Effect of Moisture Content on Rubber, Steel and Tetrafluoroethylene Materials Sliding on Textured Soils

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Abstract

There is the need to evaluate soil parameters of Nigerian soil that are necessary in the design of suitable and appropriate soil engaging implements. Laboratory investigations were carried out to evaluate angle of soil/material friction (or coefficient of soil/material friction) necessary in the design of soil-engaging implements. Facility used in the investigation was soil-material friction device or sliding shear apparatus. The soils investigated were loamy sand (IGLS), sandy loam (H3) and clay (H2) soils. The materials tested were rubber (RUB), steel (SST), galvanized steel (GAS) and Teflon (TEF). Results showed that coefficient of soil/material friction increased with moisture content to a maximum and thereafter decreased. The value ranged from 0.13 to 0.85 in the three soil textures and the trend can be described by polynomial equations for the purpose of prediction. Rubber had the highest coefficient of soil/interface friction while Teflon had the least.

Keyword: Textured soil, Coefficient of soil/material friction, Adhesion, Models

1. Introduction

Soil sliding resistance is made up of friction and adhesion forces that are brought about between the soil and material interface. It was reported (Li, et al, 2004) that sliding resistance of the soil-engaging components affects the working properties, energy consumption, efficiency, and quality of terrain machines. Adhesion of soil to terrain machines components is a universal phenomenon and can be very serious. It can decrease productivity, increase energy consumption and affect the quality of work (Gill & Vanden Berg, 1968). It was reported (Ren, et al., 2001; Qaisrani, et al., 2010; Khan, et al., 2010) that adhesion between soil and solid surfaces was dependent upon the nature and properties of soil, the material properties of the soil engaging components and the experimental conditions or working surroundings. The factors that influence the strength of soil sliding resistance include, soil moisture content, normal stress, static stage in the sliding system, soil texture, porosity, material characteristics, sliding velocity, material type, level of normal stress, stiffness of loading and rigidity of the soil materials and maximum values of the normal stress during the course of the test history (Li, et al., 2004). It was also reported (Ren, et al., 2001) that soil adhesion was increased as the proportion of clay particles in the soil increased and was highest when the soil moisture content was between plastic limit and liquid limit.

A large proportion of the energy used to operate tillage tools goes to overcome frictional sliding resistance as soil moves over the tillage tools surfaces. One approach to reducing the tillage energy requirements has been to use surfaces with low frictional properties. Values of coefficient of friction and adhesion have been determined for steel surfaces coated with the various materials including lead oxide, ceramic tile, Teflon sheet/tape, and enamel (Salokhe & Gee-Clough, 1988). In tests with inclined blade, the Teflon coated surface displayed negligible adhesion. Draught was reduced by 27% at low moisture contents but by 31% at high moisture contents (Shrinivasa, et al., 1994).

Another approach is to use a lubricating fluid to reduce soil metal friction. With the blade lubricated by a 3% solution of polymer, the average draught reduction was 16% with the appropriate rate of polymer-water-solution, which was at a rate equivalent to 103 l/ha (Li, et al., 2004). An average draught reduction in 15 trials on widely varying soils was 22% with an average application rate of 140 l/ha.

Moreover, surface morphology also significantly affects the frictional and adhesion forces. For a rusted surface the coefficient of friction may be as high as the coefficient of internal friction of the soil, and even higher than 0.8. By removing the rust, the friction may be considerably reduced, but a high degree of surface polish will result only in a minor decrease in coefficient of friction (Koolen & Kuipers, 1983).

The soil engaging implement change the soil state and the change produced depends on the nature of the soil and the soil/implement interface. A well-designed soil-engaging implement is one, which performs the manipulation required in the most efficient way, usually with a minimum effort (Spoor, 1969). The attempts that have been made to study and reduce friction were to be able to design appropriate and efficient implements that would require minimum draught and produce the required and appropriate soil condition for plant growth.

In Nigeria, this area of research has not been given the much-needed attention and published works are scanty. There is therefore the need to embark on such research in soil-tillage dynamics and especially in the specialized area of soil/implement interaction, which will provide additional information and data necessary for the design of appropriate soil engaging implements. The objective of this paper therefore is to present data and information on soil sliding behaviour at the interfaces with plane solid materials for some arable soils in Nigeria.

2. Materials and Methods

2.1 Experimental Soils and Materials

The soils studied were: loamy sand (IGLS), sandy loam (H3) and clay (H2) named according to the USDA soil textural classification. These were some of the prominent soils of Ondo state, Nigeria. The experimental soils were collected from the field from the top 25 cm. In the evaluation of soil/implement frictional parameters, a soil sliding shear apparatus was used. Details of description of the apparatus are reported (Manuwa, 2002). Other accessories include: spring balance of sensitivity 0.1g; sliders made up of the following surfaces rubber (RUB), smooth steel (SST), galvanized steel (GAS) and Teflon, polytetrafluoroethylene (TEF). The slider was rectangular in shape, with a surface area of 314.2 cm^2.

2.2 Analytical methods

Particle size analysis of the soils was performed using hydrometer method (Lambe, 1951). Organic matter content of the soils was determined using the dichromate method. Other physical and chemical properties of the soils were also determined using standard methods.

2.3 Experimentation

Soil samples were thoroughly mixed together, air-dried and passed through 2 mm sieve. The tray of the sliding shear apparatus was filled with soil initially in the dry condition compacted and surface smoothed out with a roller. Soil sample was taken and moisture content determined by gravimetric method. Experimental slider was loaded and winched along the tray while the spring balance recorded the frictional effort. Tests were repeated using different normal loads, noting the different normal loads and the spring balance reading. It was important that the surface was in exactly the same state as the previous test. The normal load ranged between 250 g and 1250 g. The procedures were replicated for the different slider surfaces and moisture contents.

2.4 Data analysis

When a material surface and soil slide relative to one another, the frictional resistance of the contact surface must satisfy the Coulomb's equation:

$$F = CaA + P\tan\delta \qquad (1)$$

where,

Ca = soil-material adhesion (Pa)

δ = angle of soil/material friction (degree)

P = normal force on surface (N)

F = frictional resistance (N)

A = contact area (m^2)

In adhesive soil, the frictional resistance, F, is mainly produced by adhesion and can be minimized if the contact area (A) is reduced (Qian, et al., 1999).

Values of frictional forces were plotted against the normal loads for particular moisture content. Regression analysis was applied to fit the best straight line for each set of observation using the criterion of the coefficient of determination (R^2). The slope of the best straight line was taken as the coefficient of soil/material friction or adhesion as the case might be. The series of these coefficients that were obtained at different moisture contents were then expressed in plots of coefficient of soil/material friction versus moisture content. Polynomial functions best fitted the relationships using R^2 as the criterion.

3. Results and Discussion

Some physical and chemical properties of the experimental soils are presented in Tables 1 and 2. The tangential stress varies with the soil moisture content in the following way: the trend was constant as the moisture increased gradually to the lower plastic limit. This phase is called 'friction phase' Thereafter the tangential stress increased rapidly to a maximum at the upper plastic limit in the region termed 'adhesion phase'. Further increase in moisture from the upper plastic limit caused the shear stress to drop gradually. This region is termed the 'lubrication phase' (Figures 1-3). At the lower plastic limit the tangential. stress increased rapidly to a maximum as the moisture increased to the upper plastic limit For all the soil textures, it was observed that friction and adhesion increased as moisture content increased until a peak point at the upper limit consistency of the soil when it reached a maximum and thereafter decreased. It was also observed that the adhesive components were relatively smaller except under certain plastic conditions where a non-scouring condition developed or where the clay ratio was sufficiently high such as in clay soil of Figure 3 as reported by Spoor (1969).

Figure 1 shows the effect of moisture content on the coefficient of soil-interface friction of the loamy sand (IGLS). The results showed that rubber and smooth steel were similar in their soil-interface friction characteristics. Also galvanized steel and Teflon had similar characteristics. It is also noteworthy that the values of the coefficient of soil-interface friction peaked when the moisture content was about 10.0% (db). The values of the models that best describe the behaviour are also presented in the figures.

Figure 2 presents the effect of moisture content on coefficient of soil-interface friction for the sandy loam (EH3). The peak values for the different materials occurred when the moisture content was about 18.0% (db). With this soil, it was observed that rubber had higher values of soil-interface friction than smooth steel and that the values for GAS and TEF were in a very close range. The values of the models that best describe the behaviour are presented in the figure.

Figure 3 presents the effect of moisture content on coefficient of soil interface friction for the clay soil (H2). It was observed that soil adhesion increased as the proportion of clay particles in the soil increased. Adhesion was highest when the soil moisture content was between the plastic limit and the liquid limit. This is similar to that reported by Ren et al. (2001). The best-fit polynomial models were also obtained for the curves using regression analysis and their values as presented in Figure 3.

Generally, in the dry phase, soil-interface friction remained almost constant as the moisture content increased gradually. In the adhesion phase the values of the coefficient of soil-interface friction increased until the lubrication phase when it peaked before it started to decrease rapidly. In the lubrication phase enough moisture was present to cause a low moisture tension and a free water surface to lubricate the soil-material surface and reduce total adhesion (Koolen & Kuipers, 1983).

The curves were best fitted with polynomial equations. Generally, the coefficient of soil-interface friction was highest with rubber, followed by smooth steel, then galvanized steel and lastly Teflon. This is expected because Teflon (polytetrafluoroethylene) has non-wetting characteristics and therefore reduced adhesion (Koolen & Kuipers, 1983; Qian, et al., 1999; Ren, et al., 2001).

4. Conclusions

The following conclusions can be drawn from this study. The coefficient of soil-material friction has been evaluated for the following materials: rubber; smooth steel; galvanized steel; and Teflon. The data is available for appropriate design of soil-engaging implements for Nigerian soils and similar soils elsewhere. The coefficient of soil/material- interface friction was highest with rubber followed by smooth steel, galvanized steel and least with Teflon. The curves were best fitted with polynomial equations with high coefficient of determination.

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Table 1. Some Physical Properties of the Soils

Soil type	Texture			Bulk density	Clay ratio	Clay + silt	LOI	colour
	Sand %	silt %	clay %	Mg/m^3		%		
Loamy Sand (IGLS)	85	3	12	1.56	13.6	15	1.12	white
Sandy loam (H3)	56	30	14	1.38	16.2	44	4.31	black
Clay (H2)	18	22	60	1.23	15	82	2.14	brown

Table 2. Some Chemical Properties of the experimental Soils

Soil samples	pH	Chemical composition				o/c %	N %	P ppm
		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}			
Loamy Sand	6.1	1.12	1.33	0.35	0.19	0.73	0.12	4.21
Sandy loam,H3	6.42	1.41	1	0.29	0.19	2.14	0.31	5.72
Clay, H2	6.51	1.31	1.24	0.27	0.15	0.34	0.14	3.57

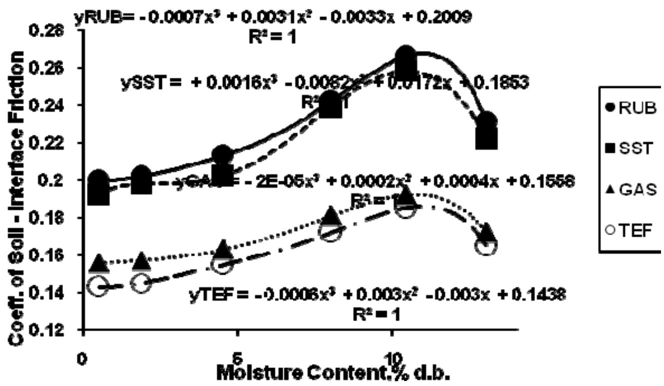

Figure 1. Soil-interface friction of Loamy sand (IGLS)

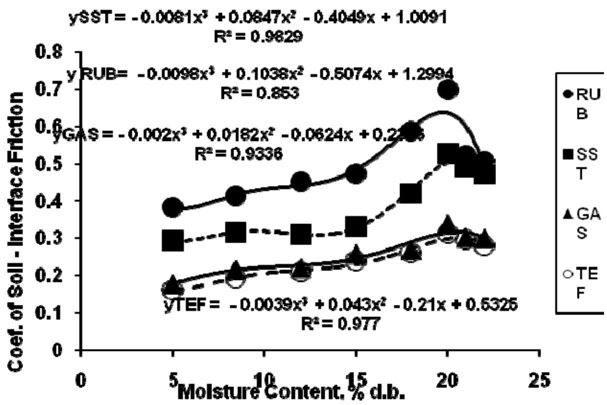

Figure 2. Soil-interface friction of sandy loam (H3)

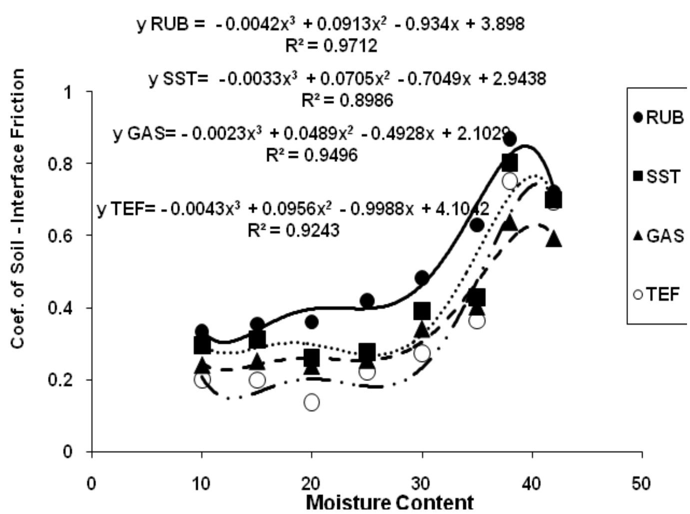

Figure 3. Soil-interface friction of Clay (H2)