Physical Properties of Rice Hull and Straw for the Handling Facilities

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This study was performed to determine the physical properties of rice hull and straw which could be used for an optimum design and operation of the handling facilities for these rice crop by-products. The properties measured were kinetic friction coefficient, bulk density, and dynamic and static angle of repose. Rice hulls with moisture content of 13% and 21% were used throughout the test while rice straws of 10% and 16% moisture were chopped into 10 mm length and used for the test.

Friction coefficient was calculated from the horizontal traction force measurement when a container holding the mass of rice hull and straw was pulled over mild steel, PVC, stainless steel, and galvanized steel surface by a universal testing machine. Bulk density was measured by an apparatus consisting of a filling funnel and a receiving vessel. Dynamic angle of repose which is the angle at which the material will stand when piled was calculated from the photos of bulk samples after they were flowed by gravity and accumulated on a circular surface. Static angle of repose which is the angle between the horizotal and the sloping side of the material left in the container when discharging was also measured in the similar way. Results and conclusions from this study are summarized as follows.

1. Kinetic friction coefficients of both rice hull and straw were in the range of 0.26 - 0.52 and increased with the moisture content. The magnitude of friction increased in the order of galvanized steel, stainless steel, PVC, and mild steel.

2. Bulk densities of rice hull decreased while those of rice straw increased with moisture content increase. Average bulk densities of rice hull and straw were 96.8 and 74.7 kg/m^3, respectively.
3. Average dynamic angle of repose for rice straw was 32.6° and those for 13% and 21% moisture rice hull were 38.9° and 44.9°, respectively.
4. Static angles of repose for both rice hull and straw showed increase with the moisture content. The values were 75.2° and 80.2° for 13% and 21% moisture rice hull, respectively. Rice straws having 10% and 16% moisture content showed 87.3° and 89.2° static angle of repose, respectively.

Key Words : Rice hull, Rice straw, Friction coefficient, Bulk density, Dynamic and static angle of repose

INTRODUCTION

In Korea, about 1.2 million tons of rice hull and 7.2 million tons of rice straw are produced annually during rice harvesting and milling and much attention has been focused on the utilization of these by-products. Although rice hull and straw have many possible usage both in agricultural and industrual area (Kim (1980), Staniforth (1979)), disposal of rice straw and hull is still a big problem with the simple incineration being the dominant method. Recently, the large-scale rice processing complex (RPC) consisting of bulk handling, drying, storage, and milling facilities all together have been established at 90 locations in Korea to make the post-harvest processing of rice more efficient. Due to enormous milling capacity of 30 ton/day, most RPC experience a serious problem of disposing rice hull.

In order to develop an efficient process and equipment for material handling, it should be proceeded first to obtain the pertinent physical properties of materials at hand. Consequently, the objectives of this study are to measure the kinetic friction coefficient, bulk density, and dynamic and static angle of repose of rice straw and hull which considered basic properties for the storing, transporting, and processing of those materials.

The influence of several variables such as sliding velocity, normal pressure, surface conditioning, and testing environment on friction coefficient measurement was studied and proper experimental procedure and technique was suggested by many workers (Bickert and Buelow (1966), and Snyder et al. (1967)). From these investigations, it is generally accepted that the sliding velocity and normal pressure, when they are beyond a certain critical value, have little effect on the friction coefficient measurement of agricultural materials on many surfaces.

The need for a knowledge of angle of repose for granular materials has long been recognized in the areas such as design of storage structures, gravity flow, packaging, and fluidized conveying (Mohsenin, 1986). The angle of repose is often classified further into the dynamic and static angle of repose. The dynamic or kinetic angle of repose is the angle between the horizontal and the slope of a cone-like pile of material dropped freely from a specified elevation. It is also referred as poured angle and angle of repose in filling or piling. When a stored bulk mateiral is suddenly discharged through a bottom opening of the container, some of the mateiral defy flowing and remain inside the bin and an angle is formed between the sloping side of the material left and the horizontal. This angle is called the static angle of repose, angle of repose in emptying or funneling, or drained angle (Kang, 1995). There is no standard procedure for the determination of static angle of repose and obviously the measured data is dependent on the individual experimental setup and test procedure used.

MATERIALS AND METHODS

Rice hull and straw of Dongjin variety were obtained from a local farm after 1995 harvest season. The rice straw was cut into about 10 mm length and both rice hull and straw were conditioned to the desired moisture contents by sun drying or water spraying. The moisture contents (all moisture contents are expressed on wet basis) for the rice hull were 13.1 and 21.2%, and those for the straw were 9.9 and 15.9%.

A. Dynamic friction corfficient

The dynamic friction coefficient is measured using an aparatus shown in Fig. 1. The apparatus uses a Universal Testing Machine (Model 1146) as not only a sample container driving unit but also a friction force sensing/recording unit. The bottomless container (100×200×50 mm) was filled with samples and pulled over various surfaces by the upward crosshead movement of the Universal Testing Machine at the speed of 500 mm/min. The traction force was measured and recorded on a strip chart. The dynamic friction coefficient of sample on the surface was later calculated from the following equation.

$$\mu_k = \frac{P-(w_v-f)}{W+w_a}$$

where,

μ_k : kinetic friction corfficient	f : traction force with empty container
P : traction force measured	W : sample weight
w_a : additional weight	w_v : tensioning weight

Prior to the tests, the sliding surfaces of mild steel, PVC, stainless steel, and galvinized steel plate were conditioned by making one hundred repeated passes over them with testing materials in order to obtain a reproducible friction force measurement as suggested by Bickert and Buelow (1966). Friction force measurement was repeated seven times for each test condition.

B. Bulk density

Bulk density was measured using an apparatus (Fig. 2) similar to the Boerner weight per bushel test device. The weight of samples dropped into and filled the 1*l* capacity vessel was measured and the bulk density was then calculated. Ten replication was made for each test.

C. Angle of repose

The dynamic repose angle was measured by using an apparatus shown in Fig. 3. After filling the hopper, the material was allowed to flow through the bottom chute, leaving a free-standing cone on the circular platform. A camera was used to take the picture of the accumulated material and the poured angle was calculated from the measurement on the photos as follow.

$$\theta_d = \tan^{-1}\left(\frac{2H}{D}\right)$$

where, θ_d : dynamic angle of repose, H : height of material heap, D : diameter of platform.

A cylindrical container of 1000×900 mm (D×H) with a hole on the flat bottom was made of stainless steel for the static angle of repose measurement. After filling the container up to a predetermined height, the material was allowed to flow through the bottom hole by opening a gate. Then some material still remained in the container leading to a shape similar to a rathole as shown in Fig. 4. The x, y dimension of the material left was measured at ten points along the circumference of top layer and averaged to calculate the static angle of repose according to the following equation.

$$\theta_s = \tan^{-1}\left(\frac{y}{d-x}\right)$$

where, θ_s : static angle of repose, y : height of material left, x : width of material left on the top layer, d : diameter of hole (275 mm and 375 mm for rice straw and hull, respectively).

RESULTS AND DISCUSSION

A. Dynamic friction corfficient

Kinetic friction coefficients of rice hull and straw on four materials are shown in Table 1 and Fig. 5. The friction coefficients increased as moisture content increased and were 0.26 - 0.47 for rice straw and 0.29 - 0.52 for rice hull, respectively. Friction coefficient was the greatest on mild steel, PVC, stainless steel, and galvanized steel in the decreasing order. There are little data available to verify the reliability of results obtained in this study. However, oat straw was reported to have higher friction on galvanized sheet metal than mild steel surface (Mohsenin, 1986) and the kinetic friction coefficients of rice and barley on a PVC were shown a little lower values than on the mild steel surfaces at various moisture levels (Kim and Lee, 1976).

B. Bulk density

Bulk densities of rice straw and hull ranged from 71.9 to 77.4 kg/m^3 and from 93.4 to 100.3 kg/m^3, respectively (Table 2). The measured bulk density of rice hull was almost the same as reported by others (Kim, 1980) and was comparable to that of oat hull which is 128.2 kg/m^3 (Mohsenin, 1986). The effect of moisture content on the bulk density was statistically significant where rice straw and hull showed an opposite trend. For rice hull, bulk density decreased as moisture content increased. A similar trend of the constant or slight decrease in bulk density for increased moisture content was found for cereal grains (Mohsenin, 1986). On the contrary, rice straw showed an increase in bulk density as moisture increased. It is assumed that the direct influence of higher moisture content on the total weight resulted in the bulk density increase for rice straw while for rice hull not only the weight change but also the change in packing characteristic would occur and brought about the decrease in bulk density as a combined result.

C. Angle of repose

Except for the dynamic angle of repose for rice straw, measurement indicated statistically significant increase in angle of repose as moisture increased. This increase of the angle of repose with moisture content increase was also found for various granular materials. It could be explained that this variation resulted from increased internal friction which help holding aggregates of solids together. The dynamic angles of repose for rice hull and straw were between 32 and 45° as shown in Table 3 where the former showed a little higher value than the latter and both fell within the typical 30 - 45° range of many agricultural granular materials (Mohsenin, 1986). For rice hull and straw, static angles of repose determined with a cylindrical container were between 75 and 90° which indicated that only the funnel-flow developed during the tests. When a funnel-flow develops in storage bin, the material flows toward the outlet in a channel formed within the bulk of solid itself. The material surrounding this channel is at rest and dead zone exists. In contrast to this, the channel expands from the outlet upward along the walls of the bin and all the solid is in motion under the mass-flow situation. The flowing channel of the granular material coincides with the walls of the hopper. The mass-flow or plug-flow would result depending on the experimental setup and other conditions.

CONCLUSIONS

1. Kinetic friction coefficients of both rice hull and straw were in the range of 0.25 - 0.52 and increased with the moisture content. The magnitude of friction increased in the order of galvanized steel, stainless steel, PVC, and mild steel.

2. Bulk densities of rice hull decreased while those of rice straw showed an increase with moisture content. Average bulk densities of rice hull and straw were 96.8 and 74.7 kg/m^3, respectively.

3. Average dynamic angle of repose for rice straw was 32.6° and those for 13% and 21% moisture rice hull were 38.9° and 44.9°, respectively.

4. Static angles of repose for both rice hull and straw showed increase with the moisture content. The values were 75.2° and 80.2° for 13% and 21% moisture rice hull, respectively. Rice straws having 10% and 16% moisture content recorded 87.3° and 89.2° static angle of repose, respectively.

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Table 1. Kinetic friction coefficients of rice straw and hull

Material	Moisture (%)	Kinetic friction coefficient			
		Mild steel	PVC	Stainless steel	Galvanized steel
Rice straw	9.9	0.29	0.30	0.25	0.26
	15.9	0.47	0.36	0.32	0.30
Rice hull	13.1	0.35	0.32	0.31	0.29
	21.2	0.52	0.41	0.42	0.40

Table 2. Bulk density of rice straw and hull

Material	Moisture (%)	Bulk density (kg/m^3)
Rice straw	9.9	71.9±1.14
	15.9	77.4±0.74
Rice hull	13.1	100.3±1.13
	21.2	93.4±0.89

Table 3. Angle of repose of rice straw and hull

Material	Moisture (%)	Angle of repose (degree)	
		Dynamic	Static
Rice straw	9.9	32.2	87.3
	15.9	33.0	89.2
Rice hull	13.1	38.9	75.2
	21.2	44.9	80.2

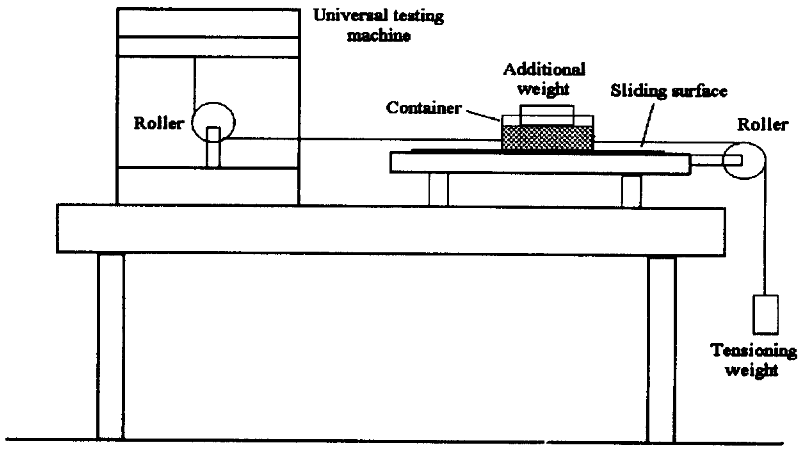

Fig. 1. Apparatus used for determining kinetic friction coefficients

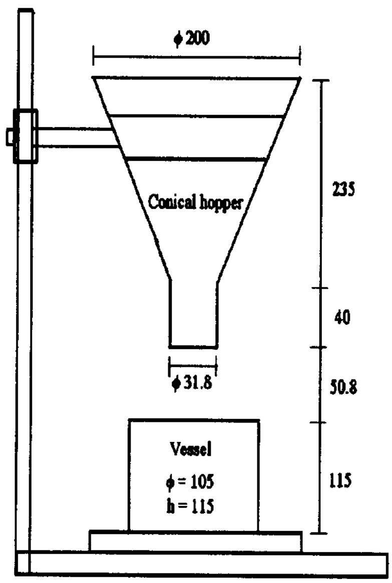

Fig. 2. Apparatus for bulk density measurement

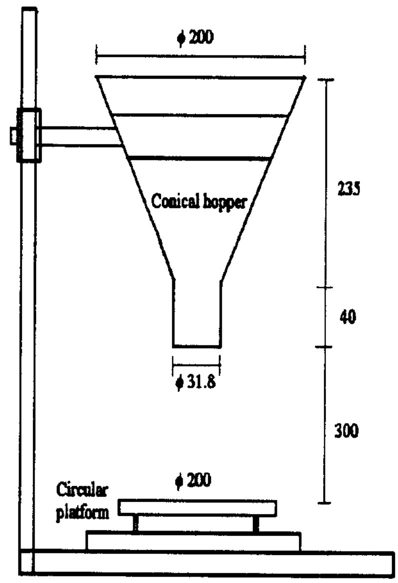

Fig. 3. Apparatus for dynamic angle of repose measurement

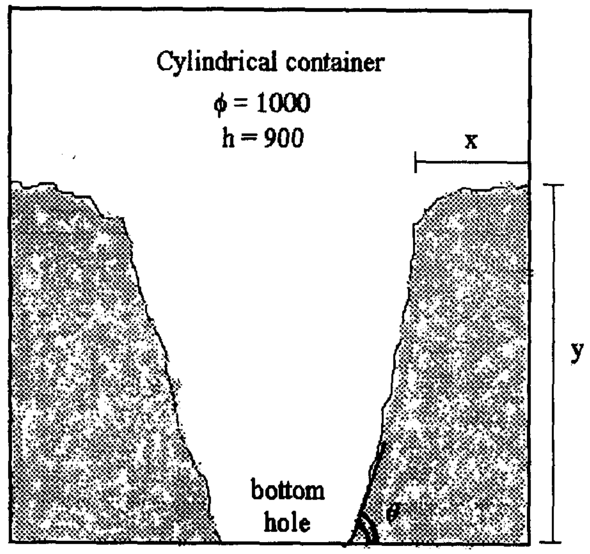

Fig. 4. Schematic diagram for the calculation of static angle of repose

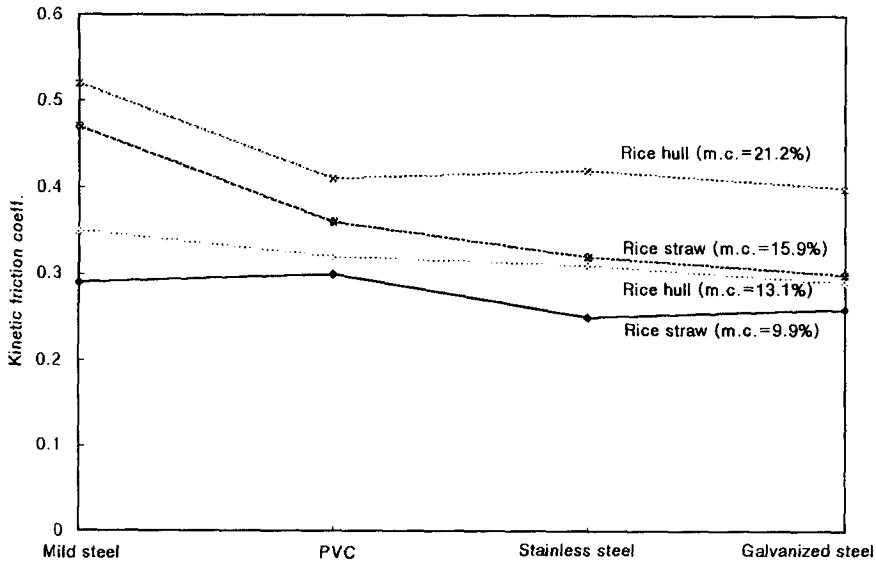

Fig. 5. Kinetic friction coefficients of rice hull and straw on various materials