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An Experimental Study of Copper Slag Stabilized Clayey Soil

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Abstract - Construction on weak and soft soils often creates major engineering problems such as excessive settlement, low shear strength, and high compressibility. Clayey soil provides weak support for pavements and reduces their service life. These issues increase construction and maintenance costs and may even lead to early pavement failure. To overcome these challenges, different soil stabilization techniques are adopted to improve the bearing capacity and engineering properties of the soil.

This study focuses on the use of copper slag, an industrial waste material, as a stabilizing additive for clayey soil. The main objective is to determine the optimum percentage of copper slag required to enhance the strength characteristics of the soil. Copper slag was mixed with clayey soil in proportions of 10%, 20%, and 30%. Laboratory tests such as Atterberg limits, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), California Bearing Ratio (CBR), and Unconfined Compression Test (UCT) were conducted to evaluate the behaviour of the stabilized soil.

The experimental results indicate that the inclusion of copper slag significantly improves the engineering properties and subgrade strength of clayey soil. Therefore, copper slag can be effectively utilized as an economical and sustainable material for soil stabilization in pavement construction.

KEY WORDS: Copper slag, clayey soil, soil stabilization, CBR values, MDD, OMC

1. INTODUCTION

Weak clayey soil creates problems such as low strength, high compressibility, and poor load-bearing capacity, which affect the stability and life of pavements and structures. Soil stabilization is an effective method used to improve the engineering properties of such soils. Industrial waste materials are widely used for stabilization because they are economical and environmentally friendly.

Copper slag, a by-product obtained during copper extraction, contains useful properties that help improve soil strength and density. Its use also reduces environmental pollution caused by waste disposal.

In this study, copper slag is mixed with clayey soil in different percentages to determine the optimum amount required for strength improvement. Laboratory tests such as Atterberg Limits, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR) are conducted to evaluate the performance of stabilized soil.

The study shows that copper slag can be effectively used for improving the properties of clayey soil and increasing subgrade strength for pavement construction.

2. LITERATURE REVIEW

I. The strength of clayey soil typically decreases when copper slag addition reaches or exceeds 40% because the mixture moves past its optimum stabilization point, which usually occurs between 20% and 30%. At such high replacement levels, the sand like particles of copper slag begin to dominate the soil matrix leading to several mechanical and structural inefficiencies.

II. Copper slag has much lower water absorption capacity than clay. When added in high quantities (like 40%) surplus water that cannot be absorbed remains in the mixture, creating larger voids in the soil matrix. These voids prevent the particles from packing tightly, leading to a decrease in overall density and compressive strength.

III. The UCS tends to decrease at 40% because excessive slag increases particle gradation gap, reduces cohesion, and lacks sufficient binder to fill voids. Clayey soil relies on cohesion for strength. Replacing a high percentage of clay with granular, non-cohesive copper slag particles disrupts the cohesive bonds between soil particles.

IV. While copper slag can increase density, at 40% replacement the lack of sufficient fine material to fill the gaps between the particles leads to a less dense, less stable matrix, lowering the shear strength.

V. While copper slag can increase density, at 40% replacement the lack of sufficient fine material to fill the gaps between the particles leads to a less dense, less stable matrix, lowering the shear strength.

VI. The maximum strength improvement in clayey soil is usually achieved at lower percentages (e.g., 12-25%). Beyond this, the mixture becomes “over-saturated” With filler, reducing the effectiveness of the clay matrix.

3. MATERIALS USED

3.1. CLAYEY SOIL

Fig.1

Clayey soil consists primarily of clay particles, which are the smallest soil particles, typically less than 0.002 millimetres in diameter. These tiny particles have a large surface area relative to their volume, giving clayey soil its distinctive properties. The soil is highly water – retentive, as the small gaps between particles trap water molecules, making it suitable for plants that require consistent moisture. However, this can also lead to poor drainage and potential waterlogging.

3.1.1 FORMATION AND COMPOSITION

Clayey soil forms through weathering of rocks, both physical and chemical, breaking down larger minerals into fine clay particles. It often contains minerals such as kaolinite, montmorillonite and illite, which contribute to its chemical and physical behaviour.

3.1.2 AGRICULTURAL USES

Clayey soil is valuable in agriculture due to its moisture and nutrient retention, supporting crops that require steady water supply. Its dense structure also provides strong root anchorage, helping plants withstand wind and heavy rain. However, careful management is needed to prevent waterlogging and ensure proper aeration for optimal plant growth.

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3.2 COPPER SLAG

Fig.2

Copper slag is an industrial waste material produced during the extraction and refining of copper metal. During the smelting process, unwanted impurities separate from the molten metal and form slag on the surface. This slag is then cooled rapidly with water, resulting in hard and granular particles. Copper slag is generally dark black in colour, contains very little moisture, and has a rough texture. Due to its good strength and granular nature, it can be effectively used in soil stabilization, and pavement construction works.

EXPANSION OF SOIL

Clayey soil undergoes changes in volume depending on the amount of moisture present in it. When water enters the soil, the soil particles absorb moisture and expand, causing swelling. On the other hand, when the soil loses moisture during dry conditions, shrinkage occurs. This repeated swelling and shrinkage behaviour can create problems in foundations, roads, and other civil engineering structures. Highly expansive soils containing minerals such as montmorillonite show greater swelling characteristics and require stabilization to improve their performance.

4. OPTIMUM MOISTURE CONTENT IN COPPER SLAG

The optimum moisture content (OMC) for copper slag, often used in geotechnical applications as a fill or subgrade material, typically ranges from 6% to 20%, depending heavily on the gradation, purity, and compaction method. It is commonly used as a replacement for soil, showing higher density, with compaction efforts aimed at 100% standard proctor density.

The Optimum Moisture Content is increased 16.64% to 21.4%, 24.6% up to by adding 2%, 4% of Copper Slag later goes on decreases 17.5% at 6% of Copper Slag.

The following properties are observed from visual classification in dry conditions. Colour: Black Colour

Odor: Decaying vegetation Texture: Fine grained Dry

strength: Medium Plasticity: Highly plastic

5. SOAKED CBR INCREASE

Soaked CBR value at 2.5mm penetration is increased from 1.576% to 7.88% by adding 4% of Copper Slag. CBR values generally

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continue to rise as slag content increases, often peaking between 15% and 25% copper slag before the lack of cohesion in the slag starts to reduce the overall strength.

6. UNSOAKED CBR INCREASE

Unsoaked values typically show a higher magnitude of improvement. For instance, some clayey soils see a rise from around 1.8% to nearly 4% at low percentages of slag.

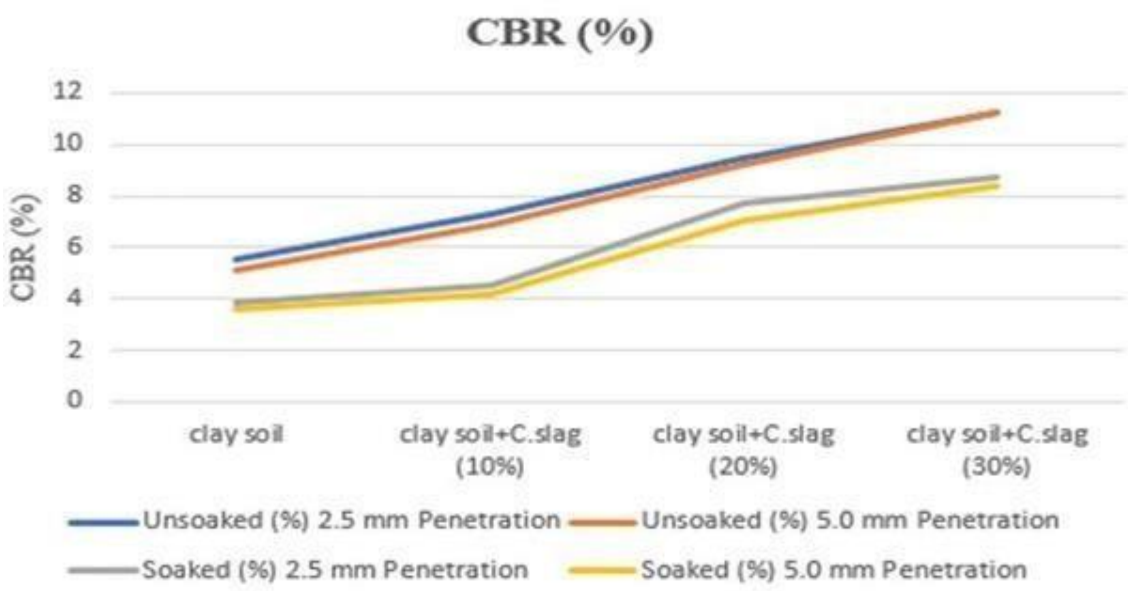

Fig.3

CONCLUSION

The experimental study carried out on clayey soil blended with copper slag focused on evaluating changes in Atterberg limits, compaction properties and strength behavior. From the observations and test results, the following conclusions were obtained:

1. Copper slag proved to be an effective stabilizing material for improving weak and problematic soils.

2. The addition of copper slag significantly enhanced the engineering characteristics of the soil, with the best overall performance observed.

3. UCS increased gradually as the copper slag content increased up to 6%, while any further increase resulted in reduction in strength.

4. The presence of copper slag contributed to better soil strength and overall stability.

5. Increasing the percentage of copper slag reduced the optimum moisture content and simultaneously increased the maximum dry density.

6. The liquid limit and plasticity index of the soil decreased with higher copper slag content, showing a reduction in plastic behavior.

7. The investigation also indicated that the most suitable proportion for copper slag was around 20% under the tested conditions.

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