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Shear Strength and Load Settlement Behaviour of Copper Slag in Sand Pile

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***Abstract*— Sand pile is a soil improvement method aims at increasing density, increasing shear strength and reducing settlement. Copper slag is a waste product which can be substituted for sand in sand piles. The performance of sand piles is dependent on strength and settlement characteristics of the sand, hence direct shear test and load test were conducted. The sand was mixed with different proportions of copper slag and the percentage of copper slag which gave maximum strength and minimum settlement is taken as the optimum percentage.**

***Keywords*— Copper Slag, Direct Shear Test and Load Test**

I. INTRODUCTION

Sand pile method is a soil improvement method that a sand is introduced into the pipe, and the pipe is withdrawn part away while the sand pile is compacted and its diameter is enlarged. This aims at increasing density, horizontal resistance and preventing the liquefaction in the sandy soils. It is used to increase shear strength and bearing capacity, and control the side displacement and the consolidation settlement by forming composite grounds consisted of original soils and compaction piles. The sand used in this method should be of good quality to be adequate for the construction criteria. Unfortunately, the installation of sand piles have become less economically viable due to the high costs and limited availability of good quality sand.

Copper slag is a waste product generated during the smelting process for the production of copper. It has been estimated that for every tonne of copper produced, about 1.8-2.2 tonnes of copper slag is generated as a waste. Due to its suitable grain size that is ranged from 0.15mm to 3mm, copper slag can be substituted for sand in sand piles, and especially its higher specific gravity is a notable feature. The performance of sand piles is dependent on strength and settlement characteristics of the sand. Therefore, in this study, Direct Shear tests and laboratory Load tests were performed to evaluate the applicability of copper slag as a substitute for sand of Sand Piles.

II. MATERIALS USED

A. *Copper Slag*

Copper Slag was purchased from M&M Industries, Ernakulam District, Kerala, India. Copper slag is a by-product formed during the copper smelting process.

B. *Sand*

The sand used for the study was purchased from M &M industries, Ernakulam District, Kerala, India. The laboratory tests were conducted to analyse the grain size distribution characteristics.

C. *Clay*

Expansive clay was taken from Puzhakkal Padam near Thrissur, Kerala. Clay was collected from depth of 3 to 4m. The clay was initially air dried in open atmosphere and crushed in particles prior to the testing.

TABLE I PHYSICAL PROPERTIES OF COPPER SLAG

Property	**Value**
Specific gravity	3.8
Dry Density (kN/m^3)	20.2
Effective size D_{10} (mm)	0.500
D_{30} (mm)	0.820
D_{60} (mm)	1.100
Uniformity coefficient (Cu)	2.2
Coefficient of curvature (Cc)	1.22
Type of soil	Uniformly graded

TABLE II PHYSICAL PROPERTIES OF SAND

Property	**Value**
Specific gravity	2.73
Dry Density (kN/m^3)	16.36
Effective size D_{10} (mm)	0.230
D_{30} (mm)	0.420
D_{60} (mm)	0.580
Uniformity Coefficient (Cu)	2.52
Coefficient of curvature(Cc)	1.32
Type of soil	Uniformly graded

TABLE III PHYSICAL PROPERTIES OF CLAY

Property	Value
Specific gravity	2.39
Liquid limit (%)	35
Plastic limit (%)	28
Plasticity index (%)	7
Shrinkage limit (%)	13
Maximum dry density (kN/m^3)	15.7
Optimum moisture content (%)	20.2
Percentage gravel sized particles	0
Percentage sand sized particles	28
Percentage fines	72

III. EXPERIMENTAL INVESTIGATION

A. Direct Shear Test

The direct shear test is a laboratory testing methods used to determine the shear strength parameters of soil. The sample is subjected to a controlled normal stress of 24.8kN/m^2, 49.9kN/m^2 and 75kN/m^2 and the upper part of the sample is pulled laterally at a controlled strain rate of 1.25 mm/min until the sample fails. The applied lateral load and the induced strain are recorded at given internals. These measurements are then used to plot the stress-strain curve of the sample during the loading for the given normal stress. Results of different tests for the same soil are presented in a chart with peak stress on horizontal axis and normal (confining) stress on the vertical axis. A linear curve fitting is often made on the test result points. The intercept of this line with the vertical axis gives the cohesion and its slope gives the peak friction angle.

B. Load Test

Load tests were performed inside a cylindrical mould of 16 cm diameter and 25 cm in height filled with clay. Load tests were conducted on the clay bed using a standard loading frame and load was applied to the loading plate of 10cm diameter (assumed to be equivalent to footing). A proving ring of 10kN capacity and a dial gauge were used to measure the load and settlement respectively. In order to drive the columns PVC rods of 5cm diameter and 25 cm height were used. Load was applied through the plunger at a rate of 1.2mm/minute.

All load test experiments were carried out on a 50mm diameter granular pile surrounded by soft clay. The cylindrical tank of diameter 160mm and 250mm height was used. The tank dimensions represent the required unit cell area of soft clay around each pile assuming triangular pattern of installation of piles (For triangular pattern Equivalent Diameter of Test Tank = 1.05 x Diameter of Tank). Unit-cell idealization is used in the present study to simplify the design of the apparatus needed to assess the behaviour of an interior pile in a large group of piles.

A thin coat of grease was applied along the inner surface of tank wall to reduce friction between clay and tank wall. Expansive clay was filled in the tank in layers with measured quantity by weight. The surface of each layer was provided with uniform compaction with a tamper to achieve a 50 mm height. Care was taken to ensure that no significant air voids were left out in the test bed. After the soft soil bed was prepared, granular pile was constructed by a replacement method. Thin open-ended seamless PVC pipe of 50mm outer diameters and wall thickness 2 mm were used to construct the granular piles. The pipe was pushed into the soil up to the bottom of the tank. Only static force was manually applied to push the pipe gently into the soil so as to minimize the disturbance in the clay soil that may change the properties of the clay. The displaced clay during the installation of granular piles was taken out and the clay bed surface in the tank was trimmed level. Outer surface of the pipe was lubricated by applying a thin layer of grease for easy withdrawal without any significant disturbance to the surrounding soil.

Granular material was moistened (with 5% of water) before charging into the pipe in order to prevent it from absorbing the moisture from the surrounding clay soil. Granular material was charged into the hole in layers in measured quantities to achieve a compacted height of 50 mm in the pipe. The pipe was then raised in stages ensuring a minimum of 5 mm penetration below the top level of the placed sand. To achieve a uniform unit weight, compaction was done with a circular steel tamper with 10 blows of 100 mm drop to each layer. This light compaction effort was adopted to ensure that there is no significant lateral bulging of the pile which creates disturbance to the surrounding soft clay. The procedures were repeated until the pile was filled to the full height.

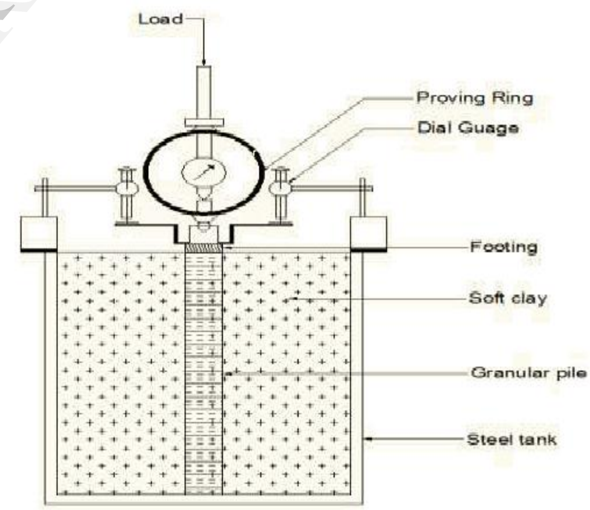

Fig 1. Experimental setup

IV. RESULTS AND DISCUSSIONS

A. Direct Shear Test With Different Percentages of Copper Slag

The samples which were tested in the direct shear apparatus were prepared in 'medium condition' with no compacting. Tests were conducted on the sand mixed with copper slag in various proportions of 0%, 10% and upto 50%. The sample is subjected to a controlled normal stress of 24.8kN/m^2, 49.9 kN/m^2 and 75 kN/m^2 .

The angle of internal friction for pure sand used in the test has only 34^0, which is not sufficient for granular pile. There is an increase in angle of internal friction from 34^0 to 42^0 when 30% copper slag is mixed with sand. After 30% copper slag, the angle of internal friction reduced to 36^0. The reason for reduced value may be due to shiny surface of copper slag , which reduces the friction between the particles.

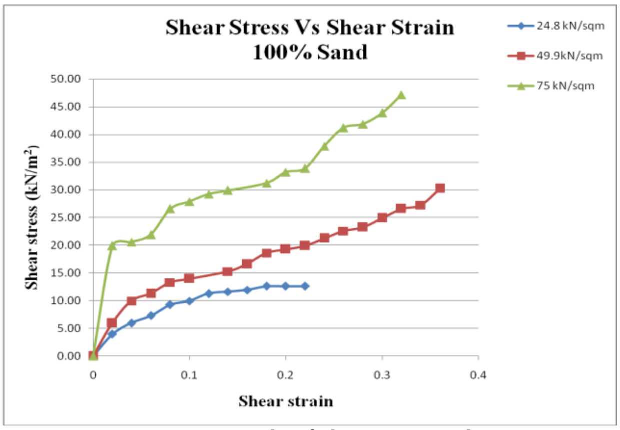

Fig. 2. Test results of Shear strain Vs Shear stress for pure sand

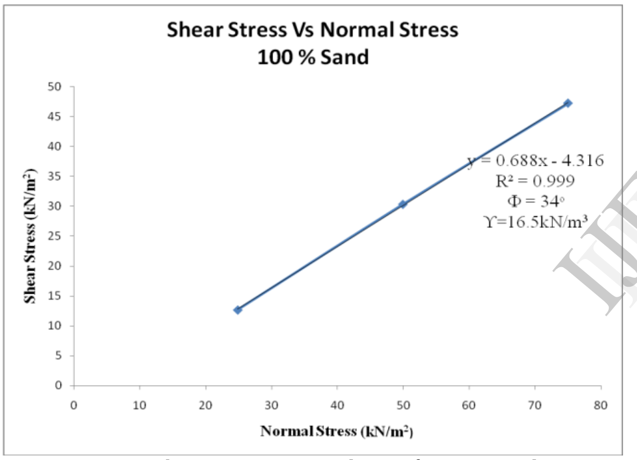

Fig.3. Shear stress Vs Normal stress for 100% sand

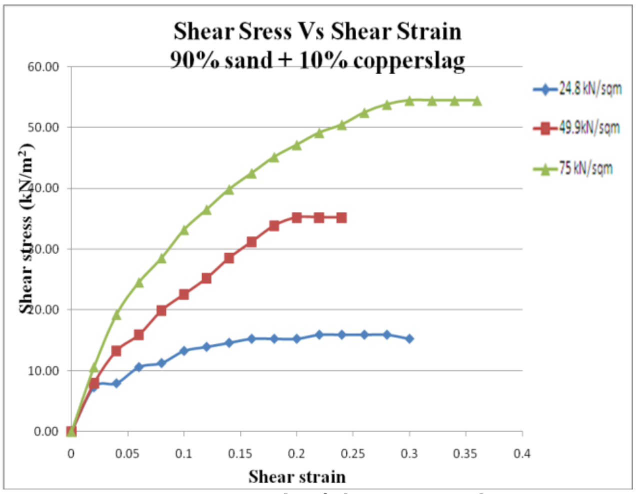

Fig. 4. Test results of Shear strain Vs Shear stress for 10% copper slag

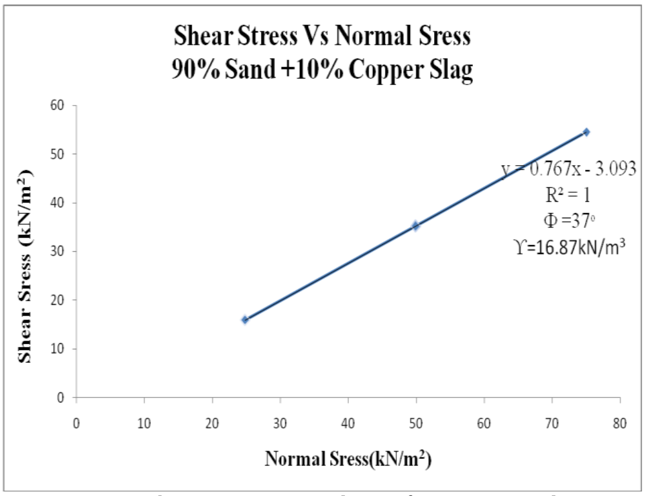

Fig.5. Shear stress Vs Normal stress for 10% copper slag

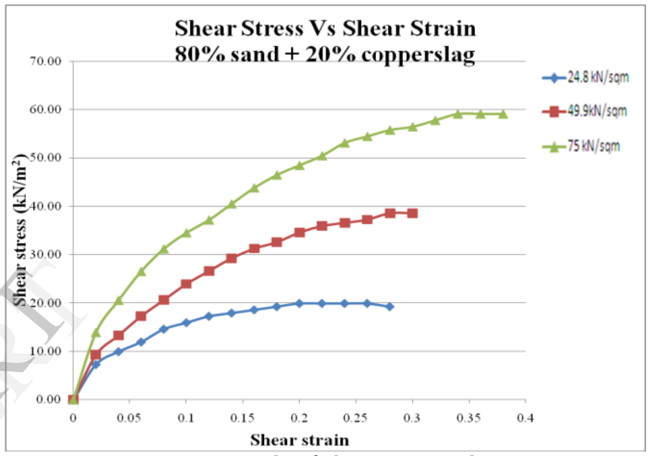

Fig. 6. Test results of Shear strain Vs Shear stress for 20% copper slag

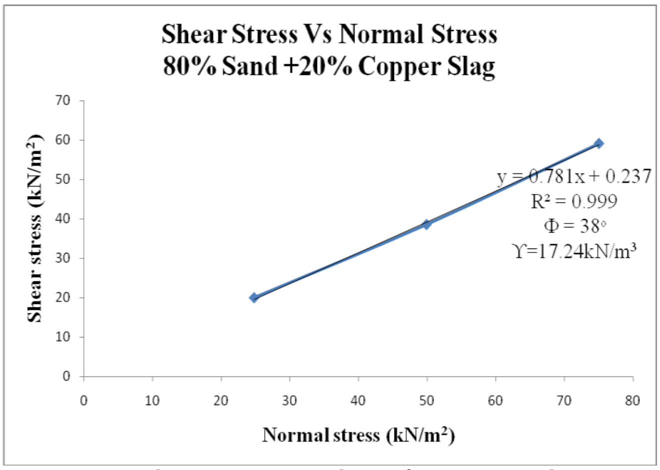

Fig.7. Shear stress Vs Normal stress for 20% copper slag

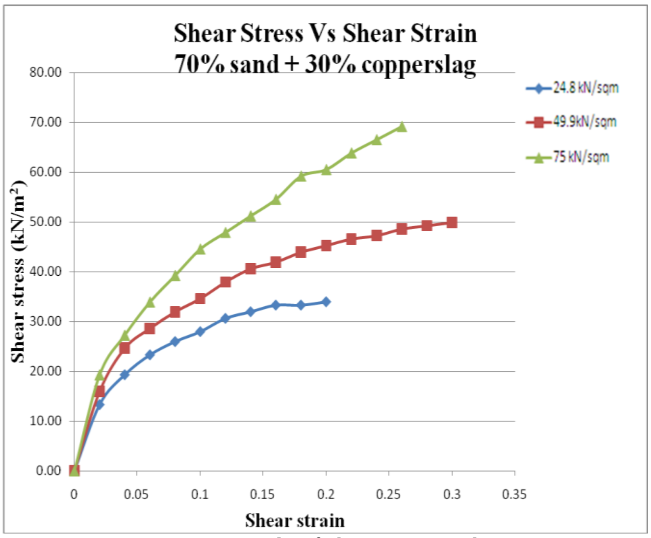

Fig. 8. Test results of Shear strain Vs Shear stress for 30% copper slag

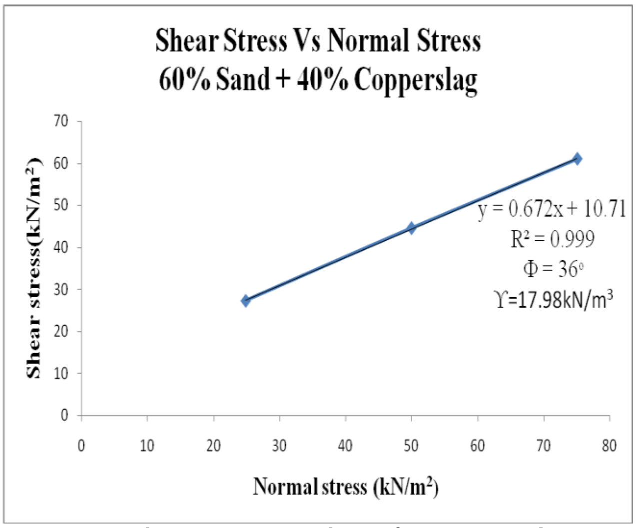

Fig.11. Shear stress Vs Normal stress for 40% copper slag

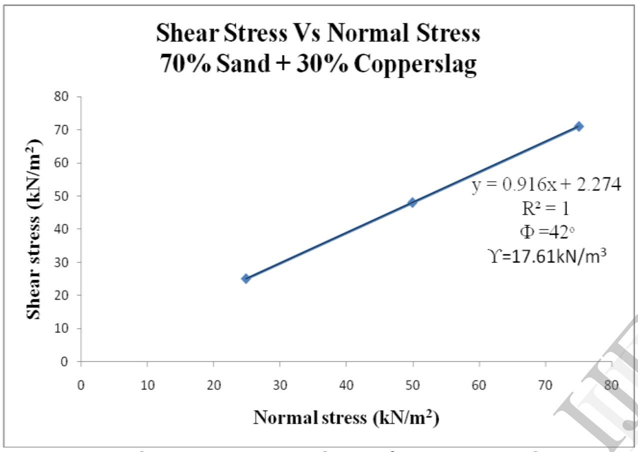

Fig.9. Shear stress Vs Normal stress for 30% copper slag

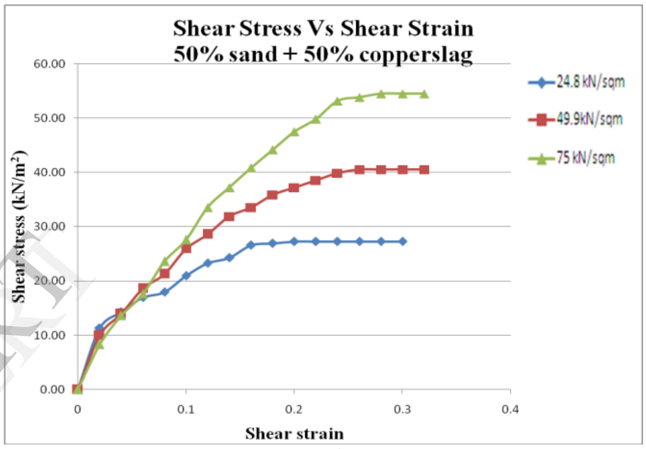

Fig. 12.. Test results of Shear strain Vs Shear stress for 50% copper slag

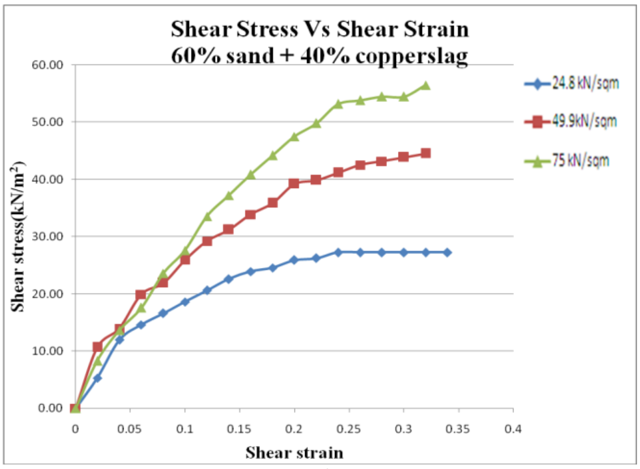

Fig. 10. Test results of Shear strain Vs Shear stress for 40% copper slag

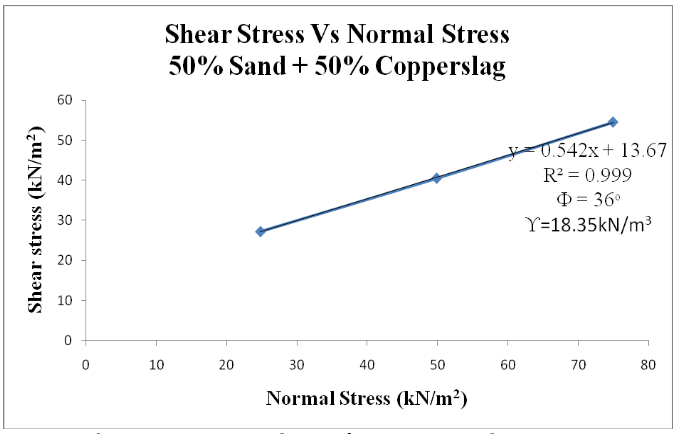

Fig.. 13. Shear stress Vs Normal stress for 50% copper slag

TABLE IV: VALUES OF ANGLE OF INTERNAL FRICTION FOR DIFFERENT PERCENTAGES OF COPPERSLAG

Combinations	Angle of internal friction
100% Sand	34^0
10% Copperslag+90% Sand	37^0
20% Copperslag+80% Sand	38^0
30% Copperslag+70% Sand	42^0
40% Copperslag+60% Sand	36^0
50% Copperslag+50% Sand	36^0

B. Load Test With Different Percentages of Copper Slag

To evaluate the feasibility of using copper slag to strengthen the expansive soil, tests were performed on fully penetrating single granular pile in unit cell tanks to investigate the improvement of load carrying capacity of copper slag mixed with sand piles with s/d ratio as 3. Load values corresponding to 12.5mm settlement was taken as the load carrying capacity. The results of load test were shown in Fig. 8.

Strength parameters of the granular pile material have an influence on load carrying capacity of the improved ground and load carrying capacity of the improved ground increases with increasing the value of the strength parameter of the pile material. the load carrying capacity of pure clay bed is 838.08N. when the sand having angle of internal friction 34^0 was used in the pile, the load carrying capacity increased to only 954.48N which may be due to low angle of internal friction. the addition of 30% copper slag increased the angle of internal friction from 34^0 to 42^0, correspondingly the load carrying capacity increased to 1943.88N. On further addition of copper slag, the load carrying capacity was decreasing due to the reduction of angle of internal friction.

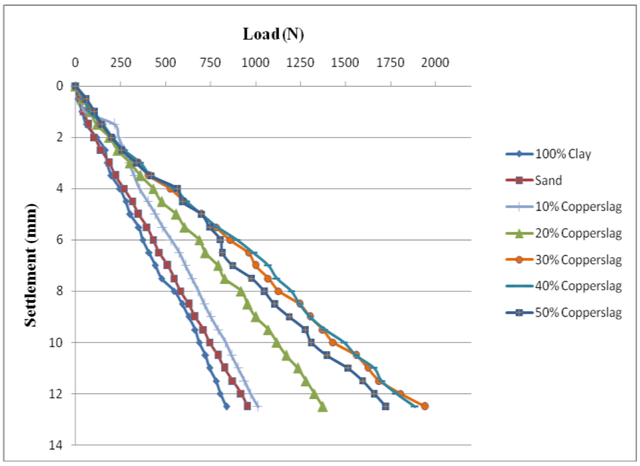

Fig. 14. Load settlement curve for different percentages of copper slag

From direct shear test and load test, the optimum percentage of copper slag was taken as 30%. When 30% copper slag was added, the angle of friction was $42^0$and load carrying capacity was 1943.88N.

V. CONCLUSIONS

Based on the study, the following conclusions were made:

- The shear strength properties of the sand-copper slag mix increases with increase in the percentage of copper slag. When 30% copper slag was mixed with sand, the angle of internal friction increased from 34^0 to 42^0.
- The load carrying capacity of pure clay bed is 838.08N. When 30% copper slag was added the load carrying capacity increased to 1943.88N.
- From direct shear test and load test, the optimum percentage of copper slag was taken as 30%.

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