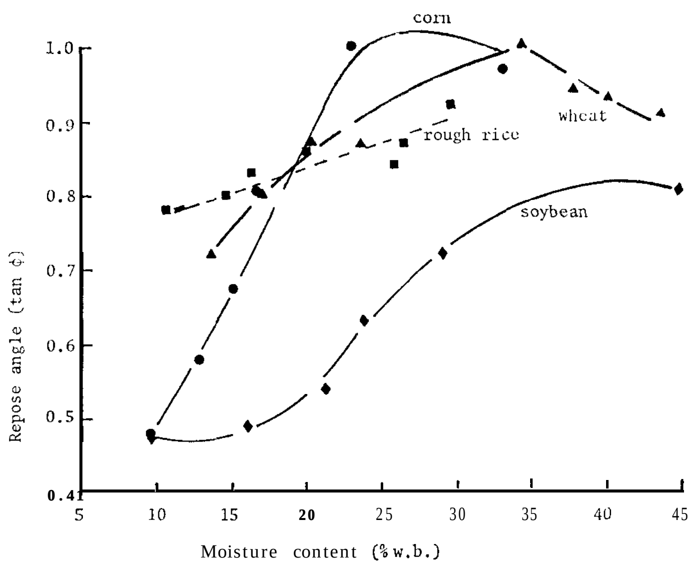

Fig. 5. Effect of moisture content on the repose angle of selected grains and soybean.

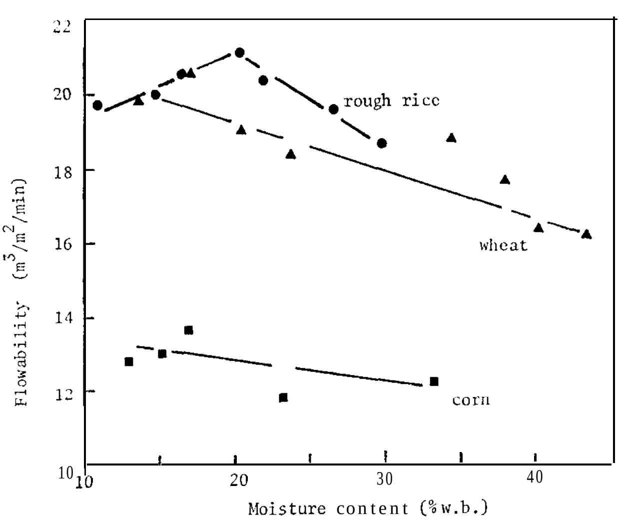

Fig. 6. Variation of flowability with moisture content of selected grains and soybean.

up to 16 % moisture content beyond which it increased rapidly up to 30 % and then increased gradually again up to 44.7 % moisture content. These observations are in agreement to those reported by Lawton and Marchant (1980) on internal angle of friction.

Fig. 6 shows the variation of flowability with moisture content. For rough rice as the moisture content increased the flowability increased linearly up to 21 % after which, as in wheat and corn, it decreased linearly up to 30 % moisture content. These results were not expected as it was thought that the flowability should decrease with increase in repose angle. However, if flowability is to be considered to depend on the specific gravity of the material, this phenomenon should be expected as this curve was similar to that of specific gravity moisture relationship (Chuma *et al.,* 1981). However, for wheat the curves were not similar. The authors therefore think that the dependence of flowability of any given material could be explained fully if the specific gravity and apparent density of the materials are both taken into account. This however is yet to be established.

Fig. 7 shows the relation between the repose angle and modified flowability of the materials. As in Fig. 6, rough rice contrasted the other materials by the flowability to increase with increase in the repose angle. Although few data were collected and there was a wide scatter of the points especially in corn and rough rice, reasonable regression coefficients of 0.921, 0.974 and 0.812 for rough rice, soybeans and wheat, respectively were found. For corn due to the wide scatter of the points attempt was not made to establish the rela-

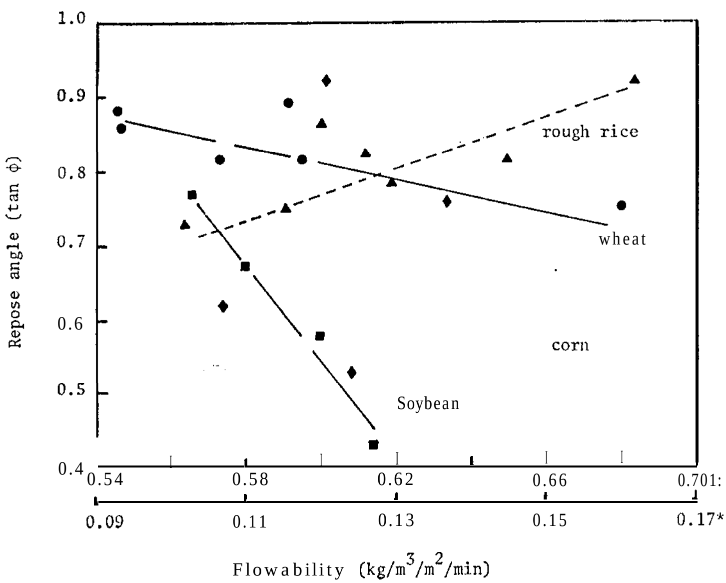

Fig. 7. Relationship between repose angle (drained angle) and modified flowability. *: Scale for corn and soybeans, #: scale for rough rice and wheat.

tionship. With more data this could be established.

CONCLUSION

Internal angle of friction, material-surface friction and repose angle of grains were found to increase with increase in moisture content. The nature of the surface to which the material is subjected to was also found to have an important bearing on the level of the coefficient of friction at any given moisture content. Flowability of rough rice was found to increase linearly with increase in moisture content reaching a peak after which it decreased linearly. Except for corn, flowability could be used for the estimation of the repose angle of the investigated grains and it might be applicable to other agricultural materials.

ACKNOWLEDGEMENTS

The authors are thankful to the Ministry of Agriculture, Forestry and Fisheries for providing the funds for the study without which the study could not have been made. The research was also supported by the Ministry of Education and Culture through Grant-in-Aid for Co-operative Research A (No. 548053).

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