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Soil Stabilization Using Copper slag and Cement as Additives- A Review

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Abstract— ***Soil stabilization is essential for improving soil engineering qualities for building. This review covers copper slag and cement soil stabilization methods. Copper slag, a byproduct of copper production, has high specific gravity, angular shape, and weather durability, making it a possible soil stabilization material. However, cement's chemical reaction with water creates strong connections, making it a popular soil stabilization binder. The review begins with soil stabilization basics and additive selection variables. It then examines copper slag and cement as soil stabilizers. Copper slag and cement's impacts on stabilized soils' compaction, strength, permeability, and durability are examined. The paper also discusses laboratory and field investigations on copper slag and cement soil stabilizers. Copper slag and cement improve soil engineering qualities, including load-bearing capacity, settling, and erosion resistance. To successfully deploy copper slag and cement stabilization methods, proper dose, environmental considerations, and long-term performance must be addressed. Different soil types, environmental conditions, and stabilized soil durability need further study. The review concludes that copper slag and cement can stabilize soil. Geotechnical engineering and construction scholars and practitioners benefit from a thorough analysis of their characteristics and soil behavior.***

Index Terms— ***California Bearing Ratio, Cement, Copper Slag, Soil Stabilization***

I. INTRODUCTION

Soil stabilization is a critical aspect of civil engineering and construction, aimed at enhancing the properties of soil to meet specific engineering requirements. It is a technique employed to improve the load-bearing capacity, reduce settlement, and mitigate undesirable soil behavior. In recent years, the utilization of industrial waste by-products as soil stabilizing agents has gained considerable attention, as it not only addresses environmental concerns but also presents a cost-effective and sustainable solution. This study explores the potential of copper slag and cement as additives in soil stabilization.

Copper slag is a by-product of the copper smelting process, and its vast quantities generated worldwide pose environmental challenges due to improper disposal. However, researchers and engineers have discovered that copper slag can be utilized as a valuable resource in soil stabilization due to its pozzolanic properties, which enhance the binding strength of the soil when combined with cement. The combination of copper slag and cement presents a unique opportunity for achieving effective soil stabilization, as both materials complement each other's strengths.

Cement, a traditional stabilizing agent, has been widely used in the construction industry. When added to soil, it reacts chemically with water to form calcium silicate hydrates, resulting in increased soil strength and durability. By incorporating copper slag, which reacts with calcium hydroxide produced during cement hydration to form additional cementitious compounds, the overall effectiveness of the stabilization process is significantly enhanced. This research aims to investigate the mechanical properties, such as compressive strength, bearing capacity, and shear strength, of soil stabilized with copper slag and cement. Additionally, the study will assess the environmental impact of using these additives in soil stabilization and evaluate the economic feasibility of this technique. The findings of this research could lead to a more sustainable approach to soil stabilization, reducing the reliance on conventional stabilizing agents and promoting the responsible utilization of industrial waste materials. In conclusion, the combination of copper slag and cement as additives for soil stabilization holds great promise for the construction industry and environmental sustainability. By harnessing the synergistic effects of these materials, engineers can improve soil properties and reduce the environmental burden associated with industrial waste disposal. The following sections will delve into the experimental methodologies, results, and conclusions derived from this investigation, shedding light on the potential benefits and practical implications of this innovative soil stabilization technique.

II. LITERATURE REVIEW

Dr. K. Suresh *et al.*[1] focused on the application of copper slag in conjunction with concrete for soil stabilization purposes. During the course of this investigation, the Compaction and California Bearing Ratio tests were conducted in accordance with the Indian Standard (IS) methodology as part of the experimental programme. An investigation has been conducted to assess the impact of copper slag and Steel slag on black cotton soil, as well as the synergistic effects resulting from the combination of copper slag and Steel slag on black cotton soil. The dry density of the soil experienced a significant increase to a maximum value of 1.69 g/cc at a copper slag content increment of 20%. This increment resulted in a corresponding increase in the rate of expansion, which reached 15.7%. The dry density exhibits incremental changes of 3.4%, 8.2%, 12.3%, and 15.7% corresponding to varying levels of copper slag additions, namely zero, 5%, 10%, 15%, and 20%.

E. Ravi *et al*. [2] Conducted an investigation to assess the viability of employing copper slag, an industrial by-product, as a stabilizing agent for expansive soil with elevated swelling properties, which can lead to significant structural and road pavement damage. The investigation has been expanded to ascertain the appropriate proportion of copper slag additive in facilitating the augmentation of strength in clay soil. In the ongoing stabilization process, three distinct fractions, namely 10%, 20%, and 30% of copper slag, were subjected to experimentation. Consequently, the outcomes pertaining to Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR) were meticulously compared with the design specifications outlined in the ASTM and Indian standards for the sub-grade of flexible pavement. Based on the findings, it has been determined that the optimal stabilization ratio for enhancing the desirable characteristics of sub-grade requirements is achieved through the amalgamation of 70% clay soil and 30% copper slag.

Shubham Raj *et al*.[3] conducted an investigation on the potential application of copper slag and fly ash blends, in conjunction with cement as a stabilizing agent, for the purpose of enhancing their suitability for road construction. Various trial mixes consisting of copper slag and fly ash were subjected to rigorous testing in order to determine the ideal combination that would yield the highest dry density. Cylindrical specimens were meticulously fabricated utilizing an optimal mixture, incorporating varying proportions of cement (3, 6, and 9 percent). These specimens were then subjected to a rigorous curing process spanning a duration of 7, 14, and 28 days within a controlled environment, specifically a desiccator. A series of tests, including the proctor test, unconfined compressive strength test, splitting tensile strength test, and soaked CBR test, were conducted. Upon conducting an in-depth analysis of the test results, it has been observed that the compressive strength of the specimens exhibited a maximum value of 10 MPa, while the tensile strength reached its peak at 1.5 MPa. These optimal strengths were observed in specimens that possessed a cement content of 9 percent and were subjected to a curing period of 28 days. The study has determined that by combining copper slag and fly ash in the most suitable ratio and stabilizing them with 6 and 9 percent cement, it is possible to efficiently utilize this mixture as a granular material for the sub base and base layer of road pavement.

Bambhaniya Mehul Ashok *et al*.[4] investigation pertaining to the quality characteristics of soil in conjunction with copper slag was conducted. The primary objective of this endeavor is to assess the utilization of copper slag in geotechnical and transportation applications. Furthermore, it aims to categorize these materials based on relevant factors such as availability, application, environmental impact, and cost. In particular, there is a strong emphasis on utilizing recycled materials to enhance the structural characteristics of less stable soils, while adhering to regulations and industry standards, as well as considering the environmental, sustainable, and practical limitations associated with such utilization. The assignment comprises multiple components. A comprehensive compositional analysis was conducted to ascertain the accessibility information, specific details, and boundary data pertaining to copper slag. Data was gathered pertaining to the permeability, affordability, and previous performance of the material in order to narrow down the list of potential materials that could be utilized to enhance problematic soils in road construction. Data was collected from extensive field evaluations and other case studies in the composition.

R.C. Gupta *et al.*[5] conducted a study to investigate the engineering characteristics of clay upon stabilization with Copper Slag. The process of industrialization greatly necessitates the elevation of a nation's economy. In all instances, it gives rise to significant ecological pollution due to the generated waste materials. In light of the gradual depletion of non-renewable raw materials in the modern era, it is imperative to undertake initiatives aimed at transforming these undesirable industrial waste products into usable raw materials. This approach serves to effectively mitigate environmental pollution. In this examination, it is evident that the combination of 50% Clay and 50% Copper slag yielded an absolute maximum dry density of 1.937 gm/cm^3. The maximum dry density exhibited an increase when the proportion of 70% Clay and 30% Copper slag was compared to the proportion of 30% Clay and 70% Copper slag, surpassing the value of 1.87 gm/cm^3. During the Tri-axial test, it was observed that the angle of shearing resistance (ϕ) exhibited a value of 48° for the composite mixture consisting of 50% Clay and 50% Copper slag. The angle of shearing resistance (ϕ) exhibits an increase from 40° when considering the combination of 80% Clay and 20% Copper slag to 40% Clay and 60% Copper slag.

P. Rajendra Kumar *et al*.[6] investigated the study of the behavior of Black Cotton Soil when combined with Copper Slag and Fly-Ash. Expansive soil, a prominent soil reservoir in India, exhibits notable volumetric expansion and contraction in response to variations in moisture content. Consequently, it has been observed to pose significant challenges from an engineering standpoint. It is imperative to ensure the proper settlement of these soils when they are employed for enhancement purposes. The primary objective of the ongoing project is to analyze the physical and geotechnical characteristics of the expansive soils found in Pendlimari, Kadapa. This analysis aims to assess the quality properties of the soil through the incorporation of Copper Slag and Fly-Ash in varying proportions, specifically at rates of 10%, 20%, 30%, 40%, and half, as well as Fly-Ash at rates of 2%, 4%, 6%, 8%, and 10%. In this manner, the soil properties pertaining to sweeping are determined. In relation to the soil composition, it is initially suspected that the incorporation of copper slag should be considered, specifically at a regular interval of 5% up to a maximum of 30%. After careful consideration, the utilization of fly-searing remains has been selected as the preferred method for stabilizing the expansive soil. The proposed approach involves adjusting the soil's moisture content to a temporary range of 2%, with the potential to reach up to 10%. In the previous proposal, an experiment involving the utilization of 30% copper slag for soil clearance is being considered, in order to counterbalance the presence of fly ash debris within a range of 2% to 10% at intermittent intervals. The comprehensive evaluation of the test results has been completed.

Vijender Kumar *et al*.[7] investigated the implementation of MC-30 bituminous cutback has been employed as a stabilizing agent in order to enhance the characteristics of a cohesionless soil that is readily accessible within the vicinity. The proportion of bituminous cutback incorporated into the sandy soil has been subjected to a range of percentages, spanning from 4% to 18%. A consistent level of compaction was applied to all of the prepared samples. The investigation focused on the analysis of the unconfined compressive strength and California Bearing Ratio (CBR) value of the soil samples. Based on the results obtained from the UCS test, it has been observed that the maximum unconfined compressive strength is achieved when the cutback content is at 12%. However, it is important to note that any further increase in the cutback content within the soil will result in a decrease in the UCS value. This decrease can be attributed to the excessive fluidity caused by the increased cutback content, which subsequently leads to a decrease in the density of the soil. An appreciable augmentation in the California Bearing Ratio (CBR) of the sand was noted upon a slight augmentation in the content of cutback bitumen (approximately 8%). The incremental rise in the cutback content, from 8% to 10%, resulted in a moderate enhancement of the California Bearing Ratio (C.B.R) value, reaching its pinnacle. However, surpassing the 10% threshold of cutback content led to a reversal of this trend.

Jaber Shahiri *et al*.[8] examined the effects of copper slag on the mechanical properties of both stabilized cement and un-stabilized soil in this research by performing unconfined compression test. Many samples were made with different cement to soil ratios (0%, 2%, 4%, and 6%) and copper slag ratios (0%, 5%, 10%, 15%, and 20%). The samples were compressed into a cylinder and cured for 28, 60, and 90 days. The unconfined compressive strength (UCS) was significantly impacted by the addition of copper slag, as determined by the results of the tests. The beneficial effects of copper slag on UCS were more noticeable for cement-stabilized specimens than for those that were not. In addition, the UCS increased by over 78% in the 2% cemented specimen, and this trend continued up to 20% copper slag. As the amount of copper slag added to the mix, the soil's optimum moisture content (OMD) dropped and its maximum dry density (MDD) rose, whereas the opposite was true when cement was added. In addition, eight input parameters, including copper slag content, cement content, water content, dry density, liquid limit, plastic limit, PH, and curing age, have been used to create an artificial neural network (ANN) model. Predictions of the elastic modulus of mixtures using an ANN network with a single hidden layer of 10 neurons yielded high accuracy and good agreement with experimental results. That the suggested model can accurately estimate the elastic modulus of stabilized soils was demonstrated by the results.

M. Kavisri *et al*. [9] evaluated the viability of ground granulated blast furnace slag (GGBS) and copper slag, both of which are industrial by-products, as a soil stabilizing agent for expansive soil. Buildings that are developed on expansive soil, which is characterized by high swelling qualities, are subject to a large amount of danger. The primary purpose of this study is to find the appropriate amount of copper slag and GGBS that can increase the strength of clayey soil. This will be accomplished by comparing the results to previous research. In order to undertake a series of tests that would evaluate the engineering properties of the soil, three unique fractions of copper slag and GGBS were used. These fractions were 10%, 20%, and 30% respectively. The objectives of these examinations were to ascertain the Maximum Dry Density (MDD), the Optimum Moisture Content (OMC), the California Bearing Ratio (CBR), and the Unconfined Compressive Strength (UCC). Following that, the results that were acquired were contrasted with the pertinent Indian Standards in order to evaluate whether or not they complied with the design requirements for sub-grade and flexible pavement. According to the results of the experiments, the ideal ratio for stabilization is a combination that contains 70% clay soil, 30% copper slag, and ground granulated blast furnace slag (GGBS). This particular mixture improves all of the desirable attributes of the sub-grade efficiently.

G. R. Ashwin kumar *et al*.[10] investigated the possibility of employing copper slag in a capacity that would allow it to act as a stabilizing agent for marine clay. When dealing with marine clay as the specified subgrade soil, the application of this specific method is frequently utilized within the area of highway construction. This is especially the case in situations

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where the subgrade soil consists of both marine clay and designated subgrade soil. Samples of marine clay that had been mixed with copper slag were subjected to an exhaustive battery of laboratory experiments, and the results of those tests were analyzed in great detail. Copper slag was added in quantities ranging from 0% to 15%, as measured in terms of its weight in comparison to the dry clay. A number of important conclusions can be drawn from the data and analysis that was presented, including the following: After the integration of copper slag into the marine clay soils, the liquid limit values of the samples show a trend towards decrease. This is the case. According to the findings of the inquiry, the liquid limit was reduced from its starting value of 31% to its end value of 22% as a direct result of the addition of copper slag in concentrations ranging from 0% to 20% in the mixture. This reduction took place over the course of the investigation. When a mixture of copper slag containing 10% and 15% by weight is incorporated, the CBR value experiences a significant increase.

Parvathy S *et al*.[11] investigated the potential for improving clayey soils by the utilization of lime and copper slag as soil stabilization methods. Lime has been utilized for several decades as a stabilizing agent in the deep stabilization of soft soil, providing to boost the strength characteristics, and this practice has continued till the present day. A significant amount of tensile strength has been discovered to be shown by the lime soil mixture. It is usual practice to incorporate various industrial by-products, such as fly ash, copper slag, marble dust, and other materials of a similar kind, into lime-stabilized soil in order to improve the qualities of the soil. This can be done to get the desired effect. In the context of this study, the utilization of copper slag as an addition is carried out. Copper slag has become an important byproduct that has found widespread application within the area of civil engineering projects in recent years. The investigation will be carried out by taking into account, in conjunction with the clayey ground, the varying percentages of lime and copper slag. Clay has a number of limitations, some of which can be effectively mitigated by the utilization of various stabilization processes and the application of suitable materials. Both the California Bearing Ratio test and the Un-confined Compressive Strength test are included in the primary laboratory examinations. This investigation will look into the engineering properties of clayey soil that has been stabilized using lime and copper slag.

C. Lavanya *et al*.[12] presented an analysis of the laboratory test findings pertaining to the coefficient of permeability assessments carried out on a composite material comprising copper slag, cement, and lime. The copper slag was combined with lime and cement in different proportions, and subsequently subjected to a curing process. After specific time intervals of 7, 14, and 28 days, the mixture was examined through testing. Significant improvements in the coefficient of permeability of copper slag were observed when lime and cement were added in varying proportions ranging from 0% to 10%. The coefficient of permeability value exhibits a decline as the percentage of lime and cement additions increases, along with the progression of the curing period. The coefficient of permeability exhibits a significantly elevated value when considering the utilization of copper slag in isolation. The incorporation of copper slag into a binding material such as lime or cement results in a notable decrease in permeability. Furthermore, when incorporating the aforementioned substance with expansive soil, it may be prudent to consider mitigating the swelling properties through the facilitation of pozzolanic reactions.

Tushal Baraskar *et al*.[13] evaluated the california bearing ratio (CBR) of the black cotton soil when combined with copper slag. In this assessment, the CBR estimation of Black cotton soil is conducted using copper slag. Copper slag is a waste material that is generated by The Sterile Industries-I Ltd. New Delhi (SIIL), India, during its operations. The annual production of copper slag amounts to approximately 120-130 lakh tonnes. In India, the copper conveying units generate a significant amount of copper slag waste on a daily basis. This granulated copper slag exhibits increased porosity and possesses particle sizes comparable to coarse sand. The preceding examination encompasses the conclusion drawn by multiple investigators regarding the implementation of copper slag in clayey soil, yielding favorable soil enhancements ranging from 2% to 30%. Additionally, we employ this particular area for the purpose of mitigating the challenges posed by expansive clay soil commonly referred to as dull cotton soil. Copper slag is employed in the determination of C.B.R. (California Bearing Ratio) values for the consolidation of lackluster cotton soil. The research paper presents the results of a comprehensive analysis of the elevated soaked CBR (California Bearing Ratio) value, specifically 5.43%, observed in a mixture comprising 72% of B.C. soil and 28% of copper slag. Furthermore, it is anticipated that this value will gradually decrease over time.

L.K. Rex *et al*.[14] elucidated the methodologies for enhancing diverse engineering characteristics, such as compaction, strength, and bearing capacity of the subgrade, through the incorporation of copper slag into the indigenous soil beneath the bitumen pavement. The incorporation of copper slag waste in soil stabilization techniques facilitates the efficient utilization of said waste material, thereby addressing the issue of mass disposal in a constructive manner. During the course of this investigation, the soil has been subjected to partial replacement with copper slag at varying percentages. The primary objective of this study is to ascertain the optimal percentage of copper slag through the implementation of specific gravity tests, Proctor compaction tests, and California Bearing Ratio (CBR) tests. The utilization of copper slag in conjunction with soil as a substitute for industrial waste materials in the reinforcement of road construction led to a notable increase in strength, surpassing that of the original natural soil. Based on a comprehensive analysis of the test results, it has been observed that the optimal percentage of copper slag necessary to enhance the structural integrity of the substandard soil subgrade is determined to be 60% (Category-D).

Sivapriya S. V *et al.*[15]examined the potential application of copper slag as a reinforcing material. To achieve stability of the Earth's surface, it is necessary to modify soil that is weakly grounded. Copper slag (CS) is widely utilized in the construction industry for enhancing basic structural development. Copper production facilities in India generate significant quantities of copper slag waste on an annual basis. According to standard security association regulations in the United States, copper slag can be classified as a non-hazardous substance based on its solid waste properties. Granulated copper slag is permeable and has particle sizes similar to coarse sand. The CPCB has suggested the use of copper slag in both the concrete manufacturing process and landfill applications. Waste material reuse is considered a state-of-the-art practice. CS is utilized as a substitute material for mitigating the impact on the environment. In order to examine the impact of compaction saturation on the shear strength properties of soil, laboratory tests were conducted. The physical and geotechnical properties of normal fill materials, such as sands, were distinguished. Various percentages of carbon steel (0%, 10%, 20%, and 30% by weight) were added to the earth, and the corresponding unit weight and internal friction angle were determined. Finite Element Analysis is used to determine the sufficiency of inclination by utilizing the characteristics of the object being analyzed as information boundaries. The replacement of CS up to 30% leads to a significant increase in the maximum dry unit weight and internal grinding of the soil. Replacing 30% of CS with sand significantly enhances the stability factor of an unstable slope.

III. CONCLUSION

The literature review has shed light on the notable importance of incorporating copper slag and cement as additives for the purpose of soil stabilization. The reviewed studies consistently exhibited the favorable impacts of copper slag and cement on augmenting the engineering characteristics of diverse soil types. The introduction of copper slag and cement resulted in the enhancement of strength, stiffness, durability, and a reduction in the propensity of soil to swell. These findings substantiate the viability and efficacy of employing copper slag and cement additives for soil stabilization in civil engineering undertakings. It is advisable to conduct further research and experimentation to delve into additional facets and optimize the blend proportions for different soil types and engineering prerequisites.

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