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Experimental Investigation of Clayey Soil Stabilization Using GGBS and Areca Fiber Inclusion

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ABSTRACT: Rapid industrialization and urbanization have led to a steady rise in the amount of land used for different types of development. Because of this, there is a shortage of suitable land (soil) for building. These days, it is common practice to build structures on troublesome soils. The purpose of this study is to investigate the potential applications of GGBS and Areca Fiber in enhancing soil qualities. The soil used for the experiment is clayey. In this work, Areca Fiber is utilized for reinforcing while GGBS serves as a stabilizing agent. As an alternative, engineers attempt to use these readily accessible materials in civil engineering construction, depending on their performance and viability. For soil stabilization, GGBS is added as an addition. By stabilizing the soil using GGBS, swell and shrink are lessened and the soil becomes stronger. To increase the tensile strength of soil, areca fiber is used as a reinforcing element. It has a 4–10 year infield service life and exceptional tensile strength in damp conditions due to its high lignin content. The required qualities of soil, such as compaction, unconfined compression, shear strength, and swelling properties, can be enhanced by adding areca nut fibers. Shear failure is limited by the reinforcement's resistance to the tensile stress created in the soil. Numerous experimental studies were carried out on various mix proportions of GGBS (10%, 15%, and 20%) and Areca fiber (1.0%, 1.5%, and 2.0%), including compaction, the California Bearing Ratio test, and the unconfined compression test. While the CBR testing were carried out for both soaked and unsoaked circumstances after 7 days of curing, the UCS tests were performed on samples at various curing times, with a maximum cure of 7 days. With areca fiber present, the soil's UCS and CBR significantly increased, and its strength values significantly improved as well. The findings indicate that in clayey soil, 1.5% Areca Fiber and 15% GGBS can be utilized as an efficient stabilizing agent.

KEYWORDS: Compaction test, CBR, UCS, Areca Fiber, GGBS

I. INTRODUCTION

Since the Sumerians of Mesopotamia used earth as a building material between 7000 and 6000 BCE, the practice has had a long and rich history. In the Fertile Crescent between the Tigris and Euphrates rivers, these ancient civilizations were the first to use mud-brick buildings, marking the beginning of urban communities. Stacked earth bricks were used in the earliest known human-built earth constructions, which date to about 10,000 BCE, highlighting the long-standing interaction between humans and the soil in construction. Earth's adaptability and essential significance in architectural history are demonstrated by the fact that it has been used for ages in the construction of domestic and religious buildings in many different cultures. Approximately one-third of the world's population still uses earth-based building techniques today.

This tendency is especially noticeable in developing countries, where more than half of the population resides in structures made of earth. Earth-based construction is gaining popularity again in wealthy nations, partly because of its benefits for the environment. These include hygroscopic qualities, effective heat conductivity, and a smaller carbon impact. These qualities fit in nicely with the current environmental issues and the worldwide movement for sustainable building techniques. Earth's transition from an antiquated building material to a contemporary building solution is not without difficulties, though.

Although earth is readily available and reasonably priced, there are problems with its durability, tensile strength, and social acceptance. Significant issues include susceptibility to wear, poor flexural capacity, and vulnerability to weather conditions. Because of the earth's low tensile strength and ductility, these problems are exacerbated in seismically active areas. Due to the difficulties in institutionalizing unstabilized ground, construction standards and norms are still in their infancy worldwide. Therefore, the history of earth in construction is a story of enduring significance and

changing challenges, requiring creativity and adaptation in its usage, especially in light of contemporary housing demands and environmental sustainability. An important development in sustainable building techniques is the use of areca fiber as a stabilizing element in earthen construction.

Areca fiber is inexpensive and plentiful, and it comes from the areca palm, a perennial crop that is widely grown in many underdeveloped countries. Its main applications are in a variety of industries, including pharmaceuticals and confections, but its potential in construction has only lately come to light. The areca kernel's outermost layer, which is frequently thrown away as waste, has demonstrated potential for improving the mechanical qualities of construction materials. Numerous researches have investigated the use of areca fiber in soil stabilization, showing how well it reinforces soil-based composites.

II. LITERATURE SURVEY

Yaniam et al. (2025) Due to the rapid expansion of municipal areas and the rising demand for construction, there is a lack of land with appropriate soil conditions. Soil stabilization is a crucial procedure since builders frequently have to use weak soil that is readily available in the area. By changing the characteristics of the soil, these methods improve its strength and durability. While a number of soil stabilization methods have been investigated, few research concentrate on how silica fume and areca fiber work together to strengthen and prolong the life of peat soil. Soil specimens were subjected to a number of tests, including UCS, CBR, SEM, EDX, compaction, physical and index properties, and more. Up to 0.5% of its dosage with soil, areca coir (20–30 mm) improved soil qualities; however, at greater doses, it has dispersion problems. Depending on the kind of soil, different weight ratios of silica fume (6%, 8%, and 10%) and areca fiber (0.3%, 0.5%, and 0.7%) are employed to create the optimal conditions. Because silica fume is a cementitious ingredient, it greatly increases the strength of peat, which causes MDD to increase and OMC to decrease. When areca reinforced soil is added, MDD is reduced and OMC is increased.

Rasheed et al. (2023) This study aims to investigate the potential of utilizing coconut shell ash and areca fiber to enhance soil qualities. Clayey soil is used for the experiment. In this study, areca fiber serves as reinforcement and coconut shell ash as a stabilizing agent. As an alternative, engineers attempt to use these readily accessible materials in civil engineering projects according to their suitability and viability. Areca fiber is added to soil as a reinforcing material to increase its tensile strength. Its high lignin content gives it a good tensile strength in wet conditions and an infield service life of four to ten years. The desired characteristics of soil, such as compaction, unconfined compression, shear strength, and swelling qualities, can be enhanced by adding areca nut fibers. Shear failure is prevented by the reinforcement's resistance to the tensile stress created in the soil. Comprehensive experimental studies were carried out on various mix proportions of coconut shell ash (5%, 10%, 15%, and 20%), including compaction, unconfined compression test, and plastic and liquid limit test.

Koundinya et al. (2023) In this study project, the use of GGBS and fly ashes to stabilize alluvial soils has been thoroughly examined in the lab. UCS, CBR, permeability, swelling potential, compaction properties, and Atterberg limits were found for control samples and compared with samples of different sequences with different fly ash and GGBS ratio percentages and curing times.

Kumar et al. (2022) Chemical methods are now widely employed to improve the qualities of soil. GGBS and lime are used in this paper to stabilize the soil. The cost of construction is reduced and made more affordable by utilizing GGBS and lime. Lime was added in amounts equal to 7% of the soil's dry weight, while GGBS was added in levels ranging from 0% to 20% of the soil's dry weight. A range of percentages were used to assess the soil's characteristics, and their variations were compared. The optimal ratio of GGBS to lime for stabilizing soil is 15% GGBS by dry weight of soil and 7% lime by dry weight of soil.

Manish Kumar Jha et al. (2022) Understanding how GGBS and copper slag interact with black cotton soils is the main goal of this study. The Black Cotton soil's engineering and geotechnical qualities need to be enhanced. Utilizing GGBS and copper slag stabilization to examine how strength increases in black cotton soil.

Abdila et al. (2021) This study sought to address the problem of damaged (collapsed, cracked, and lowered soil strength) road pavement constructions built on clay soil because clay soil has low shear strength, high soil compressibility, low soil permeability, low soil strength, and high soil plasticity. Previous research indicates that clay

soil can be stabilized with fly ash and ground granulated blast slag (GGBS). The results of these investigations, however, demonstrate that the requirements for the building of road pavement were not fulfilled, especially in relation to the subgrade soil of clay.

Varghese et al. (2020) Areca fiber, a natural material, is the outcome of this research. Despite being widely accessible in many regions of the world, areca's application in geotechnical research has not gotten much attention. This article demonstrates the applicability of areca fiber for stabilizing unstable soils through experimental tests. Crack density factor (CDF) and crack intensity factor (CIF) are two features of desiccation cracks on soil surfaces at different percentages of areca fibers that are investigated in laboratory research. The image processing technology (DIA) is used to objectively assess the morphological characteristics of crack patterns produced at each drying step.

Ramachandran et al. (2019) Organic soils are not suited for construction projects due to their poor shear strength, high swelling potential, and restricted bearing capacity. These types of soils can be stabilized and compacted. The study used three percent, two percent, and three percent of basalt fiber and three percent, six percent, and nine percent of pulverized granulated blast furnace slag. The reinforced soil was subjected to compaction and the unconfined compressive test (UCS). The experimental results have shown effective increases in shear and compressive strength.

Sudhakaran et al. (2018) This study introduces areca fiber's usefulness as a material for soil reinforcement. Areca is widely available, however its application in geotechnical engineering has not been studied. Natural areca fiber is a suitable reinforcement, according to extensive experimental study and dependability analysis, and bottom ash (BA) is used as a stabilizing agent in the current work. The test protocol includes tests for compaction, split tensile strength, California bearing ratio (CBR), and unconfined compression strength (UCS). The BA content was changed from 0 to 40%, the fiber content was changed from 0 to 1.5%, and the relevant performance evaluation was finished. Additionally, a small amount of cement (3%) was used to improve the pozzolanic reaction.

Bandyopadhyay et al. (2016) The usage of two types of industrial wastes—ground granulated blast furnace slag (GGBS) and calcium carbide residue (CCR)—in soil stability was examined in this study. These additives can effectively treat and stabilize the soil at a comparatively modest cost. According to the experimental findings, different characteristics of soil supplemented with these stabilizers at a specific proportion exhibit notable improvements when compared to the acquired natural soil. The soil can be used for the impermeable core in embankments because its permeability has decreased. UCS has increased, increasing the soil's carrying capacity. Flexible pavement design is more economical when base and sub-base courses are thinner, as seen by the greater CBR in both wet and dry conditions.

Mandal et al. (2016)

The purpose of this study is to assess the usefulness of industrial waste as a soil additive, such as fly ash and GGBS. Additionally, it seeks to lessen the problem of fly ash and GGBS being discharged in public spaces and improve the soil's engineering properties so that it can be used for road subgrade development. Because typical soil stabilization elements like cement and lime are becoming more expensive, the investigation's conclusions aim to lower building expenses. The behavior of soil in combination with fly ash and GGBS is the main topic of the current investigation. Conclusions from the experimental results indicate that some characteristics of treated soil have improved. As a result, after adding fly ash and GGBS as stabilizers, the soil's characteristics were altered and it could be utilized for infrastructure development. Additionally, changed soil lessens the harm that waste items do to the ecosystem.

Sharma et al., (2016) A blast furnace slag binder was made from fly ash and ground granulate. Different fly ash and GGBS combination ratios were used in the initial strength test. It was discovered that a 70:30 mixture of fly ash and GGBS had greater strength than either fly ash or GGBS alone, even in the absence of any chemical activators. When the binder was employed without lime, the plasticity index and the liquid limit both dropped. The OMC falls and the MDD rises as the binder content rises. The tests were conducted at three distinct curing times—seven, fourteen, and twenty-eight days—to determine the strength properties of each combination of soil binder samples. This indicates that strength rises up to 20% of the binder content before declining.

A) RESEARCH GAP

There hasn't been much research done on the combined effects of GGBS and areca fiber on the engineering properties of soil, particularly with reference to Atterberg limits, California Bearing Ratio (CBR), and Unconfined Compressive

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Strength (UCS). There is a lack of clarity regarding the ideal mix ratio and improvement trends for certain attributes. Research on the combined effects of GGBS and Areca Fiber on soil's UCS, CBR, and Atterberg limits is lacking, and the best combination is yet unknown.

B) 2.4. OBJECTIVES OF THE STUDY

The objectives of the research work are:

1. To ascertain the virgin soil's specific gravity and Atterberg's limits.
2. To ascertain the soil mixed with GGBS and Areca Fiber's compaction properties, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).
3. To assess GGBS and Areca Fiber's combined impact on Unconfined Compressive Strength (UCS).
4. To assess how Areca Fiber and GGBS together affect the California Bearing Ratio (CBR).
5. To determine the ideal ratio of areca fiber to GGBS for optimal strength.

III. MATERIALS AND METHODOLOGY

3.1 GENERAL

The primary goal of this study is to investigate how different percentages of Areca fiber and GGBS added to clayey soil altered the behavior of the soil using a variety of geotechnical laboratory experiments.

3.2 SOIL

The collected soil from the location was smashed up into lumps with a wooden hammer and left to dry outside under cover. It was thoroughly mixed and then put through a 2.35 mm IS sieve. The necessary amount of dirt for each test was taken out of polythene bags and dried for an entire day at 105°C/5°C. The soil was allowed to reach room temperature. The different qualities of virgin soil that are employed include:

S.NO.	PROPERTIES	RESULTS
1.	Liquid Limit	40 %
2.	Plastic Limit	18.5 %
3.	Plasticity Index	21.5 %
4.	Optimum Moisture Content	12.23 %
5.	Maximum Dry Density	14.47 kN/m ³
6.	Specific Gravity	2.63
7.	CBR (%) (soaked)	2.1 %
8.	CBR (%) (Unsoaked)	3.9 %
9.	U.C.S	130 kN/m ²
10.	Indian Soil Classification	CI

Table 3.1 Properties of soil used

3.3 ARECA FIBER

Fibers were recovered from areca nuts. Before being used, areca fiber was processed. The fiber was initially soaked in water for seven days. After then, the fiber was stored in acetic acid for seven days. It was then utilized for testing after being oven dried. Acetic acid is applied to areca fiber to enhance its mechanical qualities, including stiffness and tensile strength.

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Table 3.2:- Properties of Areca Fiber

Parameters	Values
Tensile strength (Mpa)	876 to 948
Elongation of the break (%)	1.47 to 1.8
Diameter (mm)	0.8 to 1.8
Density(gm/cm ³)	1.34 to 1.45
Young’s Modulus (GPa)	42 to 48

3.4 GROUND GRANULATED BLAST FURNACE SLAG

GGBS is a by-product of blast furnaces used in the production of iron. A glassy granular substance is created when molten slag is quickly quenched (cooled) with water. This substance is subsequently dried and processed into a fine powder. Slag basicity and compressive strength are often improved when there is an adequate amount of CaO present. This waste product is inexpensive and readily accessible. The ground-granulated blast furnace slag was transported from S.K. Cement Depot by courier (Ludhiana).

Table 3.3 chemical composition of Ground Granulated Blast Furnace Slag

S. No	Name of constituent	Percentage
1	SiO ₂	33.67
2	Al ₂ O ₃ + Fe ₂ O ₃	19.18
3	Calcium Oxide (CaO)	36.2
4	Magnesium oxide (MgO)	8.18
5	SO ₃	0.2
6	Na ₂ O	0.14
7	P ₂ O ₅	0.05

3.5 RESEARCH METHODOLOGY: -

The study follows an **experimental research design** to evaluate the mechanical and physical improvements in soil properties when stabilized with Areca Fiber and GGBS. Laboratory-based experiments are conducted to analyze the soil's Bearing ratio, Compaction and Compressive Strength.

The experimental program consists of:

1. **Soil Characterization Tests:** - Laboratory-based tests are carried out to assess the strength, compaction, and durability of the soil, and the study employs an experimental research methodology to assess the mechanical and physical improvements in soil qualities when stabilized with Areca Fiber and GGBS.

1) Determination of Clayey soil properties

- Liquid limit test
- Plastic limit test

2) Determination of OMC and MDD of Clayey soil by Proctor compaction test.

3) Determination of strength parameters i.e. UCS and CBR value.

2. **Soil Stabilization Process**

- GGBS is mixed with soil at varying percentages as 10%, 15%, and 20%.
- Areca fibers are added at different dosages 1.0%, 1.5%, and 2.0% by dry weight of soil.
- GGBS at 15% is constant and Areca fiber with varying content as 0.5%, 1.0% and 1.5% for each variation.
- Samples are prepared using dry mixing method followed by controlled compaction.

IV. EXPERIMENTAL RESULTS

4.1 EXPERIMENTAL RESULTS

The three primary tests that were observed were the California bearing ratio test, the unconfined compression test, and the Standard Proctor test. To examine the properties and behavior of locally accessible soil combined with Areca Fiber and GGBS at varying percentages, a thorough experimental investigation has been conducted. To determine the soil's ideal percentage in relation to the strength characteristics, just GGBS was initially injected. Areca Fiber was added to the soil and GGBS mixture after this GGBS % was fixed.

4.2 STANDARD PROCTOR TEST

The laboratory test analysis uses different combinations of 0.5%, 1.0%, and 1.5% of Areca Fiber and 15% GGBS as a constant. The following values show how the percentage of Areca Fiber and GGBS affects the ideal moisture content and dry density. The primary factors that significantly influence the strength and longevity of pavements constructed on subgrades are the soil's compaction properties as shown in figure 1 and tabulated in table 4.1.

Table 4.1: Effect of Areca Fiber and GGBS w.r.t MDD and OMC

S No.	Soil Sample	MDD (kN/m ³)	OMC (%)
1.	S	14.1	18
2.	S1	13.4	18.7
3.	S2	12.8	19.3
4.	S3	12.1	19.8
5.	S4	14.4	17.7
6.	S5	14.9	17.1
7.	S6	15.2	16.8
8.	S7	13.7	19.1
9.	S8	13.4	19.3
10.	S9	13.0	19.6

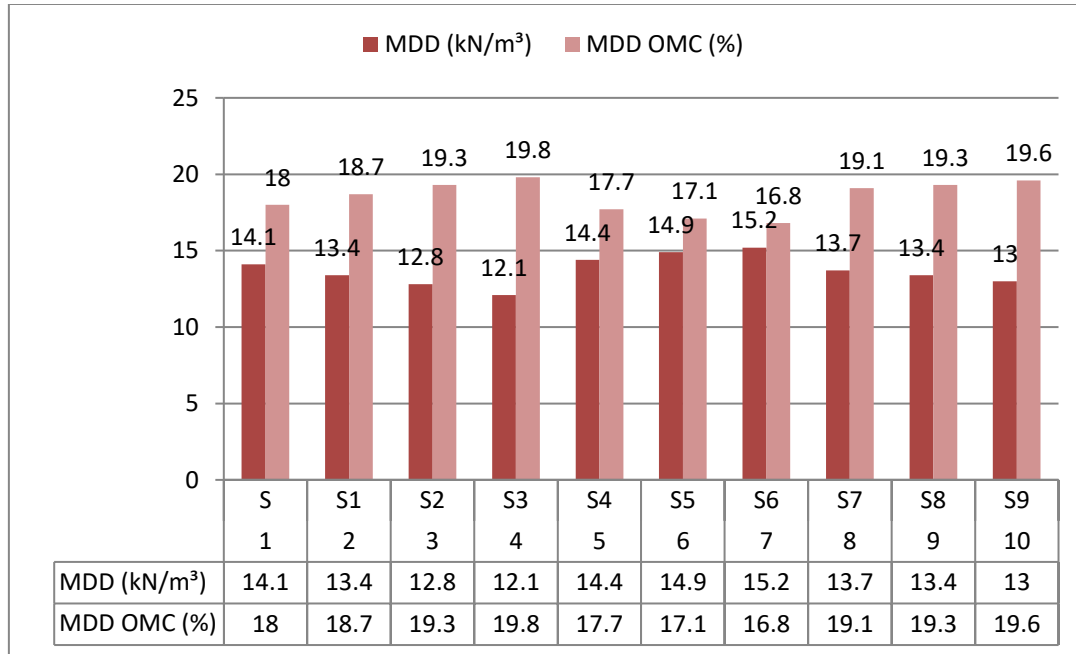


Fig. 1 Variations b/w MDD and OMC of Areca fiber, GGBS & soil with different Ratios

- When the percentages of Areca Fiber fluctuate from 0.5, 1.0, and 1.5% and GGBS is fixed at 15%, there is also an increase in OMC from 18.0 to 19.6% and a drop in MDD from 14.1 to 13.0%.
- In this study, the compaction properties of the soil were examined using varying concentrations of GGBS. MDD was observed to decrease when GGBS levels rose. Because GGBS and soil have different specific gravities, this could happen. However, the ideal moisture content increases with the amount of GGBS. This could happen as a result of GGBS's pozzolanic reaction with soil, which requires more water to finish the cation exchange process.
- When areca fiber is added to the soil and GGBS mix, MDD drops while GGBS is maintained at 15%. MDD decreases as the amount of Areca Fiber increases with different GGBS ratios when soil and slag are mixed together. As the percentage of fiber rises, the soil's OMC improves proportionately. On the other hand, areca fibers have significant water absorption properties that help to raise the OMC.

4.3 CALIFORNIA BEARING RATIO TEST

The analysis of the lab test uses different combinations of 0.5%, 1.0%, and 1.5% of Areca Fiber and 15% GGBS as a constant. The CBR of the subgrade is a crucial strength metric for estimating the subgrade thickness of the pavement. IS: 2720 (Part 16) - 1987 states that clay subgrades have low CBR values. The proportions of constant 15% GGBS with 0.5%, 1.0%, and 1.5% of Areca Fiber content are displayed in figure 2 and reported in table 4.2.

Table 4.2: Effect of Areca Fiber and GGBS w.r.t CBR Values

S No.	Soil Sample	Soaked CBR Value (%)	Unsoaked CBR Value (%)
1.	S	2.1	3.7
2.	S1	2.8	4.8
3.	S2	3.6	6.1

4.	S3	4.4	7.4
5.	S4	2.4	4.0
6.	S5	2.7	4.5
7.	S6	3.1	5.2
8.	S7	3.4	5.7
9.	S8	4.1	7.0
10.	S9	4.8	8.1

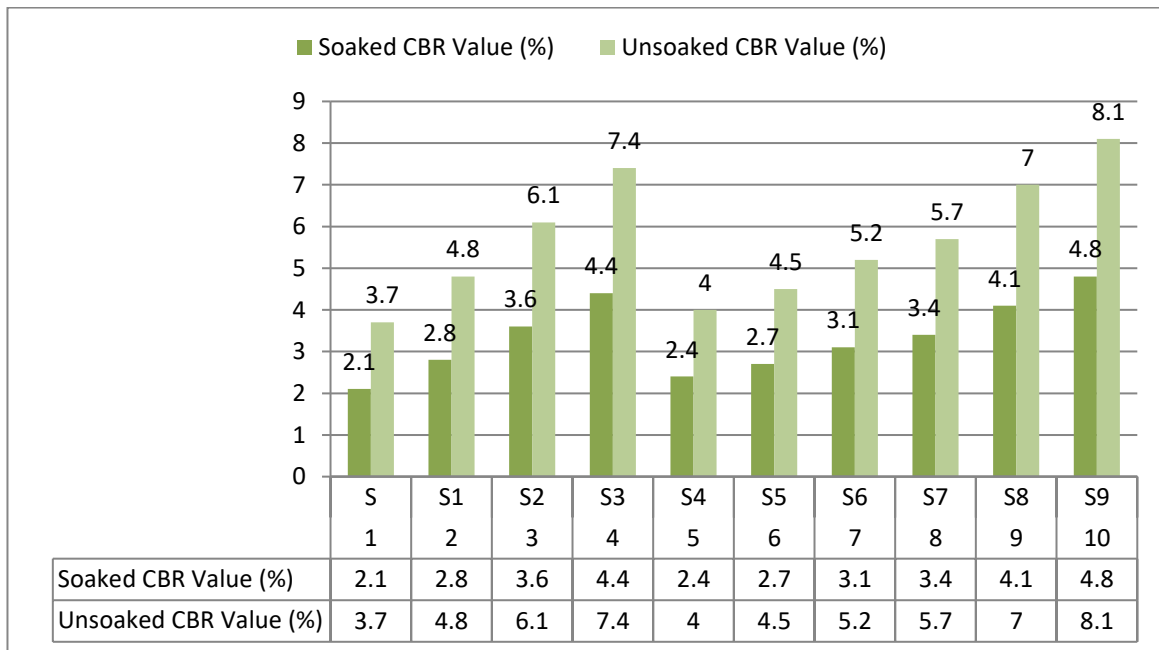


Fig: 2 Variations CBR values of Areca fiber, GGBS & soil with different Ratios

- The soaking CBR values of the soil sample are somewhat increased by the addition of GGBS. The soaking CBR value was raised by adding 0.5%, 1.0%, and 1.5% of Areca Fiber to 15% GGBS as a constant. The reaction between the pozzolonic compounds of soil-available CaOH and GGBS, which produce cementitious compounds in the soil, may be the cause of the increase in CBR value. The amount of areca fiber should be increased. This may be because stabilized soil becomes stronger as its fiber content increases, making it more resilient to applied forces.
- Both the drenched and unsoaked CBR values are shown in the tables. The CBR values are enhanced by raising the percentage ratio of Areca Fiber by 0.5%, 1.0%, and 1.5% while maintaining the 15% GGBS proportion. Soaked soil has a CBR value that is 2.28 times higher than untreated soil, rising from 2.1% to 4.8%. In a similar vein, the CBR value increases by 2.35 times in unsoaked situations as opposed to 3.7% to 8.1% in untreated soil. The CBR value rose as the percentage of 15% GGBS as a constant and 0.5%, 1.0%, and 1.5% of Areca Fiber increased because the soil's shear resistance increased to withstand the loading caused by penetration.

4.4 UNCONFINED COMPRESSION STRENGTH TEST

The laboratory test analysis uses different combinations of 0.5%, 1.0%, and 1.5% of Areca Fiber and 15% GGBS as a constant. In compliance with IS: 2720 (part-10), the UCS test was performed on both reinforced and unreinforced soil specimen samples at a constant strain of 0.125 mm/minute. Several combinations' unconfined compressive strength parameters are tested under compressive force; the results are shown in Figure 3 and reported in Table 4.3.

Table 4.3: Effect of Areca Fiber and GGBS w.r.t UCS Values

S No.	Soil Sample	UCS (kN/m ²) (7 days)	UCS (kN/m ²) (14 days)
1.	S	130	170
2.	S1	190	270
3.	S2	241	340
4.	S3	301	410
5.	S4	155	190
6.	S5	179	230
7.	S6	207	280
8.	S7	260	370
9.	S8	290	460
10.	S9	340	520

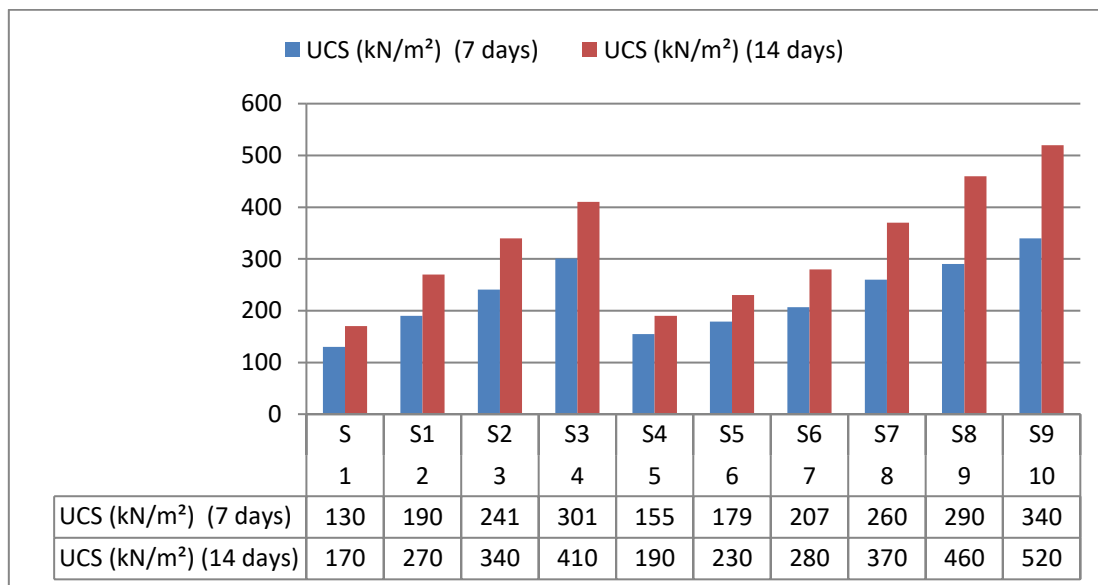


Fig: 3 Variations UCS values of Areca fiber, GGBS & soil with different Ratios

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- Based on the results, it can be seen that at 7 and 14 days, the UCS for reinforced soil is 2.6 and 3.05 times higher than that of unreinforced soil at the combination of soil+15% GGBS+1.5% Areca Fiber. For seven days, the UCS value increased from 130 kN/m² to 340 kN/m²; for fourteen days, it increased from 170 kN/m² to 520 kN/m².
- The UCS value of virgin soil also considerably rises with the addition of 0.5%, 1.0%, and 1.5% of Areca Fiber and 15% GGBS as a constant. The value increases when GGBS and Areca Fiber are added. This results from pozzolanic reactions that happen when GGBS and Areca Fiber come into contact with water during the curing process.

V. CONCLUSION

On the basis of experimentations, the following conclusions have been drawn:

1. It was seen that the OMC increased and the MDD decreased with the addition of 0.5% Areca Fiber and 15% GGBS; nevertheless, this sequence was found to persist with the addition of 1.5% Areca Fiber and 15% GGBS. This occurred as a result of the GGBS's nanoparticle mechanism and the substitution of lightweight material for soil, which lowers the MDD.
2. In comparison to the untreated soil, the addition of 1.5% Areca Fiber and 15% GGBS raises the CBR value by up to 2.28 and 2.35 times for both drenched and unsoaked circumstances. This is because the soil becomes more resistant to the loading brought on by penetration due to its increased shear resistance. The main reason for the improvement in the CBR value was when the ratio of 15% GGBS to 1.5% Areca Fiber reached the required level.
3. Ultimately, it was found that the UCS of the treated soil had increased to 15% GGBS and 1.5% Areca Fiber. For seven and fourteen days, the treated soil's UCS value is 2.6 and 3.05 times higher than that of the untreated soil.
4. The addition of 15% GGBS and 1.5% Areca Fiber to the soil has not had any negative impacts. We can conclude that the addition of 15% GGBS and 1.5% Areca Fiber significantly improved the cohesion of the clay soil.

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