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A Review on Stabilization of Expansive Soil Using Industrial & Agricultural Wastes

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***Abstract*: Expansive soils are problematic for any Construction purposes due to its Shrinkage & Swelling characteristics. Many stabilizers and Techniques have been used to stabilize expansive soils to make it appropriate for construction purposes. The selection of suitable method to address the problems caused by expansive soils is crucial, as it affects not only the soil's engineering properties but also environmental and economic factors. Theaim of this article is to review the stabilization of such expansive soils using various agricultural and industrial wastes such as SBA, Steel Slag, GGBS, FA, RHA, Saw Dust Ash, Ceramic powder, Marble Dust etc.Also, the review is focused to investigate the effect of these Stabilizers on geotechnical properties and characteristics of such soils.**

Keywords—Expansive Soil, Soil Properties, Industrial & Agricultural wastes, Soil stabilization

I. INTRODUCTION

Soil is the main thing that supports civil engineering structures and keeps them stable and safe. The performance and long-term durability of infrastructure largely depend on the mechanical characteristics and physical characteristics of the soil at the construction site. However, some soils possess unfavorable engineering properties that make them unsuitable for construction without modification.Among these problematic soils, expansive soilcommonly referred to as BCSis considered one of the most challenging materials encountered in geotechnical engineering . Expansive soils are weak soils that changes volume with changes in moisture content. They swell when wet (in the rainy season) and shrink when dry (in the summer). Such behavior frequently results in structural issues such as pavement cracking, foundation damage and differential settlement of buildings .

In India, these soils are widely distributed across regions such as Maharashtra, Gujarat, Madhya Pradesh, and Karnataka, covering a substantial percentage of the total land area. The presence of clay minerals, particularly montmorillonite, is mainly responsible for the high swelling potential of BCS. Due to their low shear strength, high plasticityand poor load-bearing capacity, expansive soils are found to be unsuitable for construction unless their engineering properties are improved through stabilization techniques . Therefore, it is necessary either to replace the weak soil with suitable material or to enhance its properties through soil stabilization.

Soil stabilization is among the most effective techniques used to strengthen weak soil by modifying its physical or chemical characteristics to enhance strength and durability. Sstabilization of soil is a practice used to modify the engineering behaviour of soil through mechanical processes or the incorporation of cementitious and chemical additives, depending on the desired performance characteristics.Mechanical stabilization refers to the densification and reorientation of soil particles through compaction, resulting in improved particle packing and enhanced strength characteristics.Chemical stabilization means adding stabilizing agents like cement, lime, fly ash, or other additives that react with soil particles to make them bind together stronger and make the soil matrix as a better . Traditionally, lime and cement have been widely used as stabilizing materials to improve soil strength and reduce plasticity. However, the increasing cost of these materials and their environmental impacts have encouraged researchers to investigate alternative stabilization materials .

In recent years, significant interest has been directed toward the use of agricultural and industrialbyproducts in soil stabilization owing to their cost-effectiveness, widespread availability, and environmental sustainability. Fly ash and steel slag (GGBS) are one of the two examples of industrial by-products that have been used successfully to make expansive soils better. FA, which is generated as a residue from thermal power plants, has been found to improve bearing capacity and enhance soil strength when mixed with expansive soil . The addition of FA also helps reduce plasticity and swelling potential in expansive soil. Similarly, agricultural wastes such as RHA, bagasse ash and sawdust ash have also been investigated as environmentally sustainable stabilizing materials .RHA has a lot of silica in it, and it also has pozzolanic properties that help make soil better in strength . Bagasse ash obtained from sugar industries has also been reported toimprove the engineering behavior of expansive soils.Recent research has further investigatedthe combined use of different waste materials to enhance efficiency of soil stabilization andusing bagasse ash and ceramic waste powder has been shown to greatly enhance the strength andbearing capacity of expansive soil. Similarly, mixtures of FA and RHA have demonstrated improved strength and compaction parameters of stabilized soil used in pavement construction . The application of waste materials in soil stabilization process provides significant engineering advantages while also serving as an environmentally sustainable solution for the effective management of industrial and agricultural wastes. Consequently, the stabilization of such soils with the help of waste materials has become a prominent focus of research in geotechnical engineering .

At present, the management of large volumes of industrial and agricultural waste has become a critical issue, as improper disposal practices can lead to significant environmental degradation and risks to human health. Improper waste disposal disturbs ecological balance and contributes to air and water pollution; therefore, the adoption of safe and sustainable waste management practices is essential.This review paper focuses on evaluating previous studies related to the stabilization of BCS using different industrial and agricultural wastes and analyzing theireffects on the strength, plasticity, and bearing capacity of soil.

II. LITERATURE REVIEW

Saxena et al. 2024RHA (0%, 15%, and 30%) and FA (10%, 20%, and 30%) were mixed with the expensive soil in different amounts and there were nine different combinations tested with UCS. Research shows that using FA and RHA can improve soil engineering properties makes the soil stronger and less affected by moisture. The best mix for stronger soil is 15% RHA to 30% FA. Regression Analysis confirms the effectiveness of this mix.

Priya et al. 2021 The Experimental Study on the stabilization of BCS using varying percentages of FA (0%, 5%, 10%, 20%, and 30%) is done. The addition of 20% FA shows the decrease in OMCincrease in MDD. The CBR test showed a substantial increase in CBR for 30% FA. Overall, the incorporation of fly ash significantly improves the compaction characteristics and bearing capacity of BCS. These results show that fly ash can be an economical alternative to traditional methods of stabilizing weak expansive soils to improve their performance.

Zulufqar Bin Rashidet al. 2018investigates how BCS performs when stabilized with 15%, 20%, and 25% FA. The ideal mix of BCS and by-product is 80% soil and 20% FA. Increasing FA leads to a drop in the plastic limit and rise in the liquid limit&lowers the soil's plasticity index. When FA exceeds 20%, the OMC increases, but the maximum MDD decreases.

Rajendra B. et al. 2017 indicates that GGBS results in lower dry density compared to both cement and FA at any mix ratio. cement yields the highest dry density but it is costly as compared to others. FA provides greater soil stability in comparison to both GGBS and cement.

Therefore, FA is recommended for soil stabilization as it is both cost-effective and environmentally sustainable.

Gupta T 2022demonstrates the using RHA (8-10%), Bagasse Ash (10-14%), and cement (4-6%), to enhance the geotechnical properties of BCS. The results showing optimal mix for maximum compressive strength is 6% cement, 14% Bagasse Ash, and 10% RHA also having good results of MDD & OMC.

Biswas et al. 2021 Mixing rice husk ash with cement made the decrease in liquid limit and MDD and increase in OMC. An optimum RHA content of 12% yielded the highest California Bearing Ratio (CBR).The silica particles present in RHA not only replace the exchangeable ions in clay minerals but also enhance the soil's strength, leading to decreased shrinkage and swelling tendencies of the clay.

Ingabire et al. 2023examined the stabilization of BCS using Saw Dust Ash (SDA) and RHA . Key findings revealed that adding 6% SDA and up to 9% RHA improved soil compaction and strength, as indicated by rise in MDD and fall in OMC. The results highlight the effectiveness of these additives in soil stabilization.

Gouda et al. 2024performed the tests carried out on natural and Bagasse Ash-treated BCSat varying concentrations of 0, 4, 8, 12, and 16% shows significant improvement in its properties. Specially, the Atterberg's limits, indicating enhanced soil behavior. Also, the compaction characteristics of treated soil improved across all concentrations. Among these, an 8% Bagasse Ash gives good results. This approach helps to reduce environmental issues related to the disposal of Bagasse Ash waste.

Khan et al. 2021taken Different proportions of BCS, yellow soil, and moorum and mixing is done with FA (20to 80%). The different samples were tested to determine index properties. Scanning Electron Microscopy (SEM) and X-ray Diffraction Analysis (XRD) were also used to look at the soil and Fly ash composition and particle properties. The results showing the Soil Stabilization of BCS is effective with 10-20% FA; higher amounts can weaken the soil reducing MDD.

Gupta et al. 2016explores the stabilization of BCS with river sand, FA, and marble dust turns it into a well-graded material. The optimal mix found is BCS (100%), SD (30%), FA (15%) & MD (12%). UCS shows 107.32% improvement with increase in MDD. TheCBR values increase by 189.20% (soaked) and 99.86% (un-soaked). XRD analysis reveals that calcium minerals, enhancing strength also reducing swelling, which replace the dominant swelling mineral, Montmorillonite.

Yadu et al. 2011 the study represents Stabilization of BC Soil with FA (5 to 15%) and RHA (3to 15%). The MDD of the soil is increased when fly ash was added. Strength evaluations through CBR and UCS tests indicated optimum dosages of 12% FA and 9% RHA, leading to improvements in soaked CBR of about 190% and 50%, respectively. The UCS for soil treated with these optimal amounts of FA and RHA was approximately 200% and 80% higher than the untreated soil. FA demonstrated superior performance compared to RHA in terms ofUCS and CBR values.

Kushwaha et al. 2019 The study includes testing of expensive soil with FA, in varying proportion from 0% to 50% for 0 to 45 days of curing period in two stages. The results were satisfactory with 20% FA and a curing time of 28 days. FA made BCS more stable by lowering its plasticity and increasing its strength. Combining FA with other additives may further enhance plasticity, strength, and other geotechnical properties.

III. RESEARCH GAP

Recent research has extensively explored the stabilization of expansive soils using various industrial and agricultural by-products, including FA, RHA, bagasse ash, marble dust,steel slag, and GGBS. The incorporation of these stabilizers has been reported to enhance the engineering properties of soil, particularly in terms of strength development and improved compaction behaviour.

However, most of the existing studies focus on individual stabilizers or limited combinations of materials, and only a few investigations compare the performance of multiple stabilizers under similar conditions. In addition, although several studies report optimum dosage levels for individual stabilizers, a comprehensive evaluation of dosage–strength relationships across different stabilizers and soil types are still limited. Therefore, a systematic analysis of the influence of different stabilizers and their optimum dosages on the strength of expansive soils is required to better understand their comparative performance and suitability for soil stabilization applications.From the above research gap, the following objectives are formulated.

- To study the engineering characteristics and problems associated with particularly black cotton soil.
- To review different soil stabilization techniques used to enhance the performance of expansive soils.
- To evaluate the efficiency of industrial and agricultural byproducts, including RHA, FA, SBA, steel slag, and GGBS, in the stabilisation of expansive soils.
- Toassess the impact of these waste materials on fundamental engineering properties.

IV. MATERIALS USED

1. **Black Cotton Soil:** BCS is a highly expansive clay soil that experiences considerable swelling when it absorbs water and shrinkage during dry conditions . Clay minerals like montmorillonite make it very plastic and cause it to change its volume. Because of these properties, structures built on untreated BCS often experience foundation cracking and pavement deformation . Similar observations regarding the problematic nature of expansive soils have also been reported by .

2. **Sugarcane bagasse Ash (SBA)**:SBA comes from burning bagasse, which is the fibrous material left over after sugarcane juice is taken out in sugar factories. The ash is rich in silica and other reactive compounds that exhibit pozzolanic behaviour, enabling it to function effectively as a stabilizer for expansive soils. Incorporation of SBA has been reported to enhance compaction characteristics while decreasing the plasticity index of black cotton soil. Similar improvements in soil strength using SBA have also been observed by .

3. **Steel Slag (SS)**:Steel slag is a waste product formed during the manufacturing of steel when impurities are removed from molten metal using fluxes. This material contains compounds such as silica and iron oxides, calcium oxide,which promote to its stabilizing properties . When used as a stabilizer, steel slag can improve the bearing capacity and strength of such soils .

4. **Ground granulated Blast Furnace Slag (GGBS)**:It is obtained as a waste product at the time of pig iron production in blast furnaces. Although GGBS is not directly cementitious, it develops hydraulic binding properties when activated by lime or alkaline materials. Using GGBS to stabilize soil makes it stronger and less susceptible to swelling.

5. **Fly Ash (FA)**:Fly ash (FA) is a fine particle byproduct that comes from burning coal in thermal power plants. It is collected from flue gases with the help of electrostatic precipitators. The material mainly contains silica, alumina and calcium compounds which provide cementitious and pozzolanic properties. Studies have shown that the addition of FA can reduce plasticity and significantly increase theCBR of expansive soils.

6. **Rice Husk Ash (RHA)**: RHA is formed by burning the outer shell of rice grains, which is separated during the milling process . The ash has a lot of amorphous silica in it, which reacts with calcium compounds in the soil to make the soil particles stick together and formation of cementitious products. The mixing of RHA has been found to improve soil strength and reduce swelling potential in expansive soils.

7. **Sawdust Ash (SDA)**: Sawdust ash is obtained by burning sawdust waste generated in timber and wood processing industries . The fine particle size of the ash contributes to improved soil gradation and enhances compaction characteristics. Research studies have also indicated that sawdust ash contributes to improved compressive strength of stabilized soils .

8. **Ceramic Waste Powder (CWP):** Ceramic waste powder is generated during the processing and

finishing operations in ceramic manufacturing industries . The material contains silica and alumina compounds that can enhance the stability and strength of expansive soils when used as a stabilizer .

9. **Marble Dust (MD)**:Marble dust is formed during cutting, grinding and polishing actions in marble processing industries. The fine particles and calcium carbonate content of marble dust can improve soil density and reduce plasticity when added to expansive soils . Studies have also reported development in compaction and strength properties of stabilized soil when marble dust is used .

10. **Brick Dust (BD)**: Brick dust, derived from crushed brick waste, has been utilized as a stabilizing material for enhancing the properties of expansive soils. The addition of brick dust improves shear strength and reduces swelling behaviour of BCS.

V. METHODS USED

1. **Atterberg Limits:**These tests are commonly used to evaluate changes in the plasticityof expansive soils after stabilization . A reduction in liquid limit and plasticity index was reported when FA was added with BCS, indicating improved soil workability . A similar reduction in plasticity index was observed with fly ash stabilization. The plasticity of expansive soil was also found to reduce when RHA and sawdust ash were used as stabilizing materials .

2. Grain Size Distribution Test: It is used to classify soils and identify structural changes after stabilization . The addition of stabilizing materials resulted in aggregation of clay particles and a reduction in fine soil fractions . A shift toward coarser soil gradation due to flocculation of clay particles was also reported when FA and RHA were added to expansive soil .

3. Specific Gravity Test: Specific gravity testing helps determine the relative density of soil particles and stabilizing materials.An increase in density of stabilized soil mixtures was observed due to the relatively higher specific gravity of stabilizers such as FA and lime. Improved compaction behaviour and increased soil density were also observed when expansive soil was stabilized with GGBS and FA.

4. Free Swell Index / Swell Potential Test: These tests are used to estimate the swelling properties of expansive soils. A significant decrease in swell potential was reported when FA was added to expansive soils. A similar decrease in swelling behaviour was also observed when RHA was used as a stabilizing material .

5. Standard Proctor Test (MDD and OMC): Standard Proctor tests are widely conducted to determine MDD and OMC of soil mixtures . Arisein MDD and a slight reduction in OMC was reported when FA was added to BCS.Improved compaction characteristics were also observed when expansive soil was stabilized with mixtures of FA and RHA.

6. Unconfined Compression Strength (UCS) Test: This test is commonly used to determine strength improvement in stabilized soils .When expansive soil was stabilized withbagasse ash and cement, the compressive strength increased significantly.Strength improvement was also reported when FA and GGBS were used as stabilizing materials. Additional strength gain after curing was observed when mixtures of FA and RHA were incorporated in expansive soil .

7. California Bearing Ratio (CBR) Test: The loadbearing capacity of soils is determined by CBR test which is used for pavement subgrades . An increase in CBR was observed with fly ash stabilization of BCS. Higher CBR values were also reported with increasing FA content in expansive soil .

VI. DISCUSSIONS

Studies have reported that untreated soil generally shows high liquid limit and plasticity index values, indicating poor engineering performance and moisture sensitivity.Accordingly, the application of stabilization techniques is essential to enhance thestrength and stability of the soil for construction purposes.

Industrial by-products such as FA and GGBS have been widely used for soil stabilization. The addition of FA reduces soil plasticity and increases strength due to the development of cementitious substances. Similarly, improvements in compressive strength and CBR values were observed when FA was mixed with BCS. GGBS has also been found to enhance strength and compaction characteristics through hydraulic reactions that improve bonding between soil particles.

Agricultural wastes such as RHA and bagasse ash have also shown positive effects on soil stabilization. These materials reduce plasticity and improve strength because of their pozzolanic properties. Similar improvements in compaction behaviour and swelling reduction were observed when RHA and sawdust ash were used in expansive soil . Here Graphical representation done for BCS stabilized with RHA.

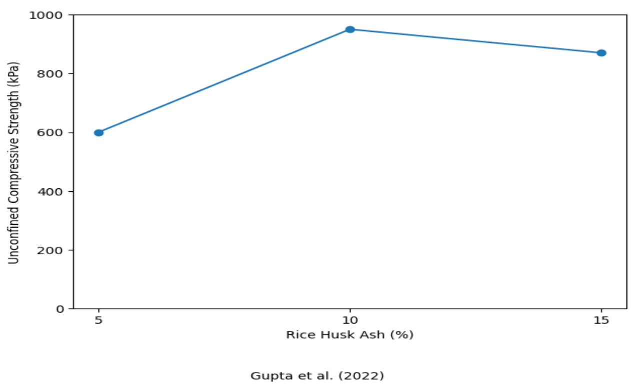

Figure 1 Compares the variation of UCS for dosages (5%, 10%, 15%) of Cement + RHA + SBA used for

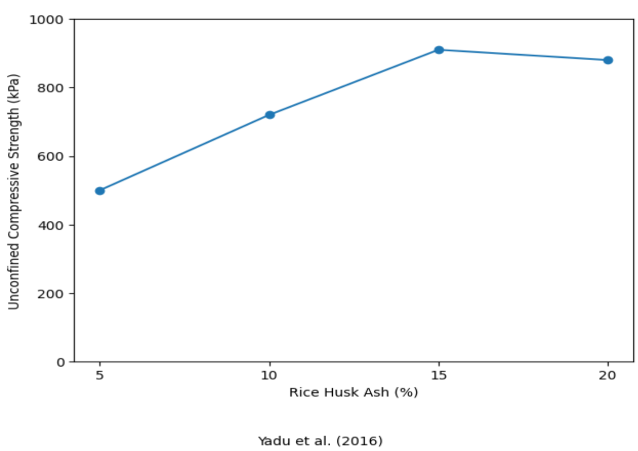

Figure 2 Compares the variation of UCS for dosages (5%, 10%, 15%, 20%) of FA+RHA+SBA+MD used for Study[12]

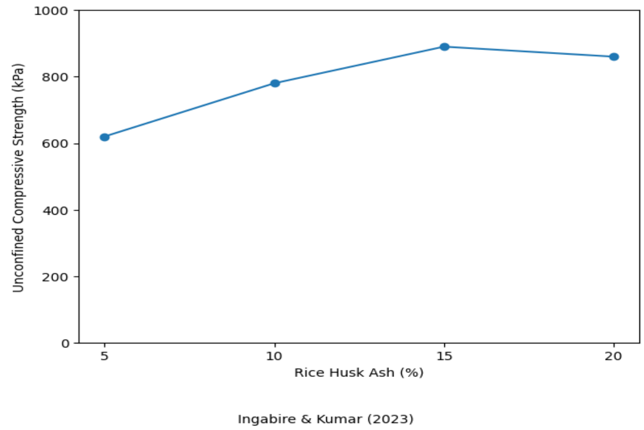

Figure 3 Compares the variation of UCS for dosages (5%, 10%, 15%, 20%) of RHA + Sawdust ash used for Study [8]

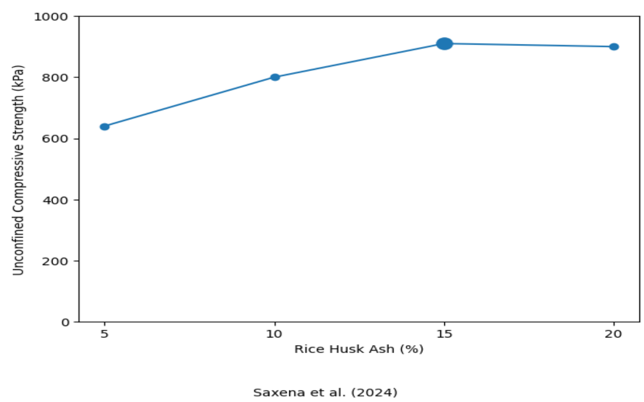

Figure 4 Compares the variation of UCS for dosages (5%, 10%, 15%, 20%) of FA + RHA used for Study

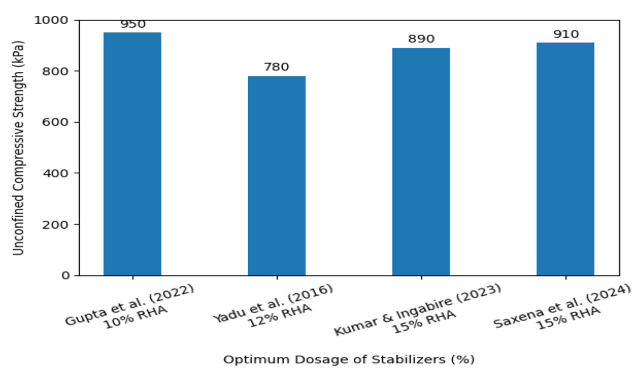

Figure 5 Compares the Maximum UCS achieved for Optimum dosage of RHA used for studies

Table 1: Comparative UCS of Soils Reported in Various Studies

S N	Authors (Year)	Type of Soil	Materials used for Stabilization	% of Stabilizers used	Highest strength achieved at % of stabilizer	Highest strength UCS (kPa)
1	Dauda et al. (2020)	BCS	Bagasse ash	5, 10, 15, 20	15	840
2	Yadu et al. (2016)	BCS	FA + RHA + SBA + MD	5, 10, 15, 20	15	910
3	Priya & Singh (2021)	BCS	FA	5, 10, 15, 20	20	820
4	Gupta et al. (2022)	BCS	Cement + RHA + SBA	5, 10, 15	10	950
5	Ingabire & Kumar (2023)	BCS	RHA + Sawdust ash	5, 10, 15, 20	15	890
6	Rajendra et al. (2017)	BCS	GGBS + FA	5, 10, 15, 20	20	1020
7	Biswas et al. (2021)	BCS	Agricultural waste ash	5, 10, 15, 20	20	860
8	Saxena et al. (2024)	BCS	FA + RHA	5, 10, 15, 20	15	910
9	Noolu et al. (2020)	BCS	Alkali activated GGBS	5, 10, 15, 20	20	1100
10	Murmu et al. (2019)	Clay soil	Industrial waste stabilizer	6, 12, 18, 24	18	920
11	Dhorey et al. (2025)	Clay soil	NaOH activated GGBS	5, 10, 15, 20	15	1180
12	K Sharma & et al. (2012)	BCS	Activated slag binder	10, 20, 30	30	1120
13	Corrêa-Silva et al. (2020)	Expansive clay	GGBS stabilized soil	10, 20, 30	20	990
14	Rios et al. (2019)	Clay soil	GGBS stabilization	10, 20, 30, 40	40	1200

The results presented in Figures 1–5 and Table 1 show that The incorporation ofagricultural and industrial waste materials significantly enhances the strength parameters of expansive soils. In case of rice husk ash stabilization, the UCS values generally increase with increasing stabilizer content up to an optimum dosage, after which a slight reduction in strength is observed. For example, Gupta et al. (2022) reported a maximum UCS of about 950 kPa at 10% RHA, while Yadu et al. (2011) and Ingabire & Kumar (2023) reported optimum strength values at approximately 15% RHA with UCS values around 890–910 kPa. Similar strength enhancement trends were also observed by Saxena et al. (2024), where the use of fly ash and rice husk ash in a mixed proportion produced a UCS value of approximately 910 kPa.

The comparative data summarized in Table 1 indicate that the optimum stabilizer dosage for most waste materials typically ranges between 10% and 20%. Agricultural wastes like bagasse ash rice husk ash generally produce UCS values between 760 kPa and 950 kPa, while industrial waste materials like steel slag,GGBS andfly ash show higher strength improvements ranging from 960 kPa to 1200 kPa. Among the reviewed stabilizers, alkali-activated slag systems demonstrated the highest strength values, reaching up to 1180–1200 kPa because strong cementitious compounds are forming in the soil matrix.

VII. CONCLUSION

This review study evaluated the stabilization of expansive soils, particularly black cotton soil, using various industrial and agricultural waste materials. Expansive soils shows high plasticity, swelling–shrinkage behaviour and low strength, which make them unsuitable for construction without stabilization. The reviewed literature indicates that the incorporation of waste materials such as rice husk ash, bagasse ash, steel slag,GGBS and fly ash substantiallyenhances the engineering properties of such soils. These stabilizers help make the material less plastic and less likely to swell, while also making it easier to compact and stronger.

Experimental results indicate that UCSnormally increases with increasing stabilizer dosage up to an optimum value. Most studies reported optimum stabilizer content within the range of **10–20%**, depending on soil type and stabilizer composition. Agricultural waste materials produced UCS values rangingfrom **760–950 kPa**, while industrial wastes like steel slag, GGBS and fly ash achieved higher strength values of about **960–1200 kPa**. Among the reviewed stabilizers, slag-based materials such as GGBS showed the highest strength improvement due to their strong cementitious reactions.Overall, the use of industrial and agricultural wastes provides an efficient and sustainable approach for enhancing the engineering performance of expansive soil.

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