

Enhancing Soil Stability Through the Utilization of Waste Fiber Materials

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1. ABSTRACT

Soil stability is a core issue in civil engineering, since soil strength and carrying capacity decide the success and survival of structures resting on it. In weak or problematic soils occurring in some regions, traditional methods of stabilization rely on chemical stabilizers or manufactured materials, which are expensive and environmentally harmful. This research investigates a different method of soil stabilization using sustainable, waste-derived materials jute fibre, sugarcane bagasse ash, Rice husk ash to improve the geotechnical characteristics of Black cotton soil. The objective is to evaluate the impact of these materials on the strength, compaction, and bearing properties of the soil under laboratory testing. [1]

The research process involved the preparation of soil samples of different mixes of jute fibre, Rice husk ash and sugarcane bagasse ash and testing them under routine geotechnical tests. These consisted of the Standard Proctor Compaction Test, and California Bearing Ratio (CBR) Test. The outcome yielded unambiguous proof of the improvement in performance. [2]

Likewise, compaction test findings revealed that Optimum Moisture Content (OMC) had risen marginally from 16.5% (natural soil) to 17.1% and 17.4% for coir-treated and coir-plus-geotextile-treated soil, respectively. The Maximum Dry Density (MDD) had correspondingly reduced from 1.68 g/cm³ to 1.63 g/cm³, reflecting the lightweight nature of the fibres and their effect on soil packing efficiency. In the CBR tests, treated soils performed better under bearing, which reflected their suitability for subgrade applications. [3]

The beneficial impacts of fibre addition are due to the reinforcement mechanism, as jute fibre, Rice husk ash and sugarcane bagasse ash impart tensile strength,

cause stress distribution, and limit deformation in the soil matrix. The result is enhanced structural integrity, settlement reduction, and durability. Crucially, these fibres can be biodegradable or recycled, hence they are environmentally friendly and cost-effective relative to conventional practice. [4]

Keywords

Jute fibre, sub grade, sugarcane bagasse ash, CBR, plasticity index, Rice husk ash, Village road

Introduction

Soil, being the basic medium for all civil engineering construction operations, is the key to ensuring stability and long-term durability of civil engineering structures. But naturally, soil tends to be lacking in mechanical strength to resist external loads and environmental stresses, especially in areas where expansive or weak subgrade soils are common. Conventional techniques for improving soil stability, i.e., chemical stabilization with cement or lime, while effective, have raised environmental issues based on the high carbon footprint generated by their manufacture and use. Under these circumstances, the introduction of sustainable and environmentally friendly options has been a focus area in geotechnical engineering. [5]

New innovations in sustainable construction have also helped highlight the appropriateness of utilizing waste materials to improve the properties of soil. Among them, waste materials like Jute Fibre, Sugarcane Bagasse Ash (SCBA), and Rice Husk Ash (RHA) have proven to be promising alternatives for soil reinforcement and stabilization.

These are normally produced as by-products of agriculture and possess a dual benefit: enhancing geotechnical behaviour and facilitating the reduction of environmental waste. Jute Fibre, with its natural tensile strength and biodegradation capability, makes the soil more resistant to cracking and deformation. SCBA and RHA, being silica and alumina-rich, create pozzolanic reactions in the soil matrix, enhancing strength and compaction properties. The combination is a very sound case for application in sustainable and economically feasible soil improvement processes. [6]

Laboratory tests, such as Standard Proctor Tests, Atterberg Limits, were performed to analyse the performance of fibre-reinforced soil. [7]

By accepting waste fibres to stabilize soil, this research adds to the increasing body of sustainable geotechnical engineering. It not only helps in recycling waste materials but also provides an inexpensive means for soil improvement, particularly in developing countries where resource availability is a key concern. The results are anticipated to have an impact on the practice of future eco-friendly reinforcement of soils and open the door for new research into long-term behaviour and field application of waste fibre-reinforced soils. [8]

Literature Review

Soil stabilization by multiple reinforcement methods has long been a point of interest in geotechnical engineering. Historically, cement, lime, or chemical additives have tended to be used but, more recently, environmental and economic issues have prompted research into sustainable alternatives to these, such as the utilization of waste fibre materials. The potential for utilising natural and waste fibres like coconut coir, jute, and synthetic waste fibres to strengthen soil has been shown by a range of studies to be both viable and beneficial. [9]

Use of Fibre Reinforcement in Soil Stabilization:

Fibre-reinforced soil (FRS) has also been seen to increase shear strength, minimize settlement, and enhance ductility. Discrete randomly distributed fibres introduced into the soil inhibit the process of crack propagation and enhance energy absorption. Research by Maher and Ho (1994) showed enhanced unconfined compressive strength in clay soils with added synthetic fibres. Fibre-soil interfacial friction and mechanical interlocking are the major mechanisms. [10]

Natural Waste Fibres – Coconut Coir and Others:

Coconut coir is a coconut processing by-product, and its use in soil stabilization is becoming popular because of its high lignin content and resistance. Studies by Ramesh et al. (2010) showed that the addition of coir fibre at an optimal percentage greatly enhanced the CBR value and reduced swelling in expansive

soils. The same was observed with jute fibres, where the reinforcement enhanced tensile strength and inhibited shrinkage cracking in clayey subgrades. [11]

Synthetic Waste Materials:

Synthetic fibre wastes like geotextiles, when recycled in soil systems, provide better drainage and strength to the soil. They find special application in subgrade reinforcement and erosion control. Research has indicated that shredded tyres and polypropylene fibres improve soil performance characteristics when blended with the soil uniformly. [12]

Environmental and Economic Aspects:

Utilization of waste materials for soil stabilization adheres to the tenets of sustainable engineering. Such techniques minimize environmental impact by limiting industrial waste and lessening reliance on virgin synthetic stabilizers. Also, such techniques enhance circular economy models and tend to be cost-effective for infrastructural developments in low-income areas. [13]

Comparative Studies and Gaps:

Although numerous studies confirm the advantages of fibre reinforcement, comparisons between natural and synthetic waste fibres under the same conditions are scarce. Long-term performance, natural fibre degradation, and scalability of fibre-treated soil structures are also topics waiting to be explored further.

This review emphasizes the promise of waste fibres in geotechnical engineering and the necessity of experimental verification of their effectiveness in local soils, particularly for extensive application in field practice.

2. Material Used:

2.1 SOIL

The soil sample used in this study was obtained from Nagla Mugaria, Uttar Pradesh, extracted from a pit of 45 cm deep, already positioned 1 meter below the nearby road subgrade base, and commonly utilized for subsequent subgrade construction purposes. For preparing the representative sample of soil, it is primarily allowed to dry for two days, then ground up finely and passed through

the 4.75mm IS sieve. Figure 1 mentioned the sample collection from the field, which is locally brought up from the roadsides of rural areas.

Table 1 Physical properties of soil sample

Sr. No	Tests	Results	As per IS Code
1	Moisture Content (%)	15.906	IS-2720 - 1973 (Part2)
2	Specific Gravity	2.63	IS- 2720 - 1980 (Part 3)
3	Plastic Limit (%)	22.40	IS-2720 - 1985 (Part5)
4	Liquid Limit (%)	35.71	IS-2720 - 1985(Part 5)
5	Plasticity Index (%)	13.31	IS-2720 - 1985 (Part5)
6	OMC (%)	14	IS- 2720 - 1983 (Part 7)
7	MDD (g/cm ³)	1.744	IS- 2720 - 1983 (Part 7)

Jute fibre:

Jute fibre is a soft, shiny, long bast fibre which can be spun into coarse and strong threads. Jute is obtained from the bark of the Corchorus plant. It is one of the cheapest natural fibres and second only to cotton in terms of world production and consumption. Because of its biodegradable, renewable, and environmentally friendly nature, jute has received significant interest in many engineering applications, especially in green construction methods. [14]

Jute Fibres have been purchased from the market of Manipuri city. The Fibres are cut into pieces of approximately 20 mm lengths and are mixed in percentage of 0.5%, 1%, 1.5% and 2% by dry weight of soil. Fig.1 shows the jute pieces of admixture which is used for present research. Physical and engineering properties of jute material are shown in table 2.



Figure 1 20mm Pieces of jute fibre Admixture

Table 2 Summary of the Physical and Engineering Properties of the Tested jute fibre Material

Sr. No.	Property	Range / Value
1	Fibre length, mm	20
2	Fibre Diameter, mm	0.3-0.45
3	Specific Gravity	1.32
4	Bulk Density, Kg/m ³	1290
5	Ultimate tensile strength, N/mm ²	3350

Sugarcane bagasse ash:

Bagasse ash is a fibre content derived from sugar cane plant after the withdrawal of sugarcane juice. Bagasse waste bagasse of sugar factory is utilized as bio fuel and in production of paper. The sugar industry gives 30% bagasse from every lot of crushed sugar cane, when burnt this bagasse the ash thus produced is termed as „Bagasse Ash“. Bagasse indicates the presence of amorphous silica, a sign of pozolonic properties, accountable in maintaining the soil particles together for Improved shear strength. [15]

The stabilizing material of bagasse ash for black cotton soil can be verified under different tests like standard proctor test, California bearing ratio, atterbergs limit etc. The bagasse ash was collected from The Kisan Sahakari Chini Mills Ltd., Kaimganj, Uttar Pradesh



Figure 2 Sugarcane bagasse ash

Table 3 Chemical properties of Bagasse Ash

Sr no.	Description of Properties	Percentage (%)
1	Silica (SiO ₂)	64.38
2	Magnesium (MgO)	0.85
3	Calcium (CaO)	10.26
4	Iron (Fe ₂ O ₃)	4.56
5	Sodium (Na ₂ O)	1.05
6	Potassium (K ₂ O)	3.57
7	Alumina (Al ₂ O ₃)	11.67

Rice husk ash:

Rice husk ash (RHA) waste is responsible for hazardous environmental issues in the atmosphere. It is capable of minimizing the environmental footprint of rice husk ash waste and reducing CO₂ emissions by substituting it partially with cement. Rice husk ash, which is rich in silica content, is gained through burning rice husks, and its pozzolanic properties make subgrade stronger. [16]

Adding RHA and fly ash, offers the industrial waste disposal a long term solution through the application of specialized construction techniques. [17] Here, under Table 3, you shall find the chemical composition of rice husk ash. RHA used in this work is obtained locally from a dumping nearby site Rice Mill, Agra Rd, Manipuri.



Figure 3 Rice husk ash

Table 4 Chemical Composition of RHA

Sr. No	Chemical Composition	Percentage (%)	Range
1	Silica (SiO ₂)	83.94	73-92
2	Alumina (Al ₂ O ₃)	0.3	0-3
3	Iron Oxide (Fe ₂ O ₃)	0.2	0-0.6
4	Lime (CaO)	1.8	1-2.5
5	Magnesia (MgO)	0.4	0-0.8
6	Potash (K ₂ O)	0.33	0-1.5
7	Loss on ignition	3.62	1-4

Methodology:

This study was undertaken to assess the efficacy of fibre waste materials in improving the strength and stability of black cotton soil. A systematic

experimental approach was used, including soil sample collection, fibre material procurement and treatment, sample preparation with different mix proportions, and a series of standard laboratory testing.

S NO	Shortform	Sample	Test performed
1	S	Black cotton soil	Natural water content, unit weight, sieve analysis, Atterberg limit test, specific gravity, optimum water content & maximum dry density, CBR test
2	S2JF	Black cotton soil + 2% jute fibre	Specific gravity, optimum water content & maximum dry density, CBR test
3	S16SBA	Black cotton soil + 16% Sugarcane Bagasse ash	Specific gravity, optimum water content & maximum dry density, CBR test
4	S10RHA	Black cotton soil + 10% Rice husk ash	Specific gravity, optimum water content & maximum dry density, CBR test
5	S+2%JF+16%SBA	Black cotton soil + 2% jute fibre +16% sugarcane bagasse ash	Specific gravity, optimum water content & maximum dry density, CBR test
6	S+2%JF+10%RHA	Black cotton soil + 2% jute fibre + 10% rice husk ash	Specific gravity, optimum water content & maximum dry density, CBR test
7	S+16%SBA+10%RHA	Black cotton soil + 16% sugarcane bagasse ash + 10% rice husk ash	Specific gravity, optimum water content & maximum dry density, CBR test
8	S+2%JF+16%SBA+10%RHA	Black cotton soil + 2% jute fibre + 16% sugarcane bagasse ash + 10% rice husk ash	Specific gravity, optimum water content & maximum dry density, CBR test

Fibre Materials Utilized:

Three waste fibre materials were identified based on their availability, sustainability, and capacity to enhance soil properties:

Sugarcane Bagasse Ash (SCBA): Received as a by-product from sugar mills after bagasse is burnt. SBA is porous, siliceous, and has the capacity to enhance pozzolanic activity in soil. [18]

Rice Husk Ash (RHA): Obtained from rice mills following burning of rice husks. Silica-rich, RHA enhances soil strength by its filler effect and pozzolanic action. [19]

Jute Fibre: A biodegradable natural fibre with good tensile strength. It was cut manually into equal lengths of about 10 mm for effective blending. [20]

Mix (Composite): Blend of all three materials—SBA, RHA, and jute fibre—in an equal weight proportion to assess their combined influence on soil behaviour.

Mixing Proportions

All the additives (SCBA, RHA, jute, and mix) were incorporated into the black cotton soil in different proportions: 1%, 1.5%, 2%, 2.5%, and 3% dry weight of the soil. For every proportion and additive, a different batch was made, and all the mixes were hand-mixed to provide even distribution of fibres in the soil mass. [21]

Sample Preparation

Following dry mixing, distilled water was added to the soil–fibre mixes to take them to their Optimum Moisture Content (OMC) based on the Standard Proctor Test. The mixture of soil was compacted into moulds suitable for each test. Consistency in compaction was ensured across all samples.

Laboratory Testing

The following laboratory tests were conducted on untreated and fibre-reinforced soil samples:

Standard Proctor Test (IS 2720 Part 7): To find the OMC and Maximum Dry Density (MDD) of plain and modified soils.

California Bearing Ratio (CBR) Test (IS 2720 Part 16): Performed on soaked samples to analyze the load-bearing capacity improvement. Four-day soaking time was maintained prior to testing.

All the tests were done in triplicate for each fibre type and mix proportion to be reliable. The mean of the results was used for analysis.

Data Analysis:

Compaction, CBR test results were tabulated and compared for every type of fibre and percentage. Trends were analyzed through graphs and charts prepared to determine optimum fibre content and ascertain which material was offering the maximum improvement in black cotton soil. The effect of every waste fibre material on strength, stiffness, and load-carrying capacity was interpreted in detail.

Experimental Setup and Testing:

For analysing the enhancement of black cotton soil's geotechnical properties with the stabilization by using waste fibre material, the improvement was investigated using a number of laboratory tests with controlled settings. The testing conforming to IS standards was undertaken in the Civil Engineering Department's Soil Mechanics Laboratory.

Material preparation:

Black Cotton Soil: Sampled from Nagla Mugaria, Uttar Pradesh (Latitude 27.2247841, Longitude 78.9651594), the soil was air-dried, pulverised, and sieved through a 4.75 mm IS sieve to have a uniform grain size.

Waste Fibre Materials:

Sugarcane Bagasse Ash (SCBA): Sampled from sugar mills and sieved using 425-micron sieve.

Rice Husk Ash (RHA): Sampled from rice mills, sieved as above for uniformity.

Jute Fibre: Chopped into 10 mm length pieces for uniform mixing.

Mixed Sample: An equal proportion by weight of SCBA, RHA, and jute fibre.

Each additive was mixed with the soil in 1%, 1.5%, 2%, 2.5%, and 3% ratios by dry weight.

Sample Preparation:

The fibre-reinforced soil was mixed thoroughly and brought to **Optimum Moisture Content (OMC)** determined from compaction tests. The moist soil mixtures were then used to prepare samples for:

- **CBR Test**
- **Compaction Test**

Each sample was carefully compacted using standard compaction energy (2.6 kg rammer, 310 mm free fall) in moulds prescribed by the IS codes.

Laboratory Tests Conducted:

A. Normal Proctor Compaction Test

(IS 2720 Part 7)

Objective: To find the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of both untreated and fibre-reinforced black cotton soil.

Equipment: Proctor mould (1000 ml), hammer (2.6 kg), balance, oven, measuring cylinders.

Outcome: Assisted in developing moisture conditions for the preparation of CBR and UCS specimens.

B. California Bearing Ratio (CBR) Test

(IS 2720 Part 16)

Objective: To analyse the bearing capacity of the subgrade material.

Procedure: Specimens were immersed for 4 days prior to testing.

Equipment: CBR moulds, loading frame, dial gauges, surcharge weights.

Testing Conditions: Load was applied in the form of a plunger at 2.5 mm/min, and penetration resistance was noted.

Result: CBR value for every sample was determined and utilized to compare performance for all fibre types and contents.

Testing Conditions

All testing was performed at ambient temperature, and attention was paid to have consistent compaction, curing, and soaking times. All tests were replicated three times for each mix and the results averaged to prevent variability.

Safety and Calibration

Prior to testing, all equipment was calibrated to have correct readings. All laboratory safety practices were observed in sample preparation, compaction, and load application.

Results and Discussion:

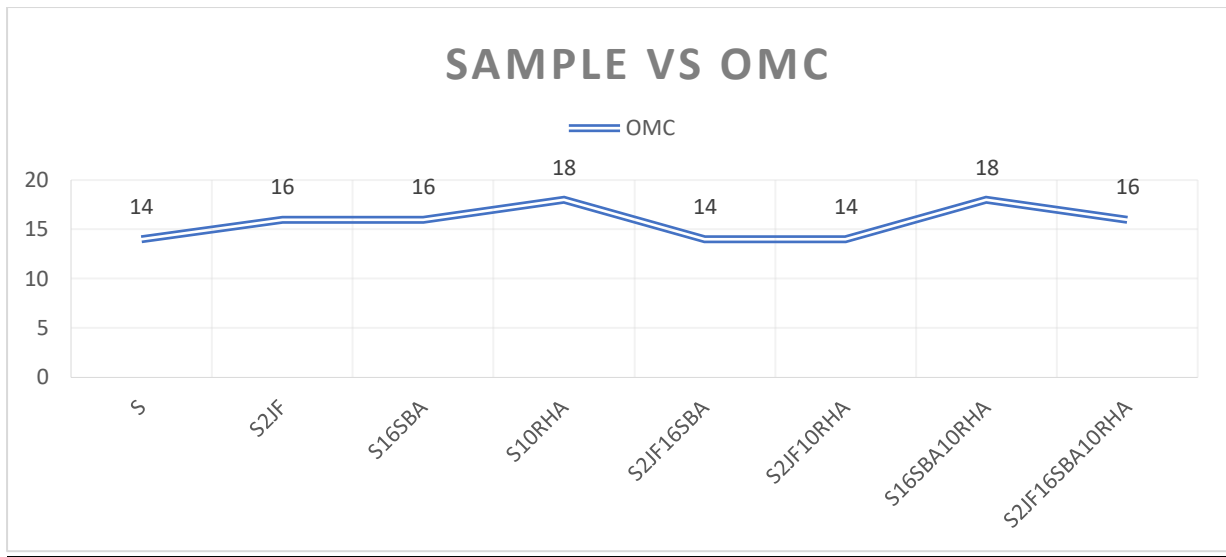
This page reports and explains the results of the experimental program to improve black cotton soil stability using waste jute fibre, sugarcane bagasse ash and Rice husk ash. Tests carried out involve the California Bearing Ratio (CBR), and Standard Proctor Compaction tests, which were conducted under different percentages of jute fibre, sugarcane bagasse ash and Rice husk ash.

Optimum Moisture Content:

Table 5 OMC of all samples

S.NO	SAMPLE NAME	OMC
1	S	14
2	S2JF	16
3	S16SBA	16
4	S10RHA	18
5	S2JF16SBA	14
6	S2JF10RHA	14
7	S16SBA10RHA	18
8	S2JF16SBA10RHA	16

Figure 4 Sample VS OMC



INITIAL = 14%

FINAL = 16%

RESULT = 14.28% INCREASE

Maximum Dry Density

Table 6 MDD of all samples

S.NO	SAMPLE NAME	MDD
1	S	1.745
2	S2JF	1.767
3	S16SBA	1.701
4	S10RHA	1.515
5	S2JF16SBA	1.727
6	S2JF10RHA	1.682
7	S16SBA10RHA	1.776
8	S2JF16SBA10RHA	1.622

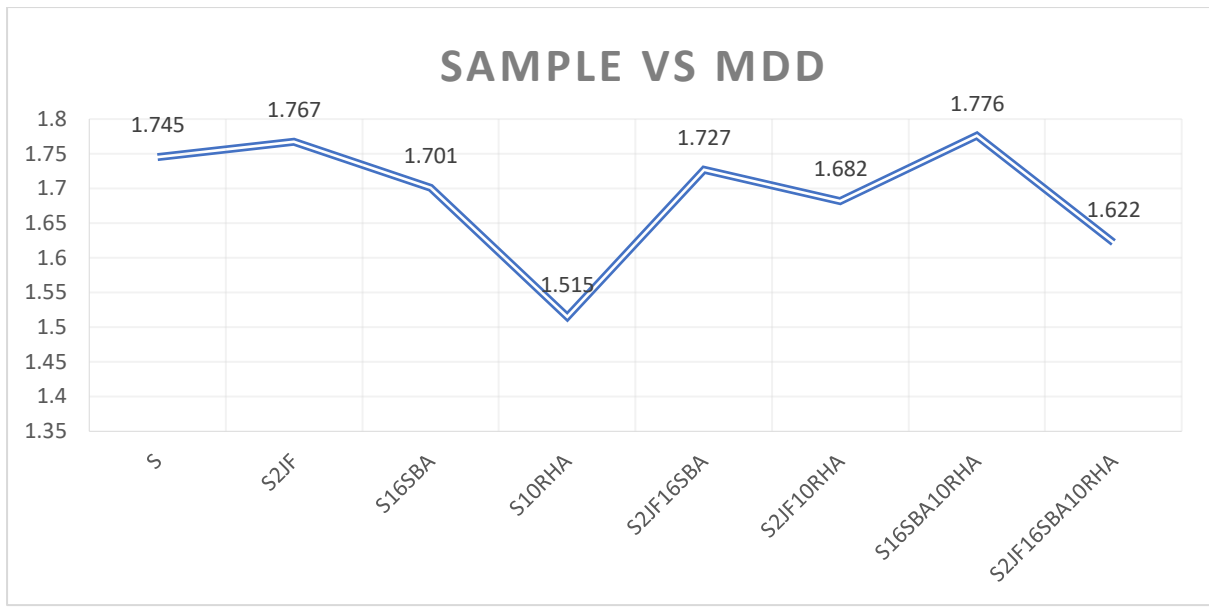


Figure 5 Sample VS MDD

INITIAL = 1.745

FINAL = 1.622

RESULT = 7.048% DECREASE

California Bearing Ratio at 2.5mm

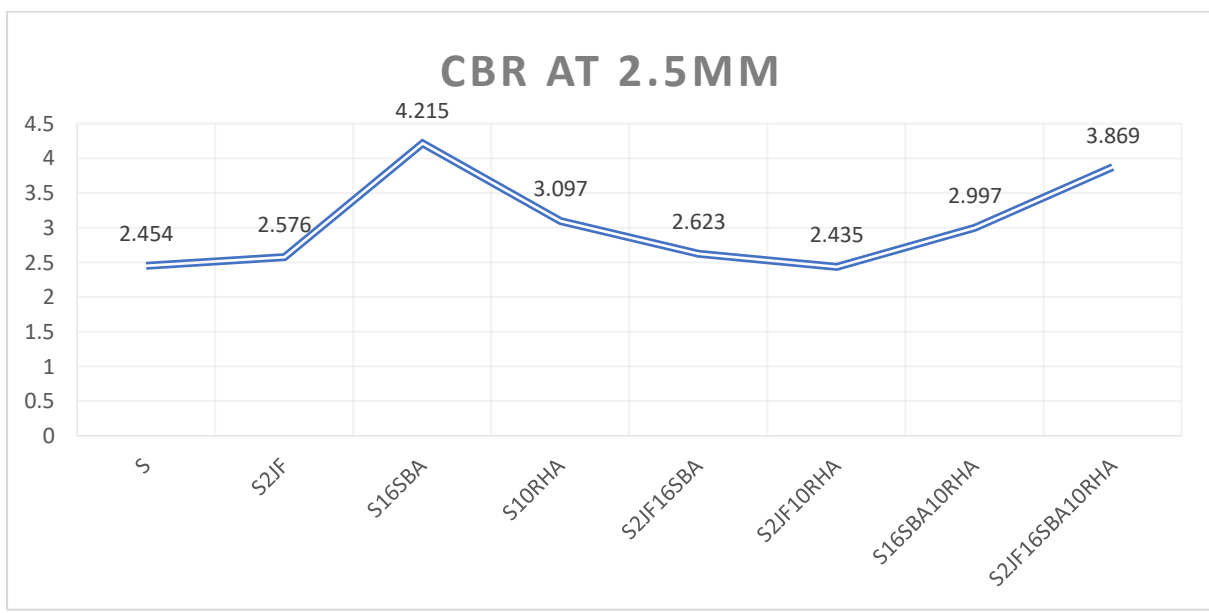


Figure 6 CBR at 2.5

INITIAL = 2.454

FINAL = 3.869

RESULT = 57.66% INCREASE

California Bearing Ratio

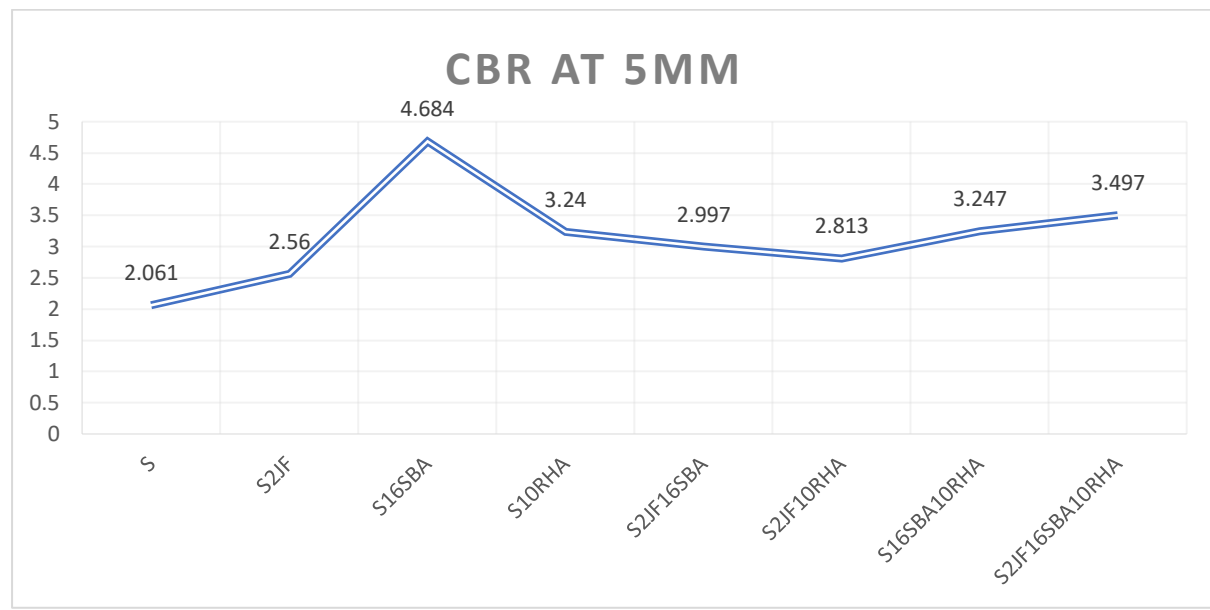


Figure 7 CBR at 5mm

INITIAL = 2.061

FINAL = 3.497

RESULT = 69.67% INCREASE

Conclusion

- Our aim was to stabilize the Black cotton soil using jute fibre, rice husk Ash and sugarcane bagasse ash.
- During experimental analysis increased value of CBR by 57.66% at 2.5 mm and 69.67% at 5mm shows increase in strength of soil.
- The addition of **jute fibre, SCBA, and RHA** to black cotton soil significantly improved its geotechnical properties, especially California Bearing Ratio (CBR).
- Jute fibre enhanced the tensile strength and ductility of the soil, reducing crack formation and increasing load resistance under unconfined conditions.

- Overall, using jute fibre, SCBA, and RHA is a sustainable and cost-effective method of stabilizing problematic soils, promoting the recycling of agricultural waste and enhancing infrastructure durability.

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