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Enhancing the Clay Soil Characteristics using Copper Slag Stabilization

, E. Ravi [1] R. Udhayasakthi [2]and T. Senthil Vadivel [3]

[1] Professor and Head, Department of Civil Engineering, Velalar College of Engineering and Technology, Erode – 638 012, Tamilnadu, India. Email: soilravi@gmail.com

[2]Assistant Professor, Department of Civil Engineering, RVS Technical Campus, Coimbatore – 641 402. Taminadu, India Email: udhayasakthir@gmail.com

[3] Professor and Head, Department of Civil Engineering, RVS Technical Campus, Coimbatore – 641 402. Taminadu, India Email: tsnsenthu@rediffmail.com

Abstract

This paper investigates the feasibility of utilizing the industrial by-product copper slag as a stabilizer in the expansion soil where swelling characteristics are higher and causes severe damage to the structure and road pavement. The study has been extended to identify the adequate percentage of copper slag additive in the strength enhancement of clay soil. Three different fractions were experimented in the current process of stabilization viz. 10%, 20% and 30% of copper slag and accordingly the results of Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and California Bearing Ratio (CBR) are compared with the ASTM and Indian standards for the design requirements of sub-grade for the flexible pavement. The results show that the combination of 70% clay soil and 30% copper slag is the compatible stabilization ratio which increases all the desirable characteristics of sub-grade requirements.

Keywords: Copper Slag, Maximum Dry Density, Optimum Moisture Content, California Bearing Ratio, Sub-grade and Flexible Pavement.

1.0 Introduction

The economic growth of any country is depended up on the infrastructural development. In every five year plan, the lion share of investment takes place for the infrastructures specifically highways and express ways. India has an extensive road network of 3.3 million kms which is the second largest in the world. The eleventh five year plan also invested more than 3.5 lakh crores in the road sector. Hence engineers are taking strenuous effort to design the quality road pavements and it depended on the strength of the sub-grade. Normally flexible pavement will be the apt choice for the construction of road. The natural soil will be the sub-grade material always, but the index properties and strength of the soil is not adequate. Then the uniformity of the sub-grade will be achieved by stabilization. The admixture such as fly ash, rice husk ash, pond ash, copper slag and some other industrial wastes are tried as a stabilizer to achieve stability and incompressibility.

Among the sub-grade soil clay is the weakest and formed in the presence of water which has to be given more concentration during road construction. Clay minerals include kaolin, smectite, illite and chlorite have volumetric change in freezing and thawing condition. This swelling characterization cause harmful effect in the structures (Wayne, 1984; Komine and Ogata 1996). The research studies have been extended to reduce the above effect by adding admixture as a stabilizer. Many mineral wastes and industrial wastes have been tried as admixtures are discussed below. The percentage of increment in the fly ash content in the soil and the increment of curing time reduces the swelling property and plasticity Cokca (2001). The research of Al-Rawas (2002) identified the effect of copper slag and the blast furnace slag in the swelling properties of clay soil resulted in the reduction of swell pressure and its percentage of swelling after the soil getting treated with slag mentioned early. Kumar and Sharma (2004) experimented with fly ash treated soil and obtained reduction in plasticity, swelling behaviour, permeability and found increase in the shear strength. The effect of lime stone and the marble powder treatment in the soil have been validated by Onnur (2009) and showcased reduction around 28% in swelling characteristics for the 5% of marble powder stabilization. Seco et al. (2011) used various additives for the experiment such as lime, gypsum, rice husk ash, steel fly ash etc for the clay soil and found 2% of lime with 1% of magnesium oxide greatly reduced swelling characteristics of the clay soil. The current study is also such an effort to increase the usage of copper slag in the expansive soil to improve the soil characteristics.

2.0 Materials and Methods

The current study used clay soil as base material and copper slag as admixture to stabilize the clay soil to enhance its basic characteristics.

2.1 Clay Soil

Clay is a fine grained natural rock or soil material that combines one or more clay minerals with traces of metal oxides and organic matter. Clays are plastic due to their water content and become hard, brittle and non-plastic upon drying. Clay minerals are formed through hydrothermal activity which intended high swelling property which has to be stabilized for strength enhancement. The clay used in this study was brought from Vellode, Erode District, Tamilnadu, India. The collected clay soil was tested for various physical properties and tabulated in Table 1. The sieve analysis result (Figure 1) has indexed more than 50% of soil particles as fine graded and liquid limit was also less than 50% which confirmed the soil as clay.

Table 1. Physical Properties of Clay Soil

S.No.	Soil Properties	Results
1.	Specific Gravity	2.55
2.	Liquid Limit	44%
3.	Plastic Limit	33.3%
4.	Plasticity Index	10.7
5.	Effective Particle Size	0.2 mm
6.	Fineness Modulus	0.775

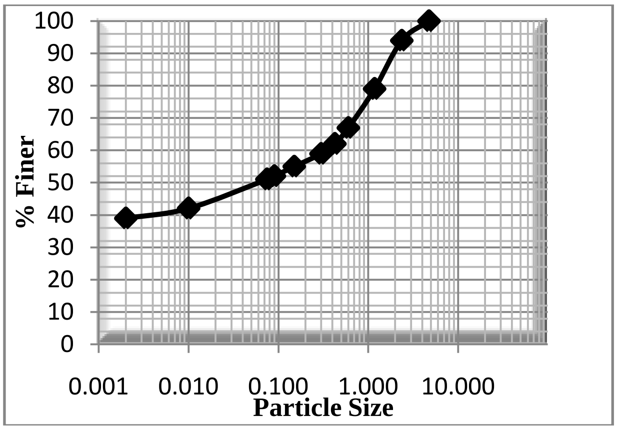

Fig 1: Grain Size Distribution

2.2 Copper Slag

Copper slag is a by-product extracted during the process of smelting. In the process of smelting, the impurities become slag and floated in the top surface of the molten metal which will be quenched in water produces angular granules and disposed as wastes. Copper slag is in black colour and granular in shape has less than 1% moisture been shown in Figure 2. The specific gravity of slag was 3.2 and the grain size mostly between 2.36 mm to 1.18 mm which very closely matches with sand property. Mostly the composition of copper slag contains oxides of copper, iron and silica.

Figure 2 Sample of Copper Slag

2.3 Soil Stabilization

Soil stabilization is the treatment for soil to enhance the physical properties. Stabilization can increase the shear strength and control the shrinkage and swelling properties of a soil which in turn improve the load bearing capacity of the sub-grade. The current study utilized copper slag as a stabilizer to treat the clay soil. The copper slag was used in three different fractions in soil such as 10%, 20% and 30% to improve the physical properties of clay soil. The above mix of treated soil samples were tested for determining water content, dry density and load bearing capacity.

3.0 Experimental Investigation

3.1 Compaction Characteristics

Compaction is the method of densification of soil intended to reduce air voids. The degree of compaction calculated based on the dry density of soil. The maximum dry density was observed at optimum water content level. The curve drawn between moisture content and dry density determines the maximum dry density and optimum water content using standard proctor compaction test. The test was carried as per ASTMD698 and AASHTO T99 and the results were tabulated in Table 2.

Table 2. Compaction Characteristics of Various Samples

S. No.	Specimen ID	Sample Specification	Dry Density (g/cc)	Optimum Moisture Content (%)
1.	C	Clay Soil	1.597	12
2.	CS10	90% Clay + 10% Copper Slag	1.604	18
3.	CS20	80% Clay + 20% Copper Slag	1.674	18
4.	CS30	70% Clay + 30% Copper Slag	1.752	14

3.2 California Bearing Ratio (CBR)

CBR is the force require per unit area to penetrate in to a soil mass with the standard circular piston at the rate of 1.25 mm/min with respect to the standard material. The test normally conducted for the undisturbed soil mass further it was compacted either static or dynamic loading. The standard loads adopted for compaction were 1370 kg and 2055 kg based on the plunger size 2.5 mm and 5.0 mm respectively. This test meant for determining sub-grade strength of roads and pavements. The obtained results are drawn as a curve and used for finding pavement layers and thickness. The tests have been carried out as per IS: 2720 (Part 16): 2002 for both soaked (4 days in water) and unsoaked samples of CBR are shown in Figure 3 and the observed results are given in Table 3.

Fig 3: Test Specimens and Setup for CBR

Table 3. CBR Values for Various Samples

S. No.	Specimen ID	Sample Specification	CBR Value Soaked	CBR Value Unsoaked
1.	C	Clay Soil	5.75	7.50
2.	CS10	90% Clay + 10% Copper Slag	12.81	22.12
3.	CS20	80% Clay + 20% Copper Slag	13.42	24.50
4.	CS30	70% Clay + 30% Copper Slag	14.00	28.00

4.0 Results and Discussion

4.1 Dry Density and OMC Relationship

The dry density is the measure of degree of compaction which indicates the compactness of the sample solid soil particles. The water content motivates the particles to become closer which increases compactness of the solid soil matrices. Hence there is an inherent relationship laid between soil densification and water. Those relationships between dry density and water content has been identified for various soil samples and shown in Figures 4 – 7. The gradual and notable increment in the maximum dry density was observed in the increment of copper slag percentage in the stabilized soil samples. The higher the replacement of copper slag confers higher dry density compared than other samples which found 8.85% increase in density than the natural clay soil. The similar tendency has been referred by the soil sample and copper slag collected and tested in Rajasthan, India by Gupta et al. (2012).

4.2 CBR Value

The CBR rating is a measure of load bearing capacity of soil used for building roads. The higher the CBR rating is the index of hardness of the surface. The current study has been established to improve the CBR value by the stabilization process using copper slag as additive and the observed results are also comprehensive enough to point out. The relationship between load and penetration of soaked and unsoaked samples was plotted and shown in Figure 8 and 9. The relevant CBR values were derived based on the corrected load and standard load. The CBR value was gradually increased with the increment of copper slag. The 30% replacement copper slag produced higher value in both soaked and unsoaked treated soil samples which proves the suitability for sub- grade of flexible pavement. Further it was very well observed that the soaking time reduces the value of CBR and increase the moisture content specifically in the top layer which was pertinent to the study of Talukdar (2014). There is an inherent relationship maintained between CBR and maximum dry density both increases together in all soil sample derived in this current study.

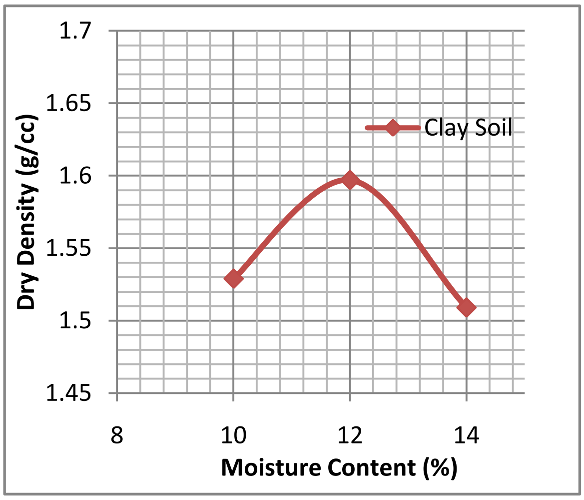

Fig 5: Dry Density Vs Moisture Content
(Clay Soil)

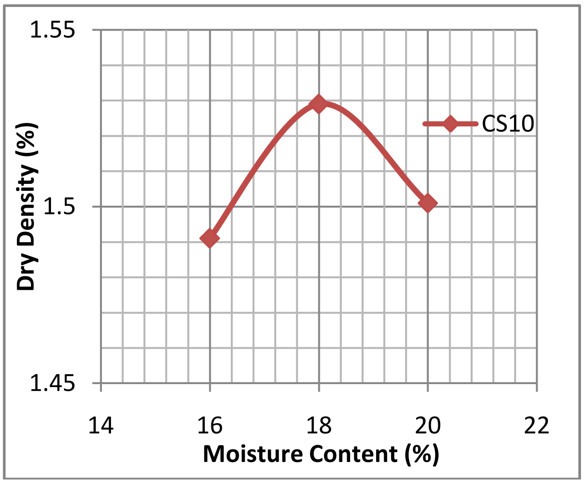

Fig 4: Dry Density Vs Moisture Content

(Copper Slag 10% + Clay 90%)

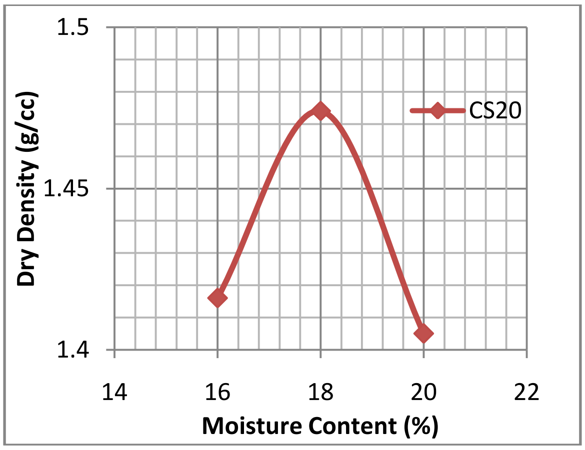

Fig 6: Dry Density Vs Moisture Content
(Copper Slag 20% + Clay 80%)

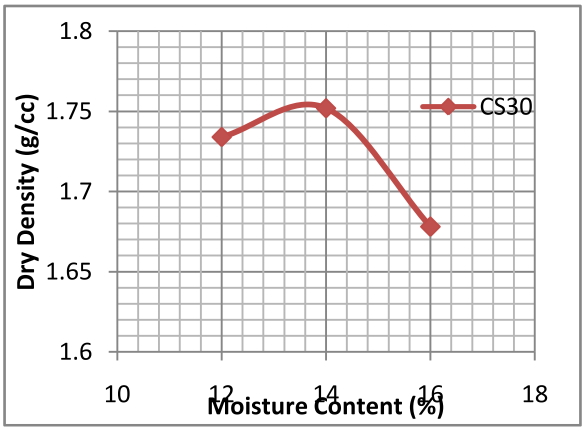

Fig 7: Dry Density Vs Moisture Content
(Copper Slag 30% + Clay 70%)

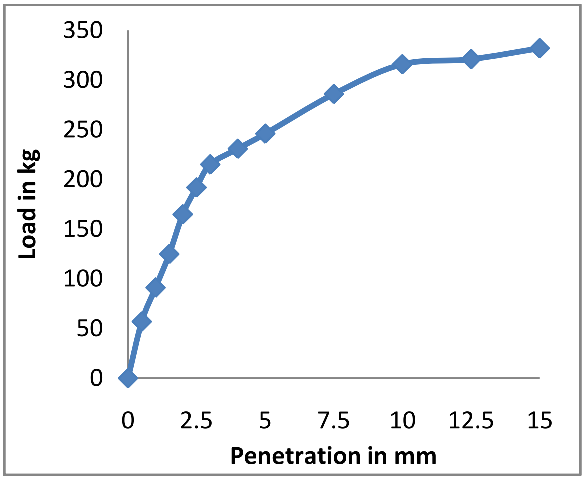

Fig 8: Load Vs Penetration Curve
(Copper Slag 30% + Clay 70%)

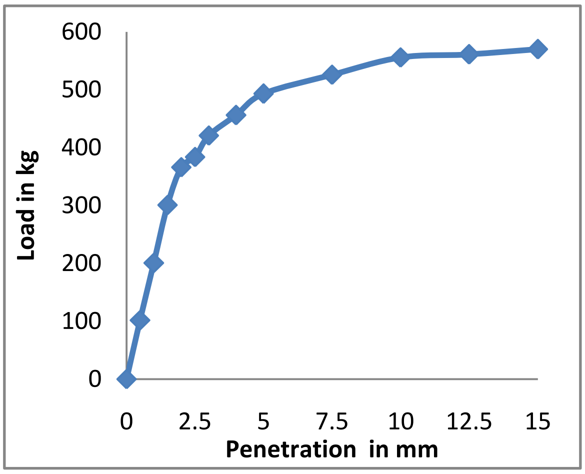

Fig 9: Load Vs Penetration Curve
(Copper Slag 30% + Clay 70%)

5.0 Conclusion

Based on the observation the following conclusion has been made.

- The increase in the percentage of copper slag will increases the maximum dry density of the stabilized clay soil which in turn will decrease the plasticity.
- The soaking time reduces the value of CBR and increase the moisture content specifically in the top layer.
- The CBR value also continuously increases accordance to the copper slag addition in stabilization process.
- Higher CBR value in the 30% addition of copper slag provides better conformity for the design of flexible pavement especially in the reduction of sub base course thickness.
- The combination of 70% clay soil and 30% copper slag is the compatible stabilization ratio which increases all the desirable characteristics of sub-grade requirements.

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About the Authors

Prof. R. Udhayasakthi is a Structural Engineer involving himself in teaching and research for more than five years. Currently he is pursuing his doctoral programme in Anna University, Chennai. His research interest includes soil behavioural analysis, soil structure interaction and ground improvement techniques.

Dr.E.Ravi is a versatile Civil Engineer with Geotechnical Engineering specialization, a total of 24 Years experience that comprise of an initial five years Civil Engineering Industry followed by Academic, Research and Management experience. He has published twenty four journals in National and International level and attended 42 conferences in India. He is leading Geotechnical Consultant in south India and resolved many soil mechanics problems.

Dr. T. Senthil Vadivel is a well known educationist in the southern part of India. He has put forth more than 16 years of service in the field of engineering education. His areas of interests are Construction Management, Innovative Construction Materials Research, Rubberized Concrete Composites, Rehabilitation of Structures, Waste Utilization and Management.