TILLAGE IMPLEMENT EFFECTS ON WET STICKY SOIL

Soni Sisbudi HARSONO

Department of Agricultural Engineering, Faculty of Agricultural Technology, University of Jember, Address: Jl. Kalimantan I Jember, East Java – Indonesia Website: www.unej.ac.id
Email: s_harsono@yahoo.com

Abstract: *The objective of the research is to reduce soil adhesion on soil tillage tools using different enamel coated through analysing soil adhesion phenomena on shear stress of tillage implement. The friction angle was found not to be related to density over the range considered. As the soil approaches saturation, part of the normal stress was moved by pore pressure so the pressure between interface particles and the surface materials decreases, which cause the friction falls. The component of adhesion entirely due to the soil water present at the interface and was thus dependent of speed of movement because of the time required for water to move to the interface. The tillage implement which are coated with a ceramic surface tends to produce a smaller soil adhesion component compare with nylatron and metal surfaces*

***Keyword**: Adhesive force, soil adhesion, shear stress, non-scouring of tillage implements*

INTRODUCTION

Sticky Soil - The universal phenomenon of soil-tillage implement adhesion is the way soil adheres to non-soil material. Adhesion of soil to components of terrain mechanics is very serious, and can decrease productivity, increase energy consumption, and affect the quality of work. According to WANG et al. (1993) and QIAN et al. (1999), the productivity of excavators and loaders decreased by about 20-30% while the adhered soil in the self-dumping bucket was about 25 to 33% of the total capacity owing to soil adhesion. HENDRICK AND BAILEY (1982) examined the resistance of a plough working, and showed that in the field it increased by 30%. Soil adhesion to cage wheel lugs also increased their tractive resistance. Methods of reducing adhesion and resistance of the surfaces of soil engaging parts have been investigated, including air and liquid injection methods electro-osmosis (LARSON AND CLYMA, 1995).

Adhesive forces exist between soil and the surfaces of soil-engaging components on a variety of terrain machines including tillage and sowing machines. This phenomenon of soil adhesion not only increases the working resistance and energy consumption of these machines. The phenomenon of soil adhesion exists when soil is in contact with a solid interface. At the interface, the sliding resistance is dependent on the adhesion, the stress normal to the interface and the angle of friction between the soil and the interface. By reducing the adhesion and interface friction angle to values less than soil cohesion and soil to soil friction angle, respectively, the sliding resistance of soil-engaging implements is reduced (HEDRICK AND BAILEY, 1982). They went on to suggest that for tillage implements, the quality of work is decreased and the energy consumption is increased due to soil adhesion. In the wet soil conditions of the regions, most farmers use a range of tilling implements, including moldboards and disc ploughs for primary tilling. Secondary tillage commonly requires power rotary and/or disc harrows.

However, these implements present problems when they are applied to the wet soils. The problems include non-scouring of implements, sinkage when in work, high draught, poor tillage performance and breakages. The energy consumption of tractors during the tillage process escalates sharply in wet soils. The farmers in the region are generally poor. These problems only serve to make the poorer, because they have extra costs when operating implements in wet soils.

Normal stress – shear stress relationship - Soil tool interaction is generally studied to develop tool designs or to analyze their response in soil. The consequence of the soil not sliding on the tool is that the soil will have no change in aggregate size which is needed by roots of plant and for soil capillarity. Sliding of soil over the tool is also necessary for the tool to maintain its desired action. If the soil adheres to the tool, the effective shape of the tool is altered as soil/soil failure occurs away from the tool surface. This change in effective shape radically changes the tools forces and the final condition of the soil. This chapter considers the effect of different surface materials on the action of tools and the outcome of the tillage process.

The shear stresses behavior at the interface between soil and implements is critical to their performance and hence is important because of the vast quantity of soils which are moved during soil tillage. The shearing characteristic of soil on a foreign material affects the performance of implements in three ways. Firstly, wear is a problem in both cultivation and earth moving equipment due to abrasive nature of many soils (WHEELER AND GODWIN, 1996). Secondly, the force required breaking up or move soil depends not only on mechanical properties of the soil, but also on soil/implement shear stress (HETTIARATCHI, 1988). Thirdly, the magnitude of the friction of the interface relative to the internal friction of the soil determines the degree of scouring of soil at the interface. The objective of the research is to reduce soil adhesion on soil tillage tools using different enamel coated through analysing soil adhesion phenomena on shear stress of tillage implement.

RESEARCH METHODOLOGY

Material - Three surface materials - These were nylatron, metal, and ceramic surface materials that cause different friction between soil and material. It was expected to obtain different forces as well. These materials were attached to the tillage implement. The dimensions were 100-mm and 70-mm in length and width respectively. The thickness was 3-mm. In order to examine the results, the data in the experiment were tested using Genstat Statistical package using 99% confident limit.

Table 1.

Size of tine for each rake angle

Rake angle (degree)	20	25	30	40	45	50	60
Surface area (cm^2)	132.5	106	90	77.5	70	57.5	42.5

Soil sample preparation - Clay loam soil samples with three moisture content, namely 25, 35, 45, 55, and 65%. Soil samples collected from different locations were analyzed in the soil laboratory to find out their mechanical textures.

After the soil was taken from the field farm, it was dried until it became easy to break up into smaller particles. When the soil reached a certain number, it was moved to the soil tank to prepare the experiment. The results showed that in order to decrease experimental error, it was better to leave the wet soil to age for at least 12 hours before using it in the experiments. During the experiment, all wet soil in the soil tank was prepared in the afternoon, and the experiments were conducted during the following day.

The wet clay loam with physical and mechanical properties was prepared for this experiment. The moisture content of the soil in the tank was monitored before and after the experiment was conducted. To avoid evaporation losses, a plastic sheet covered the wet soil.

When necessary, it was put into place to maintain the moisture content and left for a couple of days to allow the equilibrium to be established.

When the soil preparation was completed, a tine that was covered with different surface materials was applied. These were metal, nylatron and ceramic, which were fixed to the tool holder. The signal amplifying and recording equipment was switched on and an adequate interval for the strawberry data acquisition was allowed. The data logger was checked for the three channels in use employing electrical calibration shunt resistance circuits to obtain the approximated signal levels.

The dynamometer was balanced under a zero load condition and the tine was then pulled through the soil. Draught, vertical forces and moment were amplified using a strain gauge amplifier and recorded on this data logger. The tine was dismantled after each run and the tool holder returned, after which another tine configuration was mounted and run for another experiment.

Experimental equipment and instrumentation

Description of soil tank - The experiment was conducted in a soil tank whose dimensions were: 1.5m in length, 0.5m in width and 0.30m in depth, using a clay loam with a variety of soil moisture contents.

The soil moisture contents include 25, 35, 45, 55, and 65% for the shear stress experiment. The measurement of the forces and moment acting on the implement was achieved by the use of an octagonal ring transducer. The output from the sensing devices was amplified and fed into the laptop, which was connected to the octagonal ring transducer. The horizontal forces, vertical forces and moment over the entire distance through which the tines travel were recorded. The soil was clay loam, which contains a variety of high moisture contents. The carriage was moved electrically, driven by the 0.37 kW electrical motor with a carriage which ran on rails above the soil tank. The tank could move sideways while on the frame and it was removed from the frame for soil preparation and packing. A plastic sheet was set up in the base of the tank for easy mixing and remolding of soil without the soil sticking to the tank, and to maintain the soil moisture content.

Instrumentation - Force measuring dynamometer

The forces acting on the tines were measured by means of an extended octagonal ring dynamometer. The dynamometer consists of 12 strain gauges grouped on three bridge circuits. The three bridge circuits were then connected to a single transmitting cable. This dynamometer was fabricated from steel; heat treated to an ultimate tensile strength of 1540 N/m^2 and had an elastic modulus of 207 GN/m^2.

The output from each strain gauge bridge circuit was amplified using a DC differential amplifier that also supplied the working potential for the bridge circuits. Output signals from these circuits were connected directly to a multi-channel strawberry data acquisition. The traces obtained from the data logger were continuous recordings of the horizontal force, vertical forces and moment over the entire distance through which the tine was winched. The mean heights of traces with respect to the zero settings were determined and multiplied by their respective calibration constants to obtain the corresponding forces.

Variable parameters were used in the experiment as follows:

(i) Rake angles

The objective was to determine forces using different rake angles. Therefore it was expected to obtain data that showed characteristics of wet soil under pressure of different surface materials. The experiment used seven rake angles: 20, 25, 30, 40, 45, 50, and 60 degrees.

(ii) Three surface materials

These were nylatron, metal, and ceramic surface materials, which caused different friction between soil and material. It was expected to obtain different forces as well. These materials were attached to the tillage implement. The size is 100-m and 70-mm of length and width respectively. The thickness was 3mm.

(iii) Three moisture contents, namely 45, 55 and 65% were used in this experiment.

(iv). Three level speeds, namely speed 1 (0.049 m/s), speed 2 (0.095 m/s), and speed 3 (0.151 m/s).

Hence, the factors applied in this experiment can be summarised as follows:

Factor 1: Rake angles, 3 levels: 20, 25, 30, 40, 45, 50, and 60 degrees.
Factor 2: Surface materials, 3 levels: nylatron, ceramic and metal.
Factor 3: Moisture contents, 3 levels: 45 percent, 55 percent, and 65 percent
Factor 4: Speed, 3 levels: speed 1, 2 and 3.

Three replications were used in each experiment

RESULTS AND DISCUSSION

The shear and normal stress generated by the tests could be plotted as shown in the figures below. The figures and tables show the experimental result that were conducted at 5 (five) moisture contents namely 25, 35, 45, 55, and 65%, 3 (three) surfaces materials (ceramic, metal and nylatron) and different loadings (10, 20, 30, 40 kg). In the chapter, one of five moisture contents is presented.

Normal stress – shear stress relationship

The shear stress τ, has been related to the normal stress σ, as Payne (1956) explained using a Coulomb-type expression :

$$\tau = c_a + \sigma \tan \delta$$

where:

τ	=	shear stress
c_a	=	adhesive component
σ	=	normal stress
δ	=	soil implement friction angle

The component of adhesion, c_a, has been investigated which can be summarised that it was entirely due to soil moisture content present at the interface and dependent on speed of movement, the moisture tension of the soil also affect the various soil adhesion, and solid attraction is insignificant part of adhesion. Fig 1 (i) and (ii) below show these relationships for various surface materials and moisture contents.

At 25% moisture content, nylatron produces greater shear stress than other surface materials at any level of normal stress. The figures demonstrate that the shear stress which was produced by the ceramic surface was lower than other shear stress for metal and nylatron at all moisture contents.

Effect of moisture content on coefficient of adhesion

Fig 2 below shows the relationship between soil moisture content and the coefficient of adhesion (c_a) at different soil moisture contents using different surface materials. At low moisture content, the soil adhesion is low because the soil is dry and moisture tension decreases. Soil adhesion increases with increasing moisture content, once greater than approximately 35%. It increases very rapidly. In the lower range metal produces the least adhesion.

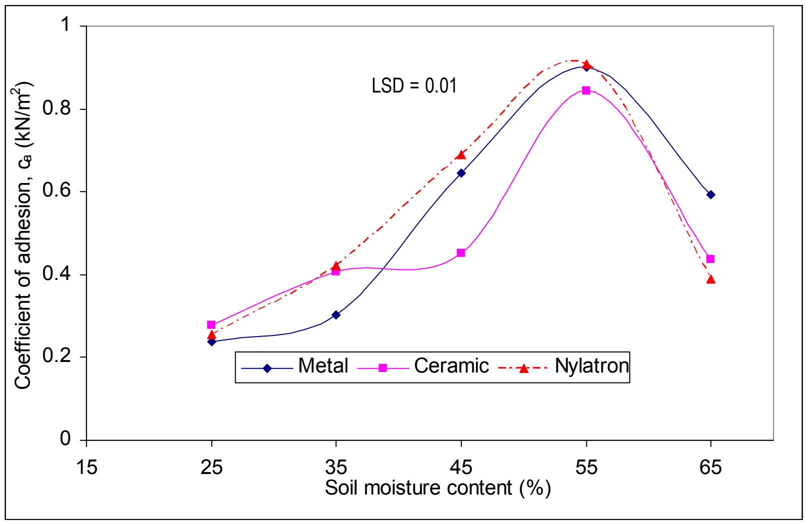

Figure 1. Relationship between soil moisture content and coefficient of adhesion - (c_a) at different soil moisture content using different surfaces

At higher moisture content, adhesion increases significantly. In this range ceramics offers the least adhesion. However, after saturation is reached at 55% moisture content, there is sufficient soil moisture content at the surface to have a lubricating effect and adhesion decreases.

Fig 2 above demonstrates that at low moisture content, the soil adhesion component is low. The significant increase occurred when the moisture content was at 45%. The peak of soil adhesion coefficient (c_a) was achieved when the moisture content was in the range of 55% which is also when the sticky point moisture content occurs. At this moisture content, the soil sticks heavily to the foreign material, especially to metal and nylatron. However, the adhesion component is lower when the ceramic surface is applied. When the soil moisture content reaches more than 55%, Fig 2 above reveals that the soil adhesion component value decreases and falls dramatically when the moisture content nearly 65%. At this moisture content, the soil might be in the saturated condition, therefore, there is some lubrication in the soil.

The LSD between surface materials against moisture content is 0.01. It shows that the relationship between soil moisture content and the coefficient of adhesion at different soil moisture content using different surfaces is significantly different. This is supported by the statistical calculation as shown in Table 2 below.

Table 2.

Analysis of variance (anova) effect of moisture content on coefficient of adhesion (c_a) component

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Material	2	0.027	0.0136	501.66	<.001
MC	4	2.061	0.515	1.902E+04	<.001
Material x MC	8	0.174	0.022	803.76	<.001
Residual	30	0.001	0.0002		
Total	44	2.263			

Effect of moisture content on soil-implement friction angle

Fig 2 below shows the relationship between soil moisture content and soil-implement friction angle at different moisture content using different surface materials. It shows that the friction angle tends to decrease as moisture content increases.

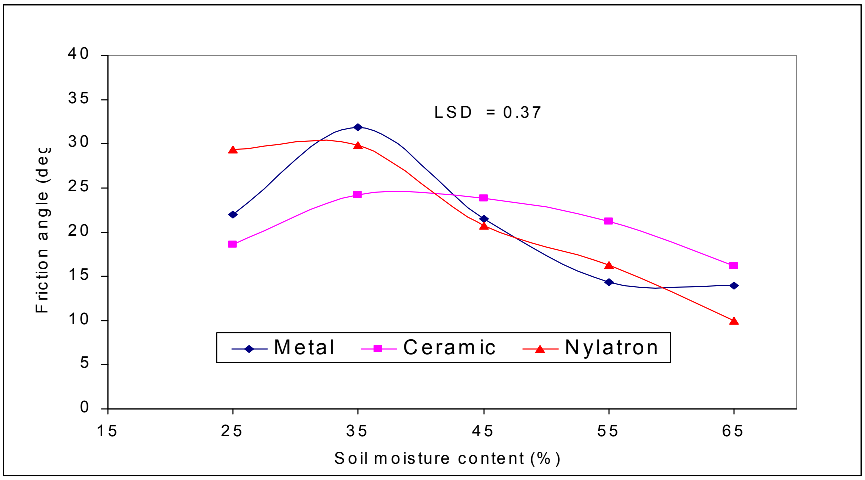

Figure 2. Relationship between soil moisture content and soil-implement friction angle at different moisture content using different surface materials

Fig 3 demonstrates that the friction angle of three surface materials increases from 25% to 35% of moisture content sharply. After it reaches optimum level, however, the friction angle decreases significantly. Between 55% and 65% moisture content, it decreases sharply. It might be above 55% moisture content; saturation begins and is completed at levels above 65% moisture content. Therefore, friction angles for all surface materials that were applied at these moisture contents tend to decrease dramatically.

The figure above shows that the soil friction angle reaches a peak when the moisture content is at 35%. At this moisture content, metal and nylatron surfaces have a higher soil friction angle compared with soil friction angle for the ceramic material. At the moisture contents of 45% to 65%, the soil friction angle decreases. In the decrease of the soil friction angle, Figure 3 above demonstrates the ceramic surface friction angle is higher than the friction angle at others surface materials.

The LSD between surface materials against moisture content is 0.37. It shows that the relationship between soil moisture content and coefficient of adhesion at different soil moisture content using different surfaces is very significantly different, except at 45% moisture content which shows that metal and nylatron surfaces are not significantly different. This is supported by the statistically calculation as shown in Table 2 below.

Table 3.

Analysis of variance (anova) effect of moisture content on soil implement friction angle

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Material	2	2.618	1.309	27.101	<.001
MC	4	1233.062	308.266	6381.433	<.001
Material x MC	8	422.498	52.812	1093.271	<.001
Residual	30	1.449	0.048		
Total	44	1659.628			

Ceramic surface

The effect of the soil moisture content on the shear stress applied at different soil moisture content using a ceramic surface is very significant as shown in Table 45 below. The shear stresses of ceramic material at the moisture content of 25 to 35%, which are shown in Fig 4 (b), are low. But, they begin to increase dramatically when the moisture content is at 45% and peaks at 55% moisture content. When saturation is approached (above 60% of moisture content), the shear stresses turn down until 65% is reached.

Table 4

Analysis of variance (anova) effect of the soil moisture content on the shear stress applied at different soil moisture content using a ceramic surface

Source of variation	d.f.	s.s.	m.s.	v.r.	Fpr.
Normal stress	3	18.641	6.214	4.145E+04	<.001
MC	4	10.326	2.581	1.722E+04	<.001
Normal stress x MC	12	1.194	0.099	663.868	<.001
Residual	40	0.006	0.0001		
Total	59	30.167			

The statistical calculation as shown in Table 4 shows that all sources of variations (normal stress, moisture content and normal stress versus moisture content) are very significantly different. With the LSD value as shown in the Figure 4 (b), all treatments are significantly different at all levels of normal stresses and moisture contents used in the experiment.

Nylatron surface

At higher moisture content, soil shear stress increases. However, at a level of 45% moisture content and greater, the soil shear stress decreases. The figure above shows that the peak of shear stress was reached when the moisture content was 35%. When the moisture content was in the range 45% to 65%, the normal stresses decreased slightly. The figure above demonstrates that the normal stresses contribute a big effect to the result of shear stresses. At the beginning, the normal stresses produced a high shear stress and reached the optimum of shear stresses when the moisture content was at 35%. However, when the moisture content increased, the shear stress decreased significantly, as is supported by the statistical result as shown in Table 5, which shows that the effect of the soil moisture content on the shear stress applied at different soil moisture content using a nylatron surface is very significantly different.

Table 5.

Analysis of variance (anova) effect of the soil moisture content on the shear stress applied at different soil moisture content using a nylatron surface

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Normal stress	3	22.866	7.622	1.103E+04	<.001
MC	4	15.176	3.794	5490.772	<.001
Normal stress x MC	12	3.339	0.278	402.771	<.001
Residual	40	0.028	0.0006		
Total	59	41.409			

DISCUSSION

The effect of the moisture content on the coefficient of adhesion is very significant. Fig 2 shows that the soil adhesions (c_a) for three surface materials tend to increase as the moisture content increases. However, it reaches a peak condition at 55% moisture content. Fig 3 shows that the coefficient of adhesion decreases sharply when it occurs at above 60% moisture content. These trends might be affected by the condition of the soil which is already saturated; therefore the soil loses its capability for adhesion to surface material. Fig 4 also indicates that the ceramic surface produces the lowest soil adhesion component from 45% to 65 % moisture content.

The frictional behaviour of soil-implement interface has been shown to be similar to that between two solid materials, i.e: the shear stress increases linearly with normal load. However, the friction behaviour is complicated by the presence of adhesion due to soil moisture content. The shear stress increases steadily and has been shown to be due to increased adhesion which was occurred with a metal interface at levels of 25% and 35% moisture content as hson in Fig 3. It shows that after the moisture content reaches 45%, the shear stress falls dramatically until 65% moisture content.

The effect of soil moisture content on friction angle (δ) is very significant ($P<0.01$). Fig 4 reveals that at low moisture content, the friction angle of the three surface materials in the experiment is low. It increases up to 35% moisture content. Then it decreases dramatically from 45% to 65% moisture content for metal and nylatron surfaces. It illustrates that the friction angle increases until 55% moisture content. It might be that the ceramic surface material affects this condition.

As the soil approaches saturation, part of the normal stress is moved by pore pressure so the pressure between interface particles and the surfaces material decrease. Therefore, the friction falls. It was noted in the experiment that water exuded from soil sample at the highest moisture content. The frictional measurements were completed in a much shorter time than was required for distribution of pore pressure.

CONCLUSION

From the data, figures and tables of the results above, the following can be concluded:

1. a ceramic surface tends to produce a smaller soil adhesion component compare with nylatron and metal surfaces;
2. the effect of the moisture content on the coefficient of adhesion (c_a) is significantly different at all surface materials;
3. a peak of coefficient of adhesion (c_a) for all surface materials occurred when the moisture content was at 55%;
4. the highest soil-implement friction angle occurs at 35% of moisture content;
5. the variety of normal stresses which were applied on different moisture content is significantly different.

BIBLIOGRAPHY

1. HENDRICK J.G AND BAILEY A.C, *Determining Component of Soil-Metal Sliding Resistance*, Transactions of of the ASABE. 25(4): 0845-0849, 1992

2. HETTIARATCHI D.R.P., *Theoritical Soil Mechanics and Implement Design*, Journal of Soil and Tillage Research (11), 1988

3. LARSON R, AND CLYMA H.E., *Evaluating the Effectiveness of Electro-Osmosis in Reducing Tillage Draft Forces*, Transactions of the ASAE, Vol. 38(5): 1281-1288, 1995

4. PAYNE P.C.L., *Field Methods of Measuring Soil-Metal Friction*, Journal Soil Science (7): 235-242, 1956

5. QIAN C, LUQUAN R, BINCONG C, BEIZHAN Y.,*Using Characteristics of Burrowing Animals to Reduce Soil-Tool Adhesion*, Transactions of the ASAE (42): 1549-1556, 1999.

6. SALOKHE V.M, AND GEE-CLOUGH., *Cage Wheel Blocking in Wet Soil*, Journal of Agricultutal Research 29 (4); 277-286, 1988

7. WANG X.L, YAMAZAKI M, TANAKA T., *Dinamic Behaviour an Open Lugged Sheel under Paddy Soil Condition*, Journal of Terramechanics (30):191 – 197, 1993
8. WHEELER AND GODWIN R.J., *Soil Dynamics of Single and Multiple Tines at Speed up to 20 km/h*, Journal of Agricultural Engineering Research (63):243-250, 1996