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Properties of Sliced Pineapple Fruit

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ABSTRACT The objective of this study was to determine the physical properties of the sliced pineapple fruits for designing reliable pineapple juice extractors' hopper, handling and storage systems. Direct shear apparatus was used for the determination of angle of internal friction and cohesion, as well as friction of sliced pineapple on surfaces of galvanized steel, stainless steel and plastic. Tests were conducted using normal pressures in the range from 10.0 to 20.5 kPa. The pineapple samples were subjected to a pre-consolidation pressure of 22.3 kPa for 35 minutes before shearing. It was found that sliced pineapple had an angle of internal friction $ø=32.2^{o}$ and cohesion, C = 2.07KPa. The highest coefficient of friction values was for galvanized steel, followed by stainless steel, while plastic had the least friction. It was observed that the normal load had a significant effect on the coefficient of friction, specifically, the coefficient of friction decreased linearly with increase in the normal load on all the surfaces tested.

Keywords: pineapple, internal friction, cohesion, surface friction.

INTRODUCTION

Pineapple fruit is the second harvest of importance after bananas contributing to over 20% of the world production of tropical fruits (Coveca, 2002). Its origin has been traced to Brazil and Paraguay in the Amazonic basin where the fruit was domesticated (Collins, 1949). According to the ***World*** (FAO, 2005) 15,287,413 MT or 34 billion pounds of pineapple fruits were produced annually. Worldwide, 82 countries produce pineapple in economic quantities on about 2.1 million acres. Brazil, Philippines, China, India and Nigeria are the top producers of pineapple fruit in the world

Pineapple juice processing industry commonly uses the continuous screw press extractors. Fundamentally, the continuous screw press consists of a screw of discontinuous worm on a shaft, rotating within perforated cylinder housing. This worm flight provides conveyance means for the sliced pineapple fruit fed through a hopper into the cylinder housing. One of the major problems in pineapple juice extraction process is the irregular flow of the sliced pineapple fruit in the hopper and the discharge of the residue at the discharge end. Hence, a proper Juice extraction system design that allows an effective discharge of waste and the feeding of the sliced pineapple fruit is essential for a smooth and reliable juice extraction process. Therefore, the frictional properties of the sliced pineapple fruit and its by-product must be considered in designing a reliable pineapple juice extractor.

Researchers have employed many methods for the determination of frictional properties of agricultural products (Buelow, 1961; Brubaker, 1967; Vis et al., 1968; Mohsenin, 1980; Sitkei, 1986; Kramer, 1994; Zhang et al. 1994; Gosh, 1966; Obetta and Onwualu 1999; Correa et al., 2007). Kramer (1994) determined the coefficient of friction of rice using the method of inclined surface. Correa et al. (2007) used a digital roughness measurement apparatus in determination of the static friction coefficient of rice. Gosh (1966) used the conventional tilting table in determination of material coefficient of friction. Zhang et al. (1994) used the direct shear apparatus to determine the friction of grain on structural surfaces. Little information is available in the literature on frictional properties of sliced pineapple fruit. In this study, direct shear apparatus was used to determine the shear strength parameters of sliced pineapple fruit and the coefficient of friction of the sliced pineapple fruit on different surfaces.

MATERIALS AND METHODS

Material Selection and Sample Preparation

Fresh pineapple fruits were bought in batches from a local supermarket in Winnipeg, Manitoba. The pineapple *smooth cayena* species was used for the experiment because it is the most common pineapple species sold in Canada. Stainless steel, galvanized steel and plastic (acrylic) were tested for surface friction because they are commonly used in the design of the pineapple processing, handling and storage systems. A kitchen knife was used for the peeling and cutting of the pineapples into size with the help of a metre rule. Most industrial pineapple cutters used in pineapple juice production produce 2-5cm cubes. In this study, the fresh pineapple fruit was peeled and cut to 2× 2×2 cm cubes right before testing to avoid drying of samples.

Testing Procedure

Determination of the shear strength parameters

A direct shear device was used in the experiment to determine the angle of the internal friction and the cohesion of the sliced pineapple fruit. The device had two equal half -shear boxes with 127 ×127×76 mm inside dimensions. The boxes were built with 13 mm thick Plexiglas. The lower half box was fixed on the test frame, and the upper half box was attached to a liner screw-drive through a load cell (fig. 1). The screw-drive was driven by a DC motor to pull the upper cell horizontally to shear the sample. The motor speed was adjusted through a controller to achieve desired shear rates. The sliced pineapple fruit was filled into the boxes manually, and a square plate of Plexiglas having a dimension of 125 ×125 × 25 mm was placed on the upper surface of the pineapple cubes (sample) in the shear boxes. A cradle sled with weights slung underneath the test frame was used in applying the normal load on the test sample (fig. 1). A 2-mm clearance was maintained between the two shear boxes to avoid friction between the shear boxes themselves, and this was achieved by putting four 2-mm steel shims at each corner between the shear boxes during the consolidation and removing them before shearing the sample. Three levels of normal loads of 160, 250 and 330 N were tested.

The sliced pineapple sample was subjected to consolidation before shearing to simulate the consolidation condition occurring in the processing hopper in the industrial pineapple juice extractors. This was achieved by using a consolidation load of 360 N, which was determined by assuming an industrial pineapple juice extractor hopper having a dimension of 0.5 m in diameter and 1 m in height. It should be noted that this consolidation was higher than the normal loads used in shear tests to avoid the effect of additional due to normal loads. A consolidation time of 35 minutes was determined through a set of preliminary tests, in which the sample was filled into the shear boxes, and the consolidation load was applied until the volume of the sample decreased to a constant level in the shear boxes (Clower et al, 1973).

The consolidation load (360 N) was removed before applying the normal load. Shearing was done at a constant speed of 1.3 mm/min. The sheer force applied to the shear box was measured by using a load cell, which was calibrated (R^2=0.9993) using a universal test machine (Series 1410, Applied Test Systems, Inc., Butler, PA). The shear displacement was measured by a LVDT. The experiment was repeated three times using different sliced pineapple samples at each level of normal loads. For each test, the shear and normal stresses were calculated from the measured shear and normal forces, using the cross-sectional area of the boxes as the sample shearing area. A graph of the shear stress and the shear displacement was obtained for each of the tests and the maximum shear stresses were then measured from the graph. Plotting the maximum shear stresses against the corresponding normal stresses gave the yield locus on which the values of the angle of the internal friction ø and the cohesion C was obtained from the slope and the intercept, respectively.

Determination of friction coefficient

Coefficients of friction of sliced pineapple on surfaces of galvanized steel, stainless steel and plastic were determined using the direct shear apparatus, with the lower half box replaced by the test surface. The test procedure was identical to that for internal friction tests, with three replications for each test at 160, 250 and 330 N normal loads. For each of the tests, the frictional force and shear displacement were recorded continuously and the values of coefficient of friction were then calculated as the ratio of the measured maximum frictional force to the normal force applied.

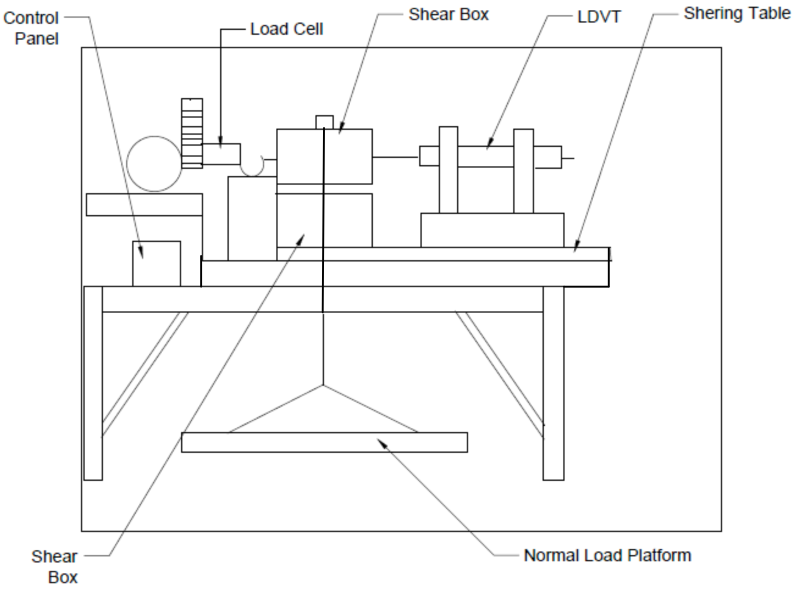

Figure 1. Schematic view of the shear testing apparatus

RESULTS AND DISCUSSION

Shear strength parameters

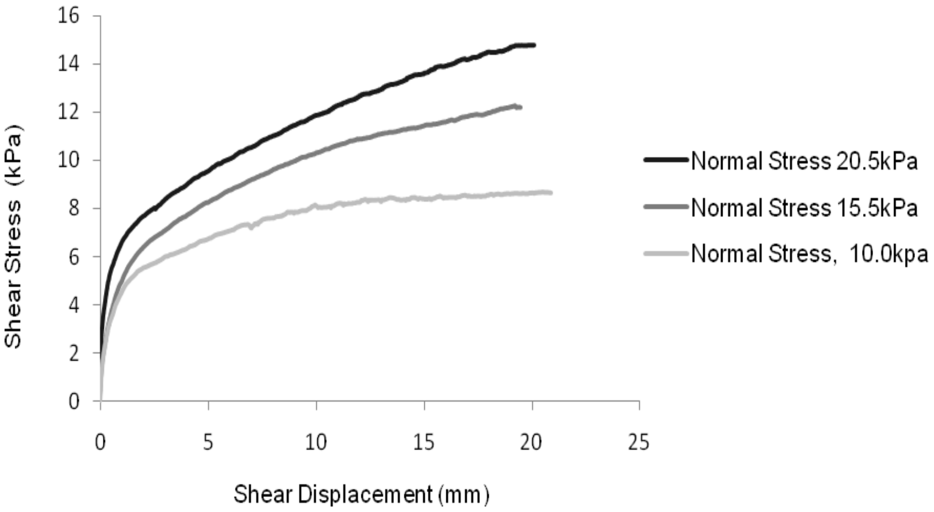

Figure 2. Shear stress against shear displacement at different normal stresses.

Typical shear stress-displacement curves from the shear test are shown in fig. 2 for the three normal stresses of 10.0, 15.5 and 20.5 kPa. It can be seen that the shear stress increased sharply to a shear displacement about 3 mm, and then continued to increase at a lower rate. The shear stress leveled off at 20 mm of displacement for the normal stress of 10.0 kPa, but did not peak at other two normal stresses at 20 mm, which was the maximum shear displacement that the test apparatus could accommodate. The maximum shear stresses were measured to be 8.2, 12.2 and 14.8 kPa for 10, 15.5, and 20.5 kPa normal stresses, respectively.

The measured maximum shear stresses were plotted against the corresponding normal stresses and a linear regression was performed to obtain the best fit line for the data. The slope and intercept of the line were used to obtain the values of the angle of internal friction and cohesion of the sliced pineapple, respectively (fig. 3). The angle of internal friction was determine to be ø =32.2˚ and the cohesion C = 2.07 kPa.

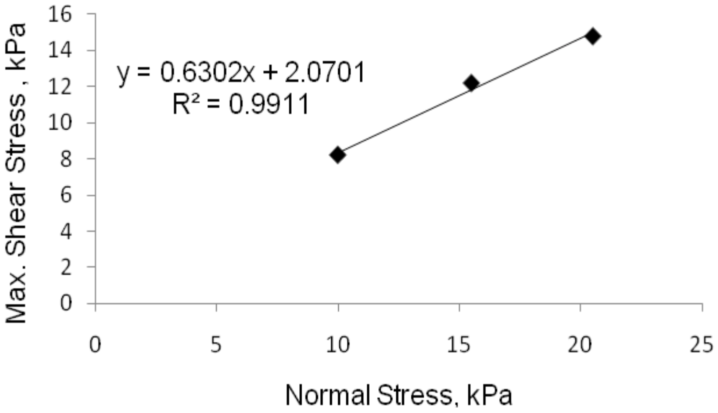

Figure 3. A typical yield locus for sliced pineapple fruits

Friction coefficient

The average values of friction coefficient were 0.39, 0.38 and 0.33 for the galvanized steel, stainless steel, and the plastic surfaces, respectively (Table 1). The highest coefficient of friction was obtained with galvanized steel ranges from 0.44 to 0.34 over the normal load from 160 to 330N while the lowest coefficient of friction was obtained with the plastic ranges from 0.38 to 0.30. The values of coefficient of friction for the stainless steel surface were approximately the same as that of the galvanized steel.

Table 1. Coefficient of friction sliced pineapple on three surfaces at different normal loads

Normal Load, N	Galvanized Steel	Stainless steel	Plastic
160	0.44(0.03)*	0.41(0.01)	0.38(0.01)
250	0.38(0.02)	0.37(0.02)	0.32(0.007)
330	0.34(0.05)	0.32(0.005)	0.3(0.004)
Average	0.39	0.38	0.33

*Standard deviation

It is interesting to note that the coefficient of friction decreased with the normal force. The analysis of variance was carried out to examine the effect of normal force on the coefficient of friction. The results indicated that both the normal force and material surface had significant effect ($\alpha<0.05$) on the coefficient of friction (Table 2). Richter (1954) showed that the coefficient of friction of high moisture content chopped corn silage decreased as the normal force increased on different surfaces tested. Zhang et al. (1994) explained that decrease in the coefficient of friction of a bulk material as the normal load increases might be as a result that a greater normal force increases the contact area between the material and the surface, and the increase in the surface contact area reduces the localized contact pressure.

Table 2. Summary of analysis of variance

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Normal Load	0.042681	2	0.021341	38.64255	3.06E-07	3.554557
Surfaces	0.018393	2	0.009197	16.65287	8.05E-05	3.554557
Interaction	0.000671	4	0.000168	0.30387	0.871559	2.927744
Error	0.009941	18	0.000552			
Total	0.071687	26				

The quantitative relationship between the coefficient of friction and the normal load is illustrated in fig. 4. The coefficient of friction over the normal loads 160, 250, and 330 N ranged from 0.44 to 0.34 for the galvanized steel, and from 0.44 to 0.34 for the stainless steel while it is 0.38 to 0.30 for plastic.

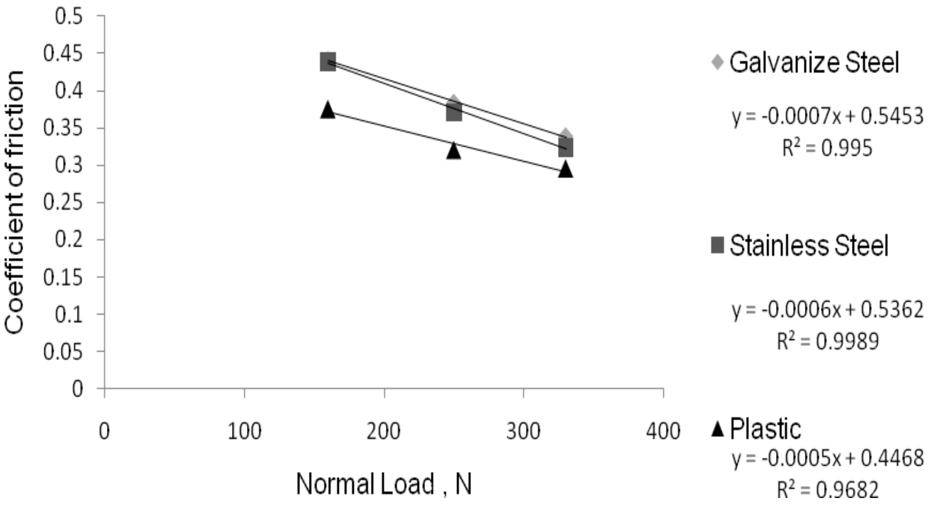

Figure 4. Effect of normal load on coefficient of friction of sliced pineapple.

CONCLUSION

The first part of the experiment involved the use of a direct shear testing apparatus for the determination of the shear strength parameters of slice pineapple fruit using three different normal loads. The angle of internal friction was obtained as ø =32.2^o and the cohesion C = 2.07KPa.

The second part of the experiment was to determine friction of the slice pineapple fruit on galvanized steel, stainless steel and plastic. Galvanize steel had the highest value of the coefficient of friction follow by the stainless steel, while plastic had the least value of the coefficient of friction. The normal loads had significant effect on the friction of sliced pineapple on all three surfaces tested.

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