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An Experimental Investigation on the Effects of Agricultural Wastes on the Cement Stabilized Clayey Soil

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***Abstract*: An experimental work was undertaken to investigate the effects of Cement, Rice Husk Ash and Coir Fibers, on various geotechnical properties and mechanical behavior of clayey soil. In many places in India, the soil lacks stability to support the wheel loads coming over the pavement. Mainly soils such as clayey or silty soils do not have sufficient strength to withstand the heavy loads coming over it and hence, pavements constructed over such soils are subjected to early deterioration. Also, subgrade quality has an impact on both the initial costs as well as on the subsequent maintenance costs. In this regard present work concentrates on investigating the effectiveness of cement, RHA and coir fibers in improving the engineering characteristics of expansive clayey soil. Soil sample is stabilized with varying percentages of cement, rice husk ash and coir fibers. The rice husk ash and coir fibers of 5-15% and 0.2 - 0.8 %, respectively, were added to the stabilized cement (5%) clayey soil. The laboratory investigations were carried out in accordance with the standard specifications and it was found that there is a considerable improvement in the properties of the soil stabilized with cement, RHA and coir fibers than the soil without stabilization.**

***Keywords*: cement, clayey soil, coir fibers, rice husk ash, stabilization.**

1. Introduction

The economic development of societies in conjunction with the increasing population and of industrial complexes, has led to the scarcity of suitable soil to sustain loading from buildings or structures. Our country covers vast soil deposits of clayey or expansive soils which have undesirable geotechnical properties such as low bearing capacity, shrinkage and swell characteristics, high compressibility and high moisture susceptibility. Therefore, several methods have been adopted to improve the geotechnical properties of such soils so that the stability and serviceability requirements can be met. Among these methods, soil stabilization has become one of the useful solutions to treat the soils to achieve the required engineering properties and specification so that structures can be placed safely without undergoing large settlements.

Any regulated process of adding materials to a soil to result in changes in the characteristics of the soil, with increase in strength and volumetric stability is known as soil stabilization. The process may include the blending of soils to achieve a desired gradation or the mixing of suitable additives which may lead to changes in the original soil gradation, texture or plasticity characteristics or forms cemetitious bonds between soil particles which promote the formation of a new stronger and stiffer mix. This method is being used for a large variety of engineering works, the most common application being in the construction of pavements i.e. soils are treated to provide for stronger and more durable road bed, sub base and base courses. Thus soil stabilization improves the roadway materials so that they can carry the traffic loads coming over it under all normal environmental conditions for the economical service life of the roadway.

Expansive soils contain clay or other minerals that cause them to exhibit large volumetric variations due to moisture fluctuations from climatic changes and therefore considered as one of the problematic soils by the highway engineers. They are considered as a potential natural hazard, which can cause extensive damage to structures due to swelling action in the form of cracking and break up of pavements, building foundations, embankments etc. Thus, it is very important that studies be done in order to reduce hazards caused by these expansive soils.

2. Literature review

Leema Peter et al (2014) states that coir waste consisting of coir pith and coir fibers from coir manufacturing industry can be used to stabilize the soft soils which form problematic subgrade for pavements due to its low bearing capacity. These coir wastes are potential threat to the land resources since it causes pollution by the polyphenol leaching and the resistance to degradation due to the stable lignin structure. Their test results showed that stabilization of soft soils with coir waste had a significant effect on the compaction, elastic modulus as well as CBR values.

Parag M. Chaple et al (2013) states that the provision of coir reinforced layer, reduces the settlement and improves the bearing capacity, which found to be economical techniques among various types of bearing capacity improvement techniques.

E A Basha et. al. (2004) states that the combination between cement and RHA yields a significant enhancing of strength as well as CBR and also addition of RHA needs a lesser amount of cement to achieve a given strength as compared to cement stabilized soils.

In order to stabilize the weak clayey soil the following admixtures are chosen i.e. cement, rice husk ash and natural fibers. From the literature review, 5% cement is fixed as constant because for most of the cases in the literature review maximum strength has been achieved for 4% to 6% of cement and the percentage of rice husk ash is varied accordingly to the literature review as 5%, 10% and 15%, correspondingly the coir fiber percent is varied as 0.2%, 0.4%, 0.6% and 0.8% for each percentage mix of rice husk ash and cement with soil.

3. Objectives of present investigation

- To investigate the geotechnical properties of the clayey soil.
- To study the behavior of admixtures and natural fibers with clayey soil.
- To evaluate the properties of the soil before and after stabilization with cement, rice husk ash and coir fibers.
- To determine the optimum percentage of rice husk ash and coir fibers for stabilizing the clayey soil.

4. Materials and methodology

A. Materials used

1) Soil

In the present investigation, clayey soil was procured from a site in Hassan district of Karnataka state. The soil was collected after removing the top soil at 1m depth and transported in sacks to the laboratory. For uniformity, the lumps of soil were first air dried, broken down to particle sizes that could pass a 4.75 mm IS sieve.

Table 1
Geotechnical properties of Expansive Soil

S. No.	Properties	Confirming to IS code	Value
1	Colour		Blackish grey
2	Specific gravity (G)	IS2720: Part III:1980	2.4
3	Liquid limit	IS 2720: Part V:1985	46.15
4	Plastic limit	IS 2720: Part V:1985	25
5	Plasticity index	IS 2720: Part V:1985	21.15
6	Maximum dry density (MDD)	IS 2720: Part VII:1980	1.92 g/cc
7	Optimum moisture content (OMC)	IS 2720: Part VII:1980	14.3%
8	Classification	IS 1498	CI

2) Cement

Cement can be used most effectively with sand, silt and clays. The stabilization of soils by Portland cement occurs in two ways i.e. reduction in plasticity caused by calcium ions released during the initial cement hydration reactions that occurs when cement is mixed with moist cohesive soils. This mechanism is basically one of a cation exchange or crowding of additional cations onto the soil. The second process is cementation which is chemical in nature and may be visualized as a result of the development of chemical bonds or linkages between soil grain surfaces. The addition of cement to soils improves their shear strength, reduce water holding capacity of clayey soils thereby not only prevents the soil from swelling and softening, but also from freeze and thaw effects. The cement used in the present investigation was Ordinary Portland Cement of grade 43 Birla Shakthi confirming to IS 8112:1989.

Table 2
Physical properties of Cement

S. No.	Properties	Conforming to IS code	Value
1	Fineness	IS 4031: Part 3: 1988	3
2	Specific gravity	IS 4031: Part 11: 1988	3.18
3	Normal consistency	IS 4031: Part 4: 1988	32%
4	Initial setting time	IS 4031: Part 5: 1988	40 min
5	Final setting time	IS 4031: Part 5: 1988	520 min

3) Rice husk ash

Rice is an important staple food for more than half of the world's population. Rice husks are the coverings of grains of rice that are obtained as a by-product during the rice milling process and also it is one of the most widely available agricultural wastes. These rice husks are used as a good fuel. When rice husk incinerated, ash is produced called rice husk ash. Rice husk ash contains highest proportion of silica. Crystalline and amorphous forms of silica are obtained based on temperature range and duration of burning of the husk. RHA in amorphous form can be used as a partial substitute for Portland cement. Therefore, stabilization of clayey soil using combination of rice husk ash and cement can yield a significant increase of strength. RHA used in this work was collected from Sahara Biotech Bannimantappa Mysore.

4) Soil

Table 3
Physical properties of Rice Husk Ash

S. No.	Properties		Confirming to IS code	Results
1	Specific gravity		IS 1727: 1967	2.145
2	Consistency		IS 1727: 1967	35%
3	Initial setting time		IS 1727: 1967	175 min
4	Final setting time		IS 1727: 1967	235 min
5	Fineness	Wet sieving 75µ	IS 1727: 1967	0%
		Dry sieving 150µ	IS 1727: 1967	0%

5) Coir fibers

Coir is a natural fiber extracted from the husk of coconut. It is the fibrous material found between the hard internal shell and the outer coat of coconut. Coconut coir contains more lignin which imparts strength and elasticity to the cellulose based fiber walls. Chemically treated soils without fibers exhibit brittle behavior, which may cause the treated soil to crack and fail suddenly. Therefore, with the addition of fibers longevity of the pavement would be expected to increase with increasing toughness. Also coir has a neutral pH level so it won't affect the chemical composition of the soil. But due to presence of an outer surface layer these coir fibers have low mechanical strength and poor interactions. Structural stability of coir fibers as soil reinforcement can be improved by several methods. In this investigation, alkali pre-treatment was done using sodium hydroxide (NaOH) solution to improve the interfacial compatibility. Coir fibers were soaked in 5% NaOH solution for 24 hrs before using it as reinforcement for the clayey soil. The treated coir fibers were washed to remove the residual alkali from the surface of fibers and then, allowed to dry at room temperature for 7 days. Thus, by this surface treatment the outer layer of coir fiber is completely removed and a better mechanical interlocking between fibers and soil matrix was achieved.

Length and diameter of coir fibers play a key role in reinforcement mechanism. Using shorter length fibers (10mm), the surface area in contact with clayey soil is comparatively less and hence there is less pull out resistance resulting in less improvement in strength, whereas the sample preparation with longer fibers (>30mm) is difficult. Also with the increase in length of coir fibers, tensile strength decreases due to higher probability of presence of defects like kink bands in longer fibers and failure through weak pectin interface. Coir fibers of large diameter increase pull-out resistance and can share more stresses induced in the soil. With higher fiber content (more than 2%) in soil, the relative volume occupied by fibers increases, indicating that the fiber to fiber interaction is dominated compared to soil to fiber interaction or soil alone thereby reducing the degree of interlocking and friction mobilized in the sample.

By considering the above facts, coir fibers of length 20-30 mm and diameter 0.20-0.25 mm were used in this investigation. The coir fiber content was varied from 0.2% to 0.8% and these fibers were randomly distributed in the soil mix. Coir fibers for this experimental work were obtained from coir factory in Jainukal Nagar, Hassan district.

B. *Methodology*

Table 4
Designation of soil combinations

S. No.	Proportion of soil combination	Designation
1	Soil	S
2	Soil + 5% cement	SC_5
3	Soil + 5% cement + 5% RHA	SC_5R_5
4	Soil + 5% cement + 10% RHA	SC_5R_{10}
5	Soil + 5% cement + 15% RHA	SC_5R_{15}
6	Soil + 5% cement + 5% RHA + 0.2% fibers	$SC_5R_5F_{0.2}$
7	Soil + 5% cement + 5% RHA + 0.4% fibers	$SC_5R_5F_{0.4}$
8	Soil + 5% cement + 5% RHA + 0.6% fibers	$SC_5R_5F_{0.6}$
9	Soil + 5% cement + 5% RHA + 0.8% fibers	$SC_5R_5F_{0.8}$
10	Soil + 5% cement + 10% RHA + 0.2% fibers	$SC_5R_{10}F_{0.2}$
11	Soil + 5% cement + 10% RHA + 0.4% fibers	$SC_5R_{10}F_{0.4}$
12	Soil + 5% cement + 10% RHA + 0.6% fibers	$SC_5R_{10}F_{0.6}$
13	Soil + 5% cement + 10% RHA + 0.8% fibers	$SC_5R_{10}F_{0.8}$
14	Soil + 5% cement + 15% RHA + 0.2% fibers	$SC_5R_{15}F_{0.2}$
15	Soil + 5% cement + 15% RHA + 0.4% fibers	$SC_5R_{15}F_{0.4}$
16	Soil + 5% cement + 15% RHA + 0.6% fibers	$SC_5R_{15}F_{0.6}$

In this project work, various tests were conducted on clayey soil to determine its index properties i.e. Specific Gravity, Grain Size Distribution, Liquid Limit, Plastic Limit and Plasticity Index. Based on the index property, the soil was classified according to IS classification. Performance of the soil was evaluated in terms of maximum dry density, shear strength and CBR values by conducting Standard Proctor Compaction Test, Unconfined Compressive Strength Test and California Bearing Ratio Test respectively. Appropriate amount of stabilizer was then added according to the desired % by weight of soil necessary for each combination. Hand mixing was done to mix the stabilizers into the clayey soil for a mixing time of 5 to 10 minutes. Compaction test, UCS test and CBR test were conducted to determine the improvements in the soil in terms of maximum dry density, shear strength and CBR values. Observations were noted and the optimum percentage of addition of rice husk ash and coir fibers was determined.

5. Results and discussion

A. *Grain size distribution*

The soil used for this present study has an appreciable amount of clay therefore wet sieve analysis test was carried out as per IS 2720-part4-1985.

Wet sieve analysis of the soil:

- Gravel = 0%
- Coarse sand = 1%
- Medium sand = 12.8%
- Fine sand = 33.4 %
- Silt and clay = 52.8%

From Hydrometer Analysis, Silt content = 14% Clay content = 86%

B. *Influence of addition of cement and RHA on plastic limit of soil*

The plastic limit of the soil is increased to 33.33% for all the percentage addition of RHA.

C. *Influence of addition of cement and RHA on liquid limit of soil*

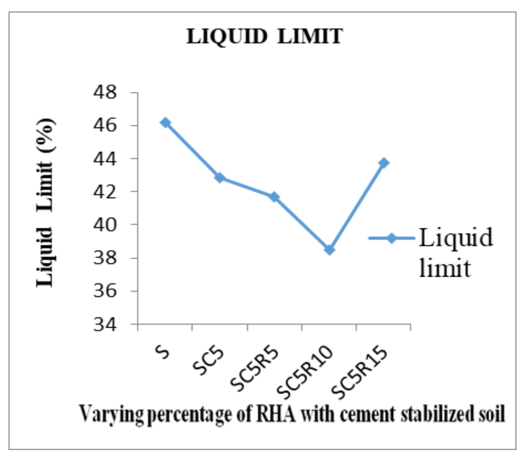

Fig. 1. Influence of cement and RHA on liquid limit of the soil

From the above graph, it shows that addition of cement and RHA into the soil reduces the liquid limit of the clayey soil. But with the increase in addition of RHA above 10% by weight of soil increases the liquid limit of the soil.

D. Influence of cement and RHA on plasticity index of the soil

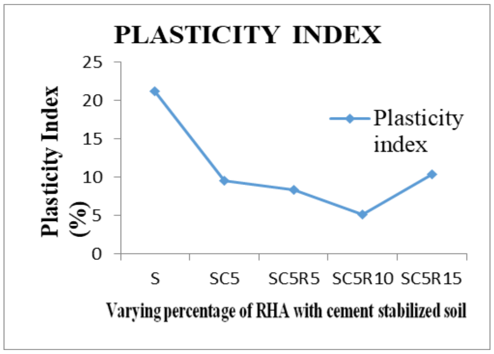

Fig. 2. Influence of cement and RHA on plasticity index of the soil

E. Standard proctor compaction test

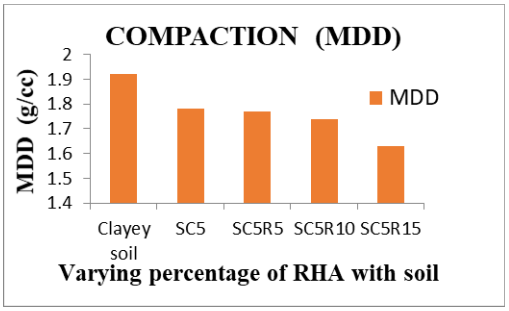

Fig. 3. Variation in MDD with addition of cement and RHA into soil

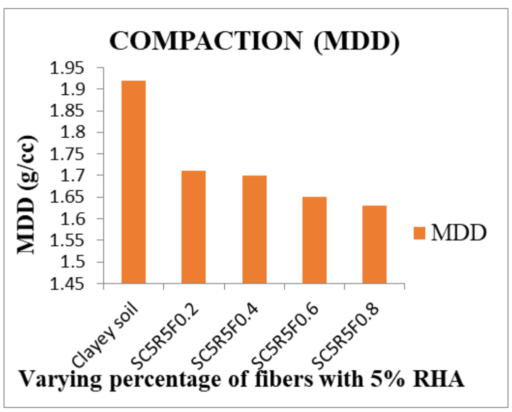

Fig. 4. Variation in MDD with varying percentage of fibers in 5% RHA-Soil mix

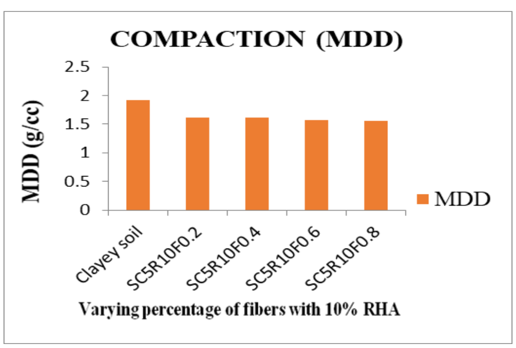

Fig. 5. Variation in MDD with varying percentage of fibers in 10% RHA-Soil mix

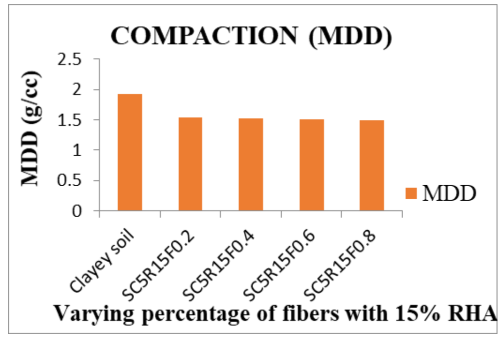

Fig. 6. Variation in MDD with varying percentage of fibers in 15% RHA-Soil mix

From the above graphs, it shows that maximum dry density (MDD) decreases with increase in the addition of RHA and coir fibers into the soil. This decrease in MDD with the increase in RHA and coir fiber content may be attributed to the relatively low specific gravity of the coir fibers and RHA particles.

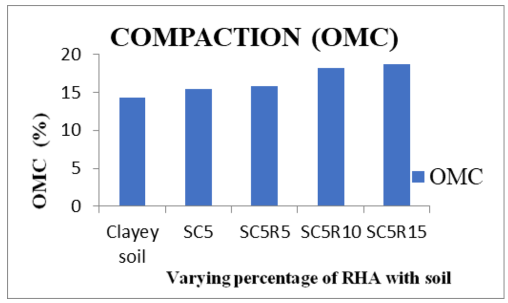

Fig. 7. Variation in OMC with addition of cement and RHA into soil

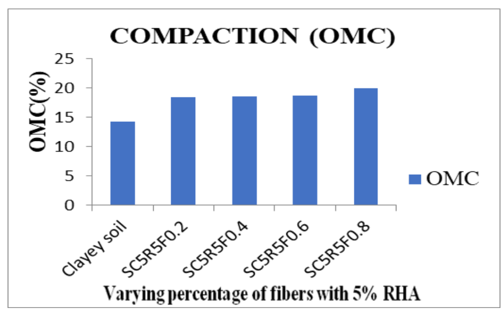

Fig. 8. Variation in OMC with varying percentage of fibers in 5% RHA- Soil mix

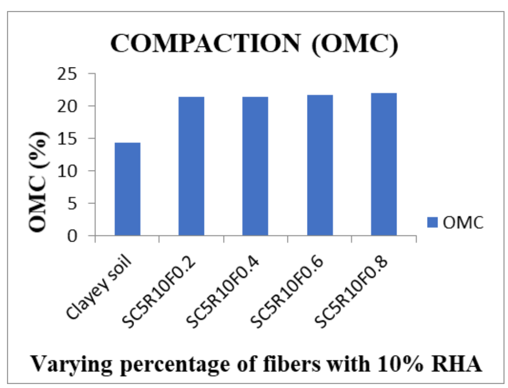

Fig. 9. Variation in OMC with varying percentage of fibers in 10% RHA- Soil mix

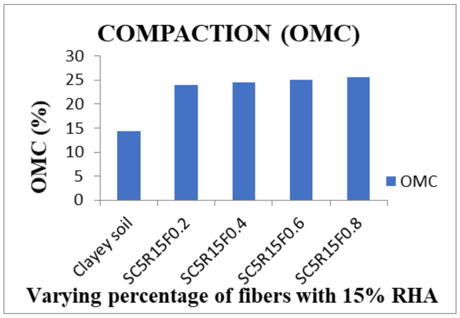

Fig. 10. Variation in OMC with varying percentage of fibers in 15% RHA- Soil mix

From all the above graphs, it shows that the optimum moisture content (OMC) increases with the addition of RHA and coir fibers into the soil. This increase in OMC with the increase in RHA and coir fiber content may be attributed to the relatively low specific gravity of the coir fibers and RHA particles.

Fig. 11. Unconfined compressive strength test

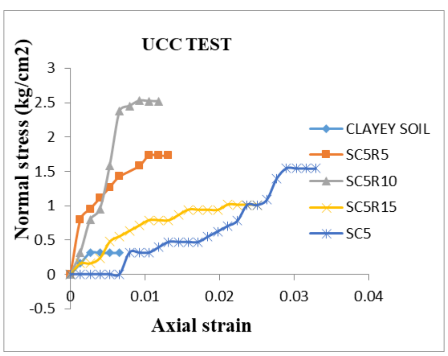

Fig. 12. UCS curve for cement and RHA in soil

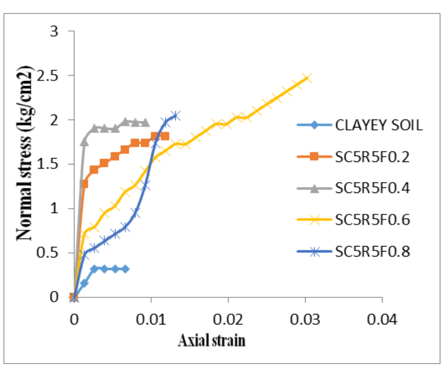

Fig. 13. UCS curve for varying percentage of fibers in 5% RHA- Soil mix

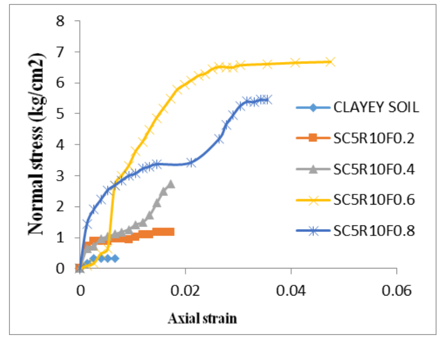

Fig. 14. UCS curve for varying percentage of fibers in 10% RHA- Soil mix

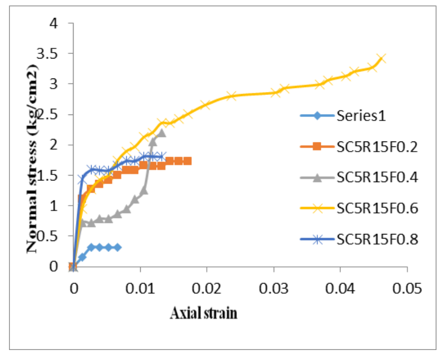

Fig. 15. UCS curve for varying percentage of fibers in 15% RHA- Soil mix

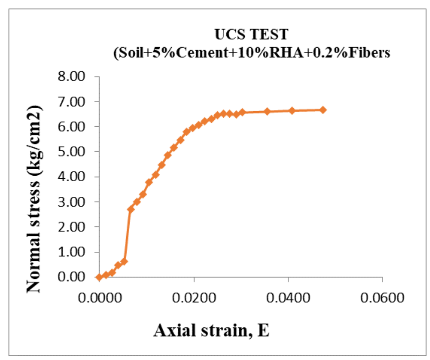

Fig. 16. UCS curve of the optimum proportion

From all the above graphs, it is observed that unconfined compressive strength of the soil goes on increasing with the addition of cement, rice husk ash and coir fibers. But with increase in coir fiber content above 0.6% by weight of soil has showed decrease in the strength value. Similarly increase in the RHA content above 10% by weight of soil has also showed a decrease in the strength value. Therefore, we can say that effectiveness in the stabilization of the clayey soil can be obtained by adopting RHA content of 10% by weight and fiber content of 0.6% by weight.

F. CBR test

Fig. 17. Soaked CBR test

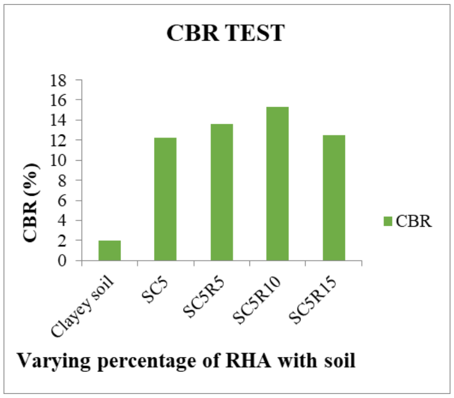

Fig. 18. Unsoaked CBR value for varying percent of RHA

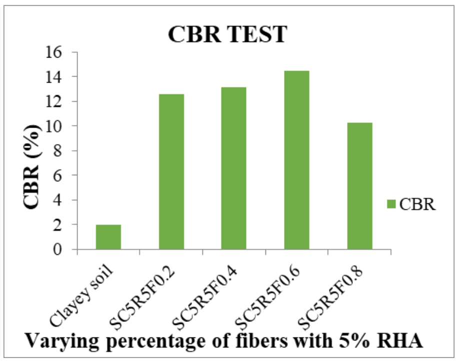

Fig. 19. Unsoaked CBR value for varying percentage of fibers with 5 % RHA

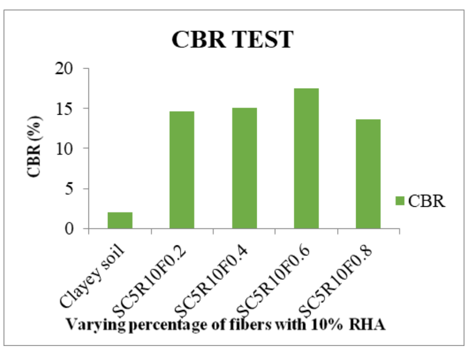

Fig. 20. Unsoaked CBR value for varying percentage of fibers with 10 % RHA

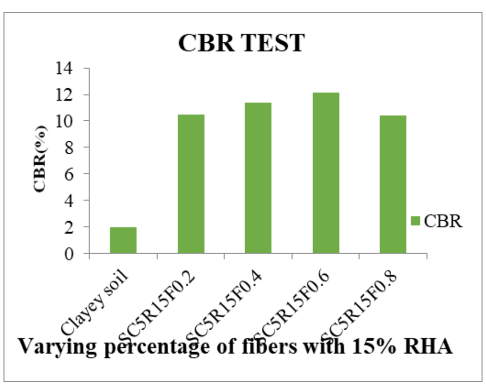

Fig. 21. Unsoaked CBR value for varying percentage of fibers with 15 % RHA

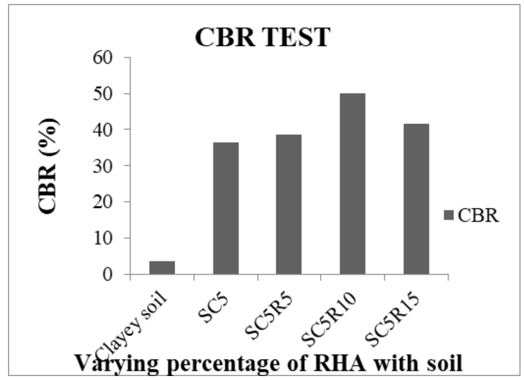

Fig. 22. Soaked CBR value for varying percent of RHA

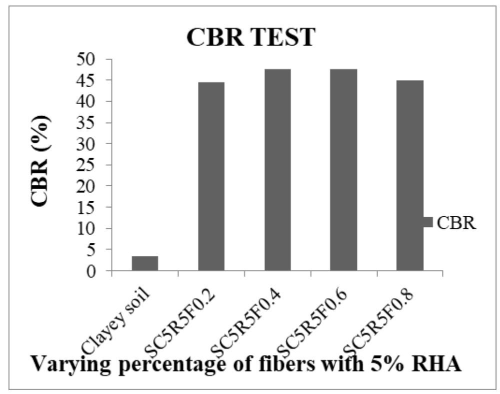

Fig. 23. Soaked CBR value for varying percentage of fibers with 5 % RHA

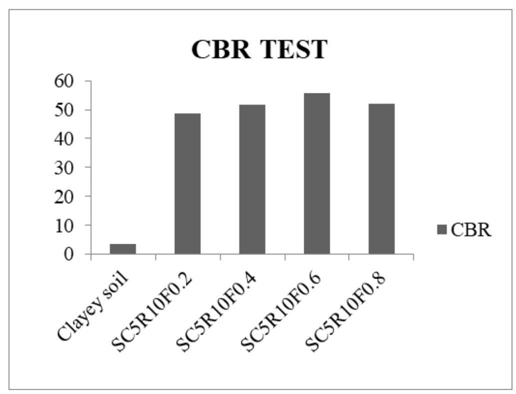

Fig. 24. Soaked CBR value for varying percentage of fibers with 10 % RHA

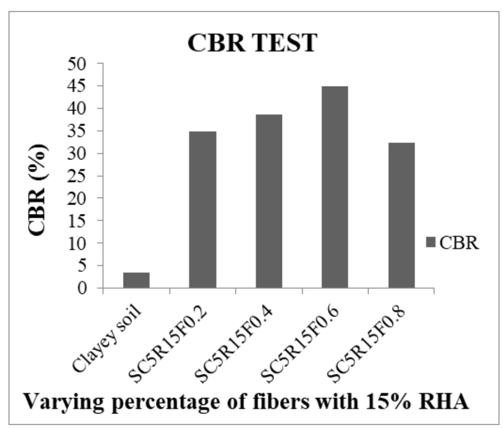

Fig. 25. Soaked CBR value for varying percentage of fibers with 15 % RHA

It can be observed from all the above graphs that the CBR value increases with the addition of admixtures into the soil for both unsoaked and soaked CBR tests. The unsoaked and soaked CBR values of the clayey soil as 2 % and 3.54 % increased to 17.52% and 55.57% respectively, with an addition of 5% cement, 10% RHA and 0.6 % coir fibers. Decrease in the CBR value for higher content of RHA may be due to excess that was not mobilized in the reaction, which consequently occupies spaces within the sample and therefore reduces bond between the soil and cement-RHA mixtures.

G. Expansion ratio

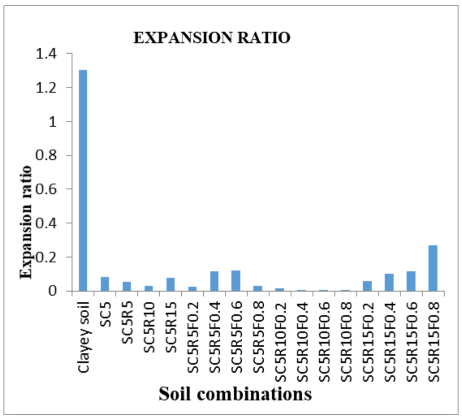

Fig. 26. Expansion ratio

From the above graph, it is observed that the swelling potential of the soil is greatly reduced by the addition of admixtures into the soil. The expansion ratio of the optimum percentage of soil mix (SC5R10F0.6) is 0.003 which is nearly equal to 0, therefore this mix can be effectively used for stabilizing the soil.

6. Conclusion

From the results of experimental investigation, following conclusions are drawn:

- Liquid limit of the soil decreased with the addition of cement and RHA into the soil thereby decreasing the plasticity index and increasing the strength of the clayey soil.
- Maximum dry density decreases and optimum moisture content increases with the addition of RHA and coir fibers into the soil. This decrease in MDD and increase in OMC with the increase in RHA and coir fiber content may be attributed to the relatively low specific gravity of the coir fibers and RHA particles.
- Unconfined compressive strength of the soil was found to increase with the addition of coir fibers up to 6% fiber content and RHA up to 10% by weight of soil. Further increase in the contents resulted in decreased strength.
- Similarly it was observed that the CBR value also increased with the addition of admixtures into the soil. The unsoaked and soaked CBR values of the clayey soil as 2% and 3.54 % increased to 17.52% and 55.57 % respectively, with an addition of 55 cement, 10% RHA and 0.6 % coir fibers. Decrease in CBR value for higher content of RHA may be due to excess that was not mobilized in the reaction, which consequently occupies spaces within the sample and therefore reduces bond between the soil and cement-RHA mixtures.
- It was also observed from both UCS test as well as CBR test that the maximum strength was obtained for the soil mix containing 5% cement, 10% RHA and 0.6% fibers.
- From the overall experimentation results which were carried out, an optimum percentage of cement-RHA-coir fibers mix in soil was arrived at 5%:10%:0.6% (by weight of soil).

7. Scope for further work

- Development of an innovative and sustainable pretreatment method that can change the morphology of coir fibers surface roughness that may cause better mechanical interlocking between fibers and soil matrix.
- Variation of strength properties of soil according to the varying length and diameter (aspect ratio) of the fibers.

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