JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A LITRATURE REVIEW ON CONSOLIDATION AND DIFFERENTIAL FREE SEWLL INDEX STUDIES ON EXPANSIVE SOIL USING VARIOUS WASTE MATERIALS AS ADDITIVE

1 G.Sanijya, 2shaik Ashraf Ali, 3 sk.md mahaj basha, 4 katta jagadeesh,5 Manoj Kumar palaparthi
1 Associate Professor, 2 final year student, 3 final year student, 4 final year student, 5final year student
1,2,3,4,5 Civil Department
1,2,3,4,5RVR & JC college of Engineering, Guntur

Abstract: Civil engineers often face issues with expansive soils, which swell with moisture and damage structures. These soils can reach great depths, requiring expensive design or treatment solutions. Soil stabilization offers a practical and cost-effective remedy by modifying soil properties to improve performance. Lime is commonly used to reduce swell potential, increase strength, and improve workability. Due to environmental concerns, industrial waste materials like copper slag, fly ash, and steel slag are also used for stabilization. Copper slag, a by-product of copper smelting, shows promise when used with hydrated lime due to enhanced pozzolanic activity. It helps reduce swelling, improve shear strength, and enhance dynamic soil behavior. This paper provides an insight of various works done by eminent researchers on swell pressure and differential free swell index of expansive soil stabilized with various additives stabilized with lime and cement.

IndexTerms **-Waste disposal, Waste Utilization, black cotton soils, Swell Pressure, Differential free swell index**

I. INTRODUCTION

Expansive soils, particularly Black Cotton Soil (BCS), present one of the most problematic soil types encountered in geotechnical engineering. Predominantly found in India, these soils are formed through the weathering of basaltic and other ancient sedimentary rocks, resulting in clay-rich deposits that contain swelling clay minerals, primarily montmorillonite, also known as smectite. Montmorillonite's crystalline structure is composed of alternating tetrahedral and octahedral sheets, which are loosely bonded by Van der Waals forces and interlayer cations. These weak interlayer bonds allow significant adsorption of water, leading to substantial volume changes under varying moisture conditions. The high swelling and shrinkage potential of expansive soils causes severe damage to civil engineering structures due to differential heaving, loss of bearing capacity, and cracking of foundations, pavements, and floors. Black Cotton Soil can exhibit crack widths exceeding 70 mm and depths over 1 meter during desiccation cycles. The seasonal variation in volume creates instability in subgrades, resulting in surface deformations, pothole formation, and overall structural distress. Consequently, these soils are classified as unsuitable for use in infrastructure projects such as roadways, airfields, embankments, and shallow foundations without appropriate modification. With the increasing pressure from urbanization and industrial development, construction activities are often forced to occur on marginal and expansive soil deposits, necessitating the adoption of effective soil stabilization techniques. Soil stabilization aims to improve the geotechnical properties of weak soils by increasing shear strength, reducing compressibility, and minimizing swelling behaviour. Stabilization methods are broadly categorized into mechanical techniques (e.g., compaction, drainage) and chemical stabilization, which involves the incorporation of admixtures such as lime, cement, fly ash, bitumen, and chemical additives. In addition to enhancing soil behaviour, chemical stabilization also offers a solution to the growing issue of industrial waste disposal. In this context, Copper Slag (CS), an industrial by-product generated during the pyrometallurgical smelting of copper ore, has emerged as a promising alternative stabilizing agent. For every tonne of copper produced, approximately 2.2 tonnes of copper slag are generated, posing significant disposal challenges. CS is characterized by its angular particle shape, high internal friction angle (up to 52°), excellent drainage capacity, and non-frost susceptibility, making it functionally equivalent to medium-grained sand. These properties suggest that copper slag can enhance the load-bearing capacity and dimensional stability of expansive soils when used as a partial replacement or additive. Previous research has shown that the integration of copper slag with traditional stabilizers such as lime and cement can result in a composite soil matrix with improved engineering performance. The course, angular particles of CS interlock with the finer soil grains, enhancing shear strength and resistance to deformation. When used in combination with fly ash or pozzolanic materials, copper slag contributes to the formation of cementitious gels, further increasing the soil's resistance to volume change and improving durability under cyclic moisture conditions. Despite its potential, the mass utilization of copper slag in soil stabilization applications has yet to be fully realized due to limited comprehensive field and laboratory validation. Therefore, there is a critical need for systematic studies that investigate the behavioural response of expansive soils treated with CS under varying dosage and compounding conditions. The present paper presents a comprehensive yet elaborate insight of various studies conducted by eminent researchers on black cotton soils in terms of swelling and swell pressure. investigates the stabilization of Black Cotton Soil using copper slag in conjunction with fixed proportions of lime and cement. The outcomes of this research are expected to contribute toward further research on sustainable geotechnical practices by promoting the beneficial reuse of industrial waste while ensuring enhanced infrastructure resilience on problematic soils.

II. works done by eminent researchers on Performance Evaluation of Expansive Soil Stabilization Techniques Using copper slag as Additives

Thompson, Broms, and Boman et al. (1989) conducted foundational work in the field of chemical stabilization of expansive soils, emphasizing the usefulness of lime treatment in reducing problematic volume changes associated with such soils. Expansive soils, which are known for their tendency to undergo significant swelling and shrinkage with changes in moisture content, pose a serious challenge in geotechnical engineering, particularly for infrastructure like roads, foundations, and embankments. The researchers highlighted that when lime is added to expansive soils, a series of chemical reactions occur—primarily cation exchange and pozzolanic reactions—that lead to notable improvements in the engineering behavior of the soil. Laboratory experiments have consistently shown that lime addition reduces the soil's plasticity, increases its unconfined compressive strength, and raises its pH, indicating changes in chemical reactivity and structure. These improvements contribute to better workability, enhanced load-bearing capacity, and reduced moisture sensitivity. However, despite these promising benefits, there remains a significant gap in research regarding the direct impact of lime on the swelling behavior of expansive soils—particularly the swell percentage and swell pressure, which are critical parameters for assessing the actual extent of ground.

Byers, Nguyen, Cardoso, et al. (1992), have focused on determining the optimum lime content using indirect methods. These methods involve analyzing the effects of lime on secondary properties such as the consistency limits (Atterberg limits), strength parameters, or pH levels, and then establishing correlations between these properties and the expected swell behavior. While such studies have been useful for preliminary design and understanding, they rely on assumptions and estimations rather than measured swelling behavior. From these correlations, it has been generally concluded that the optimum lime content for expansive soils lies between 4% and 6%, beyond which further addition may not yield significant benefits and might even adversely affect soil performance. Yet, one key unanswered question remains: What exact percentage of lime addition minimizes heave effectively without compromising soil structure or causing other issues? The need for direct testing and measurement of lime-treated expansive soil's swell characteristics—including both swell pressure and swell percentage—is therefore apparent and urgent. This will help not only in optimizing the lime content more accurately but also in tailoring the stabilization technique to site-specific conditions, ensuring long-term stability and cost-effectiveness in engineering applications. Thus, while lime stabilization is widely recognized and practiced, further research with a direct focus on swelling behavior is necessary to refine and improve this method, making it even more effective for dealing with the challenges posed by expansive soils.

Parampreet Kaur et al. (2012), in their detailed investigation on soil stabilization techniques, reported significant enhancements in the mechanical and durability-related properties of expansive soils when treated with chemical additives such as lime and copper slag. Their study revealed that the treated soils exhibited greater resistance to fracture, improved fatigue life, and better performance against permanent deformation, all of which are critical for the long-term durability of pavement subgrades and foundations built on such soils. One of the most crucial findings was the reduction in swelling potential, a key concern in expansive soils that undergo drastic volume changes with moisture variations. The treatment also helped mitigate the adverse effects of moisture, such as loss of strength and increased plasticity, which often lead to the deterioration of structures. These benefits were most prominently observed in soils with moderate to high plasticity, particularly in heavy clay soils, which are typically more reactive and susceptible to expansion and shrinkage. The inherent mineral composition of such clays makes them excellent candidates for chemical stabilization, and the improvements noted in this study validate the effectiveness of the combined use of lime and copper slag. The mechanism of stabilization, as explained by the researchers, involves a pozzolanic reaction that occurs when lime and copper slag are introduced into a reactive soil matrix. Lime, being a source of calcium, interacts chemically with the silicates and aluminates present in the clay minerals. These reactive components are solubilized in the presence of moisture, allowing them to combine with the calcium ions to form calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H). These compounds are similar to the hydration products formed in Portland cement and are known for imparting long-term strength and stability to the treated soil. The addition of copper slag, a byproduct of metal smelting, not only enhances the pozzolanic reaction due to its amorphous silica content but also improves the mechanical interlock and gradation of the soil, contributing to its load-bearing characteristics. This dual-action mechanism—chemical stabilization through lime and physical and chemical enhancement through copper slag—leads to a synergistic improvement in soil performance. As a result, the soil becomes less plastic, more resistant to environmental variations, and capable of sustaining higher loads without deformation or heave. Thus, the study by Parampreet Kaur et al. underscores the effectiveness of lime and copper slag combination as a sustainable and performance-oriented solution for stabilizing problematic expansive soils, especially those with high clay content and plasticity.

Lessen Skariah Thomas, Prachi Gupta et al. (2012) conducted an important study focused on evaluating the effectiveness of copper slag as a soil stabilizing additive, particularly in enhancing the strength characteristics of clayey soils. Their research aimed to determine the optimum percentage of copper slag that can be added to clay soils to achieve maximum strength gain without compromising other geotechnical properties. This approach reflects a growing interest in the use of industrial by-products for sustainable and cost-effective soil improvement techniques. The study revealed that the inclusion of copper slag significantly improved the bearing capacity and shear strength of clayey soils. This improvement is largely attributed to the physical and chemical characteristics of copper slag—its angular particle shape contributes to better interparticle friction, while its chemical composition, rich in silica and iron oxides, supports pozzolanic reactions when used in combination with lime or other binders. The researchers emphasized that careful determination of the optimum dosage is crucial because excessive addition of slag might lead to workability issues or undesired changes in the soil's compaction behavior. In a complementary study,

Hesham A. H. Ismaiel et al. (2013) explored the broader use of various industrial waste materials—including cement bypass dust, granulated blast furnace slag, copper slag, and slag-cement—in mitigating the problematic swelling behavior of expansive soils. Their research acknowledged the increasing demand for sustainable construction practices by utilizing industrial waste as an alternative to conventional stabilizers. The findings of this study concluded that these materials, when appropriately applied, can be effective in reducing the swelling potential of expansive soils, which is a major concern in regions with high clay content and seasonal moisture fluctuations. Among these, copper slag emerged as a promising candidate, not only due to its pozzolanic activity when combined with lime or cement but also because of its non-plastic nature and improved drainage characteristics, which help in minimizing moisture retention—one of the key factors behind swelling. Both studies collectively support the use of copper slag as an efficient stabilizing agent either alone or in combination with other binders. They demonstrate how such industrial by-products can play a significant role in improving both the strength and dimensional stability of expansive soils. Moreover, using these materials not only addresses geotechnical challenges but also contributes to environmental sustainability by reducing the dependency on virgin materials and promoting the reuse of industrial waste. This integrated approach offers a viable solution for cost-effective ground improvement, especially in infrastructural projects where expansive soils are prevalent and need to be modified for safe and long-lasting performance.

Sopheap Por et al. (2017) conducted an in-depth study focusing on the chemical stabilization of expansive soils, specifically high-plasticity clays, using cement kiln dust (CKD) and a combination of CKD with lime (L). The primary aim of their research was to investigate the effectiveness of these stabilizing agents in reducing the swelling potential of such soils and enhancing their geotechnical performance. The study meticulously analyzed how the addition of CKD, both alone and in combination with lime, influenced the deformation behavior and stress response of expansive clay soils during swelling. Their findings revealed that the chemical interaction between the stabilizing agents and the reactive components of the clay led to significant reductions in swelling and improvements in shear strength, stiffness, and structural integrity. This was largely due to the formation of cementitious compounds that bonded soil particles together, thereby reducing voids, limiting moisture ingress, and controlling volume changes. The study highlighted the importance of chemical stabilization techniques as a reliable solution for mitigating the challenges posed by expansive soils, particularly in civil engineering applications involving roads, foundations, and embankments. In a related study, Amadi A.A. and Osu A.S. (2016) emphasized the growing popularity and effectiveness of combined treatment techniques in geotechnical engineering. Their work reviewed how engineers and pavement designers are increasingly adopting multi-additive stabilization strategies using combinations of materials such as lime, cement, industrial by-products, and other chemical agents to enhance the strength, durability, and stability of subgrades and foundation soils, especially in areas characterized by expansive behavior. The researchers pointed out that relying on a single stabilizing agent may not always yield the desired improvements in all soil types. Therefore, integrated approaches offer more flexibility and superior performance, allowing engineers to tailor the stabilization method to suit site-specific soil properties and project requirements. Furthermore, Naphol Yoobanpot et al. (2017) carried out a comparative study on the use of cement kiln dust (CKD) and fly ash (FA) in improving the unconfined compressive strength (UCS) of soft Bangkok clay, with ordinary Portland cement (OPC) serving as a benchmark. The results demonstrated that the stabilized clay treated with CKD and FA showed a marked improvement in UCS, primarily due to the formation of calcium silicate hydrate (C-S-H), a critical product of the pozzolanic reaction. This compound contributes significantly to strength development and long-term durability. The presence and development of C-S-H were confirmed through X-ray diffraction (XRD) analysis, providing scientific validation for the chemical mechanisms involved in soil stabilization. The study concluded that CKD and FA, both of which are industrial waste materials, can serve as effective and sustainable alternatives to OPC in enhancing the strength of soft clays, thereby supporting more eco-friendly and economically viable ground improvement solutions. Collectively, these studies underscore the value of industrial by-products like CKD, fly ash, and combined treatment methods in addressing the persistent engineering challenges associated with expansive and soft soils. By facilitating chemical reactions that result in the formation of stable, cementitious compounds, these materials not only enhance the mechanical and deformation properties of problematic soils but also support the reuse of waste materials, aligning with modern sustainable construction practices.

Elayaraja (2009) carried out a comprehensive investigation into the behavioral improvement of black cotton soil when reinforced with geotextiles, a modern geosynthetic material widely used in soil stabilization and reinforcement applications. Recognizing the challenges posed by black cotton soil particularly its high swelling and shrinkage characteristics, poor shear strength, and susceptibility to moisture Elayaraja aimed to assess how the inclusion of geotextile layers could alter and improve the soil's engineering properties. The study involved a series of shear strength tests, including the Unconfined Compression Test (UCS), Triaxial Shear Test, Vane Shear Test, and Direct Shear Test, all of which are standard procedures for evaluating the mechanical behavior and stability of soils under various loading conditions. The results of these experiments consistently showed that the inclusion of geotextiles, especially non-woven geotextiles, led to a significant increase in the shear strength parameters of black cotton soil. These improvements were evident across all the different test methods employed. The reinforcement effect provided by the geotextile layers worked by restricting lateral deformation and distributing loads more effectively throughout the soil mass, thereby enhancing resistance to shear failure. Non-woven geotextiles, which have a fabric-like structure with high permeability and flexibility, were found to interact more efficiently with the fine-grained black cotton soil. This resulted in improved frictional resistances the soil–geotextile interface, leading to better performance in both drained and undrained shear conditions. Elayaraja's conclusions highlight the practical significance of using geotextile reinforcement in geotechnical applications involving expansive soils like black cotton soil. The study not only validated the effectiveness of geotextiles in enhancing shear strength, but also reinforced the idea that geosynthetics can serve as a cost-effective and durable solution for mitigating soil-related problems in foundation engineering, road construction, and embankment design. Through this research, the role of non-woven geotextiles was particularly emphasized as a promising material for stabilizing problematic soils, offering both mechanical reinforcement and improved drainage characteristics. This approach contributes to long-term stability and performance of civil engineering structures built on challenging soil conditions.

Yogendra K. Tandel (2009), through his focused research, concluded that copper slag serves as a highly effective soil stabilizing agent, especially suitable for improving weak soils in the construction of highway embankments. His findings supported the use of copper slag as a cost-effective and technically viable solution, particularly in regions that are geographically close to copper slag production sources. In such areas, the material becomes not only economically attractive due to reduced transportation costs but also environmentally sustainable by recycling an industrial waste by-product that would otherwise contribute to landfill burdens. The study emphasized that the reuse of copper slag in geotechnical engineering applications aligns well with sustainable construction practices, as it does not pose significant environmental risks and avoids compromising potential future land use. This dual benefit—engineering performance improvement and environmental conservation—makes copper slag a promising material for soil stabilization in large-scale infrastructure projects.

In a complementary study, C. Lavanya (2011) further expanded on the geotechnical applicability of copper slag by investigating its effects on the engineering behavior of black cotton soils, which are notoriously expansive and problematic for foundation work. Her experimental program included a comprehensive evaluation of the index properties, free swell index, compaction characteristics, California Bearing Ratio (CBR), and unconfined compressive strength (UCC) of soils treated with varying percentages of copper slag. The results demonstrated that a partial replacement of black cotton soil with copper slag in the range of 30% to 50% led to significant improvements in geotechnical properties. Specifically, the treated soils exhibited reduced swelling potential, better compaction behavior, increased strength, and enhanced load-bearing capacity—all critical factors for constructing stable pavement layers and embankments. Lavanya concluded that the partial incorporation of copper slag not only enhances the soil's mechanical properties but also makes the treated black cotton soil suitable for use in subgrade, subbase, and embankment layers of roads. This is a particularly valuable finding for infrastructure development in regions where expansive soils like black cotton soil are prevalent and pose challenges to construction stability. By integrating copper slag into the soil stabilization process, engineers can achieve both performance efficiency and material sustainability, while simultaneously promoting the reuse of industrial waste. Together, the research works of Tandel and Lavanya collectively demonstrate that copper slag is a versatile and reliable material for improving problematic soils, especially in the context of transportation infrastructure. Their studies underscore its practical value not just as a stabilizing agent but also as a sustainable resource that contributes to environmental conservation and cost savings, making it an ideal choice for eco-friendly and durable ground improvement strategies.

Ashwani Jain (2013) conducted a detailed experimental study aimed at understanding the influence of rice husk ash (RHA)on the compressibility characteristics of highly plastic clay soils. The research focused on performing one-dimensional consolidation tests, a widely used method to assess how soils behave under long-term static loading, particularly in terms of settlement and rate of consolidation. Jain systematically examined how the incremental addition of RHA, in varying percentages, affected the Compression Index (Cc)—a critical parameter that determines the magnitude of settlement a soil will undergo when subjected to loading. The study observed that with the progressive addition of rice husk ash, the Compression Index (Cc) decreased significantly, indicating a clear reduction in the compressibility of the treated clay. This reduction is essential in geotechnical engineering because it implies that the overall settlement of structures built on such soils would be lower, thereby enhancing their long-term stability. The reduction in Cc can be attributed to the pozzolanic reaction between the silica-rich RHA and the aluminous and siliceous compounds naturally present in the clay, leading to the formation of cementitious gels like calcium silicate hydrate (C-S-H). These gels help fill the voids within the clay matrix, making the soil denser and less compressible. Another important finding from Jain's study was that the time required to achieve a given degree of consolidation also decreased with increasing RHA content at a constant effective stress level. This means that not only was the magnitude of settlement reduced, but the rate at which settlement occurred was faster, a highly desirable outcome in construction projects, where faster consolidation translates to quicker project timelines and reduced risk of long-term deformation. This improvement in consolidation behavior is largely due to the enhanced permeability and stiffness introduced by RHA, which promotes faster drainage and more efficient dissipation of excess pore water pressure.

Tushal Baraskar (2014) conducted an insightful study to evaluate the effect of partial replacement of black cotton soil with waste copper slag on the California Bearing Ratio (CBR), which is a crucial parameter for determining the strength and suitability of subgrade and subbase layers in road pavement design. Recognizing the challenges posed by black cotton soil—such as its low bearing capacity, high swelling potential, and susceptibility to moisture—Baraskar focused on using industrial waste material like copper slag as a stabilizing agent to enhance its load-bearing performance. In his study, different percentages of copper slag were mixed with black cotton soil, and CBR tests were conducted to determine the optimum replacement level that yields the highest strength. The results demonstrated that the CBR value significantly increased with the addition of copper slag up to a certain point. The maximum CBR value was recorded when 28% of the black cotton soil was replaced with copper slag, indicating a notable improvement in the soil's strength and stiffness. This enhancement can be attributed to the coarse and angular nature of copper slag particles, which improve interparticle friction and reduce the soil's plasticity, thereby enhancing its resistance to deformation under load.Tushal Baraskar concluded that black cotton soils treated with around 28% copper slag are not only stronger but also more stable, making them highly suitable for use as subbase layers in flexible pavement systems. The improved CBR values suggest that the modified soil can better withstand traffic loads and environmental stresses, thus extending the service life of road infrastructure. Moreover, this approach contributes to sustainable construction practices by utilizing industrial waste materials that would otherwise require disposal, thereby reducing environmental impact and material costs. The findings of this study reinforce the practical potential of copper slag as a cost-effective soil stabilizer in road construction, particularly in regions where black cotton soil is widespread and poses a challenge to infrastructure development. By optimizing the percentage of copper slag addition, engineers can design stronger, more durable pavement systems while simultaneously promoting eco-friendly and resource-efficient construction methods.

Jinka Chandrashekhar (2015) conducted a comprehensive review and experimental study focused on the utilization of copper slag, a waste by-product from the copper industry, in geotechnical applications, particularly for improving the problematic behavior of expansive soils like black cotton soil. The objective of the study was to assess the effectiveness of copper slag when used as a partial replacement for natural soil in order to enhance its engineering properties and make it more suitable for subgrade and subbase layers in pavement construction. In the experimental phase of the study, soil samples—specifically black cotton soil—were partially replaced with varying percentages of copper slag. The modified soil samples were then subjected to a series of laboratory tests, including the determination of specific gravity, free swell index, and California Bearing Ratio (CBR). These tests were conducted to evaluate how the addition of copper slag influences critical soil parameters such as density, swelling potential, and load-bearing capacity. One of the significant observations from the study was made when a mix containing 40% copper slag and 60% black cotton soil was tested. This combination yielded notable improvements across all evaluated properties. The test results showed that the specific gravity of the soil increased, indicating a denser and more compact soil structure. More importantly, there was a reduction in the free swell index, which suggests that the expansive nature of black cotton soil was effectively suppressed due to the addition of non-expansive copper slag particles. Furthermore, the CBR values showed substantial improvement, pointing to the enhanced load-bearing capacity of the soil, a critical factor for the performance of pavement subgrades and subbases. Based on these findings, Jinka Chandrashekhar concluded that copper slag is a viable and beneficial additive for stabilizing black cotton soil. The modified soil exhibited improved engineering behavior, making it suitable for various geotechnical applications, particularly in the construction of road subgrade and subbase layers. The study emphasized that the incorporation of copper slag not only improves the strength and stability of expansive soils but also supports sustainable construction practices by promoting the reuse of industrial waste materials that would otherwise contribute to environmental degradation.

Mohammed (2015) carried out a detailed investigation on the enhancement of geotechnical properties of expansive soils, particularly black cotton soil, through partial replacement with copper slag, a waste material generated during the smelting of copper. Recognizing the problematic nature of expansive soils—characterized by their high shrink-swell behavior and low strength—Mohammed aimed to determine whether copper slag could serve as a viable stabilizing material to overcome these limitations and make such soils suitable for engineering applications, especially in road construction. In this study, a wide range of soil engineering tests were performed on the untreated black cotton soil and on samples in which the soil was partially replaced by copper slag in different proportions. The testing included grain size analysis, liquid limit, plastic limit, and plasticity index to assess the changes in consistency and classification of the soil; Standard Proctor compaction tests to determine optimum moisture content and maximum dry density; direct shear tests to evaluate shear strength parameters; and California Bearing Ratio (CBR) tests to assess the load-bearing capacity. These comprehensive tests provided a holistic understanding of how copper slag influences both the strength and deformation behavior of expansive soil. The results clearly indicated that the addition of copper slag caused significant improvements in the geotechnical behavior of the soil. The plasticity index decreased, suggesting a reduction in the soil's expansive nature and improved workability. The shear strength increased, which is essential for slope stability and foundation support, and CBR values improved, indicating enhanced suitability for subgrade and subbase applications in road pavement construction. Among the various mix proportions studied, the combination of 40% copper slag and 60% black cotton soil yielded the most favorable results, striking an optimal balance between strength, workability, and economic feasibility. Based on the findings, Mohammed concluded that 40% copper slag is the optimum percentage for improving black cotton soil, resulting in a modified soil that is significantly more stable, less plastic, stronger, and better suited for construction activities than the untreated expansive soil. This conclusion supports the broader objective of using industrial waste materials like copper slag as eco-friendly and cost-effective alternatives to conventional stabilizers. The study emphasizes that such an approach not only helps in waste management and environmental conservation, but also in developing sustainable ground improvement techniques, particularly for regions with problematic soils. In summary, Mohammed's research adds to the growing body of literature affirming that copper slag is a highly effective additive for enhancing the performance of expansive soils, and that its optimal use—especially at 40% replacement level —can provide a practical and environmentally responsible solution in geotechnical and transportation engineering projects.

Ravi (2016) conducted an in-depth study focusing on the modification of clay soil characteristics, particularly black cotton soil, through stabilization using copper slag. This investigation aimed to address the poor engineering properties of expansive clay soils, which commonly exhibit low strength, high plasticity, and high swelling potential, making them unsuitable for supporting structures and pavements without proper treatment. The study specifically evaluated the impact of copper slag addition on key geotechnical parameters, with an emphasis on its suitability for use in flexible pavement sub-base layers. To assess the effect of copper slag stabilization, the research involved laboratory testing of soil samples mixed with various percentages of copper slag. The parameters tested included California Bearing Ratio (CBR), Maximum Dry Density (MDD), and Optimum Moisture Content (OMC). These are fundamental indicators in determining soil suitability for pavement layers, where higher CBR values imply better load-bearing capacity, and changes in MDD and OMC help in understanding compaction behavior and moisture requirements during construction The experimental results revealed that the CBR values improved significantly with the addition of copper slag, showing a peak at the 30% replacement level. At this composition— 30% copper slag and 70% black cotton soil —the CBR value was found to be the highest among all mixes tested. This enhancement in strength indicates that the treated soil would be capable of bearing higher traffic loads, thereby improving its application in pavement design. Additionally, the improved CBR values implied that the thickness of the sub-base layer could be reduced, leading to cost savings in construction without compromising on pavement performance. Moreover, changes in MDD and OMC were also observed, with the MDD increasing and OMC decreasing at the optimal replacement level. These changes suggest that the copper slag particles contributed to better soil compaction and reduced water demand, both of which are favorable for field implementation. Based on the test outcomes, Ravi concluded that the optimum mix for effective stabilization was a combination of 30% copper slag and 70% black cotton soil. This blend not only enhanced the soil's load-bearing capacity but also proved to be economically viable and technically suitable for flexible pavement construction, especially in areas with problematic expansive soils. The study strongly supports the use of copper slag as a sustainable and efficient stabilizing material, turning industrial waste into a valuable resource for infrastructure development. Ravi's findings contribute meaningfully to the ongoing efforts in sustainable geotechnical engineering, promoting eco-friendly practices, cost reduction, and improved soil performance in road construction and other civil engineering applications.

Tiza Michael (2016) conducted an extensive review and experimental analysis on the utilization of various industrial solid wastes for the purpose of stabilizing expansive soils, which are known for their low strength, high plasticity, and problematic swelling-shrinkage behavior. The primary aim of the study was to explore sustainable alternatives to conventional soil stabilization techniques, particularly those that make use of readily available industrial by-products. This not only offers a technical solution to improve soil behavior but also contributes to effective waste management and cost reduction in civil engineering projects. In this study, multiple industrial waste materials were considered for soil replacement and stabilization, including red mud, copper slag, brick dust, polyvinyl waste, ceramic dust, sawdust, and fly ash. Each of these materials, commonly discarded by industries, was evaluated for its effectiveness in enhancing the geotechnical characteristics of expansive soil when mixed in varying proportions. The experimental investigation involved testing the modified soils for key engineering properties such as the Atterberg limits (liquid limit, plastic limit, and plasticity index), California Bearing Ratio (CBR), and compaction characteristics (Maximum Dry Density and Optimum Moisture Content). The results from these tests revealed a general trend of improvement in the behavior of expansive soils upon the addition of industrial waste materials. Reductions in the plasticity index were observed, which indicated a decline in the expansive nature of the soil. Furthermore, CBR values increased across most waste material combinations, suggesting improved strength and bearing capacity. Compaction characteristics also improved in terms of higher dry densities and favorable moisture contents, which are vital for achieving durable and stable pavement or foundation layers. Based on the comprehensive analysis, Tiza Michael concluded that almost all the industrial waste materials studied were effective in enhancing the engineering performance of expansive soils, often delivering results that were comparable to or better than traditional stabilizers like lime or cement, but at a significantly lower cost. The use of such materials not only improves soil behavior but also promotes eco-friendly and sustainable construction practices by reusing waste that would otherwise contribute to environmental pollution. The findings of the study highlight the potential of industrial solid wastes as viable, economical, and sustainable alternatives for soil stabilization. Tiza Michael's research encourages civil engineers and construction professionals to adopt innovative materials and practices, especially in regions where expansive soils pose a challenge and resources for conventional stabilization may be limited. This approach aligns with global goals of sustainability, waste reuse, and cost-effective infrastructure development.

Mohan Chand (2017) undertook a comprehensive experimental investigation to study the behavior of Black Cotton Soil (BCS) stabilized with the addition of copper slag and steel slag, two major industrial by-products known for their potential as soil stabilizers. The primary motivation behind this research was to address the poor geotechnical characteristics of black cotton soil, especially its low shear strength, high moisture sensitivity, and swelling-shrinkage behavior, which make it unsuitable for construction without proper treatment. To evaluate the improvements, various laboratory tests were performed, including Standard Proctor Compaction Test, Unconfined Compression Test (UCS), and California Bearing Ratio (CBR) Test. The results of the study clearly demonstrated that the addition of 20% copper slag and steel slag significantly enhanced the maximum dry density (MDD), optimum moisture content (OMC), CBR, and shear strength of the black cotton soil. These enhancements point toward improved load-bearing capacity, reduced moisture sensitivity, and greater compaction characteristics, all of which are critical in pavement subgrade and foundation applications. The synergistic effect of copper slag and steel slag was found to not only improve the strength but also to promote a denser and more stable soil matrix.

In a parallel study, Rajendra Kumar (2017) explored the effect of combining black cotton soil with copper slag and fly ash in different proportions. This investigation focused on evaluating changes in Atterberg limits (liquid limit, plastic limit, and plasticity index), free swell index, compaction characteristics, and unsoaked CBR values. The combination of 30% copper slag and 10% fly ash (by weight of soil) yielded the most favorable results. The mixture showed an increase in maximum dry density and CBR, while there was a notable reduction in plasticity and free swell index, indicating that the expansive behavior of the soil was effectively controlled. Together, these studies clearly establish the viability of using copper slag in combination with other industrial by-products like steel slag and fly ash for the stabilization of expansive soils. Not only do these combinations improve the strength and compaction properties, but they also address the critical issue of swelling , which is often neglected in stabilization studies Building on these findings, the current project expands the scope of investigation by focusing not just on strength parameters like UCS and CBR—which are commonly studied—but also on swell pressure and differential free swell index , which are directly related to the shrink-swell behavior of expansive soils. By blending copper slag with lime and cement stabilized expansive soils, the study aims to understand the influence of copper slag as an additive in controlling the volumetric changes associated with moisture variation. This multidimensional approach addresses a vital gap in existing research, where most studies prioritize strength over deformation behavior, even though it is the swell-shrink characteristics that cause real-world failures in structures built on expansive soils. The findings from this project will therefore not only validate the role of copper slag in enhancing strength but will also provide direct evidence of its efficacy in mitigating swelling-related issues, thereby reinforcing its potential as a sustainable and efficient additive for stabilizing expansive soils.

III. conclusions

- ❖ Expansive soils, particularly black cotton soils, exhibit significant volume changes with moisture variation, leading to structural failures in pavements, foundations, and embankments.
- ❖ Lime stabilization effectively improves soil properties through cation exchange and pozzolanic reactions, reducing plasticity and enhancing strength. However, direct studies on its influence on swell pressure and swell percentage remain limited.
- ❖ Copper slag (CS), a by-product of the copper industry, has emerged as a sustainable stabilizing agent due to its pozzolanic potential, high angularity, and improved drainage characteristics.
- ❖ Studies indicate that partial replacement of soil with 28–40% copper slag enhances CBR, reduces free swell index, and increases maximum dry density, making it suitable for subgrade and subbase applications.
- ❖ Industrial waste materials such as CKD, fly ash, and steel slag further support soil stabilization while promoting environmental sustainability and resource efficiency.
- ❖ The combined use of lime and copper slag results in synergistic improvements, with lime facilitating chemical bonding (C-S-H, C-A-H formation) and copper slag contributing to mechanical interlocking and gradation enhancement.
- ❖ Geotextile reinforcement, especially using non-woven materials, improves shear strength and load distribution while restricting lateral deformation, making it a valuable supplement to chemical stabilization.
- ❖ Recent research emphasizes multi-additive stabilization techniques, allowing better adaptability to site-specific soil behavior and improving long-term performance.
- ❖ Overall, copper slag combined with traditional stabilizers and geosynthetics offers a technically viable, cost-effective, and environmentally sustainable solution for improving expansive soils in infrastructure projects.

REFERENCES

1. Thompson, M.R. (1966). "Lime reactivity of Illinois soils". Journal of Soil Mechanics and Foundation Engineering Division, ASCE, Vol. 92, No. 5, pp. 67-92.
2. BYERS, J.G. (1980). "Treatment of expansive clay canal lining." Proceedings of the Fourth International Conference on Expansive Soils, Denver, Colorado, U.S.A., pp. 401- 420.
3. Hesham, A. H. Ismaiel (2013). “Cement Kiln Dust Chemical Stabilization of Expansive Soil Exposed at El-Kawther Quarter, Sohag Region, Egypt.” International Journal of Geosciences, 4, 1416-1424, DOI:10.4236/ijg.2013.410139.

4. Amadi, A. A, Osu, A. S. (2016). "Effect of Curing Time on Strength Development in Black Cotton Soil – Quarry Fines Composite Stabilized with Cement Kiln Dust (CKD)." Journal of King Saud University – Engineering Sciences, 34:1613–1630(2016), https://d oi.org/10.1016/j.jksues.2016.04.001.
5. S.Elayaraja, Dr.P.D.Arumairaj (2009), "Study on the Shear Strength of Black Cotton Soil Reinforced with Geosynthetics", National Conference on "Advances in Steel Concrete and Composite Structures".
6. Yogendra K Tandel and Jignesh B Patel (2009)," Review of Utilisation of Copper Slag in Highway Construction", Australian Geomechanics Vol 44.
7. C. Lavanya, Asst.Prof, A. Sreerama Rao, N. Darga Kumar (2011), "A Review on Utilization of Copper Slag in Geotechnical Applications", Proceedings of Indian Geotechnical Conference, Kochi (Paper No.H-212).
8. Ashwani Jain, Nitish Puri (2013), "Consolidation Characteristics of Highly Plastic Clay Stabilised with Rice Husk Ash", International Journal of Soft Computing and Engineering (IJSCE), ISSN: 2231-2307, Volume-2, Issue-6.
9. Tushal Baraskar, S.K Ahirwar (2014), "Study on California bearing ratio of black cotton soil use waste copper slag", International Journal of structural and civil engineering research, Vol.3.
10. Jink Chandrshekhar, Timir A Chokshi (2015), "A Review on Utilization of Waste Material Copper Slag in Geotechnical Applications", International Journal for Innovative Research in Science and Technology, Vol. 1.
11. Mohammed A. Qureshi, Hevin M. Mistry, Vikas D. Patel (2015), "Improvement in Soil Properties of Expansive Soil by Using Copper Slag", International journal of Advance Research in Engineering in Science and Technology, Vol.2.
12. Brajesh Mishra, ravi Shanker Mishra (2015), "A Study on Stabilization of Black Cotton Soil Use of Fly Ash, ferric Chloride and Stone Dust", International Journal of Engineering and Science, Vol.5, Issue No. 10, PP- 20-25.
13. Chayan Gupta, Ravi Kumar Sharma (2016), "Black Cotton Soil Modification by the Application of Waste Materials", Periodica Polytechnica Civil Engineering, 60(4), pp. 479-490.
14. E. Ravi, R. Udhayasakthi, T. Senthil Vadivel (2016), "Enhancing the Clay Soil Characteristics using Copper slag Stabiliation", Journal of Advances in Chemistry, Vol.12, Issue No. 26.
15. Tiza Michael, Sitesh Kumar Singh, Anand Kumar (2016)," Expansive Soil Stabilization using Industrial Solid Wastes a Review", International Conference of Recent Trends in Engineering and Science, Vol. 16.
16. Rishi Srivastava, Shalinee Shukla, R.P. Tiwari, Ayush Mittal (2016), "Effect of Woven Polyester Geotextile on the Strength of Black Cotton Soil", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5.
17. A. Mohan chand, V. Ramesh babu, B. Ramesh Babu and K. Niveditha (2017), "Behavior of Black Cotton Soil with Addition of Copper Slag and Steel Slag", International Research Journal of Engineering and Technology (IRJET) e-ISSN:2395- 0056, p-ISSN: 2395-0072 Vol. 04.
18. P. Rajendra Kumar, P. Suresh Praveen Kumar, J. Maheshwari (2017), "Laboratory Study of Black Cotton Soil Blended with Copper Slag and Fly Ash", International Journal of Innovative Research in Science, Issue No 2.