Study on Seepage and Strength Characteristics of Black Cotton Soil Admixed with Copper Slag

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ABSTRACT:
The usage of industrial by-products in construction has been common globally adopted due to shortage of natural materials. Copper slag is one such by-product which is available from the copper industry in India. Their disposal and recycling have gained prominence as usage of such materials serves the sustainability goals of the nation. Whereas, black cotton soil is well known for highly expansive nature, low permeability and poor strength. Many researchers have worked on reinforcing black cotton soil to check its ability to serve as subgrade material but enhancement of drainage characteristics of black cotton soil requires more attention. Present study is to observe the change in permeability and strength characteristics of black cotton soil by adding varying percentages of copper slag and to obtain to the optimum percentage of copper slag. Permeability tests, CBR tests and direct shear tests were conducted for black cotton soil along with copper slag by varying the percentages of copper slag as 20%, 30%, 40% and 50%. Permeability has increased subsequently with the increase in percentage of copper slag in black cotton soil and at 50% of copper slag content permeability reached to as that of medium sand and CBR value increased by four times. The optimal percentage of copper slag from the study is observed as 30% in addition to the improved shear strength.

Keywords: Black Cotton Soil, Copper Slag, Permeability, Seepage Characteristics

1 Introduction

Dealing with established fact of swelling and shrinkage behavior of expansive soils there are numerous works channelized towards ways to stabilize the behavior of expansive soils. The research works are specific to the property of soil which is focused on. Among different problems that are associated with expansive soils seepage is crucial as there is an application of using expansive soils as subgrade material of pavements which becomes unavoidable at one or the other point. Black cotton soil is one such expansive that is extensively found in south India and covers 15% of the Indian land. The problems associated and possible solutions can be understood by the work of Katti(1979).

Mixing lime, fly-ash and other alternatives has been recurrent throughout the research in improving the characteristics of expansive soils. The pozzolanic substances that comes out as waste in agricultural, industrial and domestic activities are experimented as admixtures in soils. Saw dust is one such material. Addition of Saw dust and Sawdust Ash has significant effect in improving CBR and UCS values based on the works on Butt et al (2016), Ogunribido (2012), Reddy et al (2016) and James et al (2019), but the durability of material is question remained unanswered. Usage of fly-ash is proven to increase CBR and compressive strength according to Show et al (2003) and Trzebiatowski (2005). The paper by J B Niyomukiza (2021) states that though there is lot of research around using waste material for geotechnical enhancement the application part is found to be very rare.

Copper slag is one of the industrial discards that comes out as by-product of smelting of copper itself. While the two by-products of smelting are copper rich matte and Copper slag which has copper content less than 0.8% as mentioned by Gorai (2003). According to Prasad and Ramana (2016) Copper slag is good replacement for convention al structural fill. Copper Slag has several applications. The pozzolanic activity of slags is studied by Douglas (1985). Generally due to lower content Cao Copper Slag is pozzolanic (Deja and Malolepszy (1989) and Douglas and Mainwaring (1985). By increasing the Cao content, the cementitious nature of Copper Slag increases. In nature due to its high hardness and density it can be used for abrasive tools, roofing granules, cutting tools, abrasive, tiles, glass, road-base construction, railroad ballast, asphalt pavements, cement and concrete industries. Using copper slag as an admixture would be good experimentation and also serves the sustainability aspect. Fly ash, Rice-ask husk, Marble dust and other industrial are being used as admixtures but the specific gravity of copper slag is more than the former materials and ranges between 2.8 to 3.8 (Gorai (2003)) which adds a natural benefit to the Copper slag. Granulated Copper slag has specific gravity lesser than that of the air-cooled copper slag. CRRI suggests Copper Slag as replacement of river sand and fine aggregate in concrete. Addition of 30% to 60% of copper slag as per Chandrasekhar et al (2015) would improve the characteristics of soil. Copper slag's grain size distribution curve is similar to that of medium sand Chandrasekhar et al (2015). Suresh (2018) have worked on a comparison on steel slag and copper slag. Works of Ravi (2016) and Qureshi (2015) indicates that copper slag content varying in between 30% to 40% is ideal and increases maximum dry density. And also decreases the plasticity.

Although there is significant work in using copper slag as additive for black cotton soil. The research work is not much focused on seepage characteristics. Enhancement of seepage of black cotton soil is vital because constant retention of water makes the case worse for swelling. With proper drainage the problems with black cotton soils can be trimmed down. The characteristics of copper slag matches with that of medium sand and enhances the permeability of black cotton soil. The current study emphasizes the variation of properties of black cotton soil with the changes in percentage of copper slag added. Permeability stands as one of the index parameters of Seepage characteristics and Cohesion, Angle of internal friction and CBR are measure of strength attributes.

2 Materials

Expansive clay soils are extensively found in the Andhra Pradesh and Telangana States of India. Expansive clay used in the present study was collected from the Gundala Mandalam in the Telangana state of India. Initially, the basic tests were conducted on a clay sample, and the basic properties of clay are presented in Table 2. The clay sample plasticity index is 40%, and its free swell index (FSI) value is 220%. The percentage of fine sand fraction present in the soil was 63.

Table 1. IS Code for Tests Conducted.

Name of the Test	IS Code of Practice
Grain Size Analysis	IS: 2720 (Part-IV): 1985
Liquid Limit and Plastic Limit	IS: 2720 (Part-V): 1985
Compaction	IS: 2720 (Part-VIII): 1980
California Bearing Ratio	IS: 2720 (Part-XVI): 1987
Coefficient of Permeability	IS: 2720 (Part-XVII): 1986
Direct shear test	IS 2720(Part -XIII):1986

Table 2. Properties of Soil

Soil Properties	Values
Grain size analysis	
Gravel (%)	4
Sand (%)	33
Silt and Clay (%)	63
Consistency Limits	
Liquid Limit (%)	75
Plastic Limit (%)	35
Plasticity Index	40
IS Classification	CH
Maximum Dry Density (kN/m^3)	14
Optimum Moisture Content (%)	18
Coefficient of Permeability, k (cm/sec)	0.53×10^{-7}
California Bearing Ratio (%)	0.71

Copper slag was collected from Sterilite Industries, Tuticorin, Tamil Nadu, India. The physical and chemical properties are presented in Tables 3 and 4 respectively. Copper slag has a 99% fine sand fraction. The specific gravity of copper slag is 3.6, and its hardness found on Mohs scale is in the range of 6.5 to 7. The maximum dry unit weight of copper slag is 23.5kN/m^3. The iron oxide and silica mineral compositions are predominant in the copper slag.

Table 3. Properties of Copper slag

Property	Value
Hardness, Moh's Scale	6.5 – 7.0
Specific Gravity	3.6
Plasticity Index	Non-Plastic
Swelling Index	Non-Swelling
Granule Shape	Angular, Sharp edges
Grain Size Analysis	
Gravel/Size (%)	1
Sand/Size (%)	98.9
Silt & Clay/Sizes (%)	0.05
MDD (kN/m^3)	23.5
OMC (%)	6
Direct Shear test	
Cohesion (kN/m^2)	0
Angle of internal friction (degree)	40
Permeability(cm/sec)	15.43 x 10^{-3}
CBR (%)	3.5

Table 3. Chemical composition of copper slag

Property	(% wt)
Iron Oxide, Fe_2O_3	55 - 60
Silica, SiO_2	28 - 30
Aluminum Oxide, Al_2O_3	1 - 3
Calcium Oxide, CaO	3 - 5
Magnesium Oxide, MgO	1.0 - 1.5

3 Methodology

Permeability, CBR and direct shear tests were performed on the black cotton soil (BCS) by mixing it with 20%, 30%, 40% and 50% of copper slag as CBR test and direct shear test contribute in measuring strength whereas permeability tests contribute towards seepage characteristics. For each percentage of copper slag, the tests were repeated thrice. The values of angle of internal friction (ø) and unit cohesion (c) are determined from the direct shear test. Direct shear tests were carried out on samples of size 60mm x 60mm x 20mm. Copper slag possess high angle of angle of internal friction which varies by the adding it to black cotton soil as shown in Fig 1. Coefficient of permeability is index for measuring seepage characteristics. Constant head permeability test was conducted on sample prepared as per MDD and OMC of the soil as mentioned in Table 1. With the addition and increasing the percentage of copper slag in the soil the mixture was no longer having a pure cohesive nature as the copper slag has the particle size same as that of sand and the results are shown in Fig 2. CBR test was conducted on un-soaked soil samples which are mixed with varying quantities of copper slag as per IS: 2720 (Part 16): 2002 and the observed results are shown in Fig 3.

4 Results and discussions

It is evident from the graph in Fig 1 that there is a constant decrease in cohesion and increase in angle of internal friction on a steady rate which justifies the overall fact of increase in strength with increase in percentage of copper slag. And it can be seen that at 30% of copper slag the rate of decrease in cohesion and rate of increase in angle of internal friction is 22.67% and 30.53%, highest of all variations which makes 30% as ideal composition of copper slag when admixed with soil.

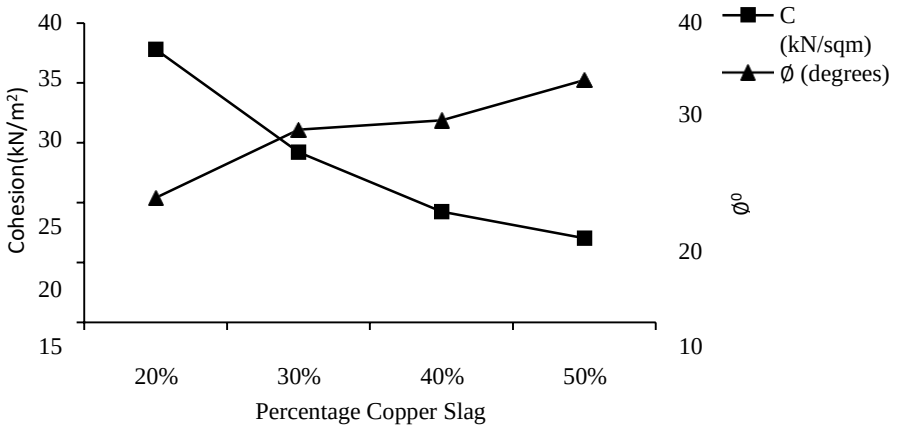

Fig. 1. Variation of Shear strength parameters i.e., cohesion and angle of internal friction with percentage of Copper Slag

From Fig 2 and Table 4, the variation of coefficient of permeability can be seen with varying copper slag content. The increase in permeability owes to the fact that the rising quantity of copper slag increases the percentage of particles in the range of sand. It is also clear that there is an increase in permeability but the greater variation is observed only at 50% of copper slag content. If design requirements aim towards higher seepage, then adding copper slag content close to 50% would serve the purpose but more than that would become soil replacement.

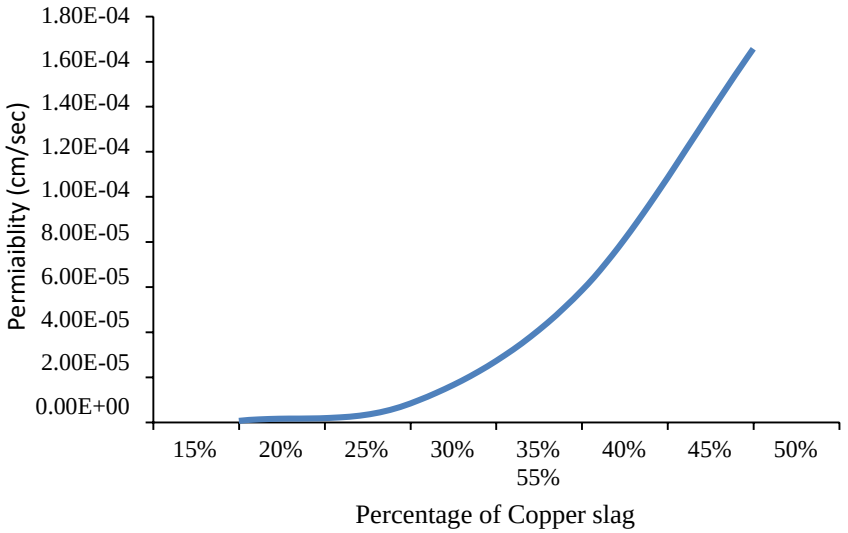

Fig 2. Variation of Coefficient of permeability with varying percentage of Copper Slag

Table 4. Variation of permeability with composition of Copper Slag (CS)

Composition	Permeability
BCS + 20% CS	6.90E-07
BCS + 30% CS	8.36E-06
BCS + 40% CS	5.85E-05
BCS + 50% CS	1.66E-04

The CBR value also kept subsequently increasing with the variation of copper slag content when compared to the bare black cotton soil the CBR at 50% got almost increased by four times. The variation of 25% in CBR is observed in between 30% and 40% which is maximum and satisfies the research of Ravi (2016) and Qureshi (2015) whose work indicates that adding 30% to 40% of copper slag is ideal.

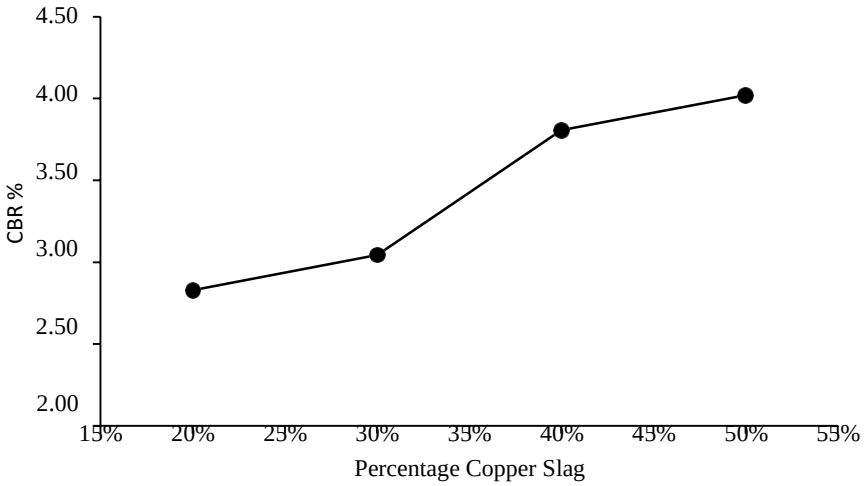

Fig 3. Variation of CBR with varying percentage of Copper Slag

4 Conclusions

The potency of copper slag in enhancing the properties of expansive soil like black cotton soil is experimented in this current work focusing on the seepage properties. Soil classification tests and compaction test are performed to understand the basic nature of the soil. Physical and chemical properties of copper slag are found out. For the salient part permeability test, CBR test and direct shear test were performed on soil samples by varying the percentages of copper slag of 20%, 30%, 40% and 50%. We can deduce from the results that

- The rate of variation of both the shear strength parameters is high and converge at 30% of copper slag mixed with black cotton soil which satisfies literature recommendations.
- The value of coefficient of permeability is constantly increasing with percentage of copper slag and at 50% of copper slag the value of permeability matches with that of silty sand. In order to optimize the process of adding admixture maintaining the permeability requirement and strength aspect a parallel additive which would promote the permeability can be added as some percentage of copper slag.
- At 50% copper slag content CBR value got quadrupled. But the rate of increase was highest in between 30% and 40%.

In the view of all the properties adding copper slag content of 30% or in between 30% to 40% would be exemplary.

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