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Experimental Study on Stability of Black Cotton Soil Mixed With GGBS, Nano-Silica and Rice Husk Ash

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Abstract: *Black cotton soil (BCS), known for its high plasticity, low strength, and significant swelling and shrinkage behaviour, poses serious challenges for civil engineering infrastructure. This study investigates the stabilization potential of BCS using an innovative blend of industrial and agricultural by-products—Ground Granulated Blast Furnace Slag (GGBS), nano-silica, and Rice Husk Ash (RHA). The primary objective is to enhance the geotechnical properties of BCS while promoting sustainable and cost-effective construction practices.*
A series of laboratory experiments were conducted by incorporating varying percentages of GGBS (10%–30%), nano-silica (0.3%–0.9%), and RHA (5%–15%) both individually and in combination. Tests performed include Atterberg limits, standard Proctor compaction, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and free swell index. Results indicate significant improvement in UCS and CBR values with the combined addition of 30% GGBS, 10% RHA, and 0.6% nano-silica, along with a notable reduction in plasticity and swelling potential.

Keywords: *GGBS (Ground Granulated Blast Furnace Slag), Nano-silica, Rice husk ash (RHS) , stabilization, unconfined compressive strength (UCS).*

1. INTRODUCTION:

Black cotton soil is a type of expansive clay soil widely found in semi-arid and tropical regions, particularly in countries like India, Ethiopia, Sudan, and parts of the USA. In India, it covers nearly 20% of the total land area, especially across states like Maharashtra, Madhya Pradesh, Gujarat, and Andhra Pradesh. It is known as "black cotton" soil because it has traditionally supported cotton cultivation due to its high fertility.

Although several studies have investigated the stabilization of expansive soils using individual materials such as GGBS or rice husk ash, limited research has been conducted on the combined effect of GGBS, nano-silica, and rice husk ash on black cotton soil. The synergistic interaction among these materials may significantly enhance soil stability and strength characteristics while reducing environmental impact and construction costs.

The soil originates from the weathering of volcanic basalt rocks and is rich in montmorillonite—a clay mineral that exhibits significant volume changes with moisture variations. This results in high swelling when wet and substantial shrinkage during dry conditions. These volume changes lead to serious engineering problems, especially in foundations, roads, pavements, and other load-bearing structures.

Modern research emphasizes the use of industrial and agricultural waste materials as alternative stabilizers, which are not only effective but also environmentally friendly. In this study the materials are used to enhance the soil properties such as Ground Granulated Blast Furnace Slag (GGBS), Rice Husk Ash (RHA), Nano-Silica offer pozzolanic activity, improve soil strength, and reduce swelling tendencies. These additives react with the calcium in soil or lime to form cementitious compounds likecalcium silicate hydrate (C–S–H), which improve the soil structure and load-bearing properties.

This section of the paper discusses the procedures being conducted in the laboratory. Stabilization of soil by GGBS couldn't just take care of the issue of appropriate stabilization of black cotton soil, yet in addition settle the issue of removal of a modern waste for example GGBS. The properties of black cotton soil can be modified by stabilizing the soil with the use of additives or stabilizers like Lime (6%), GGBS (30%) & Nano silica (0.3%, 0.6% & 0.9%). There is increase in various geotechnical properties like liquid limit, and plastic limit, Plasticity index, compaction characteristics, unconfined compressive strength, and swelling pressure were determined. An experimental investigation is carried out to study the influence of admixture in soil with respect to the strength characteristics. In this comparative study laboratory tests such as Atterberg's limit, Compaction test, swelling index and California, Unconfined compressive strength (UCS) test were carried out for black cotton soil.

1.1 Materials

A. Black cotton soil

Soil used in experimental investigation was a locally available black cotton soil from Patel Nagar Bhopal Madhya Pradesh. The soil was classified as CH and based on FSI value the soil had high swell characteristic. Black cotton soil possesses great threat for the construction of the buildings due its less characteristics shear strength and high swelling characteristics. The structures on Black cotton soil (BC soil) bases develop undulations at the road surface due to loss of strength of the sub-grade through softening during monsoon. Due to its characteristics, it forms a very poor foundation material for road construction.

Fig 1 .Black cotton soil

B. Ground Granulated Blast Furnace Slag (GGBS)

The blast furnace slag is produced as a by-product during the manufacture of iron in a blast furnace. Molten blast furnace slag has a temperature of 1300-1600C and is chilled very rapidly to prevent crystallization. Ground-granulated impact furnace slag is gotten by extinguishing liquid iron slag from a shoot furnace in water or steam, to create a polished, granular item that is then dried and ground into a fine powder. The granulated material thus produced is known as granulated blast furnace slag. Blast furnace slag has a glassy, disordered, crystalline structure which can be seen by microscopic examination which is responsible for producing a cementing effect. Ground Granulated Blast Furnace Slag was gotten from Janta steel and cement bhopal, Madhya pradesh.

Fig 2. Ground Granulated Blast Furnace Slag (GGBS)

C. Nano-silica

The nano-silica powder which was utilized in the trial examination for stabilizing the black cotton soil was acquired from Shankareshwar Minerals Bhopal having size 250nanometer shown in fig .

Fig.3 Nano silica powder

D. **Rice Husk Ash**

stabilization of black cotton soil is the use of rice husk ash (RHA). RHA is a by-product of the burning of rice husks and has been found to be an effective stabilizing agent due to its pozzolanic properties. When mixed with black cotton soil, RHA reacts with the calcium hydroxide in the soil to form cementitious compounds, which helps to reduce the soil's swelling and improve its load-bearing capacity. The process of stabilizing black cotton soil with RHA involves excavating the soil to the desired depth and then mixing it with RHA using a mixer. Water is then added to the mixture to obtain the desired consistency, and the soil is compacted using rollers or vibrators. Rice husk ash is collected at Jai Bhawani Agency Bhopal.

Fig 4 Rice husk ash

2. LITERATURE REVIEW:

A literature search focused on information pertaining to soil, ggbs, nano silica and waste like Ground Granulated Blast Furnace (GGBS) are used to improve the strength, bearing capacity of the soil and reduce shrinkage and Swelling index of the soil. This search involved domestic and international sources available from public agencies, industry, academic institutions, and other organizations.

Manaviparast (2025): A Comprehensive Review on Clay Soil Stabilization Using Rice husk ash and lime sludge Very recent review comparing RHA and lime sludge as sustainable alternatives, summarizing experimental findings and knowledge gaps for scale-up.

Muthiah Maheswaran (2025) : "Synergistic effect of agro-industry by-product and silica nanoparticle on the fresh, mechanical, durability and microstructure enhancement of fly ash and GGBS" — Demonstrates that combining RHA with nano silica and FA/GGBS improves mechanical and durability properties of geopolymer stabilized materials—focus on sustainable building materials.

Lihua Li (2025): "Mechanical properties of soil reinforced by fibre and alkaline activated rice husk ash, and rainfall erosion model tests" . Very recent experimental paper investigating polypropylene fibre + alkali-activated RHA for slope/subgrade reinforcement; shows fibres improve toughness and ductility while geopolymer matrix gives stiffness.

Ikeagwuani & Ross (2019): "Emerging trends in expansive soil stabilisation" — Comprehensive review describing conventional (lime, cement) and emerging methods (geopolymers, industrial by-products, nanomaterials), with comparisons of performance, environmental impacts and recommendations for practice.

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Barman et al. (2022):"Stabilization of expansive soils using chemical additives" — Review and meta-analysis showing how additives (lime, cement, GGBS, nano silica) influence engineering properties; highlights optimum dosages and the accelerating role of nano silica in pozzolanic reactions.
Parthiban et al. (2022): "Role of industrial based precursors in the stabilization (geopolymer focus)"— Reviews geopolymer-based stabilization (FA, GGBS, RHA) for expansive soils, explaining parameters (alkaline activator, Si/Al ratio) that control strength and durability.
Hanifi Canakci, (2019):"Performances of Using Geopolymers Made with Various stabilizers for deep mixing" stabilizers for deep mixing" . Experimental study showing geopolymer binders made with fly ash, slag and RHA can significantly increase UCS of clay when used in deep mixing; provides microstructural evidence of new binding gels.
Almuaythir et al. (2024) :"Sustainable soil stabilization using industrial waste ash" — Focus on multiple industrial wastes (silica fume, kiln ash, RHA, GGBS); compares engineering performance and notes which by-products best replace cement for different soil types.
Khajeh et al. (2024) :"A state-of-the-art review on the application (lime sludge etc.)" — Recent review of lime sludge and related wastes for soil stabilization; examines treatment routes, environmental leachability and engineering outcomes.
Bell (1996): "Lime stabilization of clay minerals and soils" — Classic experimental/interpretive study that explains the mechanisms (cation exchange, flocculation, pozzolanic reactions) by which lime improves strength and reduces plasticity of clays; shows how mineralogy (kaolinite vs montmorillonite) controls the response.
Ikeagwuani & Ross (2019):"Emerging trends in expansive soil stabilisation" — Comprehensive review describing conventional (lime, cement) and emerging methods (geopolymers, industrial by-products, nanometer.
Mehta & Others (2018): "Sustainable geopolymer concrete using GGBS" — While focused on concrete, this influential paper provides background on activation of GGBS and RHA that is directly transferable to geopolymer soil stabilization formulations.
Canakci / PMC & related works (2019–2023): "Performances of geopolymers and by-products for soil stabilization" (multiple experimental papers) Aggregate experimental evidence that fly ash, slag, glass powder, marble, RHA and other by-products can be combined and activated to create effective stabilizers—includes practical mix windows and microstructural support.
Ar Razi Alvee (2021) : "Experimental study of the Mechanical Properties and micro structure of geopolymer paste containing nano silica from agricultural waste and crystalline admixtures" — Lab work demonstrating that adding 2–4 % nano silica (from RHA) to geopolymer/soil mixes increases compressive strength and refines microstructure—nano silica accelerates matrix densification.

3. OBJECTIVES : To investigate the engineering properties of untreated black cotton soil, including Atterberg limits, compaction characteristics, unconfined compressive strength (UCS and swelling behaviour.

- To evaluate the effect of Ground Granulated Blast Furnace Slag (GGBS) on the strength and stability of black cotton soil when used as a stabilizing agent in varying proportions.
- To study the influence of nano-silica (from rice husk ash) on the geotechnical behaviour of black cotton soil and its synergistic effect when combined with GGBS.
- To determine the optimal mix ratio of GGBS and nano-silica that results in maximum improvement in strength and reduction in plasticity and swelling characteristics of the soil.
- To explore the potential of using industrial and agricultural by-products (GGBS and rice husk ash) as sustainable alternatives for soil stabilization.

4. METHODOLOGY : The research methodology involved systematic laboratory tests to study the stability of black cotton soil blended with Ground Granulated Blast Furnace Slag (GGBS), Nano Silica, and Rice Husk Ash (RHA). The soil sample collected from the site was first tested for its natural properties: liquid limit , plastic limt, plasticity index , specific gravity , and maximum dry density with an optimum moisture content of . To improve stability, the soil was mixed with varying percentages of GGBS , Nano Silica , and RHA . Compaction tests showed an increase in maximum dry density to 1.82 g/cc and reduction in OMC . The unconfined compressive strength improved from (untreated) to with the optimum mix. These results confirm that the additives significantly enhance the load-bearing and swelling resistance of black cotton soil.

The remaining tests performed on the soil sample are as follows:
a) Specific gravity
b) Test for free Swell Index
c) Unconfined Compressive Strength

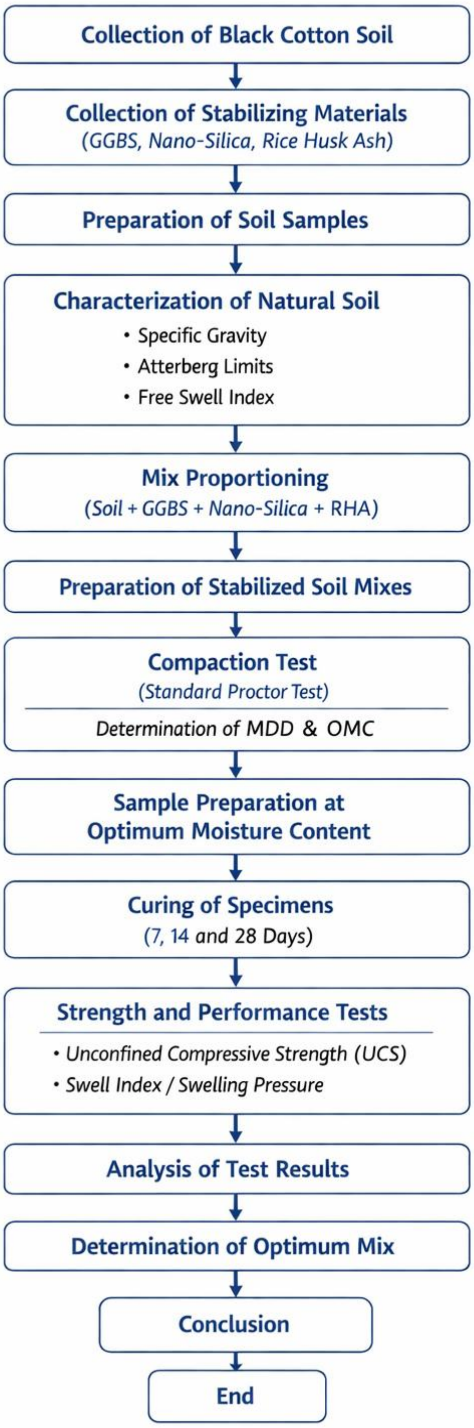

Fig. 5 Methodology flow chart

5. RESULTS & DISCUSSION :

In this investigation, different tests were led on stabilized soil and characteristic soil. After the basic test on soil conducted then next step will be similar test conducted for GGBS, RHA and nano silica with different percentage which percentage gives better strength, higher CBR value, more UCS values and less OMC it will be taken to next procedure of testing. After complication of test on GGBS, RHA and nano silica finalize the combination. Which combination gives better strength, higher CBR value, more UCS values and less OMC it will be considered for final project. Comparing the values of GGBS and RHA which combination gives better strength, higher CBR value, more UCS values, and less OMC that combination is mixed with % of nano silica.

The experimental investigation on the stabilization of Black Cotton Soil (BCS) using Ground Granulated Blast Furnace Slag (GGBS), Nano-silica, and Rice Husk Ash (RHA) demonstrates that a combined stabilizer mix significantly enhances the geotechnical properties of expansive soil. The primary objective of this project was to evaluate how varying percentages of these additives influence consistency limits, compaction characteristics, swelling behaviour, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS). Overall, the study confirms that blended stabilizers create a strong pozzolanic reaction, resulting in reduced plasticity, improved strength, and better suitability for construction applications.

The consistency limit tests reveal that all stabilizers help in reducing soil plasticity, making the soil less expansive and easier to work with. The Plastic Limit increased from **27.8% (untreated soil)** to **35.78%** for the combination of **BCS + 10% GGBS + 1% Nano-silica + 5% RHA**, indicating improved workability. Similarly, the Liquid Limit gradually decreased with additives, and the Plasticity Index dropped sharply from **36.92** for untreated soil to **11.22**, the lowest for the blended mix. This demonstrates that the combination of GGBS, Nano-silica, and RHA significantly minimizes soil plasticity through enhanced binding and reduced clay activity.

The Specific Gravity of soil showed slight reduction with increasing percentages of additives, especially RHA, due to its naturally low density. However, this reduction is not detrimental and aligns with expected pozzolanic behaviour. Compaction test results indicate substantial improvement in Maximum Dry Density (MDD) with GGBS and Nano-silica. The highest MDD recorded was **1.85 g/cc** for the mix containing **15% GGBS**, confirming that GGBS plays a major role in enhancing compaction and particle interlocking. The Optimum Moisture Content (OMC) also decreased with additives, except in mixes containing higher RHA, which tends to absorb more moisture.

Free Swell Index (FSI) results show a dramatic reduction from **135%** for untreated soil to just **45%** for the blended mix of **10% GGBS + 1% Nano-silica + 5% RHA**. This proves that the stabilizers effectively mitigate swelling potential by reducing pore spaces and forming cementitious products. The Soil becomes significantly more stable and suitable for foundation and pavement construction.

Strength parameters showed the most notable improvements. The UCS results displayed the strongest enhancement, rising from **85 kN/m²** for untreated soil to a maximum of **220 kN/m²** for the mix of **BCS + 10% GGBS + 1% Nano-silica + 5% RHA**. This demonstrates a powerful synergistic effect between the three additives, producing denser, harder, and more durable soil structures.

The experimental findings prove that the combination of **10% GGBS + 1% Nano-silica + 5% RHA** offers the **best overall performance**, delivering the highest strength, lowest plasticity, greatest swelling reduction, and improved compaction characteristics. This optimized stabilizer blend makes Black Cotton Soil more reliable for engineering applications, particularly in road construction, embankments, and foundation support systems.

Table 1. Liquid Limit values of Black Cotton soil Stabilized with GGBS, Nano silica, RHA

S.NO.	SOIL MIXED COMPOSITION	LIQUID LIMIT %
1	Pure black cotton soil (BCS)	64
2	BCS + 10% GGBS	57
3	BCS +15%	55
4	BCS +1% Nano silica	52
5	BCS+2% Nano silica	50
6	BCS+5% Rice husk ash	58
7	BCS+10% Rice husk ash	55
8	BCS+10% GGBS+1% Nano silica	50
9	BCS+10% GGBS+5%RHA	52
10	BCS+10% GGBS+1% Nano silica +5% RHA	47

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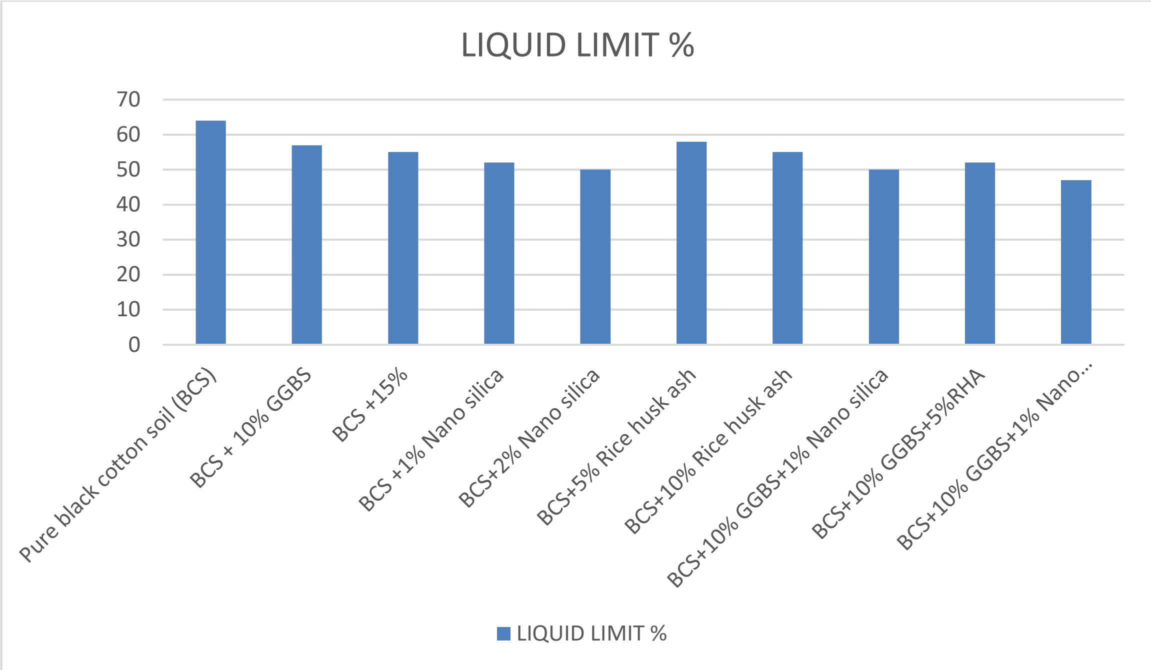

Fig.6 Liquid limit

The liquid limit decreases with the addition of GGBS, Nano Silica, and RHA. Nano Silica is more effective in reducing the LL compared to GGBS or RHA alone, due to its micro-filling and pozzolanic effect. Combinations (GGBS + Nano Silica + RHA) give the lowest liquid limit, improving soil workability and stability.

Table 2. Plastic Limit values of Black Cotton soil Stabilized with GGBS, Nano silica, RHA

S.NO.	SOIL MIXED COMPOSITION	PLASTIC LIMIT %
1	Pure black cotton soil (BCS)	27.8
2	BCS + 10% GGBS	30.5
3	BCS +15%	32.5
4	BCS +1% Nano silica	33
5	BCS+2% Nano silica	32
6	BCS+5% Rice husk ash	29
7	BCS+10% Rice husk ash	31
8	BCS+10% GGBS+1% Nano silica	35
9	BCS+10% GGBS+5%RHA	33
10	BCS+10% GGBS+1% Nano silica +5% RHA	35.78

- BCS + 10% GGBS + 1% nano-silica gives 35%.
- The highest plastic limit is obtained with BCS + 10% GGBS + 1% nano-silica + 5% RHA = 35.78%.
- The addition of GGBS, nano-silica, and RHA-individually or in combination-improves the plastic limit of Black Cotton Soil, making it less plastic and more workable.
- The combined use of all three stabilizers produces the maximum improvement, indicating a synergistic effect the enhances soil behaviour more effectively than any single additive alone.

Table 3. Plasticity Index (PI) values of Black Cotton soil Stabilized with GGBS, Nano silica, RHA

S.NO.	SOIL MIXED COMPOSITION	LIQUID LIMIT %	PLASTIC LIMIT %	PI
1	Pure black cotton soil (BCS)	64	27.8	36.92
2	BCS + 10% GGBS	57	30.5	26.5
3	BCS +15%	55	32.5	22.5

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4	BCS +1% Nano silica	52	33	19
5	BCS+2% Nano silica	50	32	18
6	BCS+5% Rice husk ash	58	29	29
7	BCS+10% Rice husk ash	55	31	24
8	BCS+10% GGBS+1% Nano silica	50	35	15
9	BCS+10% GGBS+5%RHA	52	33	16
10	BCS+10% GGBS+1% Nano silica +5% RHA	47	35.78	11.22

The Plasticity Index consistently decreases with the addition of GGBS, nano-silica, and RHA. The lowest PI (11.22) is achieved when all three stabilizers are combined, showing that the mixture significantly reduces soil plasticity and improves the engineering behaviour of Black Cotton Soil.

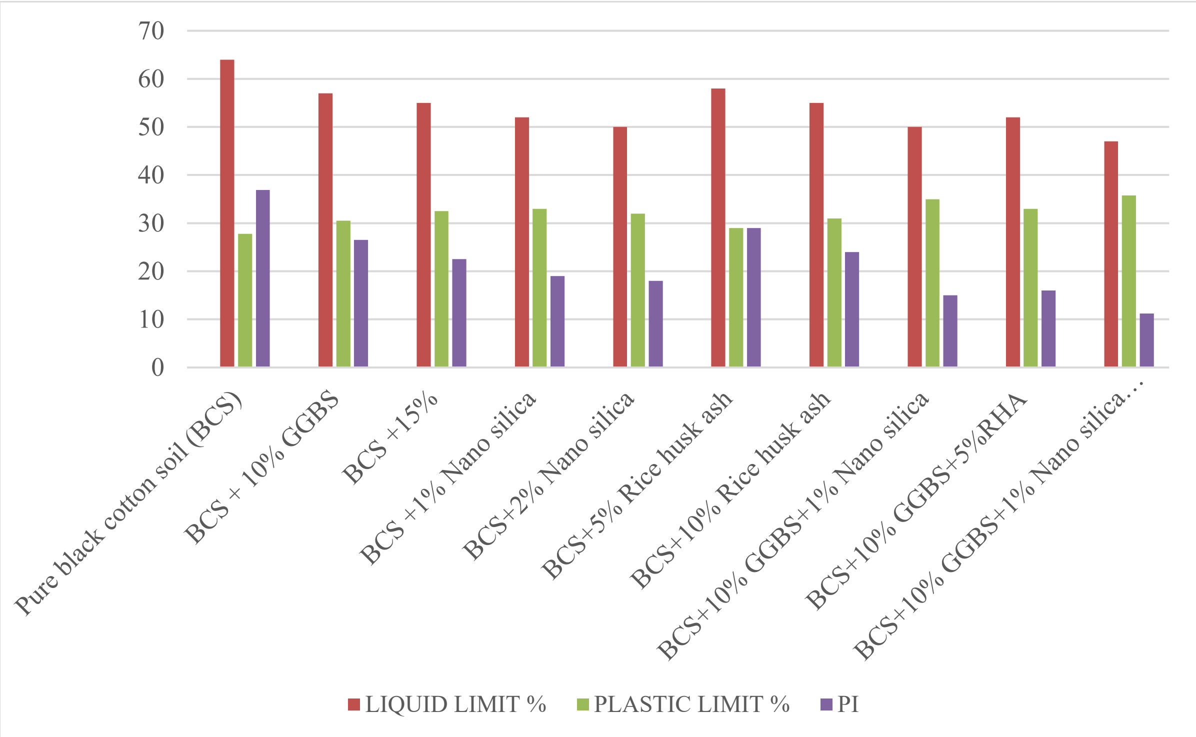

Fig. 7. Plasticity Index (PI)

Table 4. Specific gravity of Black cotton soil stabilized with GGBS, Nano silica, RHA

S.NO.	SOIL MIXED COMPOSITION	SPECIFIC GRAVITY
1	Pure black cotton soil (BCS)	2.70
2	BCS + 10% GGBS	2.74
3	BCS +15%	2.74
4	BCS +1% Nano silica	2.63
5	BCS+2% Nano silica	2.64
6	BCS+5% Rice husk ash	2.53
7	BCS+10% Rice husk ash	2.56
8	BCS+10% GGBS+1% Nano silica	2.66
9	BCS+10% GGBS+5%RHA	2.56
10	BCS+10% GGBS+1% Nano silica +5% RHA	2.59

Table 5. Compaction test of black cotton soil stabilized with GGBS, Nano silica and RHA.

S.NO.	SOIL MIXED COMPOSITION	MDD(g/cm^3)	OMC%
1	Pure black cotton soil (BCS)	1.65	20
2	BCS + 10% GGBS	1.80	17
3	BCS +15%	1.85	16
4	BCS +1% Nano silica	1.65	18
5	BCS+2% Nano silica	1.65	18
6	BCS+5% Rice husk ash	1.57	21
7	BCS+10% Rice husk ash	1.55	22
8	BCS+10% GGBS+1% Nano silica	1.80	16
9	BCS+10% GGBS+5%RHA	1.60	19
10	BCS+10% GGBS+1% Nano silica +5% RHA	1.65	20

MDD - Maximum Dry Density, **OMC** - Optimum Moisture Content
The MDD of Black Cotton Soil increases significantly with the addition of GGBS and nano-silica, indicating improved compaction and strength.
RHA, due to its low density, decreases the MDD but increases OMC. The highest MDD (1.85g/cm^3) is achieved with 15% GGBS, showing that GGBS is the most effective stabilizer for improving compaction characteristics.

Table 6.Free Swell Index (FSI) of Black cotton soil with stabilized GGBS, Nano silica, and RHA.

S.NO.	SOIL MIXED COMPOSITION	FSI
1	Pure black cotton soil (BCS)	135
2	BCS + 10% GGBS	85
3	BCS +15%	72
4	BCS +1% Nano silica	105
5	BCS+2% Nano silica	92
6	BCS+5% Rice husk ash	105
7	BCS+10% Rice husk ash	93
8	BCS+10% GGBS+1% Nano silica	65
9	BCS+10% GGBS+5%RHA	62
10	BCS+10% GGBS+1% Nano silica +5% RHA	45

This shows that blended stabilizers create a strong pozzolanic reaction, greatly reducing soil expansiveness and improving its suitability for construction.

Table 7. Unconfined Compressive Strength (UCS) of black cotton soil with stabilized GGBS, Nano silica and RHA

S.NO.	SOIL MIXED COMPOSITION	UCS(KN/m^2)
1	Pure black cotton soil (BCS)	85
2	BCS + 10% GGBS	125
3	BCS +15%	175
4	BCS +1% Nano silica	120
5	BCS+2% Nano silica	135
6	BCS+5% Rice husk ash	107
7	BCS+10% Rice husk ash	126
8	BCS+10% GGBS+1% Nano silica	198
9	BCS+10% GGBS+5%RHA	185
10	BCS+10% GGBS+1% Nano silica +5% RHA	220

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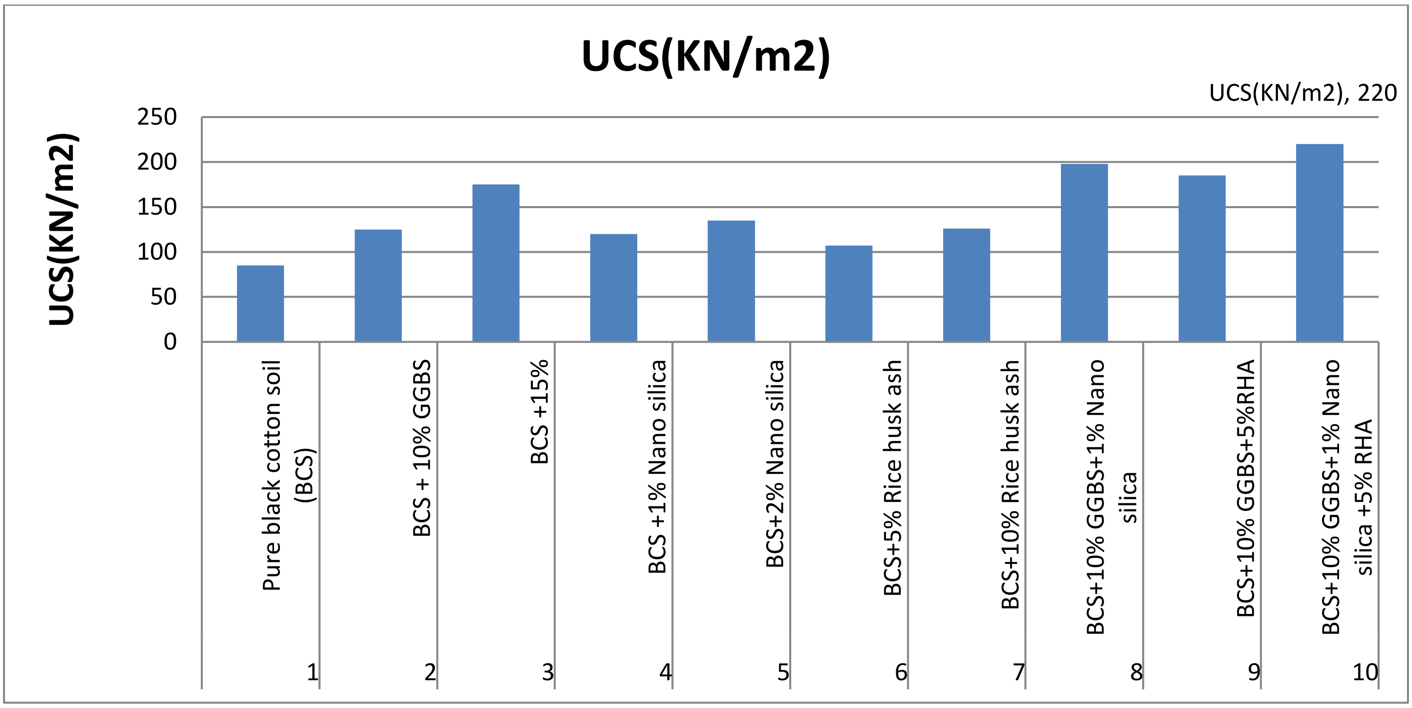

Fig.8 UCS value

The highest strength is achieved when GGBS, nano-silica, and RHA are blended together, demonstrating a strong synergistic effect through pozzolanic reactions.

6. CONCLUSION:

The results of the study indicate that the utilization of industrial waste materials can provide an economical and efficient solution for waste management while simultaneously improving the engineering properties of problematic soils. The experimental investigation shows that the combination of black cotton soil with **10% Ground Granulated Blast Furnace Slag (GGBS)** and **1% nano-silica** significantly enhances the strength characteristics of the soil. The addition of these stabilizing agents increases the **maximum dry density (MDD)** of black cotton soil while reducing the **optimum moisture content (OMC)**, indicating better compaction characteristics. It was also observed that an increase in the percentage of GGBS contributes to improved soil stability. Furthermore, the stabilized soil mixture exhibits higher **compressive strength values**, demonstrating its suitability for geotechnical and pavement engineering applications. The treatment of black cotton soil with GGBS and nano-silica also leads to a reduction in **swelling pressure**, **free swelling index**, and the **liquid and plastic limits**, thereby decreasing the expansive behavior of the soil. Overall, the study concludes that the optimum proportion of **black cotton soil mixed with 10% GGBS and 1% nano-silica** provides significant improvement in the stability and strength properties of black cotton soil, making it a sustainable and effective method for soil stabilization.

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