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Shear Strength Characteristics of Coal Dust Mixed Pilani Soil

Kamalesh Kumar[1], Utpal Sannyashi[2]

[1] Department of Civil Engineering, Birla Institute of Technology & Science, Pilani, Jhunjhunu, Rajasthan 333031, India

[2] Department of Civil Engineering, Birla Institute of Technology & Science, Pilani, Jhunjhunu, Rajasthan 333031, India

Abstract

Cooking coal dust has the potential to replace traditional admixtures used to improve soil properties. The low cost of this coal dust is an added benefit as it can be used either alone or in combination with regular admixtures in the construction of foundations, embankments, retaining walls etc. The aim of this paper is to determine the shearing strength parameters of Pilani soil mixed with varying coal dust amount. The experimental values will give us a better understanding of the range of coal dust usage in construction. Disposal of the huge amount of produced coal dust poses a potentially serious environmental threat due to paucity of land for disposal. Therefore, using coal dust in construction can, in addition to reducing expenditures, will also solve the headache of its safe disposal and help in preventing environmental degradation. Direct shear testing was conducted at in-situ water content & at OMC conditions.

Keywords: *Coal Dust, Admixtures, Shearing Strength Parameters, Pilani Soil, Direct Shear Testing, In-Situ Water Content, OMC.*

1. Introduction

Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two (Sherwood, 1993). All soil stabilization methods fall into two broad categories. In mechanical stabilization, soil stabilization can be achieved through physical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing. In chemical stabilization, soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. Cement, Lime, Fly Ash, Blast Furnace Slag and Pozzolanas are usually added in soil in chemical stabilization. Not much information is available in literature on the effect of coal dust addition into soil on to its shear strength parameters.

Large deposits of coal over vast expanse of lands attract mining companies, power stations and petrochemical companies and thus the development of coal towns with rail and road networks. High traffic volume of large quantities of coal across coal cities often result in the gradual accumulation of fine coal dust particles on road pavements, rail ballast and sleepers. This coal dust also gets mixed with the soil of the vicinity. The effect of coal dust on the direct shear friction angles of local soil were investigated under in-situ water content and at OMC conditions at four different coal dust compositions.

The surface texture of coal dust mixed soil has significant impact on its strength properties. The strength is derived from cohesion in the soil–coal dust mixture and interlocking properties of the soil–coal dust mixture. The inter-locking properties depend on angularity, flatness and elongation. Soil–coal dust mixture interlocking and interfacial properties are dependent on the wetting characteristics and contact angle at the interface, and these properties can be significantly altered by the coal dust content as well as the water amount.

In the present study, coal dust (available as waste material with cooking coal suppliers) has been added in local sandy soil. Cohesion and angle of internal friction variation has been investigated of coal dust mixed local soil. Direct shear testing has been done for this purpose. The direct shear test is used to measure the shear properties of soil. The test is performed on multiple specimens. A specimen is placed in a shear box which has two stacked square rings to hold the sample; the contact between the two rings is at approximately the mid-height of the sample. A confining stress is applied vertically to the specimen, and the upper ring is pulled laterally until the sample fails. Failure shear stress for the applied confining stress is recorded. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion (c) and the angle of internal friction, commonly known as friction angle (ϕ). The results of the tests on each specimen are plotted on a graph with the failure stress on the y-axis and the confining stress on the x-axis. The y-intercept of the line which best fits the test results is the cohesion, and the slope of the line is the friction angle.

The coal dust was mixed in Pilani soil in proportions – 0%, 6%, 12% and 18% by total weight. Direct shear testing of these specimens was conducted at in-situ water content and at optimum moisture content (OMC) to find out the cohesion and angle of internal friction variation. Using the results from the study, approximate value of shear strength was also found at aforementioned water contents of coal dust mixed experimental soil at 2 meters below ground surface for 0%, 6%, 12% & 18% of coal dust content.

Direct shear tests can be performed under several conditions. The sample is normally saturated before the test is run, but can be conducted at the in-situ moisture content as well as at OMC. The rate of strain can be varied to create a test of undrained or drained conditions, depending whether the strain is applied slowly enough for water in the sample to prevent pore-water pressure buildup. Direct shear test machine is required to perform the test. The test using the direct shear machine determines the consolidated drained shear strength of a soil material in direct shear. Consequently, experimental results of present study are of significance to freely draining Pilani soil.

The advantages of the direct shear test over other shear tests are the simplicity of setup and equipment used, and the ability to test under differing saturation and drainage conditions. These advantages have to be weighed against the difficulty of measuring pore-water pressure when testing in undrained conditions, and possible spuriously high results from forcing the failure plane to occur in a specific location.

2. Experimental Details

The soil used for the direct shear testing experiment was dug out from a depth of 1.5 m from the ground surface from Birla Institute of Technology & Science campus using Standard Technique. Its average in-situ water content was found to be 6.4%. Average bulk and dry densities were 1.67 gm/cc and 1.57 gm/cc respectively. Results of the compaction test (Standard Compaction Test – IS Equivalent) indicates optimum water content = 15.5% and maximum dry density = 1.633 gm/cc for the collected soil. Based on the sieve analysis experiment, the soil was found to be sand which was poorly graded.

Coal dust was mixed in the collected experimental soil. This coal dust was obtained in crushed form from a cooking coal supplier in Delhi at a nominal price. Its specific gravity was found to be 1.514 & % retained on 75 micron sieve was found to be 95%. Both soil and coal dust were air dried before doing direct shear testing on samples made from them.

For z gm. of air dried soil and y% air dried coal dust in it, let weight of air dried coal dust = x gm. Then,

$$\left(\frac{x}{x+z}\right)100 = y \quad (1)$$

From Eq. (1), for z = 400 gm., & y = 0, 6, 12 & 18 respectively, x comes out to be 0 gm., 25.53 gm., 54.54 gm. and 87.8 gm. respectively.

For z gm. of air dried soil and x gm. air dried coal dust in it, weight of water = p gm. for water content of q%. Then,

$$\left(\frac{p}{z+x}\right)100 = q \quad (2)$$

For z = 400 gm. and x = 0 gm., 25.53 gm., 54.54 gm. & 87.8 gm. respectively, p comes out to be 25.6 gm., 27.23 gm., 29.09 gm., & 31.22 gm. for q = 6.4 (In-situ water content) from Eq. (2). Similarly, for z = 400 gm. and x = 0 gm., 25.53 gm., 54.54 gm. & 87.8 gm. respectively, p comes out to be 62 gm., 65.96 gm., 70.45 gm., & 75.61 gm. for q = 15.5 (OMC) from Eq. (2). Weight in gm. of water and its volume in cc. is same as unit weight of water = 1 gm/cc. These required weights of coal dust and volumes of water were added in 400 gm. air dry soil to prepare samples with 0%, 6%, 12% & 18% coal dust content at in-situ water content as well as at OMC. Coal dust was mixed in soil first and then water was added in the soil – coal dust mixture. Ordinary tap water was used in all the experiments. All the samples were freely draining during direct shear tests. Failure shear stresses were determined for five different normal stresses, which were then used to find out cohesion and angle of internal friction. Results are summarized in Table 1 & 2.

Table 1: Direct shear test results at in-situ water content

Normal Stress (kg/cm^2)	Failure Shear Stress (kg/cm^2)			
	Coal Dust Content = 0%	Coal Dust Content = 6%	Coal Dust Content = 12%	Coal Dust Content = 18%
0.1388	0.07925	0.06164	0.09686	0.08805
0.2083	0.14088	0.08805	0.12768	0.16290
0.4167	0.25976	0.23334	0.26416	0.29938
0.8333	0.54154	0.50632	0.59877	0.58997
1.1111	0.60318	0.55034	0.81451	0.84533

Table 2: Direct shear test results at OMC

Normal Stress (kg/cm^2)	Failure Shear Stress (kg/cm^2)			
	Coal Dust Content = 0%	Coal Dust Content = 6%	Coal Dust Content = 12%	Coal Dust Content = 18%
0.1388	0.06604	0.07925	0.11887	0.10126
0.2083	0.12327	0.13208	0.14088	0.13208
0.4167	0.19812	0.23334	0.23775	0.32580
0.8333	0.50632	0.47109	0.53713	0.64280
1.1111	0.67362	0.79690	0.84533	0.81011

Results of Table 1 & 2 are also plotted in Fig. 1, 2, 3 & 4. Equations of straight line of best fit have also been indicated for each coal dust content in both the figures.

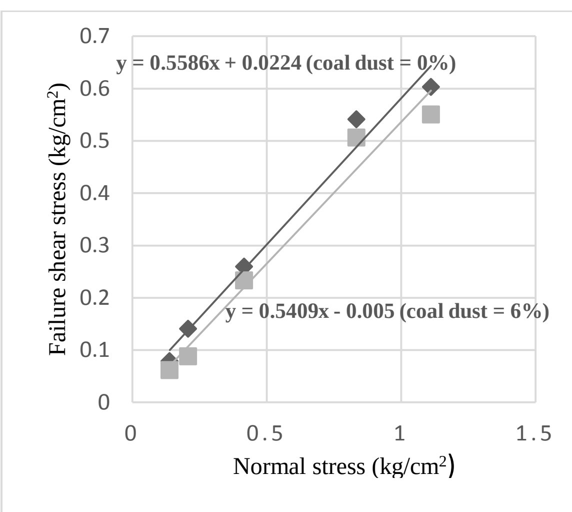

Fig. 1 Direct shear test results at in-situ water content (0% & 6 % coal dust content)

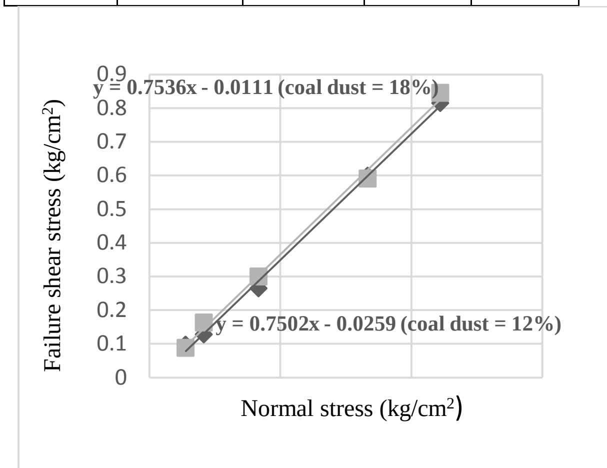

Fig. 2 Direct shear test results at in-situ water content (12% & 18% coal dust content)

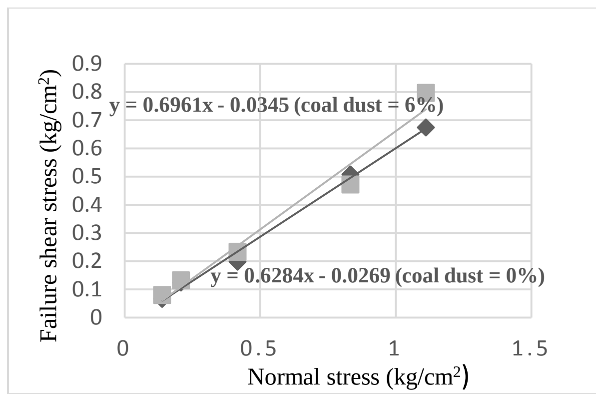

Fig. 3 Direct shear test results at OMC (0% & 6% coal dust content)

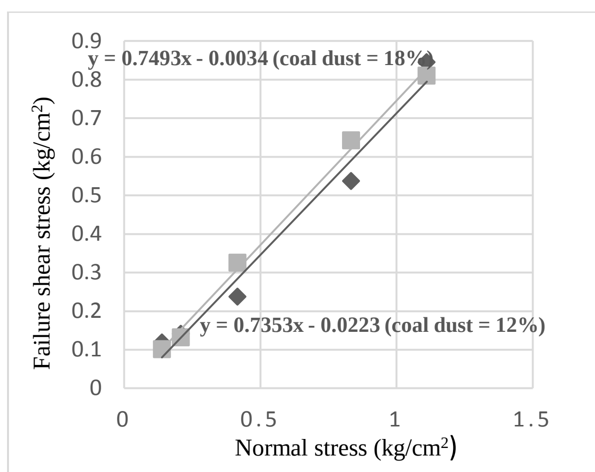

Fig. 4 Direct shear test results at OMC (12% & 18% coal dust content)

From Fig. 1, Fig. 2, Fig. 3 & Fig. 4, it is clear that for the experiments at in-situ water content, negative value of cohesion is obtained in all cases (i.e. 6%, 12% and 18% of coal dust) except when no coal dust is added. This is an anomaly as all soils can at most be cohesionless i.e. have zero cohesion. For all the experiments at OMC water content, negative value of cohesion is observed, even when no coal dust is added. This is an anomaly as all soils can at most be cohesionless i.e. have zero cohesion. The anomaly could be due to experimental error. Since cohesion value is very close to zero in all the samples of present study, all samples have been considered cohesionless. Slope of equation of straight line of best fit from Fig. 1, Fig. 2, Fig. 3 & Fig. 4 has been used to find out the angle of internal friction values of all the samples of present study. These values are shown in Table 3.

Lot of construction in the place of study has foundation (shallow foundation type) depth at 1.5 meters below ground surface. Knowledge of the shear strength at the same depth is useful due to variety of geotechnical reasons. Shear strength of all the samples of present study has been calculated & has been shown in Table 3 for 1.5 meters depth at in-situ water content & OMC conditions. Calculation is for overburden only. In-situ dry soil density has been used for shear strength calculation at in-situ water content & maximum dry soil density (obtained from compaction experiment in the study) has been used for shear strength calculation at OMC. Values are given in Table 3. Shear strength variation at these two water contents with coal dust content is also shown in Fig. 5. As all samples are cohesionless and are of freely draining type, following equation has been used to calculate shear strength (τ_f):

$$\tau_f = (\gamma_d)(z)(\tan\phi) \qquad (3)$$

γ_d = 1.57gm/cc or 1.57T/m^3 for in-situ water content in Eq. 3. Similarly, γ_d = 1.633gm/cc or 1.633T/m^3 for OMC in Eq. 3. 'z' = 1.5m, for 1.5m depth below ground surface. 'ϕ' values are available for different coal dust contents at in-situ water content as well as at OMC in Table 3.

Table 3: Shear strength variation with coal dust content

Coal dust content	In-situ water content		OMC	
	ϕ (deg.)	τ_f (T/m^2)	ϕ (deg.)	τ_f (T/m^2)
0%	29.18	1.315	32.14	1.539
6%	28.4	1.273	34.84	1.705
12%	36.87	1.766	36.32	1.8
18%	37	1.774	36.84	1.835

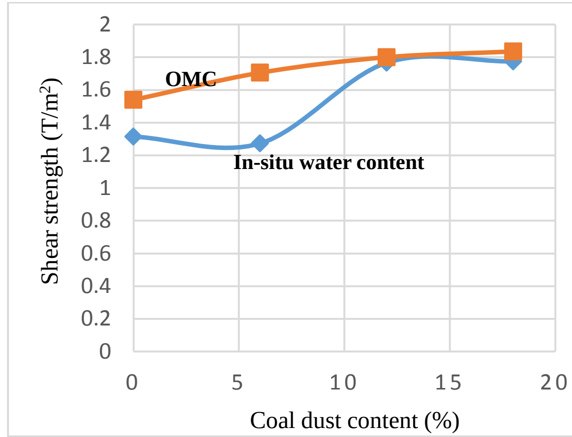

Fig. 5 Shear strength variation with coal dust content

3. Discussion of Experimental Results

From Table 3 and from Fig. 5, it is clear that local soil used in the experimental investigation has maximum shear strength with 18% coal dust in it (at 1.5m below ground surface) at in-situ water content as well as at OMC field conditions. When this percentage of coal dust is added in excavated soil (till 3m from ground surface) from the place of study (at in-situ water content as well as at OMC), this coal dust mixed soil is refilled to corresponding field conditions, and then shallow foundations for different structures are constructed, soil will have enhanced shear strength as well as load carrying capacity compared to no coal dust mixed soil. Shear strength as well as load carrying capacity will be higher at OMC than at in-situ water content at 18% coal dust content.

As per geotechnical field applications, other coal dust contents can also be added either at in-situ water content or at OMC to get required shear strength in the experimental soil used in the present study.

4. Conclusions

Based on cohesion intercept (in Fig. 1, Fig. 2, Fig. 3 & Fig. 4), for all the samples in present study, it was concluded that all the samples were cohesionless. At in-situ water content, angle of internal friction was found to decrease with increase in coal dust content from 0% to 6%. With increase in coal dust content from 6% to 18%, angle of internal friction was found to increase at in-situ water content. Shear strength at the required depth was thus showing the same trend of variation at in-situ water content. At OMC, angle of internal friction was found to continuously increase with increase in coal dust content from 0% to 18%. Shear strength at required depth was thus showing same pattern of variation at OMC as well. Practical significance of the study has already been discussed in the previous section. Similar study can be conducted for other place soil also for shear strength assessment when coal dust is mixed in it at in-situ water content as well as at OMC. Soil could have cohesion or no cohesion in it.

Coal dust is available as waste material. Its safe disposal with minimal environmental damage is quite significant. Mixing it with local soil at in-situ water content as well as at OMC and using the mixture for different geotechnical applications is one such alternative. In the present study, different percentages of coal dust were added in local soil at in-situ water content as well as at OMC. Angle of internal friction was found to increase with coal dust addition at in-situ water content as well as at OMC, with respect to no coal dust added condition excepting 6% coal dust condition at in-situ water content, in which angle of internal friction was found to decrease with respect to no coal dust added condition.

As concluded in the study, coal dust addition in sandy soil if results in substantial angle of internal friction gain with respect to no coal dust added condition, it will result in increased shear strength as well as increased load carrying capacity of coal dust mixed soil with respect to no coal dust added soil. It will also result in safe disposal of coal dust with no significant environmental damage.

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