The Moisture Content Effect on Some Physical and Mechanical Properties of Corn (*Sc 704*)

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Abstract

Physical and mechanical properties of grains are necessary for designing the facility of storage, handling and processing of agricultural products. Physical and mechanical properties of corn grains were determined as a function of moisture content in the range of 4.73-22% w.b. (wet basis) using standard techniques. The average length, width, thickness, geometric mean diameter, equivalent diameter, arithmetic diameter, sphericity, grain volume, surface area and aspect ratio ranged from 11.62 to 12.60 mm, 7.27 to 7.98 mm, 4.47 to 4.71 mm, 7.20 to 7.77 mm and 7.63 to 7.96 mm, 7.77 to 8.43 mm, 62.31% to 62.00%, 209.66 to 265.00 mm^3, 137.69 to 160.09 mm^2 and 63.05% to 63.77% as the moisture content changed from 4.73-22% w.b. With increase in moisture content, the bulk density was found to decrease from 710 to 649 kgm^{-3} whereas true density and porosity increased from 1250 to 1325 kgm^{-3} and 43.2% to 51.02%. In the moisture range from 4.73% to 22% w.b., studies on rewetted corn grains showed that the thousand grain weight (TGW) increased linearly from 271.0 to 321.4 g. The static coefficient of friction of corn grains increased linearly against surfaces of three materials, namely, plastic (0.32–0.51), plywood (0.48–0.60) and galvanized iron (0.38–0.65) and the static angle of repose increased from 49º to 58º when the moisture content increased from 4.73% to 22% w.b. The mechanical properties of corn were determined in terms of average rupture force and rupture energy. Rupture energy of corn grains generally increased in magnitude with an increase in moisture content, while rupture force decreased for compression.

Keywords: Physical and mechanical properties, Moisture content, Sc 704 corn variety

1. Introduction

One of the leading food crops of the world and the most important crops in Iran is corn. Little researches concerning the effects of moisture content on physical and mechanical properties of this crop are available in Iran. To design equipment for the handling, separation, conveying, drying, storing, aeration and processing of corn grains, determining their physical properties of crops as a function of moisture content is essential. The size and shape are, for instance, important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1980). Bulk density, true density, and porosity (the ratio of intergranular space to the total space occupied by the grain) can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, which may lead to higher power to drive the aeration fans. Cereal grain densities have been of interest in breakage susceptibility and hardness studies. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi Varnamkhasti et al., 2007). The knowledge of some important physical properties such as shape, size, volume, surface area, thousand grain weights, density, porosity, angle of repose of different grains is necessary for the design of various separating, handling, storing and drying systems (Sahay and Singh, 1994). Bulk density, grain density and porosity are major considerations in designing the drying and aeration and storage systems, as these properties affect the resistance to air flow of the mass. Gumble and Maina (1990) observed that angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures and the coefficient of friction between seed and wall in the prediction of seed pressure on walls. It is important in filling flat storage facility when grain is not piled at a uniform bed depth but rather is peaked (Mohsenin, 1980). Hence, this study was performed to consider some moisture dependent physical and mechanical properties of corn grain namely, dimensions, geometric mean, equivalent and arithmetic diameter, sphericity, thousand grain weight (TGW), surface area, bulk density, true density, porosity, static angle of repose, static coefficient of friction against different materials, rupture force and rupture energy.

2. Materials and Methods

The 4.73% w.b. of Sc704 corn grain (Figure 1) was used in this study. The grains were obtained from Plant and Seed Institute in Karaj. The initial moisture content of seeds was determined by oven method (Tabatabaeefar, 2003) and in order to achieve the desired moisture levels as 12, 16, and 22% w.b., the rewetting formula was used. To allow the moisture be absorbed by samples, they were placed in refrigerator.

$$Q = \frac{W_t(M_f - M_i)}{(100 - M_f)} \tag{1}$$

In order to determine length, width, and thickness of about 40 randomly selected grains of each sample, a digital caliper was used. The geometric mean, D_g, equivalent, D_p and arithmetic diameter, D_a, in mm were calculated by considering prelate spheroid shape for a corn grain and therefore using these equations (Mohsenin, 1980):

$$D_g = (LDT)^{\frac{1}{3}} \tag{2}$$

$$D_p = \left[L\frac{(W+T)^2}{4}\right]^{\frac{1}{3}} \tag{3}$$

$$D_a = \frac{(L+W+T)}{3} \tag{4}$$

The sphericity (Sp), defined as the ratio of the surface area of the sphere having the same volume as that of grain to the surface area of grain, was determined using following formula (Mohsenin, 1980).

Notations	
L length, mm	Φ static coefficient of friction
W width, mm	θ_{st} static angle of repose, deg
T thickness, mm	ε porosity, %
S surface area, mm^2	D_g geometric mean diameter, mm
R^2 correlation determination	D_p equivalent diameter, mm
R_a aspect ratio	D_a arithmetic diameter, mm
M moisture content, %	V volume, mm^3
M_i initial moisture content, %	S_p sphericity, %
M_f final moisture content, %	ρ_b bulk density, kgm^{-3}
W_t total weight of sample, g	ρ_t true density, kgm^{-3}
Q weight of required water, g	F_a average rupture force, N
E_a average rupture energy, N.mm	TGW thousand grain weight, g

$$S_p = \frac{(LDT)^{\frac{1}{3}}}{L} \tag{5}$$

Thousand grain weight (TGW) was measured by counting 100 seeds and weighing them in an electronic balance with an accuracy of 0.001g and multiplying by 10 to give mass of 1000 grains. Jain and Bal (1997) used these equations for calculating grain volume, V and surface area, S:

$$V = 0.25[(\frac{\pi}{6})L(W+T)^2] \tag{6}$$

$$S = \frac{\pi B L^2}{(2L-B)} \tag{7}$$

Where:

$$B = \sqrt{WT} \tag{8}$$

The aspect ratio (R_a) was calculated by (Omobouwajo et al., 1999).

$$R_a = \frac{W}{L} \tag{9}$$

The Toluene displacement method was used to determine true density which is the ratio of mass sample of grains to its pure volume (Mohsenin, 1980). Bulk density is the ratio of the mass sample of grains to its total volume. A container was used to determine the bulk density. It was filled by a constant height, striking the top level and then weighing the container (Dashpande et al., 1993). The porosity is the ratio of free space between grains to total of bulk grains and it was calculated by:

$$\varepsilon = \frac{\rho t - \rho b}{\rho b} \times 100 \tag{10}$$

The coefficient of static friction was determined with respect to different surfaces: plywood, plastic and galvanized iron by the apparatus which is shown in Figure 2. A small rectangular frame which is open at both ends was filled with the seeds at the desired moisture content and placed on adjustable titling surface such that the metal cylinder did not contact the surface. Then the surface was raised gradually until the filled rectangular just started to slide down (Razavi and Milani, 2006).

The angle with the horizontal surface at which the material will stand when piled is the static angle of repose. This was determined by using the apparatus (Figure 3) consisting of a plywood box of 140-160-35mm and two plates (fixed and adjustable). The box was filled with sample, and then the adjustable plate was inclined slowly allowing the seeds to follow and assume a natural slope (Tabatabeefar, 2003).

From forces acting on the grain with speed load of 5 mm/min, rupture strength for corn grain was determined (see Figure 4). The procedure was to put the seed on desired section and selecting speed of loading and then applying force until the grain is fractured. Instron Universal Testing Machine (Model Santam STM-5), that is equipped with a 25 kg compression load cell and integrator, was used for this test. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation. The individual seed was loaded between two parallel plates of the machine and compressed at this condition until rupture occurred as is denoted by a bio-yield point in the force-deformation curve. Once the bio-yield was detected, the loading was stopped. The mechanical properties of corn grain were expressed in terms of rupture force and rupture energy.

3. Results and Discussion

3.1 Size and shape

The dimensions' summary of Sc704 corn is shown in Table 1. The mean dimensions of 10 samples at a moisture content of 4.73% w.b. were: length 11.62 mm, width 7.27 mm, and thickness 4.47 mm. All dimensions were increased with an increase in moisture content from 4.73% to 22% w.b. The increasing trend in axial dimensions, with gain in moisture content, was due to filling of capillaries and voids upon absorption of moisture and subsequent swelling (Table 1).

With an increase in moisture content of corn grains from 4.73 to 22% w.b., the surface area of corn grains increased from 137.69 to 160.09 mm^2. Milani et al. (2007) reported an increased in surface area of cucurbit seeds of three varieties at different moisture contents in the range of 5.18 - 42.76% (w.b.).

The sphericity of corn grains decreased from 0.62 to 0.59 with an increase in moisture content from 4.73 to 12% w.b. but in the range of 12–22 % w.b., sphericity increased from 0.59 to 0.62. The volume and aspect ratio of corn grains had the same behavior. The geometric mean diameter of corn grains increased from 7.2 to 7.78 mm and arithmetic diameter from 7.79 to 8.43 mm. Esref and Halil (2007) found similar result for white speckledred kidney bean grains. The equivalent diameter increased significantly at the 5% level of probability from 7.35 to 7.95 mm. The grains' volume increased from 209.66 to 265.00 mm^3 with the moisture level increment.

3.2 Thousand grain weight

One thousand grain weight (TGW) increased from 271 to 321.4 g as the moisture content increased from 4.73% - 22% w.b. (Figure 5). Linear relationship for one thousand grain weight based on moisture content, M, was determined as follows:

$$TGW = 2.924M + 256.0 \qquad R^2 = 0.996 \qquad (11)$$

A linear increase in one thousand grain weight as an increase in seed moisture content has been noted by Tabatabaeefar (2003) for wheat. He represented that the TGW increased linearly from 23.2 g to 39.7 g when the moisture content increased from 0 to 22 % d.b.

3.3 Bulk and true densities and porosity

The values of the bulk density for different moisture levels varied from 710 to 649 kg m^{-3} (Figure 6). The bulk density of grain was found to bear the following relationship with moisture content:

$$\rho_b = - 3.357M + 723.6 \qquad R^2 = 0.948 \qquad (12)$$

A similar decreasing trend in bulk density has been reported by Gupta and Das (1997) for sunflower seed. Parde et al. (2003) reported that the standard bulk density of Koto buckwheat increased significantly from 603.90 to 612.90 kgm^{-3} with an increase in moisture content from 14.8 to 15.8 %. With a further increase in moisture content, the standard bulk density decreased significantly.

The true density varied from 1250 to 1325 kgm^{-3} when the moisture level increased from 4.73% - 22% w.b. (Figure 7). The true density and the moisture content of grain can be correlated as follows:

$$\rho_t = -0.498M^2 + 17.59M + 1178 \qquad R^2 = 0.997 \qquad (13)$$

The porosity of corn grains increased linearly at the 5% level of probability from 43.2 % to 51 % with the increase in moisture content from 4.73% - 22% w.b. (Figure 8). The relationship between porosity and moisture content can be represented by the following equation:

$$\varepsilon = 0.441M + 42.01 \qquad R^2 = 0.897 \qquad (14)$$

Baumler et al. (2006), reported an increase in porosity against moisture content variations and have then evaluated the relationship between porosity and moisture content for safflower seed as:

$$e= 0.34M + 39.53 \qquad R^2 = 0.930 \qquad (15)$$

3.4 Coefficient of friction

The static coefficient of friction of corn grain on three surfaces (plastic, plywood and galvanized iron) against moisture content in the range of 4.73% - 22% w.b. are presented in Figure 9. It was noted that the static coefficient of friction increased with increase in moisture content for all the surfaces. This is due to the increased adhesion between the grains and the material surfaces at higher moisture values. Increases of 56.8%, 25.9% and 69.4% were recorded in the case of plastic, plywood and galvanized iron, respectively, as the moisture content increased from 4.73% - 22% w.b. At all moisture contents, the least static coefficient of friction occurred on plastic. This may be because of smoother and more polished surface of the plastic than the other materials used. The relationships between static coefficient of friction and moisture content on plastic, plywood and galvanized iron can be represented by the following equations:

$$\Phi_{plyw} = 0.007M + 0.422 \qquad R^2 = 0.828 \qquad (16)$$

$$\Phi_{galv} = 0.015M + 0.307 \qquad R^2 = 0.998 \qquad (17)$$

$$\Phi_{plas} = 0.010M + 0.284 \qquad R^2 = 0.975 \qquad (18)$$

Similar results were found by Sahoo and Srivastava (2002) for okra. Parde et al. (2003) reported that the friction coefficient against plywood, galvanized steel and concrete surfaces for the Koto buckwheat cultivar increased significantly 0.26 to 0.31, 0.25 to 0.29 and 0.38 to 0.43 respectively, with increase in moisture content from 14.8 % to 17.9 %.

3.5 Angle of repose

The results for the static angle of repose with respect to moisture content are shown in Figure 10. The values of the static angle of repose were found to increase significantly from 49 to 58° in the moisture range of 4.73to 22 % w.b. The following relationship was obtained for static angle of repose of corn with its moisture content.

$$\theta st = 0.546M + 46.27 \qquad R^2 = 0.963 \qquad (19)$$

Parde et al., (2003) observed that the emptying angle of repose for Koto buckwheat cultivar remained constant at about 23.5° from 14.8 to 15.8% m.c. and then increased significantly and the filling angle of repose did not vary significantly at 14.8 to 16.6% but raised significantly to 28.4° at 17.9%.

3.6 Rupture force

The force required to start grain rupture at different moisture contents is shown in Figure 10. From this Figure it can be seen that the force required initiating grain rupture decreased with the increase in moisture content. The rupture force values ranged from 298.11 N to 198.44 N. The results demonstrate that, in the range of moisture content investigated (4.73–22%), the rupture force along principal axis is highly dependent on moisture content (Figure 11). For the curve, the grains at less moisture content need greater rupture force. The small rupturing force at higher moisture content may be due to the fact that the corn grain might have soft texture at high moisture content. Figure 10 shows that rupture force decreased to a minimum value at a moisture content of 16% and then increased with increase in moisture content from 16% to 22%. This might have resulted from the fact that when the corn grains were compressed, further absorption of water by shell made grain inside to swell up and fill the clearance between the inside of grain and the shell so became structurally turgid and this made an increase in rupture force again. Vursavus and Ozguven (2004), Altuntas and Yıldız (2005) and Olaniyan and Oje (2002) reported similar result for apricot pit, faba been and shea nut, respectively. The relationship between rupture force and moisture content of corn grain compressed can be expressed mathematically as follows:

$$F_a = 0.632M^2 – 23.10M + 396.2 \qquad R^2 = 0.942 \qquad (20)$$

Guner at el. (2003), Vursavus and Ozguven (2004) and Altuntas and Yildiz (2005) reported similar results.

3.7 Rupture energy

Rupture energy results are shown in Figure 12. The range of rupture energy values was from 64.67 to 130.8 N mm. The results showed that the rupture energy (Figure 12) is highly dependent on moisture content for the investigated moisture content range (4.73–22% w.b.). The highest rupture energy was at the moisture content of 22%. The rupture energy was low at the lower moisture content levels. The relationship between moisture content and rupture energy of corn grain can be represented mathematically as follows:

$$E_a = 0.727M^2 - 15.80M + 124.4 \qquad R^2 = 0.979 \qquad (21)$$

Guner et al. (2003), Oloso and Clarke (1993) and Altuntas and Yildiz (2005) reported similar results.

4. Conclusions

The conclusions drawn from this study on physical properties of corn grains for moisture content range of 4.73% to 22% w.b are as follows: The average length, width, thickness, geometric mean diameter, equivalent diameter, arithmetic diameter, sphericity, thousand grain weight, angle of repose, grain volume, surface area, true density, porosity and aspect ratio of corn grains ranged from 11.62 to 12.60 mm, 7.27 to 7.98 mm, 4.47 to 4.71 mm, 7.20 to 7.77 mm and 7.63 to 7.96 mm, 7.77 to 8.43 mm, 62.31% to 62.00%, 271 to 321.4 g, 49° to 58°, 209.66 to 265.00 mm^3, 137.69 to 160.09 mm^2, 1250 to 1325 kgm^{-3}, 43.2 % to 51 % and 63.05% to 63.77% respectively. The static coefficient of friction of corn grains against different materials (plastic, galvanized iron and plywood) were increased with increase in moisture content. The galvanized iron had the highest static coefficient of friction while the lowest friction happened in plastic surface. The bulk density were found to decrease from 710 to 649 kgm^{-3} as the moisture content increased from 4.73% to 22% w.b., The mechanical properties of corn were determined in terms of average rupture force and rupture energy. With an increase in moisture content, rupture energy of the corn grains generally increased in magnitude while rupture force decreased with increase in moisture content.

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Table 1. Some physical properties of Sc 704 variety considering moisture content.

MC (% w.b.)	4.73	12	16	22
L (mm)	11.26±1.48	12.12±1.61	12.48±1.48	12.60±1.93
W (mm)	7.27±0.94	7.03±1.03	7.42±0.87	7.98±1.25
T (mm)	4.47±1.06	4.25±0.94	4.56±0.79	4.71±1.21
D_g (mm)	7.20±0.53	7.10±0.66	7.49±0.60	7.77±0.72
D_p (mm)	7.36±0.50	7.27±0.58	7.64±0.58	7.96±0.66
D_a (mm)	7.79±0.48	7.80±0.55	8.15±0.52	8.43±0.39
S_p (%)	62.32±5.88	58.77±3.19	60.22±4.88	62.00±5.74
S (mm^2)	137.69±14.09	133.84±10.91	148.62±12.37	160.09±13.13
V (mm^3)	209.66±27.81	202.24±20.33	234.32±29.47	265.00±30.31
R_a (%)	63.05±7.95	58.37±7.66	59.75±6.56	63.77±8.71

Figure 1. Corn Seeds

Figure 2. Apparatus to determine coefficient of static friction

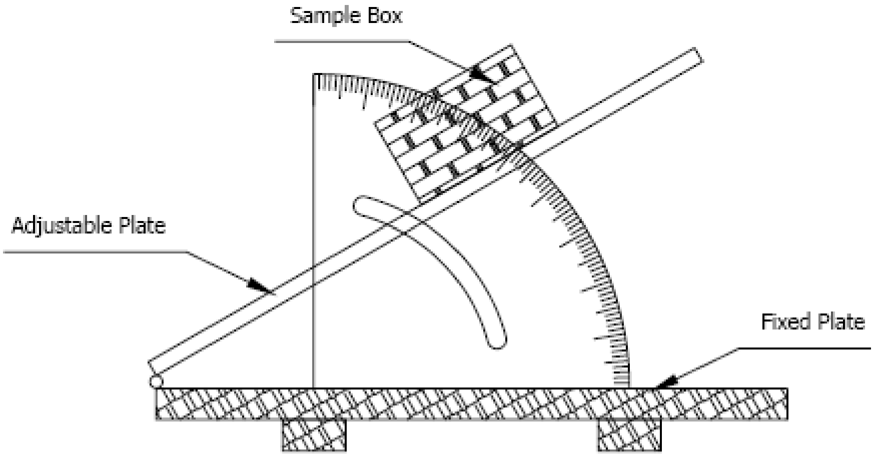

Figure 3. Empting angle of repose device

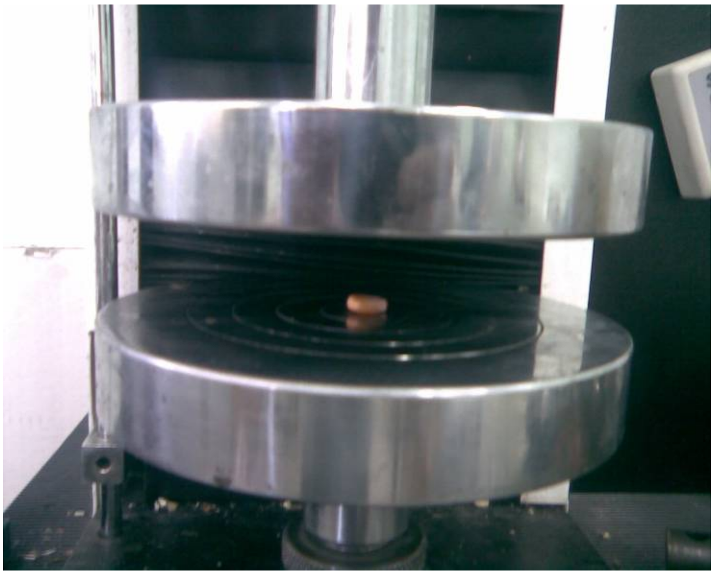

Figure 4. Apparatus for testing rupture strength

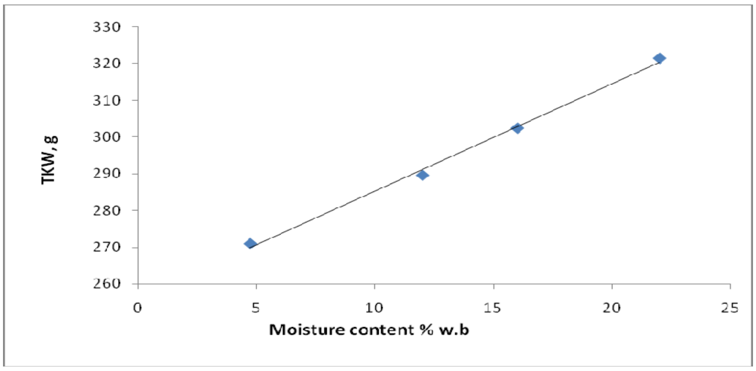

Figure 5. Effect of moisture content on thousand grain weight

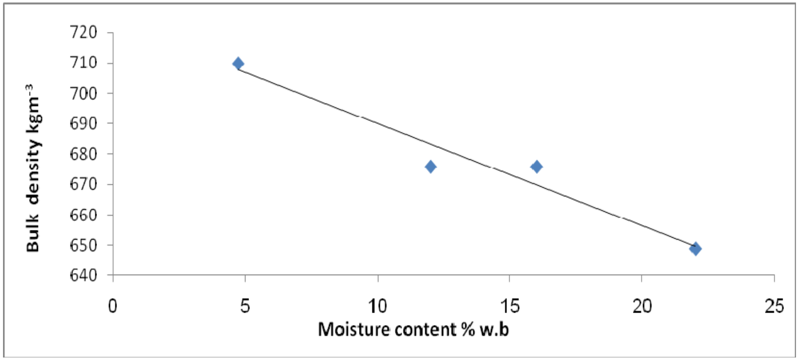

Figure 6. Effect of moisture content on bulk density

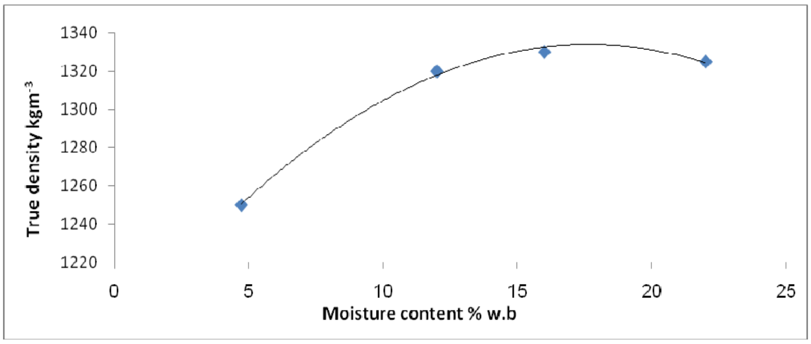

Figure 7. Effect of moisture content on true density

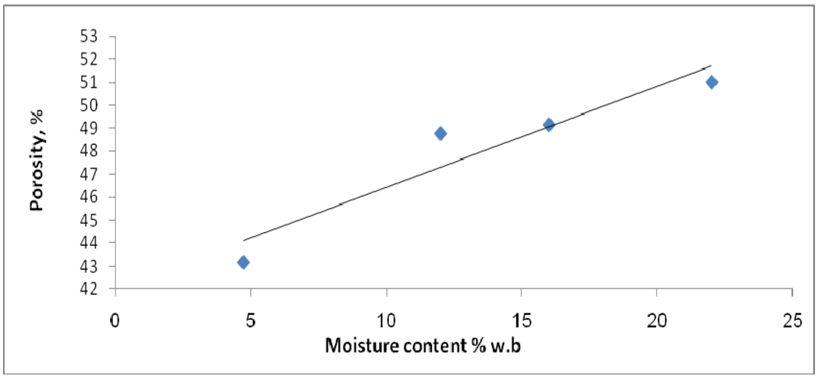

Figure 8. Effect of moisture content on porosity

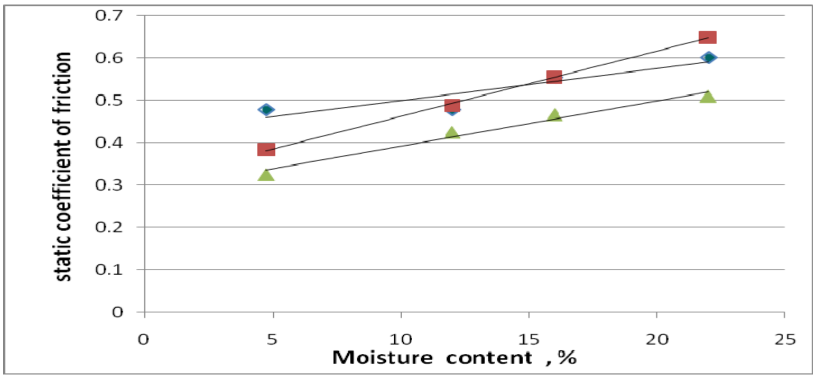

Figure 9. Effect of moisture content on static coefficient of friction: plastic (∆); galvanized iron (□) and plywood (◊).

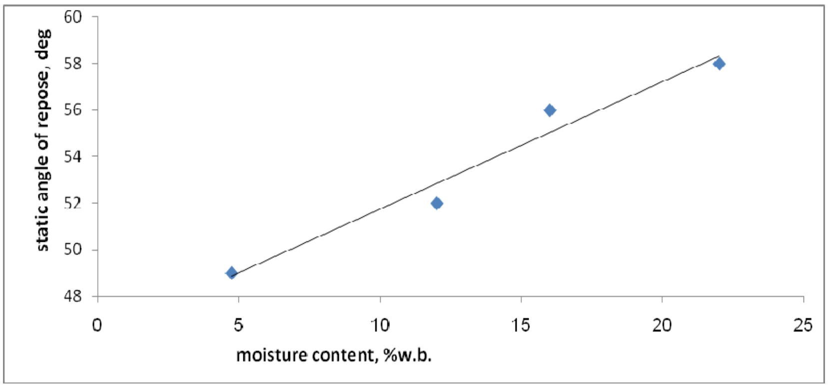

Figure 10. Effect of moisture content on static angle of repose

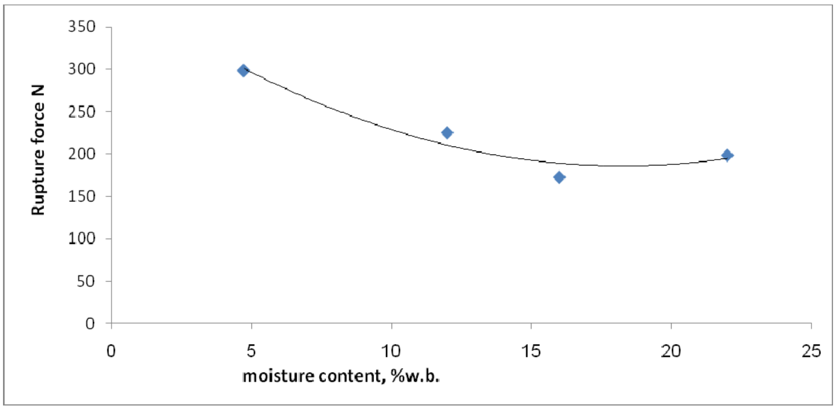

Figure 11. Effect of moisture content on rupture force

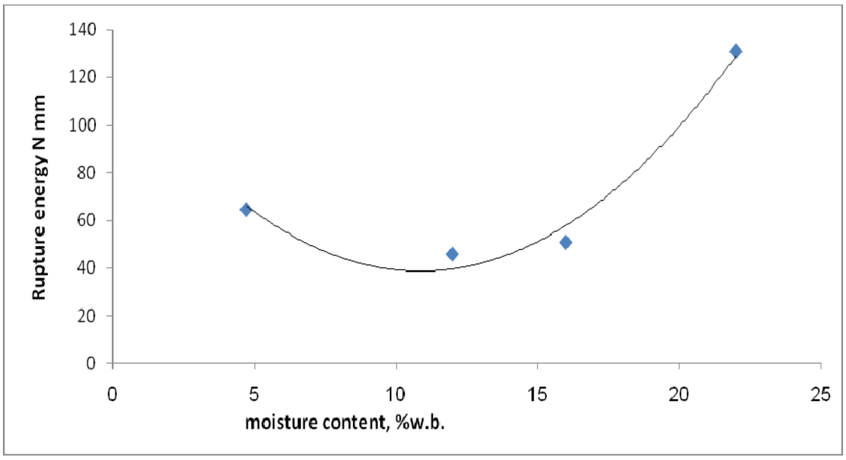

Figure 12. Effect of moisture content on rupture energy