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EFFECT OF TEMPERATURE ON ADHESION OF CLAY SOIL TO STEEL

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ABSTRACT. Soil adhesion is one of the important factors in measuring the amount of energy consumption. In this paper, the effect of temperature on the amount of clay soil adhesion was investigated. The soil used in this research was saturated clay mud. In order to measure adhesion, a specific instrument was designed. The dimensions of the metal plate were 210×70×20 mm and its weight was 2.5 kgf. The metal plate alloy was st37. The adhesion was calculated from the difference between weight of water used for clearing the metal plate of the soil and the weight of the metal plate. Six levels of temperature from 5 to 30°c were applied. A refrigerator and an oven were used for getting the required temperature. The test was performed three times for each level. Results showed that an increase in temperature from 5 to 30°c decreases the soil adhesion. Three equations such as linear polynomial, exponential and quadratic polynomial correlated with the experimental data and the result showed that the quadratic polynomial model had the best correlation with experimental data.

Key words: Soil adhesion; Energy consumption; Clay soil; Correlation.

INTRODUCTION

Adhesive soils which cannot be self-unloaded occupy 1/2 to 1/3 of the whole truck capacity during a dump truck transporting soil (Tong, 1992). It is said that the energy consumption to overcome the sliding resistance of soil to the ploughshare surface is about 30-50% of the whole energy consumption during cultivation (Hendrick and Bailey, 1982). Human beings can obtain a great benefit if such adhesion and friction are reduced even slightly. Normal adhesive force at the soil–tool interface depends on various factors including soil properties, tool material and tool surface, soil water content and interfacial conditions. Zeng (1995) claimed that the soil adhesion to soil-engaging tool increased with normal

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stress on it. The normal adhesion can be treated as having action similar to that of normal load at the interface (Fountaine, 1954; Gill and Vanden Berg, 1968; Zeng, 1995; Shi-qiao, 2004) described such interface at four water content levels. Many researches were carried out on the physical and engineering properties of soil. Rajaram and Erbach (1999) studied the effect of wetting and drying on soil physical properties. In another research, Zheng Pan *et al*. (1998) compared the relationship between paddy soil adhesion to steel and to rubber. Pesonen-Leinonen *et al*. (2006) determined soil adhesion to plastic surface using a radioactive tracer.

There are various mechanisms through which two particles in the nature exert force on each other; the force of attraction between them is a usual natural phenomenon. Depending on the particle type, it can be cohesion-if the two particles are from the same parent material, or can be adhesion-if the two are from different parent material. Cohesion and adhesion are the molecular phenomena occurring at the interface of liquid and gas, resulting from the electrical interactions of solid microscopic particles. The maximum distance up to which the force of cohesion between molecules can act is known as their *molecular-range* ($\approx 10^{-7}$cm) (Oswal, 1994). An imaginary sphere drawn around a molecule with its radius equal to the molecular range and its center coinciding with the center of the molecule is called the *sphere of influence* of the molecule. May it be farm implements, construction machinery or any other soil-engaging tools, their larger force requirement increases the input energy and hence lesser work is resulted per unit effort supplied, which is especially significant in sticky soils. In agricultural applications, soil-tool adhesion is of greater importance–especially when prevailing soil is rich in clay content and hence sticky by nature. Various investigations have been carried out to study adhesion mechanism, to quantify soil adhesion properties, to determine their contributing factors, and to develop means of reducing soil-adhesion (Gill and Vanden Berg, 1968; Chancellor, 1994; Ren *et al*., 2001).

The present study was conducted to determine clay soil adhesion in various temperatures to control energy consumption.

Nomenclature			
A	Area of plate, mm^2	W_p	Weight of plate, kgf
$a_1,\ldots,a_7$	Dimensionless coefficient in models	R^2	Coefficient of determination
P_a	Adhesion, Mpa	$RMSE$	Mean square error
g	Gravity acceleration, m/s^2	SSE	Some of square error
W_w	Weight of water, kgf	T	Temperature, °c

MATERIALS AND METHODS

Soil description

The present investigation was carried out at the College of Abouraihan of the University of Tehran. Saturated clay mud was used in the entire of this study. Clay soil was obtained from an agricultural field in Varamin City. The soil type used in this study, according to the USA soil classification, was clay soil with 50 to 80% clay (particle diameter less than 0.01 mm).

Experimental procedure

A plastic container with 25 cm length, 12 cm width and 7 cm height was used in experiments. This plastic container was used for preparing clay mud with uniform qualification. For preparing the clay mud, 1.5 liter water was added to 4 kgf of clay soil until saturated clay mud was obtained. A blade was used to achieve a uniform mixture. After preparing a uniform mixture, a blade was used to smooth the mud surface. Sample product was packed into refrigerator and oven in order to get different temperatures.

A refrigerator (HY108, Emerson, Iran) was used for controlling the sample temperature range from 5°C to 15°C. For each change in the temperature of refrigerator, the sample was kept into the refrigerator for seven hours until temperature was uniform all over the sample. The container and sample were covered with plastic sheet to reduce moisture loss by evaporation. The room temperature was 20°C. In order for the sample to reach 25°C and 30°C of temperature an oven was used (E.O.155, Camos, Iran) and the sample was kept in the oven for 3 hours to reach uniform temperature.

Three thermometers were put into different positions of the sample. The sample was kept into the refrigerator. The temperature of all the three thermometers was read every one hour. After seven hours, the temperatures of the three thermometers were close to the temperature needed for the experiment. This process was repeated for the sample lying in the oven and the time needed to reach a uniform temperature throughout the sample was three hours.

In order to make up for the water loss which occurs as a result of evaporation the sample was weighed before and after being placed in oven and of the decreased weight was replaced by adding of water.

Measurement of adhesion

In order to measure soil adhesion, a specific instrument was designed. This instrument includes a pulley, a rope, two containers, a valve and a smooth metal plate with 210 mm length, 70 mm width, 20 mm thickness and 2.5 kgf weight. The metal plate alloy was st37 (*Fig.1*).

For measuring the adhesion, the metal plate was first set on the sample surface slowly. The metal plate was set on the sample surface for 30s then the rope was set on the pulley and one end of the rope was attached to the metal plate by a hook and the other end was attached to an empty container. The water was added to the empty container slowly and steadily in order to prevent damping effect when pouring water into the container. Adding water continues until the plate detaches from the sample surface. After separating the plate from the sample, the amount of the water inside the container was measured by an electronic precision balance having an accuracy of 0.001 kgf. The adhesion was calculated as the difference between the weight of the added water and the weight of the plate.

Each experiment was carried out three times in each temperature range.

$$P_a = \frac{(W_w - W_p) \times 9.81}{A} \qquad (1)$$

where P_a is the adhesion of soil in Mpa, W_w is the weight of water in kgf, W_p is the weight of plate in kgf and A is the area of plate in mm^2.

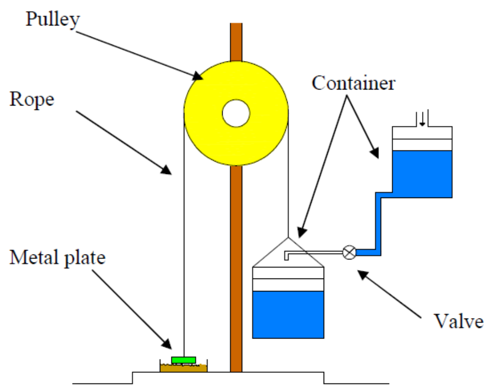

Figure 1 - Schematic view of apparatus for measurement

The experimental data was fitted to the equations proposed in the literature for adhesion as shown in *Table 1*. The coefficient of adhesion was estimated from the experimental data using the regression analysis (spss 13) which minimizes residual sum of squares.

The models were fitted by means of a numerical curve-fitting in MATLAB computer program. Three criteria were used to verify the models coefficient of determination (R^2), sum of square error (SSE) and mean square error (RMSE).

Table 1 - Empirical equations describing the adhesion

Name of the equation	Equation	Eq. No.
Linear polynomial	$P_a = a_1T + a_2$	(2)
Quadratic polynomial	$P_a = a_3T^2 + a_4T + a_5$	(3)
Exponential	$P_a = a_6 \exp(a_7T)$	(4)

RESULT AND DISCUSSION

The results of the variance analysis of clay soil adhesion are given in *Table 2*. The results indicated that there was a significant difference among all temperatures in 1 % of probability.

Mean values of adhesion for saturated clay soil as a function of temperature are shown in *Fig. 2*. As can be seen from *Fig. 2*, one of the important factors influencing the adhesion is temperature. Adhesion was decreased with an increase in the temperature of the sample. With an increase in temperature from 5 ºc to 30 ºc, adhesion of clay soil was decreased from 8.53×10^{-4} to 1.57×10^{-4} Mpa.

The curve fitting procedure was performed for three semi-empirical models. The statistical results of the three semi-empirical models that are determination coefficient R^2, sum of square error SSE and mean square error RMSE are given in *Table 3.*

Table 2 - Analysis of variance for adhesion of soil at different temperatures

Source	df	Sum of squares	Mean of squares	F
Treatment	5	1.163×10^{-6}	2.327	21.19**
Error	12	1.318×10^{-7}	1.098	
Total	17	1.295×10^{-6}		
CV%			22.72	

** Corresponding to 1% probability

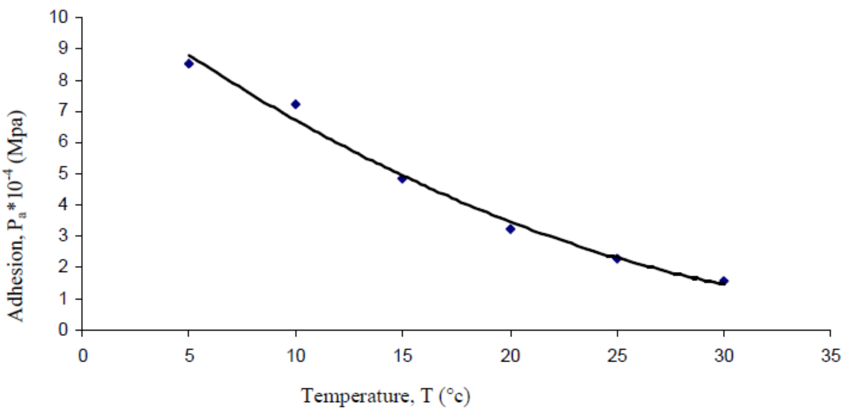

Figure 2 - Experimental and predicted adhesion for saturated clay mud using quadratic polynomial as a function of temperature

Table 3 - Result of statistical analysis of the modeling of adhesion

Model name	Adhesion		
	R^2	RMSE	SSE
Linear polynomial	0.9674	0.5622	1.264
Quadratic polynomial	0.9902	0.3556	0.3793
Exponential	0.9787	0.4548	0.8275

The coefficient values of linear polynomial, quadratic polynomial and exponential models for determining the adhesion of saturated clay soil are represented in *Table 4*. The results indicated that the highest value of R^2 and the lowest values of SSE and RMSE could be obtained by quadratic polynomial model. A comparison of the experimental and predicted adhesion values using quadratic polynomial model is illustrated in *Fig. 2*.

Table 4 - The coefficient values of linear polynomial, quadratic polynomial and exponential model

Model name	coefficient	
Linear polynomial	a_1	-0.2928
	a_2	9.737
Quadratic polynomial	a_3	0.006159
	a_4	-0.05084
	a_5	11.17
Exponential	a_6	12.34
	a_7	-0.06417

CONCLUSIONS

The temperature was effective on the adhesion of clay soil.

With an increase in temperature from 5 ºc to 30 ºc, the adhesion of clay soil was decreased about 82%.

The results showed that the quadratic polynomial model had the strongest correlation with the experimental data.

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