An Analysis of Materials Adhesivity Level on Excavator's Bucket in Open Pit Coal Mining

by Barlian Dwinagara

An Analysis of Materials Adhesivity Level on Excavator's Bucket in Open Pit Coal Mining

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ABSTRACT

This paper investigated materials adhesivity as one of the equipment productivities factors in an open-pit coal mining operation. The parameters of adhesivity investigated in this study were obtained from physical and mechanical properties of soil. The parameters were cohesion (C), density (γ), grain size (% clay and % sand), moisture contents (w), plasticity index (PI), and liquid limit (LL). The data was measured from extensive laboratory testing on disposal materials, composed of clay-sized grains with the moisture content of 8.06 – 47.98%. The materials were also classified as a very plastic material (Plasticity Index > 17%). The relationship of several parameters as materials adhesivity level (a) was formulated using multivariate regression analysis, used as a prediction of adhesivity levels on disposal materials. Therefore, actual adhesivity was also analyzed using physical models modified from the direct shear test as a verification. The result was quite similar with a standard deviation of 0.007, suggesting that the estimation value would be applicable in open pit coal mining operation.

Keywords: Adhesivity, Soil Properties, Multi-Variate Regression, Physical Models, Open Pit

INTRODUCTION

Mining, especially in open pit systems, includes excavation and overburden (i.e., soil and weak rock material) removal activities which the digging equipment affects the productivity and the energy consumed. Soil and rock materials potentially stick on the digging bucket reducing the productivity level since the equipment may be difficult to operate. Adhesiveness is not only related to the tensile force between the soil material and the digging material bucket forming material, but also the tensile force between the material itself (cohesion) causing the sticky material to become thicker.

Kooistra (1998) suggested a theory that adhesion affects contact between the soil and other material. Adhesion is explained through Mohr Coulomb's sheath behavior with an approach that is almost the same as the approach used on soil shear strength. According to Hendrick and Bailey (1982), the soil adhesive properties (the normal force parameters and the adhesive shear angle) greatly affect the ability of the soil to slip on a surface of another material plane. Decreasing the level of adhesivity to below the value of cohesion and shear angle in the soil may affect the reduced level of soil adhesiveness.

The adhesiveness of the material is closely related to the physical and mechanical properties of the excavated material encountered, especially parameters such as material composition, moisture content, plasticity index, liquid limit, plastic limit, and material adhesivity. Therefore, this study determined key parameters affecting adhesiveness which is the ideal material disposal conditions, so that adhesiveness can be minimized.

METHODOLOGY

The parameters of adhesivity in this study was obtained from physical and mechanical properties of soil. The parameters were cohesion (C), density (γ), grain size (% clay and % sand), moisture contents (w), plasticity index (PI), and liquid limit (LL).

Through a similar approach to the concept of the Mohr Coulomb, the methodology for testing adhesive in the laboratory was conducted with a direct shear testing.

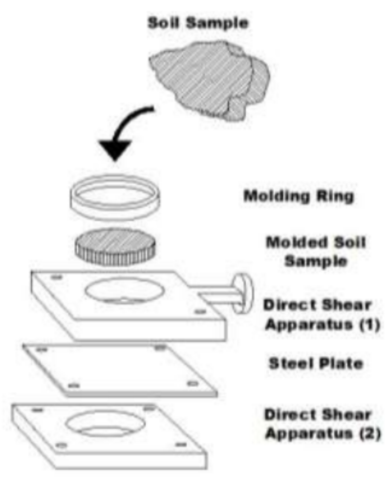

Figure 1. Illustration of Adhesivity Testing Through Direct Shear Test

The laboratory testing methodology was adjusted to the direct shear test, but an adjustment was made to the friction plane of the shear tool, which originally in the form of soil material replaced by a steel plate. Accordingly, the results of the initial parameters in the form of cohesion was replaced by the value of adhesion, namely friction between the ground and the surface of the steel plate. Illustration of adhesivity testing is shown in **Figure 1**.

Through this test, the parameter adhesion value was obtained which the friction force between the soil sample and the surface of the steel plate replaced the cohesion value in the direct shear test. As an interpretation of the difference in outcome parameters in direct shear testing, the test method was described as shown in **Figure 2**.

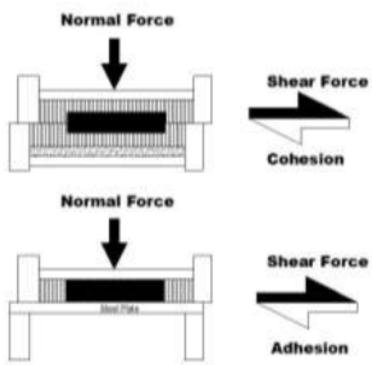

Figure 2. Cohesion and Adhesion Parameters in Direct Shear Testing

RESULTS AND DISCUSSION

Based on the natural weight and dry density data group of laboratory tests on material disposal at the study site, showed that the weight of the original content (natural density) of material disposal at the study site ranged from 16.19 to 23.20 kN/m^3 with an average value of 19.25 kN/m^3. The value of the original weight in the data (mode) was 20 kN/m^3. The original weighted data group had a standard deviation of 1.47 kN/m^3. The natural moisture content was 8.06% to 47.98% with an average value of 21.97%. Material disposal had an average porosity of 40.55% with a range between 22.79 - 57.34%.

The great percentage of pores in a soil aggregate stated that the soil is looser because of the amount of space between the soil grains. This caused the aggregate volume of the soil to have less weight in each volume unit, which is defined by the weight value of the contents. These soil characteristics were proved in **Figure 3**, stating the influence of porosity on the value of the weight content at disposal research site. The graph shows that the porosity percentage on the soil has a negative influence on the value of the original soil density. the higher porosity in the soil aggregate actually indicates a decrease in the value of the weight of the contents. The relationship between these two parameters is illustrated through a non-linear regression approach on 55 physical properties testing data with a high coefficient of determination, 0.90.

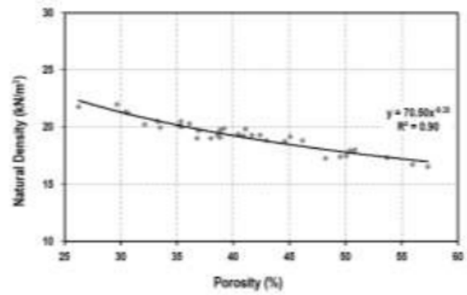

Figure 3. Graph of Porosity Effect on the Disposal Natural Density

In addition to analyzing the influence of porosity with the weight value of contents, also analyzed the effect of porosity on the original moisture content contained in the soil. **Figure 4** shows a graphic interpretation of the relationship between porosity and original water content in disposal is presented. The graph shows that there is a correlative relationship between porosity and original water content contained in the material disposal at the study site. The relationship shown in the graph is a positive relationship graph, in the form of linear regression. This confirms that the greater the value of the water content in the soil. This correlative relationship is caused by the porosity representing the percentage of pores or space between the grains in a soil aggregate, so that the greater the space between grains also defines the greater space provided by soil aggregates in storing water and air. The correlative relationship produces a relatively strong coefficient of determination that is equal to 0.903.

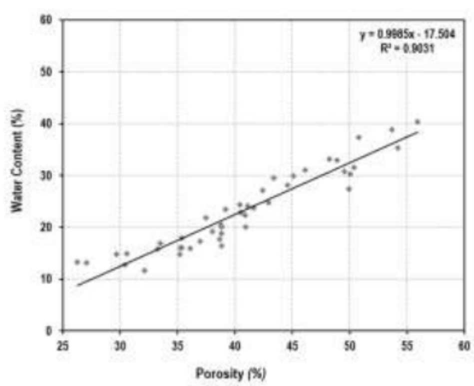

Figure 4. Graph of Porosity Effect on Original Disposal Water Content

Disposal material at this research is dominated by material with a very plasticity level with a percentage of 66.23% (**Figure 5**). Material with a very plasticity level is represented by material with a plasticity index value greater than 17%. In the medium plasticity group, which have plasticity index value is at 7-17%, shows a smaller amount of data compared to very plastic material, which is at a percentage of 34%. Material with low plasticity level was not found in the test results at the study site, so it can be concluded that the majority material at of research sites has a high plasticity level or very plastic.

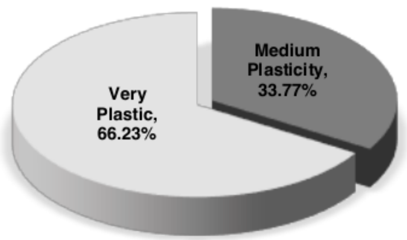

Figure 5. Percentage of Disposal Plasticity Level at Research Site

The percentage values of the disposal grain size distribution are shown in **Table 1** shows that overall material disposal at the research site is dominated by clay grain material, while the grains of sand are valued at the lowest.

Table 1. Disposal Grain Size Distribution for Each Depth

No	Depth Range	Average Grain Size Distribution		
		Clay	Silt	Sand
	(m)	(%)	(%)	(%)
1	0,00 - 10,00	39,63	46,36	13,74
2	10,00 - 20,00	38,36	46,02	14,42
3	20,00 - 30,00	41,23	40,05	18,72
4	30,00 - 40,00	40,03	37,08	22,89
5	40,00 - 50,00	46,80	34,57	18,61
6	> 50,00	51,98	39,95	8,08

In **Figure 6**, there can be seen that the correlative relationship between the percentage of grain size and the plasticity index is illustrated through linear regression. The relationship curve for the size of the sand grains explains that the greater the percentage of sand content in the soil, the plasticity index formed in the soil actually decreases, in contrast to the curve in the size of clay grains, which defines a correlative relationship positive, where an increase in the percentage of the amount of clay content will cause an increase in the soil plasticity index. The coefficient of determination shown on the graph gives the influence of the clay grain size distribution is 0.700 to the plasticity index, while that of the sand grains is only 0.500.

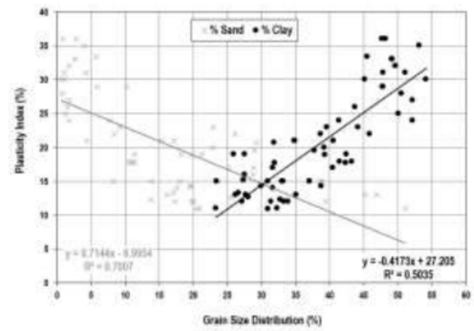

Figure 6. Percentage of Disposal Plasticity Level at Research Location

Furthermore, laboratory testing is carried out in more detail on two types of samples with different constituent materials. Sample 1 (S1) is a sample with a dominant constituent material in the form of clay and sample 2 (S2) is a material with a dominant constituent material in the form of sand. The composition of the constituent grains of both types of samples can be seen through the following test results.

Table 2. Disposal Grain Size Distribution for Each Depth

Sample Code	*Grain Size Distribution*			
	Clay	*Silt*	*Sand*	*Gravel*
	%	%	%	%
S1	47,28	47,22	5,50	0
S2	21,86	31,14	47,00	0

The results shown in the table above show that the sample group S1 is dominated by clay compilers, with a percentage of 47.28%, while the aggregate percentage with grains of sand is only 5.50%. Unlike the case with the aggregate grains compiling the S2 sample group, the percentage of sand is more dominant with a percentage of 47%, while the clay is only 21.86%.

Based on the cohesion parameters and the internal friction angle shown in **Table 3**, it can be concluded that the cohesion value in the S1 sample group is relatively greater than the sample disposal groups S2. Cohesion values in the S1 sample group were in the range of 0.19 - 0.46 kg / cm^2. In the sample group S2 with aggregate-dominated material the size of the sand grain residual cohesion values obtained in the range of values 0.15 - 0.36 kg / cm^2.

Table 3. Recapitulation of Direct Shear Test Test Results

Sample	Sample Code	Water Content	Cohesion	Internal Friction Angle
		%	kg/cm^2	°
Disposal (Clay Dominant)	S1_A	21,87	0,37	31,01
	S1_B	25,25	0,43	21,85
	S1_C	27,60	0,37	21,85
	S1_D	34,71	0,19	16,70
	S1_E	19,08	0,46	31,01
Disposal (Sand)	S2_A	20,00	0,36	35,07
	S2_B	22,65	0,33	31,01
	S2_C	24,77	0,23	31,01
	S2_D	29,41	0,28	31,01
	S2_E	35,80	0,15	31,01

Adhesivity testing has been carried out to obtain the disposal adhesivity parameters. In this study, testing only takes into account the adhesion parameters produced between the disposal material and steel as the material representing the surface of the excavator's bucket.

Table 4. Recapitulation of Adhesivity Direct Shear Test

Sample	Kode *Sample*	Kadar air	Adhesi	Sudut Geser Dalam
		%	kg/cm^2	°
Disposal (Clay Dominant)	S1_A	21,87	0,12	21,85
	S1_B	25,25	0,29	21,85
	S1_C	27,60	0,33	21,85
	S1_D	34,71	0,23	26,61
	S1_E	19,08	0,07	21,85
Disposal (Sand Dominant)	S2_A	20,00	0,03	26,61
	S2_B	22,65	0,14	21,85
	S2_C	24,77	0,13	21,85
	S2_D	29,41	0,12	16,70
	S2_E	35,80	0,09	21,85

The recapitulation of the test results shown in **Table 4** shows that in the sample group S1 the adhesion value was in the range of values 0.07 - 0.33 kg / cm^2 with a moisture content between 19.08 - 34.71%. In the S2 sample group the range of adhesion values was between 0.03 - 0.14% for variations in water content between 20.00 - 35.80%.

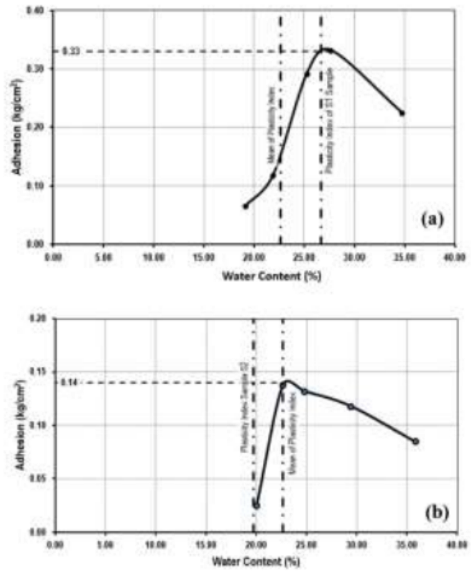

Figure 7. Effect of Moisture Graph on Adhesion of Sample Disposal (a) Sample S1 and (b) Sample S2

The effect of the water content value contained in the disposal on the adhesion value in each sample group is depicted as illustrated in **Figure 7**. It is explaining that the adhesion value in each sample group has a peak phase and a decrease phase. The peak phase of general adhesion values in all test groups is in the range of 22-30% moisture content. In the range of values, the adhesion value increased until the maximum value then dropped again. In the sample groups S1 and S2, the maximum value of disposal adhesion is close to the average plasticity index value of the soil, both as a whole and the sample group itself. This can be a validation of previous studies that stated same things.

Based on the results obtained, it was concluded that a correlative relationship between water content and disposal adhesion value at the study site in **Figure 8**. On the same graph, the maximum adhesion value in each sample group is at a relatively different water content. Sample S1 group showed a peak adhesion value of 0.33 kg / cm^2 at a water content value of 29.21%, while in the sample group S2 a peak adhesion value of 0.14 kg / cm^2 was at a water content value of 28.73%. The value of water content at the time of peak adhesion conditions in the sample group S2 explains that the material with the sand constituent material has a peak phase with less water content compared to clay. Soil material dominated by sand compilers also shows much smaller adhesion value compared to clay.

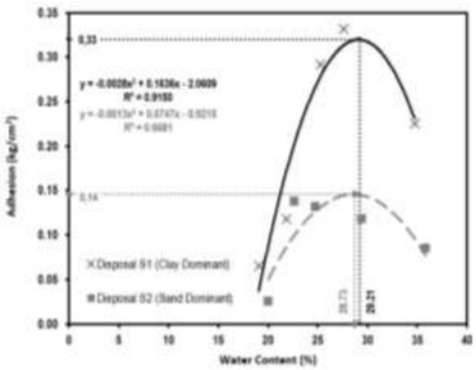

Figure 8. Graph Effect of Water Content on Disposal Adhesion at Research Sites

As a comprehensive analysis of the relationship on each related parameter, a multiple regression analysis is then performed to assess the relationship of water content, plastic limit, liquid limit, plasticity index, cohesion, percentage of clay grains, percentage of grains of sand, and weight of contents to adhesion so that it can be determined an Regression equation from the values of the test parameters that have been obtained. The analysis was conducted with a confidence level of 95% and a real level of 5%. The results of the analysis are summarized in **Table 5**

Table 5. Results of Beta Coefficients of Statistical Regression Analysis

Parameter	Coefficients	Standard Error
Intercept	74,6671	17,0908
Water Content	-0,0169	0,0073
Plastic Limit	0	0
Liquid Limit	0,0112	0,0063
Plasticity Index	0,0084	0,0101
Cohesion	0,0091	0,1387
%Clay	-1,4908	0,3420
%Sand	-0,9167	0,2099
Natural Density	0,7092	0,3826
Multiple R	0,93	
R Square	0.,84	

In **Table 5** it is stated that the adhesion parameter is influenced by several test parameters as mentioned above and has a fairly strong influence relationship. This is indicated by the coefficient of determination (R^2) of 0.84. Similar to the value of compound R (multiple R) which states the relationship between the dependent variable (adhesion) with all independent variables (test parameters such as water content, weight weights, consistency limits, cohesion, and grain size distribution) as a compound, that is equal to 0.92. Because of that case, it can be concluded that the test parameters which become the input parameters in the analysis have a significant influence on the adhesion value so that the relationship can be stated in a statement function whose coefficients are determined in **Table 5**. In this table, each test parameter has a coefficient value with varying standard error values. Then the regression equation can be written as follows:

$$a = 74{,}67 - 0{,}0169w + 0{,}0112(LL) + 0{,}0084\,(IP) + 0{,}0091C - 1{,}4908(\%Cl) - 0{,}9167\,(\%Sd) + 0{,}7092\gamma \quad \textit{(Equation 1)}$$

which:

a	= Adhesion (kg/cm²)
w	= Water Content (%)
LL	= Liquid Limit (%)
IP	= Plasticity Index (%)
C	= Kohesion ((kg/cm²)
%Cl	= Percent Grain of Clay (%)
%Sd	= Percent Grain of Sand (%)
γ	= Natural Density (g/cm³)

The regression is then validated in the analysis, this is done in order to determine the difference between the original adhesion value and the predicted adhesion value. This difference value is referred to as the residual value in . Based on the residual values shown in the 15 data, it was concluded that the deviation between the original adhesion value and the predicted value was relatively small, amounting to 0.0074.

Table 6. Validation of Predicted Adhesion Value

Sample Code	Adhesion	*Predicted Adhesion*	*Residuals*
S1_A	0,12	0,1733	-0,0533
S1_B	0,29	0,2629	0,0270
S1_C	0,33	0,2652	0,0647
S1_D	0,23	0,2571	-0,0271
S1_E	0,07	0,0812	-0,0112
S2_A	0,03	0,0323	-0,0023
S2_B	0,14	0,0969	0,0430
S2_C	0,13	0,1134	0,0165
S2_D	0,12	0,1615	-0,0415
S2_E	0,09	0,1057	-0,0157
	Mean		0,0074

CONCLUSION

Based on the results discussed in this study, several conclusions are summarized as follows:

1. Disposal at the research site has an natural water content of 21.97%, porosity value of 40.55%. Characteristics of the dominant constituent grains in the form of clay with a very plastic material category and a peak adhesion value of 0.15 - 0.33 kg/cm² at moisture content of 28.73 - 29.21%. It shows that the actual material disposal at the research location is at the maximum adhesiveness phase.
2. The greater the sand material as the size of the constituent disposal reduces the plasticity index on the material that can affect the stickiness level.
3. The maximum phase of stickiness (adhesion

value) is close to the plasticity index value.

4. Relationship between water content parameters (w), natural density (γ), grain size distribution of clay (% Cl), sand (% Sd), cohesion (C), liquid limit (LL), and Plasticity Index (IP) with adhesion values (a) can be stated in the equation : $a = 74{,}67 - 0{,}0169w + 0{,}0112(LL) + 0{,}0084\ (IP) + 0{,}0091C - 1{,}4908(\%Cl) - 0{,}9167\ (\%Sd) + 0{,}7092\gamma$

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