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Research Article

Effect of Drying on Selected Physical Properties of "*Asontem*" Cowpea Variety

Ato Bart-Plange, Komla Agbeko Dzisi, and Jonathan Ampah

Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Correspondence should be addressed to Ato Bart-Plange, abartp@yahoo.com

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Storage, handling, processing, and other postharvest operations of agricultural products require information about their physical properties for the design of related machinery. This study was carried out to evaluate the effect of drying on some physical properties of "*asontem*" cowpea variety within the moisture content range of 19.00% wb and 9.58% wb using standard techniques. Four levels of moisture content were used namely, 19.00%, 15.13%, 11.50%, and 9.58% wb. The average length, width, and thickness decreased with decreasing moisture content from 8.16 to 7.11 mm, 6.36 to 6.28 mm and 4.77 to 4.61 mm respectively. The geometric mean diameter, surface area, and volume decreased nonlinearly with decreasing moisture content from 6.27 to 5.89 mm, 123.88 to 109.46 mm^2, and 130.23 to 108.02 mm^3, respectively. 1000 grain mass decreased non-linearly from 132.85 to 120.92 g and true density increased non-linearly with decreasing moisture content from 1063.80 to 1185.92 kg/m^3. The filling angle of repose decreased non-linearly from 29.34 to 27.92°, while the coefficient of static friction also decreased non-linearly from 0.36 to 0.29, 0.35 to 0.28, and 0.31 to 0.21 for plywood, mild steel, and rubber, respectively.

1. Introduction

It is estimated that globally cowpea is cultivated on about 14.5 million hectares with an annual production of over 4.5 million tonnes [1]. Cowpeas are among the most important food legume crops in the semiarid tropics covering Asia, Africa, Southern Europe, and Central and South America with the ability to fix atmospheric nitrogen through its root nodules into the soil [2].

Physical properties of grains are important in the design of storage and processing equipment. They are important factors in solving problems associated with the design of machines or analysis of the behaviour of the product during agricultural processes such as planting, harvesting, handling, threshing, sorting, and drying [3].

Physical properties such as dimensions, mass, volume, projected area, and surface area are most important in grading systems. Dimensional grading of products decreases the packaging and transportation costs and allows usage of proper packaging models [4, 5]. Length, width, and thickness determination is useful in the design of seed metering devices, sorting sieves, pneumatic conveying systems, planters and combine harvesters. Clearance between the cylinder and the concave of a combine harvester is also reliant on size and shape dimensions [3]. Shape is important in orienting fruits and vegetables prior to mechanized operations such as peeling, removal of cores and pits, or positioning for machine-assisted packing. For example, the bottom part of pears is ellipsoidal, but the upper portion is conical; hence, the centre of gravity is nearer the bottom. When pears fall into the notch of a belt roller, they assume a position in which their centre of gravity is as low as possible and therefore their stem ends point upwards and this is good for separation purposes [3].

The rate of heat transfer to a material also depends on the heat transfer coefficient which is related to the surface area. The smaller the volume of material per unit surface, the better its condition for rapid heat transfer. The effects of size and surface area on drying rates of particulate materials can also be characterized by using the surface-to-volume ratio. When diffusion of water within the particle limits drying rate, larger particles dry more slowly than smaller particles of the same shape. Also, the ratio of surface area to volume affects drying time and energy requirements [3]. The 1000 grain mass of cereal grains is a useful index to "milling outturn" in measuring the relative amount of dockage or foreign material in a given lot of grain, and the amount of shrivelled or immature kernels [6].

Pneumatic sorting tables are used to separate seeds of cereal crops by true density. Seeds of various impurities such as *Centourea*, rye grass, field mustard, and wild oats greatly differ in true density from the seeds of cereal crops. The true density of grain mixtures is determined either in solution or in suspension [7, 8]. True density data have been used in research to determine the dielectric properties of cereal grains [9, 10].The angle of repose is also important in designing equipment for mass flow and structures for storage. The angle of repose is particularly useful for calculating the quantity of granular materials which can be placed in piles or flat storages [3]. The knowledge of coefficient of friction of food grains on various structural surfaces is necessary in the analysis and design of postharvest equipment such as grain bins, silos, and conveyors. A machine can only be started or stopped if forces of static friction or dynamic friction are overcome by a power source. Therefore, information on both static and dynamic coefficient of friction is vital in estimating the power requirement of machines [11].

Several researchers have determined the physical and mechanical properties of different agricultural products as a function of moisture content in order to provide essential data for the design of processing equipment. These include researchers such as Baryeh for bambara groundnuts; Bart-Plange et al. for maize; Varnamkhasti et al. for rice and Kiliçkan et al. for spinach seed [6, 12–14].

Cowpea processing in Ghana is mainly done using traditional methods. It has, therefore, become imperative to investigate the characteristics of the crop with a view to better understand the physical properties that come to play during mechanical processing and handling operations. A lot of research has been carried out on the effect of rewetting on the physical properties of grains with little attention to the effect of drying. Some work on physical properties of some varieties of cowpea has been done by other researchers from other countries [15–18]. The physical properties of some varieties of cowpeas in Ghana have also been found, such as that for "*asetenapa*" and "*adom*" varieties. Some work has been done on the effect of rewetting on the physical properties of "*asontem,*" an early maturing variety of cowpea [19]. However, no work appears to have been done on the effects of drying which can also affect the physical properties.

The objective of this study was to determine the effect of drying on size and shape properties, 1000 grain mass, true density, filling angle of repose, and coefficient of static friction for the "*asontem*" cowpea variety which may facilitate the design of some machines for its processing.

2. Materials and Methods

2.1. Sample Preparation. The "*asontem*" cowpea variety was obtained from the Crops Research Institute of the Council for Scientific and Industrial Research (CSIR) at Fumesua, Kumasi. The grains were already clean from chaff and other foreign materials. The initial moisture content of the grains after conditioning was determined using the standard oven method. The grains were then sun-dried to three other lower moisture content levels of 15.13%, 11.50%, and 9.58% at periodic intervals. They were cleaned again to remove any foreign material present before the commencement of the experiment. All the physical properties were determined at four moisture contents with four replications at each moisture content level. The initial moisture content of 19.00% wb was obtained by keeping a ground sample of 5 g in the oven at 130°C ± 1 for 2 hours [20]. The lower moisture contents were obtained by drying to obtain a sample mass using

$$M_f = \frac{M_i(100 - m_i)}{100 - m_f}, \quad (1)$$

where M_f: the desired mass of sample (g), M_i: initial mass of sample (g), m_f: final moisture content of sample (%wb), and m_i: final moisture content of sample (%wb).

2.2. Dimensional Properties Determination. 100 grains were picked at random from the bulk grains and their principal dimensions of length (L), width (W), and thickness (T) determined with a micrometre screw gauge at 0.01 mm accuracy. Based on measurements of the length, width and thickness, data for the geometric mean diameter (D_g), surface area (S_a), and volume (V) were determined using the mathematical equations (2), (3), and (4), respectively:

$$D_g = (L \times W \times T)^{1/3}, \quad (2)$$

$$S_a = \pi\left(D_g^2\right), \quad (3)$$

$$V = \frac{\pi}{6}\left(D_g^3\right). \quad (4)$$

2.3. Grain Mass Determination. 100 grains were picked at random from each of the four samples and weighed on an electronic balance to 0.01 g accuracy at every predetermined moisture content level. The mass was then multiplied by 10 to give the 1000 grain mass and the average recorded. Similar methods have been used by Tunde-Akintunde and Akintunde for beniseed, Tavakoli et al. for barley grains and Gharibzahedi et al. for pine nut [8, 21, 22].

2.4. True Density Determination. In the determination of the true density, 100 grains were picked at random, and the mass was determined. Toluene was poured into a measuring cylinder and the volume recorded. The grains were then poured into the cylinder, and the new volume of toluene was recorded. Due to its less absorbent nature, toluene (C_7H_8) was used in place of water. Again, its surface tension is so low that it fills even shallow dips in a seed, and its dissolution power is low [23, 24]. The true density was found as an average of the ratio of the mass of grains to the volume of toluene displaced by grains:

$$\text{True Density: } \ell_t = \frac{M}{V_2 - V_1}, \quad (5)$$

where M is the mass of grains in kg, V_1 is the initial volume in m^3, and V_2 the final volume also in m^3.

2.5. Filling Angle of Repose Determination. The grains were poured from a height of 15 cm unto a circular wooden plate of radius 10 cm. The height of the heap was then measured and the angle of repose determined from (6):

$$\text{Tan } \gamma = \frac{h}{r} = \frac{h}{10}, \qquad \gamma = \tan^{-1}\left[\frac{h}{r}\right], \tag{6}$$

where h is the height of the heap and r the radius of the plate.

Similar methods have been used by Bart-Plange and Baryeh for category B cocoa beans and Bart-Plange et al. for "*obatanpa*" maize variety [13, 25].

2.6. Static Coefficient of Friction Determination. The static coefficient of friction (μ) was determined against three structural surfaces namely, mild steel, plywood, and rubber. The tilting table apparatus was used. A cylindrical PVC container, hollow at both ends of dimension 100 mm diameter and 50 mm height, was filled with cowpeas and lifted slightly about 2 mm, so as not to touch the friction surface. The surface was gradually raised using the screw device until the cylinder along with the sample just begun to slide down. The angle of inclination which is the angle between the friction surface and the horizontal was read from a protractor. The coefficient of friction was calculated from:

$$\mu = \tan \theta, \tag{7}$$

where μ is the coefficient of static friction, and θ is the angle of tilt of table.

2.7. Experimental Design and Data Analysis. All tests were conducted at four levels of moisture content with four replications at each level. The experimental design used was the completely randomised design (CRD). Analysis of variance (ANOVA) was carried out on the data using Microsoft Excel version 2010 at a significance level of 5%. The least significant difference (LSD) was determined, where a significance difference existed between treatments means.

3. Results and Discussion

3.1. Dimensional Properties. The length decreased nonlinearly from 8.16 to 7.11 mm, width from 6.36 to 6.28 mm, and thickness from 4.77 to 4.61 mm with decreasing moisture content as shown in Figures 1, 2, and 3 respectively. Length, width, and thickness dimensions showed significant differences at the 5% level. The decrease in the linear dimensions can be attributed to the removal of moisture causing shrinkage in volume of the grains. Length recorded the highest decrease in dimension (12.9%) followed by thickness (3.4%) and then width (1.2%).

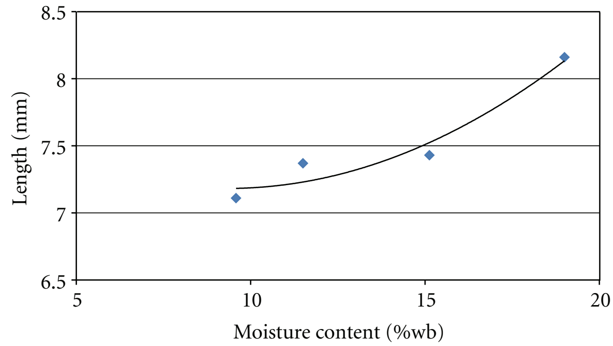

Figure 1: Variation of length with moisture content.

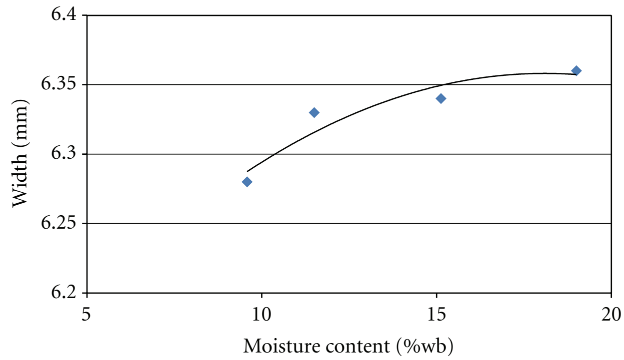

Figure 2: Variation of width with moisture content.

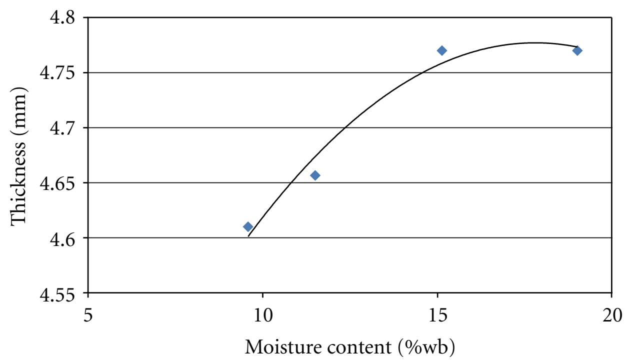

Figure 3: Variation of thickness with moisture content.

The relationship can be represented by the following equations:

$$\begin{aligned} L &= 0.0102\,M^2 - 0.1900\,M + 8.0688, & R^2 &= 0.9436, \\ W &= -0.001\,M^2 + 0.0353\,M + 6.0387, & R^2 &= 0.8983, \\ T &= -0.0026\,M^2 + 0.0928\,M + 3.9512, & R^2 &= 0.9739. \end{aligned} \tag{8}$$

Results of this study agrees with work done by Henshaw, who found the seed length, width, and thickness of different varieties of cowpea to range from 6 to 10 mm, 4 to 7 mm, and 3 to 5 mm, respectively [17]. Baryeh found that the linear dimensions of Bambara groundnuts increased with

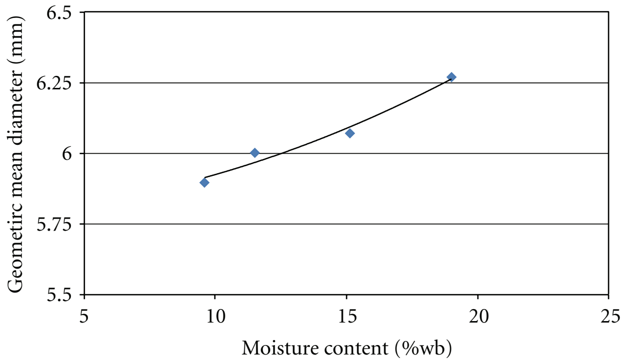

Figure 4: Variation of geometric mean diameter with moisture content.

increasing moisture content up to 25% beyond which there was no appreciable change. Length recorded the highest decrease in dimension (12.9%) followed by thickness (3.4%) and then width (1.2%) [12].

3.2. Geometric Mean Diameter. Values for the geometric mean diameter decreased from 6.27 to 5.90 mm as shown in Figure 4. The equations describing drying trend are as follows:

$$D_g = 0.0012\,M^2 - 0.0024\,M + 5.7802, \qquad R^2 = 0.9727. \tag{9}$$

Wang et al., Tavakoli et al., and Ozturk et al. found the geometric mean diameter to increase linearly with increasing moisture content for flaxseed, barley grains, and common beans, respectively [8, 26, 27].

3.3. Surface Area. The surface area decreased non-linearly from 123.88 mm^2 at 19.00% wb to 109.46 mm^2 at 9.58% wb as shown in Figure 5. Significant differences were found to exist at $P < 0.05$. The equation describing the drying trend is as follows:

$$S_A = 0.0532\,M^2 - 0.0868\,M + 106.09, \qquad R^2 = 0.9733. \tag{10}$$

3.4. Volume. The variation of volume with moisture content is shown in Figure 6. Volume decreased non-linearly from 130.23 mm^3 at 19.00% wb to 109.07 mm^3 at 9.58% wb, representing a decrease of 16.30%. Drying conditions showed significant differences among all treatment at $P < 0.05$. The equations describing drying trend is as follows:

$$V = 0.112\,M^2 - 1.0078\,M + 108.54, \qquad R^2 = 0.9679. \tag{11}$$

Increase in volume with increasing moisture content has been found by Igbozulike and Aremu for *Garcinia kola* seeds [28].

3.5. Grain Mass. Drying recorded a reduction of 9.86% in mass from 132.85 to 120.93 g as shown in Figure 7. Values for drying were found to be significantly different at the 5% level.

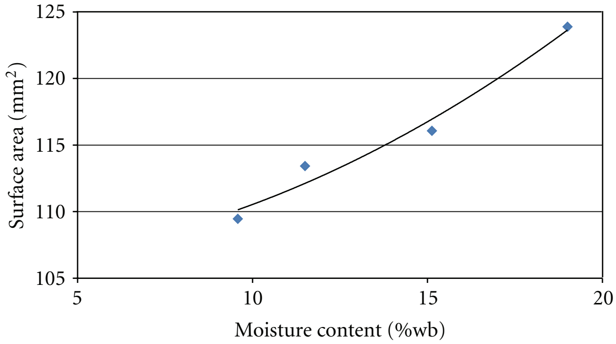

Figure 5: Variation of surface area with moisture content.

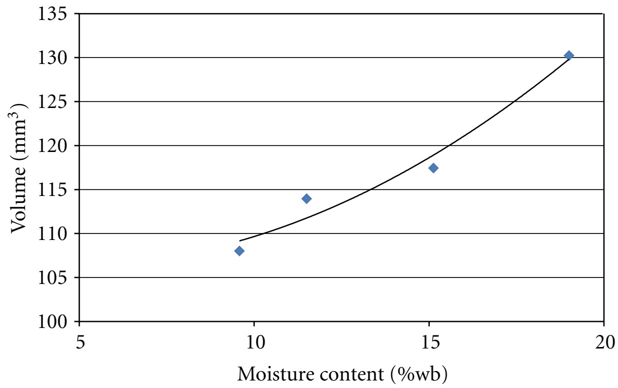

Figure 6: Variation of volume with moisture content.

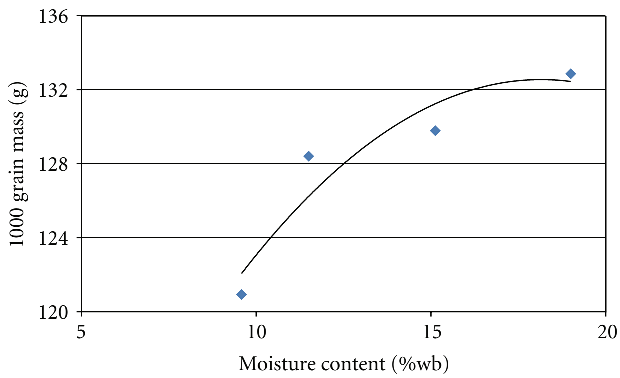

Figure 7: Variation of 1000 grain mass with moisture content.

The variation in 1000 grain mass for drying can be expressed as follows:

$$1000_m = -0.1426\,M^2 - 5.1784\,M + 85.54, \qquad R^2 = 0.8921. \tag{12}$$

Tchiagam et al. in a study on physical properties of cowpea found the average hundred seed mass to be 20.46 g. This is higher which could be attributed to the varieties and moisture content ranges used [15]. Linear variations in 1000 grain mass have been recorded by Singh and Goswami for cumin and Gharibzahedi et al. for black cumin [29, 30].

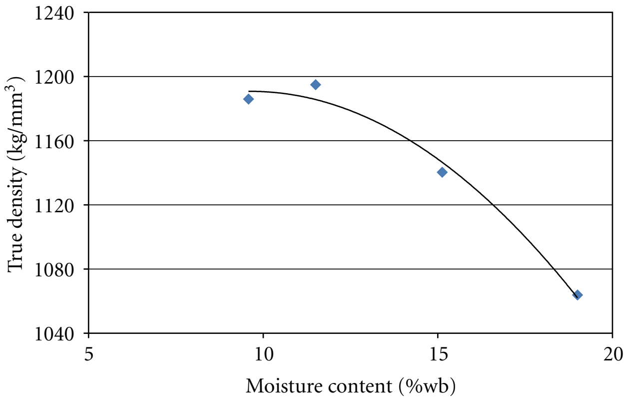

Figure 8: Variation of true density with moisture content.

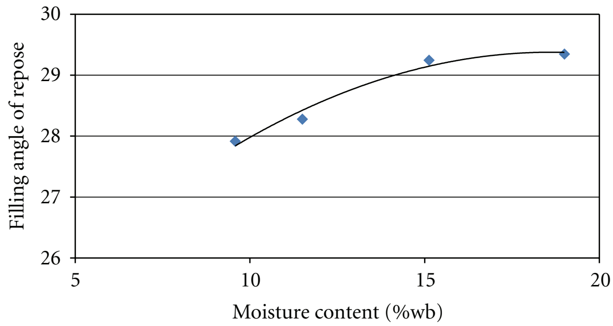

Figure 9: Variation of filling angle of repose with moisture content.

3.6. True Density. Figure 8 shows the variation of true density with moisture content. True density decreased non-linearly with decreasing moisture content from 1185.92 to 1063.80 kg/m^3. The variation with moisture content for drying can be expressed as follows:

$$\ell_t = -1.4677 M^2 + 28.285 M + 1054.5, \qquad R^2 = 0.9861. \tag{13}$$

All the values for drying were found to be significantly different at $P < 0.05$.

Yalçin found the true density of cowpea seeds to range from 1154.8 to 1104.1 kgm^{-3} with increasing moisture content from 12.01% to 39.90% db [16].

3.7. Angle of Repose. The filling angle of repose decreased non-linearly with decreasing moisture content from 29.35° at 19.00% wb to 27.91° at 9.58% wb as shown in Figure 9. The decrease in filling angle of repose may be due to a decrease in surface roughness as well as size of individual grains which affect their ability to form a heap. The variation of the filling angle of repose with moisture content can be expressed as follows:

$$\theta_f = -0.0188 M^2 + 0.701 M + 22.853, \qquad R^2 = 0.9753. \tag{14}$$

Results obtained showed no significant difference at the 5% level.

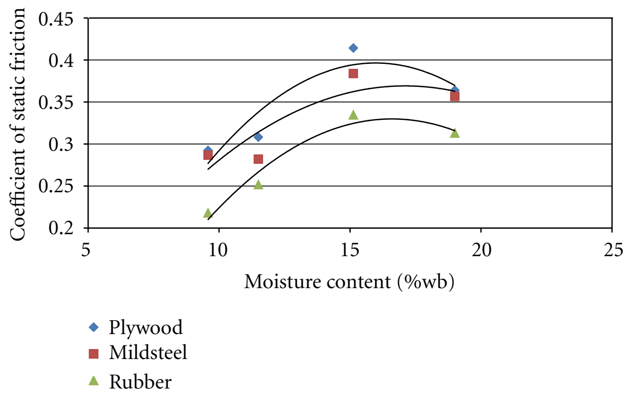

Figure 10: Variation of coefficient of static friction with moisture content.

Maunde et al. found the angle of repose for cowpea seed and pod to be 39 to 36° and 29.6 to 30.9°, respectively for two indigenous varieties which compares well with the results of this study [18]. Several researchers including Joshi et al. for pumpkin seeds and Singh and Goswami for cumin seeds have found the angle of repose to vary with varying moisture content [29, 31].

3.8. Coefficient of Static Friction. The coefficient of static friction decreased non-linearly with decreasing moisture content from 19.00 to 9.58% wb as shown in Figure 10. The three surfaces recorded decreasing coefficients namely, plywood (0.36 to 0.29), mild steel (0.35 to 0.28), and rubber (0.31 to 0.21). The coefficient of static friction for plywood recorded the highest value followed by mild steel and lastly rubber. The decrease in coefficient of static friction may be due to the decrease in grain weight due to moisture loss which increases its ability to slide. The variation with moisture content for plywood, mild steel, and rubber can be expressed respectively as follows:

$$\begin{aligned} \mu_p &= 0.0029 M^2 - 0.0933 M + 0.3490, \qquad R^2 = 0.8326, \\ \mu_m &= 0.0018 M^2 - 0.0599 M + 0.1434, \qquad R^2 = 0.7659, \\ \mu_r &= 0.0024 M^2 - 0.0806 M + 0.3388, \qquad R^2 = 0.9547. \end{aligned} \tag{15}$$

Yalçin found static coefficient of friction of cowpea seed to increase linearly with moisture content against surfaces of four structural materials namely; rubber (0.364–0.394), aluminium (0.212–0.296), stainless steel (0.176–0.238), and galvanised iron (0.324–0.36). This agrees with the results of this current study [16].

4. Conclusion

The investigation of selected physical properties of "*asontem*" cowpea variety under drying conditions revealed the following:

(1) the length, width, and thickness decreased non-linearly from 8.16 to 7.11 mm, 6.36 to 6.28 mm, and 4.77 to 4.61 mm, respectively;

(2) the geometric mean diameter, surface area, and volume decreased non-linearly with decreasing moisture content from 6.27 to 5.89 mm, 123.89 to 109.46 mm^2, and 130.23 to 108.02 mm^3, respectively;

(3) the true density increased non-linearly with decreasing moisture content from 1063.80 to 1185.92 kg/m^3;

(4) the 1000 grain mass decreased non-linearly from 132.85 to 120.93 g;

(5) the filling angle of repose decreased from 29.35 to 27.92° in the moisture range of 19.00% wb and 9.58% wb;

(6) the static coefficient of friction decreased non-linearly with decreasing moisture content on all the three surfaces namely, plywood (0.36 to 0.29), mild steel (0.35 to 0.28), and rubber (0.31 to 0.21).

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