"Analogy of Blended Copper Slag and Lime as Sub-grade Materials in Flexible Pavement Layers – A Sustainable Construction"

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Abstract

Expansive Soils have high swelling and shrinkage properties which pose a significant challenge for construction of sub grade for pavements on them. Such soils have very low CBR and low shear strength that can be improved by stabilization using suitable additives. In the present study, highly compressible clay soil with a liquid limit of 75% was procured from Hanchinal village, Bijapur district, Karnataka state and tested for its basic properties. The soil was mixed with Copper Slag and Lime to improve its Engineering properties. Initially soil was mixed with different proportions of copper slag varying from 10 % to 40% by dry weight and tested for strength and plasticity. Further, Lime was added to soil with varying proportions from 3%, to 9% by the dry weight of the soil, and experiments were conducted after 7 days to 14 days of curing. Results indicated additive copper slag and lime were together blending had led to the optimum values at 30% and 5%. The micro structural analysis of such were studied using SEM. Results indicated that clay soil mixed with 5% lime and 30% copper slag exhibited a CBR of 15%, maximum dry density of 18kN/m^3, and optimum moisture content of 18%.

Key Words:– Clay Soil, Copper Slag, Lime, CBR, SEM, UCS

1. Introduction

Roads constructed on poor, weak clayey subgrade are liable for distress resulting in early failure of the pavement. Clayey soil subgrade has undesirable properties such as high swell and shrinkage characteristics along with a high susceptibility to moisture. Hence such soils need to be stabilizedusing different methods [19] to improve their engineering properties for their enhanced performance utilizing locally available wastes [11]with clayey soil can be highly beneficial to meet this challenge.

[1]Janani, Vet.al studied the strength properties of soils treated with varying percentages of calcenied clay for different curing periods. The test results indicate that the maximum strength was attained for 8% admixture-treated soil. Salih and Abdulla, [2] stabilized Low plasticity clay soil with different percentages of crushed limestone and found essential improvement in the geotechnical properties with the addition of 20% crushed limestone. [3]Mohammad Hamzaet.al Conducted an experimental study on the effect of the addition of polypropylene fiber on expansive clays, on the engineering properties such as compaction characteristics, UCS, Elastic modulus, CBR, and Swelling consolidation parameters. Results showed improvement in the strength parameters of treated soils with optimal fiber content at 0.4% by weight of soil. [4]Ramesh, H. Nstudied the suitability of Bagasse ash and Lime for Expansive soil treatment and concluded that 15% Bagash was optimum, additional 4 % Lime was added which showed the best results. Microstructure studies confirmed the presence of cementitious compounds with the addition of lime after curing. [5]Venugopal,

Get.al investigated the effect of chemical RBI on the strength characteristics of expansive soil. Tests on samples with various percentages of RBI Grade 81 showed that RBI Grade 81 is effective in improving the engineering properties of expansive soil. [6]Damtew Tsige Melese Conducted this study to evaluate the improvement in properties of expansive soil modified with scoria. laboratory tests included the Atterberg limit, UCS, consolidation test, California Bearing Ratio, and compaction characteristics, CBR value, and consolidation increased after adding up to 20% of scoria, which was the optimum percentage required for improvement of the soil. [7]Chetan, B. Aattempted to study the effect of weather changes on UCS of Black cotton soil when Portland cement and Fly ash were added to the soil in different combinations for curing periods. The UCS values increased at higher cement and fly ash contents and with the curing period, whereas a decrease in UCS values was observed for saturated samples.

[8]Vasiya presented their experimental work on black cotton soil improved with various proportions of Terrazyme and evaluated their engineering properties. The optimum dosage of Terrazyme was found to be 2% by weight of dry soil showing a reduction in liquid limit, plasticity index, free swell index, optimum moisture content, and compression index.

[9]K. Singh Randhawa et. alaimed to determine the optimum content of lime added to Indian black cotton soil to improve the soil's unconfined compressive strength (UCS). It was found that the optimum value of lime content required to strengthen the weak soil was 9%.

[10]Sureka Naageshet.al investigated to bring out the effect of different methods of compaction on the UCS of Lime treated soils and untreated soils. Laboratory investigation included pH, Atterberg limits, citation exchange capacity (CEC), compaction, UCS, CBR, Scanning Electron Micrographs (SEM), and EDAX before and after lime treatment. The results indicate that the dry unit weight and UCS of roller-compacted lime-treated soil are lower than that of dynamic compacted soil. [11]Niyomukiza et. al, identified that the usual stabilizers like cement, lime, and bitumen posed environmental challenges. This study provided a review of the use of waste materials, focusing on their efficacy, the optimum percentage, and research gaps. Wastes considered in this study include waste tires, sawdust, sawdust ash, and fly ash. [12]H. N. Ramesh et.al investigated the soil stabilized with waste products; such as rice husk ash (RHA) and carbide lime (CL) that showed excellent pozzolanic properties, which were used as additives to stabilize black cotton soil. The optimum dosage of RHA and CL was found to be 20% and 8%, respectively. [13]Laura Morettiet.al investigated the results of X-ray diffraction (XRD) tests and scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDS) tests on natural and lime-treated clay. The obtained results show that 3% of CaO is the percentage of quicklime able to modify the material (initial consumption of lime (ICL)) and 5% of CaO is the percentage able to stabilize it (lime stabilization optimum (LSO)). Also, the EDS analyses validated the XRD results in terms of the chemical composition of the examined soil. [14]M A Ashraf et.al, used Lime-powder in variable percentages as a stabilizer for the soil samples. The compressive strengths of lime-stabilized soil were evaluated for different curing periods and found that strength increased with the increase in the curing period. At 8% lime content, maximum compressive strength was found in paddy land soil while at 6% lime content

maximum compressive strength was found in hilly soil. [15]Shubham Raj et.al, investigated copper slag and fly ash mixed with cement as a stabilizer for their proper use in road construction. Different trial mixes of copper slag and fly ash were tested for obtaining the optimum mix to achieve maximum dry density. For specimens for different curing periods. Lab tests concluded that copper slag and fly ash when mixed in optimum proportion and stabilized with 6 and 9 percent cement can be effectively used as granular material in sub-base and base layers of road pavement.

[16]Kavisri, Pet.al evaluated the use of industrial by-product copper slag and Ground Granulated Blast Furnace Slag (GGBS) as a stabilizing agent in the expansive soil for which different percentages of the copper slag and GGBS were used for testing the engineering properties of soil. The result showed that 70% clay soil and 30% copper slag and GGBS is the stabilization ratio that met the sub-grade requirements. [17]Bambhaniya Mehul Ashokbhai et.al, discussed the physical and geotechnical properties of copper slag. Copper slag was mixed with local soil in different proportions and tested for improvements in the soil. [18]Suresh, Ket.al aimed at determining the behavior of black cotton soil reinforced with steel slag and copper slag randomly. The soil samples were prepared at different percentages of steel slag and keeping 20% copper slag constant. CBR test for 4 day soaking period for both treated and untreated soil samples was determined. [19]Habiba Afrin reviewed the physical and chemical properties of soil in different types of stabilization methods such as mechanical and chemical stabilization. [20]Rajendra Kumar stabilized the expansive soil with varying percentages of copper slag. Secondly, fly ash was selected as a stabilizing agent to stabilize the expansive soil at varying percentages and regression analysis was used to find the optimum percentages.

[21]Vishwas studied the effect of chemically treated coir fibers on the shear strength, bearing ratio, and settlement behavior of clay. The clay in the present study was reinforced with untreated, sodium hydroxide-treated, and potassium permanganate-treated coir fibers. The shear strength behavior of unreinforced as well as reinforced clay is examined by conducting a series of unconfined compression strength, and direct shear tests. The results of UCS tests on saturated and unsaturated clay indicated that the deviator stress at the failure of clay and clay with untreated coir fibers can be increased by treatment with potassium permanganate and sodium hydroxide.

[22]Jaber Shahiriet.al conducted; UCS tests have been conducted to investigate the impacts of copper slag on the mechanical characteristics of stabilized cement and un-stabilized soil. The test results indicated that the inclusion of copper slag and cement had a significant effect on the UCS. An artificial neural network (ANN) model was developed using eight input parameters. The results proved that the proposed model can be efficiently applied to predict the elastic modulus of stabilized soils. [23]Lavanya Cstudied the Shear strength of cement/lime-stabilized copper slag, the laboratory test results related to the shear strength of the copper slag mixed with cement and lime were done separately. The percentage of cement and lime mixed with the copper slag was 4% & 6%. That gave the best results. [24]Parvathi.S and Anitha Nelson investigated the improvement in the properties of clayey

soils stabilized with varying percentages of copper slag and lime. The laboratory tests showed improvement by use of an optimum 6% of CS along with 6% Lime.

[25]Rajesh Prasad Shukla and Niraj Singh Parihar presented the results of laboratory tests conducted on black cotton soil mixed with micro-fine slag with different proportions. The changes in the physical and strength parameters of the soil were evaluated. The optimum amount of micro-fine slag used in the soil was 6-7% for the best test results

[26]Ebenezer Akin Oluwasola et.al evaluated the suitability of using electric arc furnace (EAF) steel slag and copper mine tailings (CMT) as substitutions for conventional aggregates used in pavements for roads and highways. Four mix designs containing slags at different proportions were investigated. The findings showed that substituting natural granite aggregates with these slags improved the performance properties of asphalt mixtures. The mixture containing 80% EAF steel slag and 20% CMT was found to be optimum.[27]Mohammed A. Qureshi et.al, attempted to study the copper slag – Black cotton soil mix for use in sub-grade improvement in pavements. The geotechnical properties of different mixes such as un-soaked CBR and Direct shear strength were determined. The study concluded that the 40% Soil+60% copper slag mix was found to be optimum for improvement in pavements.

[28]Y. Keerthiet.al discussed economical and efficient means of using cement kiln dust (CKD) for various applications. It has been established that the chemical compounds found in soil; quartz, feldspar, dolomite, calcite, montmorillonite, kaolinite, etc. react with the chemical constituents found in different identified chemical stabilizers. Stabilization of clayey soil by using cement kiln waste at 50% proportional mix was optimum.

[29]Neeraj Kumar Sharma discussed the Stabilization of cohesive soil by the addition of both fly ash and lime. Analysis using X-ray diffraction, SEM, coupled with energy dispersive spectroscopy, thermal gravimetric analysis, zeta potential, and pH value test was carried out to evaluate the stabilization mechanism. The micro-level analysis confirmed the breaking of the montmorillonite structure present in the untreated clay after stabilization. [30]George Wang and Russell Thompson.: showcased the use of ferrous and nonferrous slags in civil and highway construction

The Literature reviews highlighted the effect of using lime which is most commonly used for stabilization of expansive soil [2],[9][14],agricultural wastes [1],[4],chemical additives[3],[7],[21] and industrial wastes [7],[15],[16],[18],[20],[26],[28],[29],[31]for the improvement of engineering properties of the expansive soil [6]and investigated at the micro structural level[10],[13],[29],for changes after the stabilization and its use In road construction [30]

The present study focused on finding the optimum mix of copper slag and Lime which is very effective that can be used for the improvements of Black cotton soil to meet the requirements of Subgrade for flexible pavements.

2. Materials

In the present study, highly compressible clay soil, copper slag, and Lime are used.

Copper slag: Copper slag was procured from Sterlite Industries, Tuticorin, Tamil Nadu Copper slag is a non-plastic, black-colored material with sand size particles having more ferrous oxide and silica content. The Uniformity coefficient Cu was observed as 2.0 and the coefficient of curvature Cc was 0.9 with a specific gravity of 3.80. The Chemical Composition of Copper slag is mentioned in Table1 below.

Table 1 Chemical properties of copper slag

Compounds	%
Silica SiO_2	38.86
Alumina(Al_2O_3)	6.26
Ferric Oxide(Fe_2O_3)	7.35
Titanium Oxide(TiO_2)	0.13
Sodium Oxide(Na_2O)	1.42
Potash(K_2O)	1.15
Chloride(Cl)	0.06
Copper(Cu)	0.9
Total Iron (Fe)	39.9
Ferrous Oxide (FeO)	43.68

Expansive clay soil

An Expansive clay Soil was procured from Hanchinal, located 7.3 km from Bijapur, Karnataka, at a depth of 1.5 m below the ground surface. The soil was dried, pulverized, and stored in air-tight containers. The soil exhibits a liquid limit of 75%, a free swell index of 80%, with 45% clay-size particles and a very low CBR of 1%. The maximum dry density and optimum moisture content were found to be 16.6 kN/m^3 and 24% respectively.

Lime

Hydrated Lime in the form of Ca $(OH)_2$ which was locally available in powder form was used in the present study.

3. Methodology

The untreated clay soil was tested for index properties and a few engineering properties such as compaction, compressive strength, and CBR as per ASTMD1883.

Clay Soil was mixed with copper slag in various percentages varying from 10% to 50% in increments and tests were carried out to determine its index properties and compressive strength. To ensure the non-reactivity of copper slag, the soil-slag mixes were cured for 1 day, 7 days, and 14 days before testing. The optimum percentage of copper slag was determined.

The clay soil was treated with lime alone in different percentages such as 2%, 3%, 5%, 7%, and 9%, and cured for 1 day, 7 days before testing for consistency limits. However, soil lime mixes were cured for 7 days and 14 days before testing for unconfined compressive strength Finally Clay soil was treated with an optimum 30% of copper slag and varying percentage of lime such as 2%, 3%, 5%, & 7% to evaluate the combined effect of copper slag and Lime.

The fabric of the materials and their mixes were studied by Scanning electron microscopy (SEM).

4. Results and discussions

4.1. Effect of copper slag on properties of Clay soil

Upon addition of copper slag to clay the sand-sized particles in the mix increase and there is a reduction in the amount of clay minerals due to which the activity of the mix reduces considerably clay particles adhere to the surface of copper slag in the mixes.

Table 2 Effect of copper slag on clay soil

% of copper slag	LL, %	PL,%	PI, %	MDD, kN/m^3	OMC, %
0	75.5	48.4	27.1	15.75	26.03
10	60.1	37.0	23.1	17.42	24.13
20	56.1	35.3	20.8	17.95	22.89
30	53.5	34.0	19.5	18.11	20.79
40	55.4	35.2	20.2	18.62	19.78

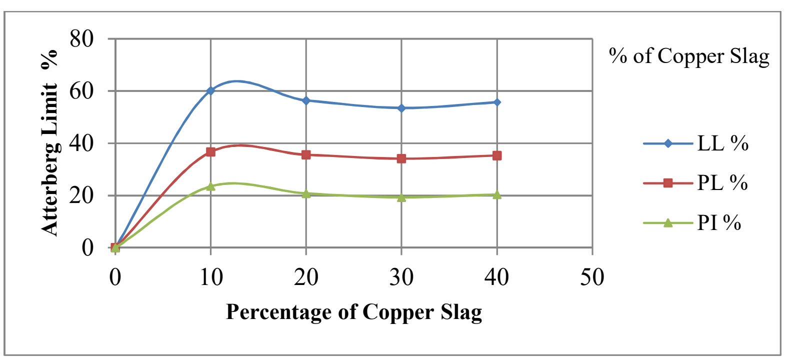

Figure 1 Variation in Atterberg limits of soil treated with copper slag

(i)Effect of copper slag on the liquid limit, Plastic limit, and plasticity index of clay soil

The liquid limit of clay soil decreases with the addition of copper slag as shown in Table 2. It can be observed that the liquid limit of clay soil decreases with an increase in copper slag content as shown in Figure 1 above.

(ii)Effect of copper slag on Compaction Properties slag on clay soil

A modified proctor test was conducted as per ASTM D4318, and ASTM D5080-20 to determine the optimum moisture content (OMC) and maximum dry density (MDD) of soil Mix.

Test results of untreated and soil treated with copper slag are shown in Table2.

Upon addition of copper slag to clay soil in increments, the MDD was observed to increase, and a reduction in OMC was observed [27]. The results are shown in Figure.2.

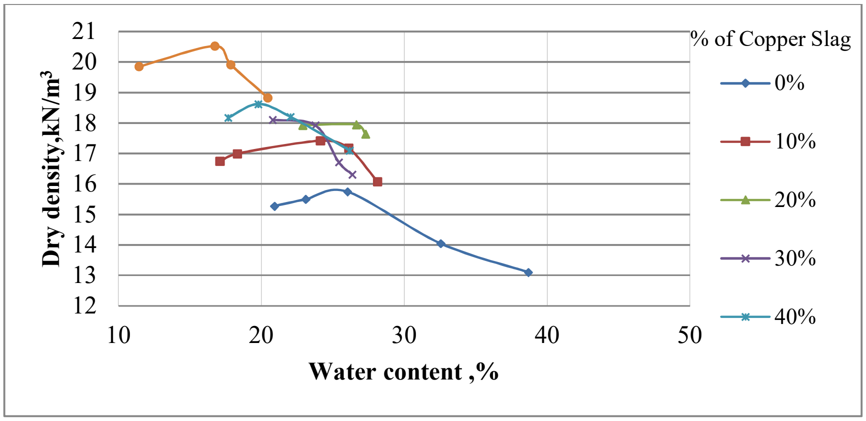

Figure 2 Compaction Properties of soil treated with different percentages of copper slag

It was seen that the MDD of clay soil 15.75 kN/m^3 increased to 18.11 kN/m^3 with the addition of 30% copper slag to the soil. While OMC 26% of clay soil decreased to 20.7% upon the addition of 30% slag content.

(iii)Effect of copper slag on Unconfined Compressive Strength (UCS) of Clay soil

UCS tests were performed on clay soil–copper slag mixes as per ASTMD 2166-00.

From Figure 3 it is observed that the UCS of clay soil slag mix increases with an increase in copper slag content, a maximum value of UCS was 266.18 kPa observed with 30% slag content. The stress-strain curve is shown in Figure 3.

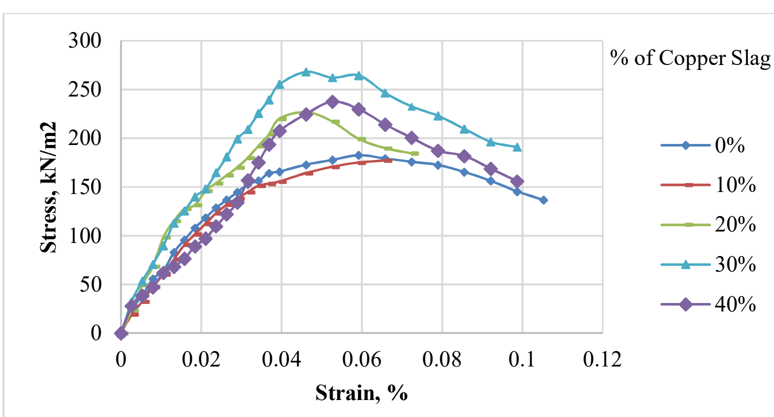

Figure 3 Stress-Strain curve for soil treated with different percentages of copper slag

(iv) Effect of Copper slag on CBR of clay soil

California bearing ratio test (CBR) was carried out as per ASTMD1883 on the clay soil samples treated with copper slag. Both soaked and un-soaked CBR tests were performed for lay soil-slag mixes and samples soaked for 4 days before testing. From Table3 it is observed that soaked CBR increases with an increase in Copper slag content[17] For 30% copper slag content, CBR was found to be 3.32%, upon increasing slag content to 40% soaked CBR increased to 4.52%.

The load versus penetration curves are mentioned in Figure 4. However, with 40% slag content, the workability of the mix was reduced, and slight segregation of copper slag was observed. [27]. this is due to the presence of an excess of copper slag particles after filling the voids in the matrix.

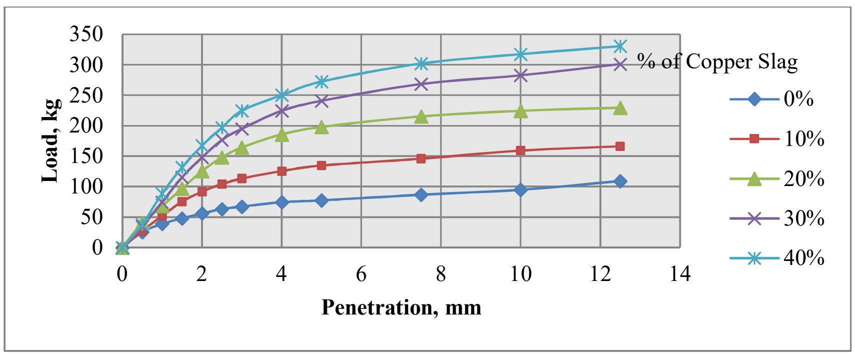

Figure 4 Load v/s penetration for Clay-Copper slag mixes

Table 3 Effect of copper slag on CBR of clay soil

Percentage of copper slag	CBR % (Un Soaked)	CBR % (Soaked)
0	4.62	1.09
10	7.6	1.47
20	10.8	2.21
30	12.89	3.32
40	14.38	4.52

4.2 Effect of Lime on Properties of Clay Soil

Hydrated Lime in the form of $Ca\ (OH)_2$ which was locally available in powder form was used for this study.

Hydrated Lime was added in various percentages 2%,3%,5%,7%,9%, and 11% to the expansive clay soil and the properties of the soil lime mix were investigated. Liquid limit, Plastic limit Tests, Modified Proctor compaction tests, and soaked and un-soaked CBR tests were conducted as per ASTM standards on soil lime mixes.

(i)Effect of Lime on Liquid Limit, Plastic Limit & Plasticity Index

The addition of lime to clay soil shows that the Liquid Limit decreased from 75.5% to 60%, and the plasticity Index reduced from 27% to 26%. The results are shown in Table 4 and Figure 5

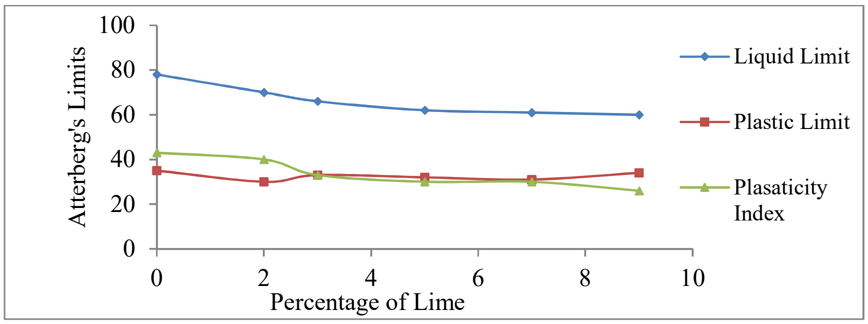

Figure 5: Effect of lime on Atterberg's limit

The decrease in the Atterberg values is due to the reduction in the thickness of clay particle layers. The cation exchange capacity of soil lime mixes also decreases which causes subsequent flocculation of particles. The clay particles get coated and bond with lime. [2],[9]

(ii)Effect of Lime on Modified Compaction Properties of clay soil

The addition of lime in varying percentages to clay soil shows a decrease in dry density from 16.07 kN/m^3 to 15.09 kN/m^3 while an increase in OMC from 20.5% to 27% was observed. The results are shown in Table 4 & Figure 6

Table 4 Effect of varying percentages of Lime on Atterberg Limits, MDD OMC, of Clay soil

Soil lime mix	Atterberg Limits (%)			Modified Compaction	
	LL	PL	PI	MDD (kN/m^3)	OMC (%)
Clay Soil +0%Lime	75.5	48.4	27.1	15.75	26.03
Clay soil + 2% Lime	70	30	40	16.07	20.5
Clay soil + 3% Lime	66	33	33	15.58	21
Clay soil + 5% Lime	62	32	30	15.58	22
Clay soil + 7% Lime	61	31	30	15.39	24.5
Clay soil + 9% Lime	60	34	26	15.09	27

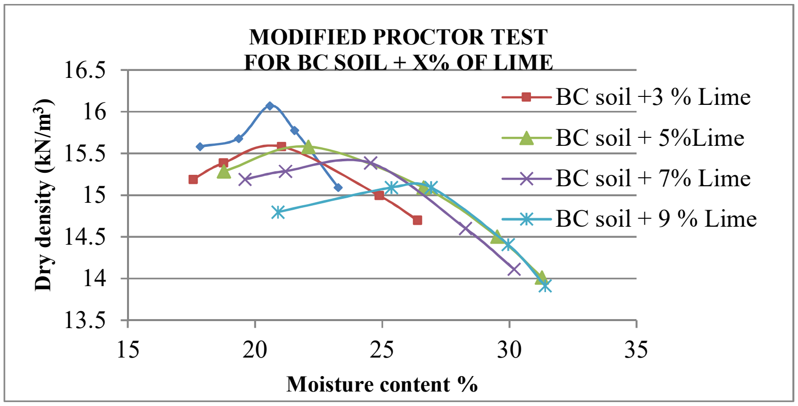

Figure 6 Effect of lime on MDD& OMC of soil

(iii)Effect of Lime on CBR of clay soil

Soaked CBR tests were conducted with 3% and 5% lime addition to the soil, results are shown in Table 5. It was observed that the addition of 3% lime exhibited a soaked CBR of 5.6%, and with 5% lime content, soaked CBR was 10.2%.

Table 5 Effect of Lime on CBR of clay soil

	CBR % (unsoaked)	CBR % (soaked)
Untreated soil	4.62	1.09
Soil + 3% Lime	43.9	5.6
Soil + 5% Lime	48.2	10.2

The addition of 3 % lime increased the soaked CBR five folds and with the addition of 5% lime to clay soil, CBR increased nine folds [9]

(iv) Effect of Lime on UCS of Clay soil

Treating soil with lime an increase in UCS was observed as shown in Table 6 [9]For example, the UCS of soil samples treated with 3% lime and cured for 7 days increased 3.4 times. Similar results were observed when samples were treated with 5% lime and cured for 7 days

Table 6 Effect of Lime on UCS of Clay Soil

SOIL MIX	UCS (0 days)	UCS kPa (7 days)	UCS kPa (14 days)
Clay soil	182	-	-
Clay soil + 3 % Lime	-	600	620
Clay soil + 5 % Lime	-	630	660

4.3 Clay Soil stabilized with the Copper Slag and Lime

(i) Effect of Lime on Atterberg Limits of soil slag mixes

The 30% copper slag was added to clay soil stabilized with different percentages of lime and index properties, and compaction properties were determined. The following Table7 shows the results. Figure 7 shows there is an increase in the Atterberg values due to the presence of copper slag particles which reduce the cation exchange capacity as the density of ion particles is reduced. The clay particles are not free for flocculation and the reaction with lime is not rapid due to the presence of Copper slag particles. Untreated Clay soil has high plastic behavior which is reduced considerably with the addition of copper slag and Lime [24]

Table 7 Atterberg Limits of Clay Soil-slag-Lime Mixes

Soil-Lime-slag mix	LL %	PL %	PI %	MDD kN/m^3	OMC (%)
Clay soil +2% Lime+30% CS	49	33	16	17.67	17.4
Clay soil +3% Lime+30% CS	51.5	34	17.5	18.03	18.0
Clay soil +5% Lime+30% CS	52	34.5	17.5	18.15	19.6
Clay soil +7% Lime+30% CS	53.5	35	18.5	18.75	12.2
Clay soil +9% Lime+30% CS	54	36	18	18	13.5

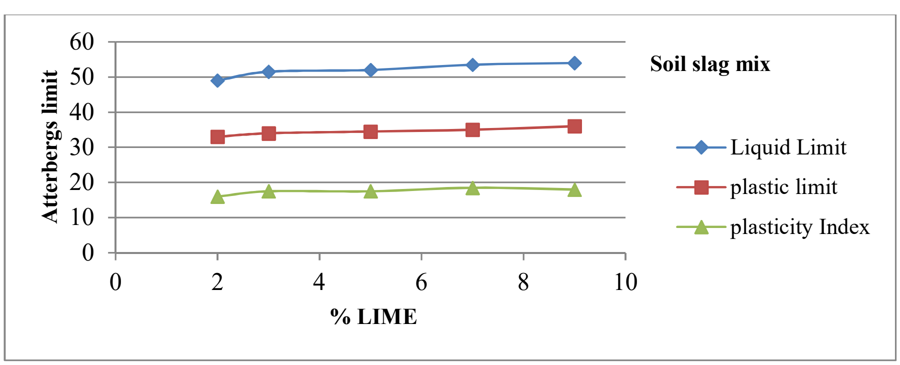

Figure 7 Variation in Atterberg's limit of clay-slag-Lime Mix

(i)Effect of Lime on Compaction Properties of soil slag mixes

The addition of a constant 30 % of copper slag along with lime in varying percentages to clay soil shows a small increase in dry density from 17.67kN/m^3 to 18 kN/m^3 while OMC decreased from 17.4 % to 13.5 as shown in Table 7. The results of a modified compaction test on soil slag lime mixes are shown in Figure 8

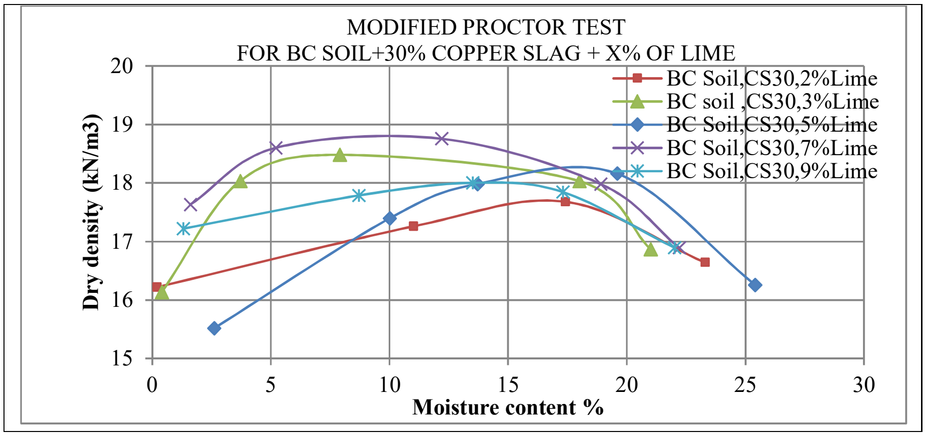

Figure 8 Effect of Lime on Compaction Properties on Soil – slag Mix

(iii)Effect of Lime on CBR of soil slag mixes

Table 8 Effect of Lime on CBR of Soil-slag Mix

	CBR % (Unsoaked)	CBR % (Soaked)
Clay soil	4.62	1.09
Clay soil +30% CS	12.89	3.32
Soil + CS(30%)+3% Lime	**58.25**	**31.92**
Soil + CS(30%)+5% Lime	53.97	26.66

Soaked CBR tests were conducted for clay soil-slag mix along with 3% and 5% lime added. From Table 8. It was observed that the addition of 3% lime to the Soil slag mix exhibited a soaked CBR of 31.92 % and when clay soil slag mix was added with 5% lime content, the soaked CBR decreased to 26.66%. Hence, 3% lime content with 30% slag is considered as optimum mix in the present study.

(iv)Effect of Lime on UCS of soil slag mixes

Upon the addition of 3% Lime to the soil-slag mix, an increase in UCS was observed. The UCS was found to be 680 kPa after 7 days of curing and increased to 710 kPa with 14 days of curing. The results are shown in Figure 9.

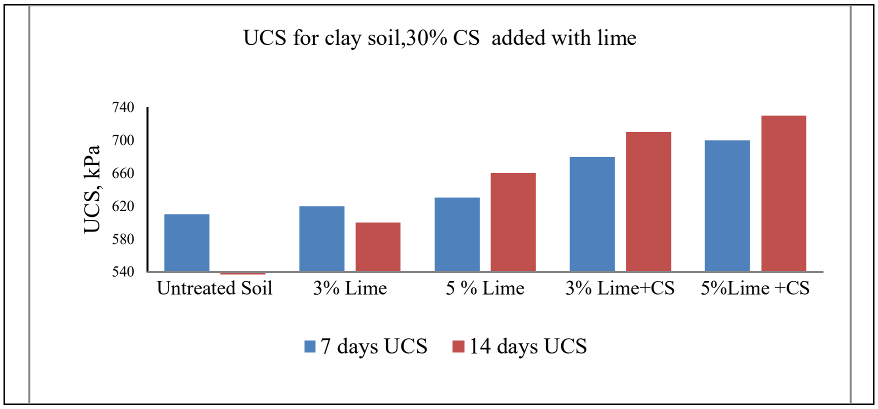

Figure 9: Effect of Lime on UCS Properties on Soil – slag Mix

5. Microstructure studies

5.1 Effect of addition of Lime, copper slag, and combination on Microstructure of clay soil

Scanning Electron Microscopy was carried out using the VEGA3 TESCAN instrument, at 50 x and 500 x resolution and a volt of 5.0 kV, to get a microscopic view of materials.

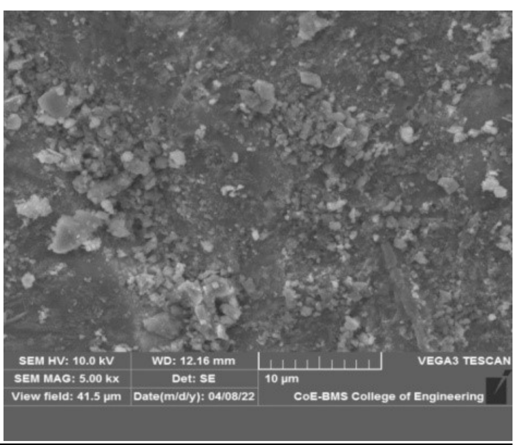

Figure 10 SEM of Copper slag

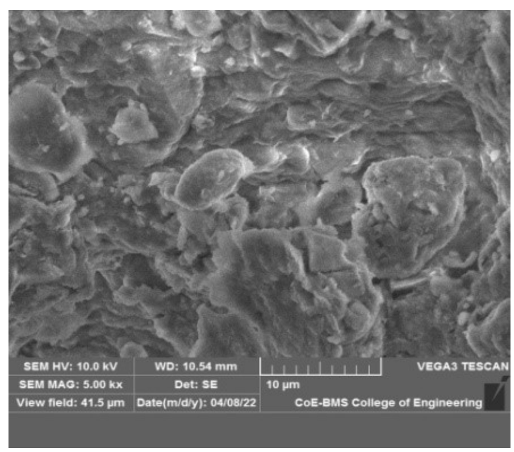

Figure 11 SEM of Clay soil

Figure 10 shows the SEM of copper slag; the slag particles are of different shapes with irregular arrangement

Figure 11 shows SEM of Clay Soil a dense clay matrix with no connectors or aggregations.

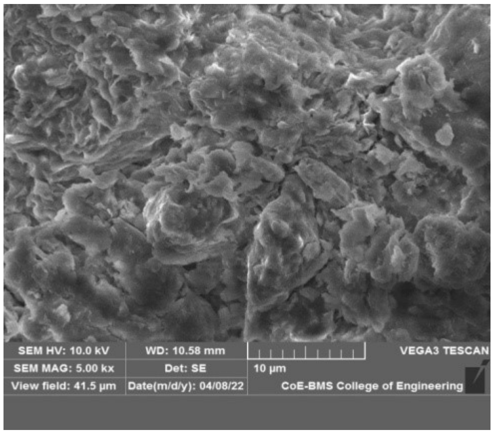

Figure 12 SEM of clay soil and 30% copper slag mix

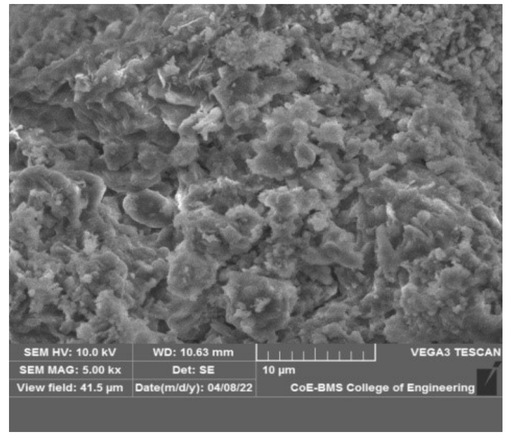

Figure 13 SEM of Clay soil and Lime 3%

Figure 12 shows the SEM of the Clay Soil - Copper slag Mix. The particles are larger and the number of voids in the clay soil treated with copper slag has reduced when compared to untreated Clay soil. The reduction in the number of voids is mainly due to the filling effect of copper slag.

Figure 13shows the SEM of Clay Soil and 3 % Lime Mix, a flocculated structure upon lime treatment with the formation of small clusters due to pozzolanic reactions between clay and Lime [13]during the initial stages of curing.

Figure 14 shows the Micrographs of that Clay soil-Copper slag- Lime mix, which confirms the flocculated structure with the formation of denser clusters indicating the presence of cementitious material for the treated soil sample[29]. Also seen are extensive gel structures due to a reaction between lime and clay soil.

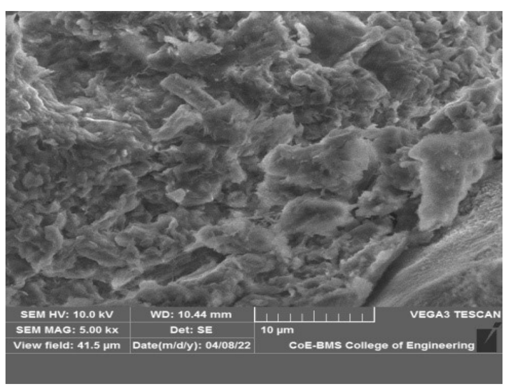

Figure 14 SEM of Clay soil, Copper Slag (30%), and Lime (3%)

Conclusions

Based on the experiments carried out in the present study following conclusions are as follows.

Clay soil exhibited a liquid limit of 75% with a plasticity index of 27% with a very low CBR of 1% and was found unsuitable as a subgrade material for flexible pavements. The CBR Strength of BC soil sub grade can be improved marginally when 30% copper slag is added, since copper slag is an inert material. Addition of 5% lime alone to BC soil improved the CBR of the soil lime mix to 5%, which is a minimum required value for rural roads as per

IRC: SP: 72-2015 However, 5% lime stabilized BC soil failed after 5 cycles (Which is less than 12 cycles) in a durability test, indicating lime alone does not satisfy the long term performance criteria of BC soil subgrade. It is observed that the addition of copper slag alone to clay soil will not meet the desired strength requirement. Hence lime is to be added.

Micro structural changes in the fabric of soil upon lime treatment show the presence of crystalline cementitious products which leads to high CBR strength upon the addition of copper slag and lime to clay soil. High strength is also attributed due to the cation ion exchange process upon the addition of lime and also due to the high specific gravity of copper slag.

From futuristic point of view, wherein a village road may be upgraded to other district roads(ODR) or Major district roads (MDR), a sub grade strength of 8% CBR is required as per IRC IRC:37 – 2018 Page | 132 In the present study, CBR of 26% was obtained when BC soil was treated with both lime and copper slag. Hence, a combination of BC soil (65%), lime (5%) and Copper slag (30%) is recommended as subgrade layer from testing and performance consideration. Steel slag was found to be highly suitable as a sub base as Grade -1 material and is recommended for roads with heavy vehicle movement such as in an industrial area. A composite layer consisting of sub grade stabilized with both Lime and copper slag and with a sub- base of steel slag is recommended as there is a reduction in pavement thickness and has good strength and durability. The analysis promised the feasibility of using industrial waste materials copper slag and steel slag in road construction. The report provides comprehensive findings and a solid foundation for using industrial waste materials extensively in road construction, thereby improving poor subgrade soil properties, optimizing pavement design and promoting Sustainable construction.

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