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REVIEW ARTICLE

A review on the effect of eggshell powder on engineering properties of expansive soil

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Abstract

Objectives: To find the optimal percentage of eggshell powder which when mixed with expansive soil results in effective foundations for buildings. **Methods:** In this study, samples from Katreni Kona near Amalapuram, East Godavari District of Andhra Pradesh in the southern part of India was selected to collect the expansive soil which was open excavated at 2.0 m depth beneath the surface of the ground for the study. Eggshell powder (ESP) mixed with expansive soil in different percentages of 5%, 10%, 15% and 20% by dry weight was considered for evaluation. The treated and untreated samples were subjected to Compaction, California bearing ratio (CBR) (soaked and unsoaked) and Unconfined compressive strength (UCS) tests. **Findings:** The clay content was reduced with an increase in density and liquid limit, subsequently the plastic limit was reduced with the increase of UCS by adding the eggshell powder to the soil. The optimal dried density of the soil was increased from 14.42 kN/m^3, 14.59 kN/m^3, 14.71 kN/m^3, 14.88 kN/m^3 and 14.81 kN/m^3,and optimum moisture content was decreased from 28.24 %, 26.42%, 26.09%, 24.48% and 23.02% respectively when 0% to 20% of eggshell powder was mixed with soil. The CBR values were increased until 15% ESP at which the maximum value was attained, and further addition decreased the CBR. **Novelty:** The engineering nature of expansive soil is extremely enriched with ESP stabilization. The optimum percentage of ESP was 15% when compared with other percentages that were assessed in this investigation. The solidity of soil increased with a reduced number of voids that connect the soil cells, and consistency boundaries of the land were reduced by using ESP. The CBR value with a percentage increase of ESP indicated that the soil is more suitable for foundation.

Keywords: Eggshell powder; Differential Free Swell (DFS); expansive soil; CBR; UCS; stabilization; compaction

1 Introduction

In recent days, enhancing the properties of soil is a serious concern owing to the fact that soils with enriched properties are typically are not readily available in nature or may be present in minor quantities so as to meet the construction requirements. Numerous problems were previously reported when constructions were raised using soft soil including issues towards shear failures, unnecessary settlements, differential settlements, etc. One such alternative to overcome these issues is by the usage of fillers like eggshell powders, seashell powders, lime, etc., with the original soils so as to form stabilized soils. Using old stone powders and plastic glass strips in geotechnical applications by performing compaction tests, and CBR combination of stone dust ratio of 5%, 10%, 15%, etc., and plastic glass strips of 0.5%, 1%, 1.5%, etc., the maximum dry density are 1.94g/cm^3, and the optimum moisture content is 18.91%, the percentage of CBR further increases with a 15% stone dust and 1.5% plastic strips, as well as a higher mixture of stone dust and plastic strips, reduce the maximum dry density and increase of Optimal moisture content (omc). Several studies have revealed that mixing 50% of the stone dust with soil reduces the water requirement during compaction in the field, increases the Maximum dry density (MDD) and contributes 30% of the stone dust for achieving an effective specific gravity. The cheaper value of stone dust to improve CBR and UCS to 10%-15% and came to the conclusion that stone dust can be used as an economical stabilizer which effectively improves the technical properties of a highly cohesive soil[1,2]. Using industrial waste to improve the soil is an economical and ecological method. GGBS industrial waste, available at low cost, is combined in an expensive soil in a percentage range and various laboratory experiments were conducted to improve the soil strength. 1.68% dry density, 14.2% of water content for 30% GGBS and 1.48% dry density, 13.6% water content for 4% lime were observed from the test completion by independently mixing GGBS and limestone soil BC. In comparison, with lime, GGBS has a higher value of liquid limit than represented by the lime, whereas, lime produces a greater plastic limit value. Tests were carried out by D. Srinadh et al.,[3] and Atahu M.K. et al.,[4] in improving the geotechnical properties of expansive soil with a study of expansive soil stabilization using industrial iron powder as an additive in various percentages. From the results, it can be supposed that the increase of iron powder percentages in soil decreases the values of liquid limit and the plastic limit remains constant while decreasing the plasticity index (PI). 6% of iron powder in soil achieved the highest dry density and higher CBR values. This 6% of iron powder replacement in the soil is recommended based on the results in order to achieve soil strengths indicators as highest dry density and higher CBR values. Silmi Surjandari N. et al.,[5] have studied the ESP mixture and its consequence in clay soil with higher plasticity. Samples of sticky soil possessing 0-1.25 liquidity index were combined with ESP over a dissimilar percentage of 0%, 10%, 15% and 20% levels. They have carried out extensive laboratory analysis, and their results showed that how their selected mixture affects the properties like liquidity index and compressive strength. The liquidity index was observed to be largely affected by the mixture formed using ESP. Increased liquidity index results in reduced strength, which was their foremost outcome.

Shekhawat P., et al.[6] analyzed the applications of fly ash and eggshell powder so as to attain a rational geopolymer towards the construction of pavements. Moreover, they have analyzed the effects of curing towards improving the mechanical strength. They used three activators Na_2SiO_3/NaOH with 0.5, 1.0 and 2.0 encompassing 10M NaOH concentrations. An optimal temperature of 50°C/80°C was employed for curing the mixture. The MDU increased with a corresponding rise in these activators. Their microstructural evaluation studies revealed that the resultant cement was attained towards the ESP-FA geopolymer by incorporating optimal activator ratios with reasonable temperature for curing.

Brooks R.M.,[7] studied soil stabilization with fly ash and rice husk ash, and from the behavior of stress deformation due to unlimited compressive strength showed that the breaking stress and deformations increased by 106% and 50% when the fly ash content increased from 0 to 25%. While 47% of improved CBR, 97% of the unlimited compressive stress is increased when the Rice husk ash content (RHA) was increased from 0-12%. The expansive sub-grade soil is therefore strengthened by recommending RHA and fly ash content of 12% and 25% respectively. A 15% of fly ash content is recommended for mixing with RHA to form a layer that reduces swelling as performance in laboratory tests is satisfactory.

Around 188,000 tons had to be imported while Iraqi egg production was 42,000 tons. In 2011, the total yearly consumption together with these two figures was 230,000 tons. According to Foroutan R., et al.,[8], eggshell constitutes a 10-11% in a total weight of the egg. In Iraq, the yearly production of eggshell waste according to the above statistics is about 23,000 tons, considering that the weight of the shell is (10%). In the country, landfill pollution can be reduced by effectively generating and managing this large amount of waste. The use of eggshells to stabilize the soil will therefore be an available option when there is the absence of an effective waste management policy. The process of improving or treating the technical properties of soil layers by adding other types of soils and minerals, or by binding the proper chemical compositions into the powdered soil and then compact for soil stabilization.

In order to find out the optimal percentages in addition to the effect on the properties of the soil strength, various eggshell powder percentages were treated to the expansive soils and have made an attempt in this present work for studying about their geotechnical properties of expansive soils[9,10]. Because of the finding optimal of 15% ESP and forming a close packing density by effectively bounding the eggshell powder, increased total strength values are provided in the test results.

So as to assess different constructions that were carried out using gypsum soils, Abdulrahman S.M. et al.,[11] carried out their research towards assessing the gypsum-based constructions in Iraq. Different locations in Iraq were considered to select the samples and assessing their properties of buildings that were raised using gypsum. Different percentages of ESP ranging from 4%, 8%, 12%, 16% and 24% that were mixed with the collapsed soil have been analyzed by the authors. Also, the analysis was done with different percentages of the collapsed soil before and after mixing ESP. The effects of ESP on liquidity index, stabilization and soil strengths were studied.

Owuamanam S. & Cree D.,[12] reviewed the egg and seashells manufacture with perception towards the amount of bio-$CaCo_3$ which were formed from the above waste combinations. These bio-$CaCo_3$ fillers with polymer composite resulted in increased tensile strengths, flexural strengths and impacts towards durability were reflected. For improving the compatibilities amid bio-$CaCo_3$ and polymer fillers, research works over surface modifiers were also analyzed. They concluded with the idea of formulating better composites by considering these waste materials, so that, the added value could be attained towards egg and seashells.

Anoop S.P. et al.,[13] studied the features of soil stabilization with the replacement of lime with eggshell fillers. They have carried out experimental investigations so as to assess the betterment of attaining soil stabilization with the help of eggshell powder instead of lime. A conclusion was made in such a way that, by substituting eggshell powder in the place of lime, the resultant soil stabilization was increased when compared with the untreated soils. Here, 0.5%-2.0% of eggshell powders were introduced to the overall soil weight in the formation of the mixture. Thus, 25% substitution of lime with eggshell powders offered increased tensile strengths, and thereby largely be applicable for the real-world purpose.

Oluwatuyi O.E. et al.,[14] defined the peculiar conclusions over laboratory assessments towards lateritic soil that was treated with crushed eggshell powder and cement, both mixed in equal proportion, as a mixture for the construction of highways. These fillers were added to the soil ranging from 0%-8% over the soil weight. Subsequently, these mixtures were assessed with numerous experimental investigations. Results showed an increase in CBR value with increased stabilization. Moreover, the UCS value was observed to be increased. Accordingly, 8% mixing of crushed eggshell powder with the overall soil weight offered increased stabilization and was potentially applicable in highway constructions.

2 Materials Used

This section describes the properties of various materials used in the laboratory experiments.

2.1 Expansive soil

Table 1. Geotechnicalproperties of expansive soil

S. No.	Property	IS Code	Expansive Soil
1.	Liquid Limit (%) WL	IS 2720 Part V	80.32
2	Plastic Limit (%) WP	IS 2720 Part V	32.15
3.	Plasticity Index (%) IP	IS 2720 Part V	48.17
4.	Soil Classification	–	CH
5.	Specific Gravity G	IS 2720 Part III	2.63
6.	Grain Size Distribution	IS 2720 Part IV	
	Sand (%)		4
	Silt (%)		13
	Clay (%)		83
	Coefficient of Uniformity (Cu)		6.7
	Coefficient of Curvature (Cc)		2.01
7.	Differential Free Swell (%) DFS	IS 2720 Part XI	130
8.	Optimum moisture content (%) OMC	IS 2720 Part VIII	28.24
9.	Maximum dry density (kN/m3) MDD	IS 2720 Part VIII	14.41
10.	Unconfined compressive strength (kPa) UCS	IS 2720 Part X	136.7
11	Soaked CBR (%)	IS 2720 Part XVI	1.33

In India, samples from Andhra Pradesh of East Godavari District, Katreni Kona near Amalapuram are selected to collect the expansive soil which is open excavated at 2.0 m depth beneath the surface of the ground for the study of this present work. The soil that is air-dried was allowed prior to testing to pass through 4.75mm sieve. The medium passed through a 425-micron sieve was used for consistency tests. For the consistency tests, 425 microns sieve is used in which soil is passed through it. Table 1 depicts the geotechnical properties of the expansive soil.

Fig 1. Expansive soil

Fig 2. Eggshell and powder

2.2 Egg Shell Powder (ESP)

Home, restaurants, hotels, fast-food centers, hatcheries and poultries are the domestic sources from which the waste of eggshell is produced and then which can be pulverized in mills as given in Figures 1 and 2. Because the eggshell powder has a similar chemical composition to lime it can be used as the best substitute for lime which is synthesized artificially but cannot be used as a material for stabilization. Magnesium carbonate or lime and calcium are the main components included in its chemical composition. Its composition mainly includes calcium and magnesium carbonate (lime). Table 2 depicts the chemical properties of eggshell powder.

Table 2. Eggshell powder's chemical composition

Chemical Composition	Weight (%)
C	21.1286
Na_2O	0.1046
M_gO	0.9261
P_2O_3	0.4149
SO_3	0.3264
K_2O	0.0542
C_3O	76.9922
Fe_2O_3	0.0132
SrO	0.0396

3 Study Design

The present study has been planned in two stages. In the first stage, it is proposed to carry out individual geotechnical properties in laboratory materials used during the study.

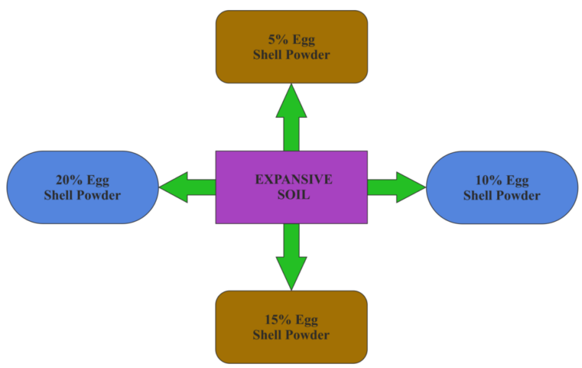

Fig 3. Flow chart showing different percentages of eggshell powder blend with expansive soil

In the second phase, stabilization method tried in the laboratory carried out blending with different percentages of eggshell powder 0%, 5%, 10%, 15% and 20% are blend with soil and various geotechnical properties studied were by ore tested as per IS Code provisions to calculate the optimum percentage as in Figures 3 and 4. From the laboratory experimentation and comparison made, it was obvious to know the improvement in geotechnical properties. The details of each of the stages are explained in the following sections

4 Laboratory Experimentation

Soils that are used throughout this work were tested in various ways to find the index and other significant properties in the laboratory. The eggshell powder with different percentages is mixed to conduct the experiments of Differential free swell (DFS) index, Atterberg's limits, Compaction test and the CBR test in finding the optimal quantities and their impact on the point of view of expansive soil strength properties. The details of these test results were presented in the following sections.

4.1 Differential free swell index

According to IS: 2720 (Part 40)-1977, the sample passing through the IS 425 micron sieve has been selected to carry out this test.

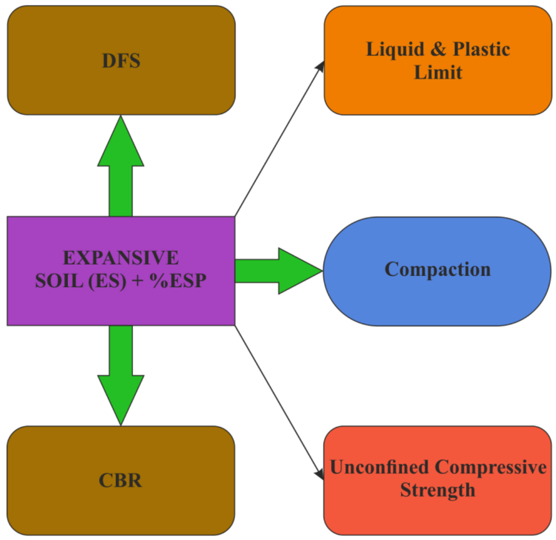

Fig 4. Flow chart showing different laboratory experiments carried by blend eggshell powder with expansive soil

4.2 Index properties

The Index properties such as liquid limit values and plastic limit values of the samples have been attempted in this work founded by following the recommendations of regular procedures related to the I.S: Codes of practice [IS: 2720 (Part-5)-1985; IS:2720 (Part-6)-1972] (15,16).

4.3 Compaction properties

As per the IS: 2720 (Part VIII) -1983 compaction test, testing of various eggshell powder percentages for an expansive soil blending is conducted with the maximum dry density and optimal moisture content (17).

4.4 California Bearing Ratio (CBR) test

As per the IS: 2720 Part XVI-1987 recommendations as shown in Figure 5, testing of various eggshell powder percentages of the treated and untreated expansive soil samples that are prepared under the unsoaked or soaked conditions have been carried out with the CBR (18).

4.5 Unconfined Compressive Strength (UCS)

These tests are carried out in the laboratory under the IS Code (IS: 2720, Part X (1991) (19) from compaction parameters i.e., Maximum dry density and optimum moisture content at a displacement rate of 1.2 mm/min. Proving ring used 2 kN capacity for testing all specimens tried as shown in Figure 6

5 Results and Discussions

The index and other significant geotechnical properties of the materials that were used throughout the work were found in this paper by conducting few laboratory tests. Various laboratory experiments were conducted by blending up different percentages of ESP mixing with expansive soil to find the optimal percentages and their outcome on geotechnical properties.

5.1 Differential free swell index

As shown in Figure 7, from 130%, 121%, 109%, 85% and 64% with addition to the variation in ESP from 0% to 20%, it is found that there is a decrease in the outcome of differential free swell in expansive soil when treated with different ratios of ESPs.

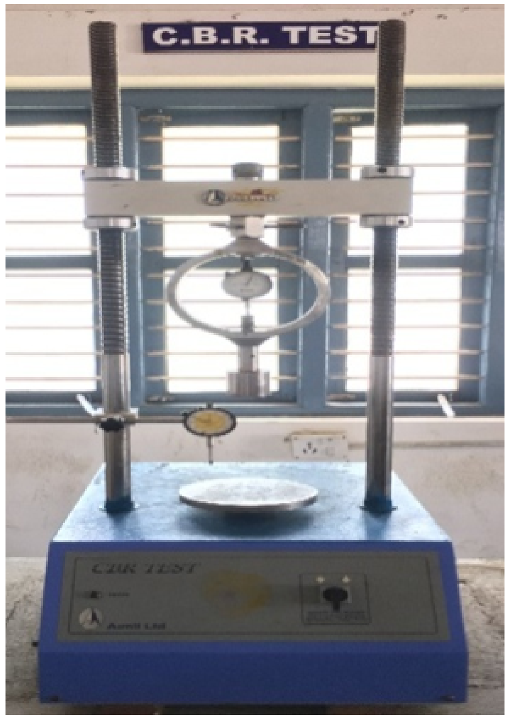

Fig 5. California bearing ratio test apparatus

5.2 Variation of liquid and plastic limit properties

From Figure 8, it can be seen that the liquid limit values are decreasing for soil blending of various percentages of ESP from 81.12%, 73.34%, 66.53%, 59.61% and 53.76%. Because of the process of action exchange that usually acquires a long time when such stabilizers are not present, the value of the liquid limit is decreased which is due to the chemical reaction with the soil that leading to a cementing effect.

5.3 Effect on compaction parameters

The compaction parameters OMC Vs MDD values' variation in expansive soil when treated with different percentages of eggshell powder is presented in Figure 9. The utmost dried density of the soil has been increased from 14.42 kN/m^3, 14.59 kN/m^3, 14.71 kN/m^3, 14.88 kN/m^3 and 14.81 kN/m^3,and optimum moisture content was decreasing from 28.24 %, 26.42%, 26.09%, 24.48% and 23.02% respectively when 0% to 20% of eggshell powder was blended with an addition of 5% ESP. From the above optimum, moisture content values are decreased continuously and maximum dry density was obtained at 15% ESP, because the eggshell powder's reaction with the soil creates a higher cementing effect.

5.4 Effect on CBR

In addition to different percentages of ESP to expansive soil, the unsoaked and soaked CBR values are increased from 2.12%, 1.33%, 3.98%, 2.69%; 5.65%, 3.14% and 4.97%, 3.11% in addition to eggshell powder and is represented in Figure 10. It was observed that the CBR values were increased up to 15% ESP which attains a maximum value, and also further addition decreases the CBR as per Figure 11.

5.5 Effect on unconfined compressive strength

Using laboratory tests, the unconfined compressive strengths were conducted by blending different percentages of eggshell powder as per IS 2720 - part X at different curing periods 0, 7, 14 and 28 days as presented in Figure 12. Blending ESP to expansive soil, the Unconfined compressive strength (UCS) values were found to be increasing up to 15% addition (Table 3), and by adding further, it decreases at different curing periods. In view of 15%, ESP as an optimum percentage, maximum UCS

Fig 6. Unconfined compressive strength test apparatus

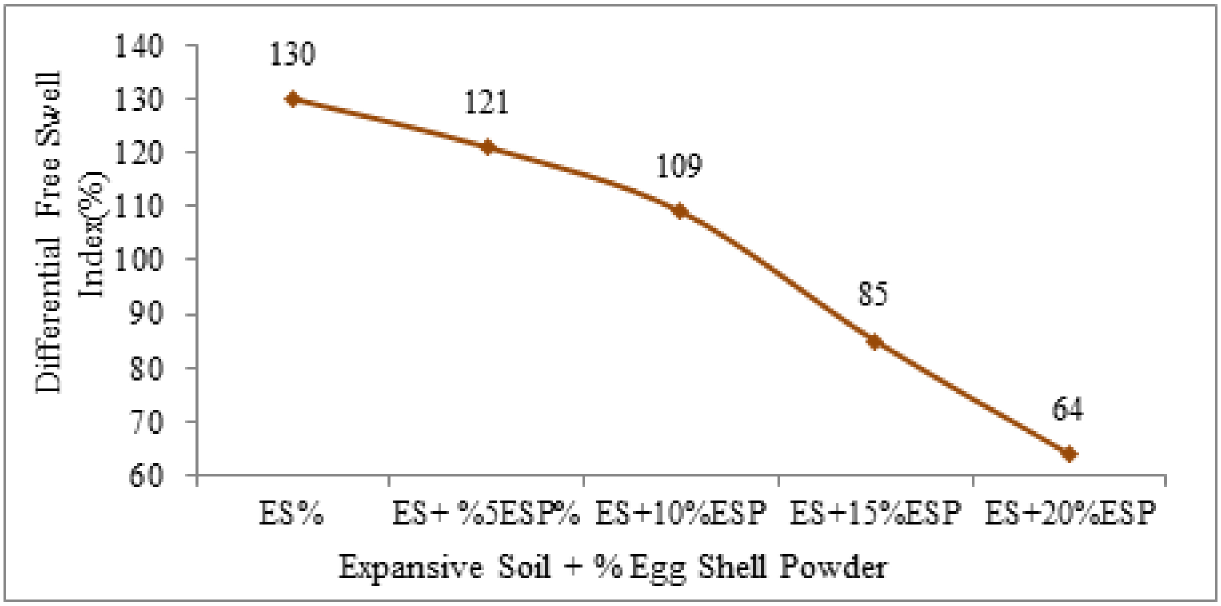

Fig 7. Differential free swell variation in expansive soil when treated with different % of egg shell powder

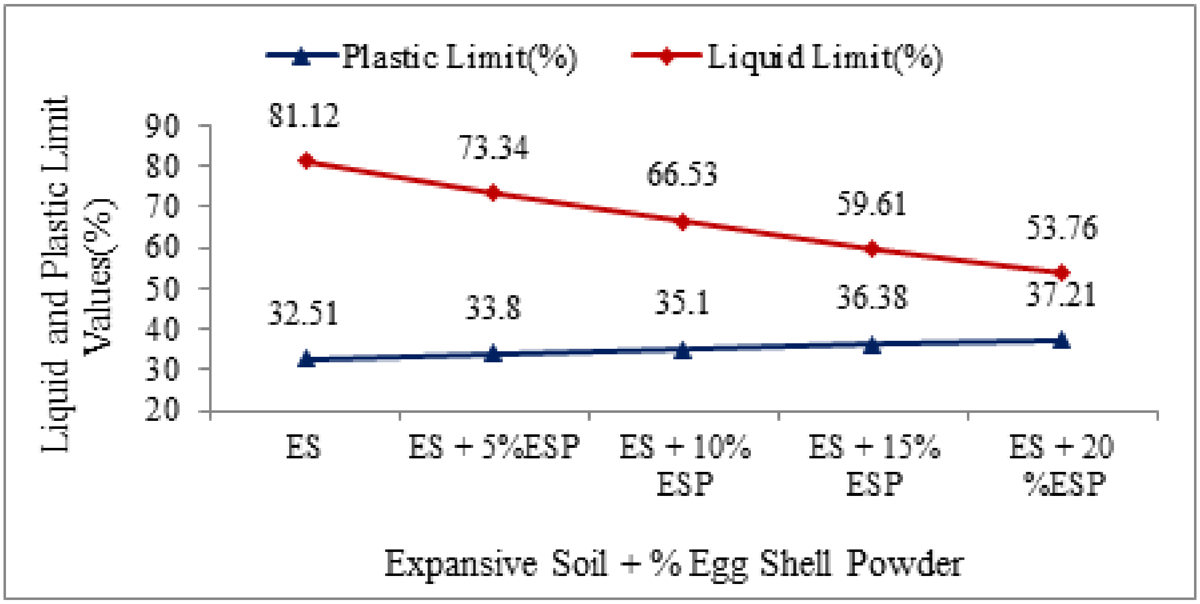

Fig 8. Variation in liquid and plastic limit parameters of expansive soil when treated with different percentages egg shell powder

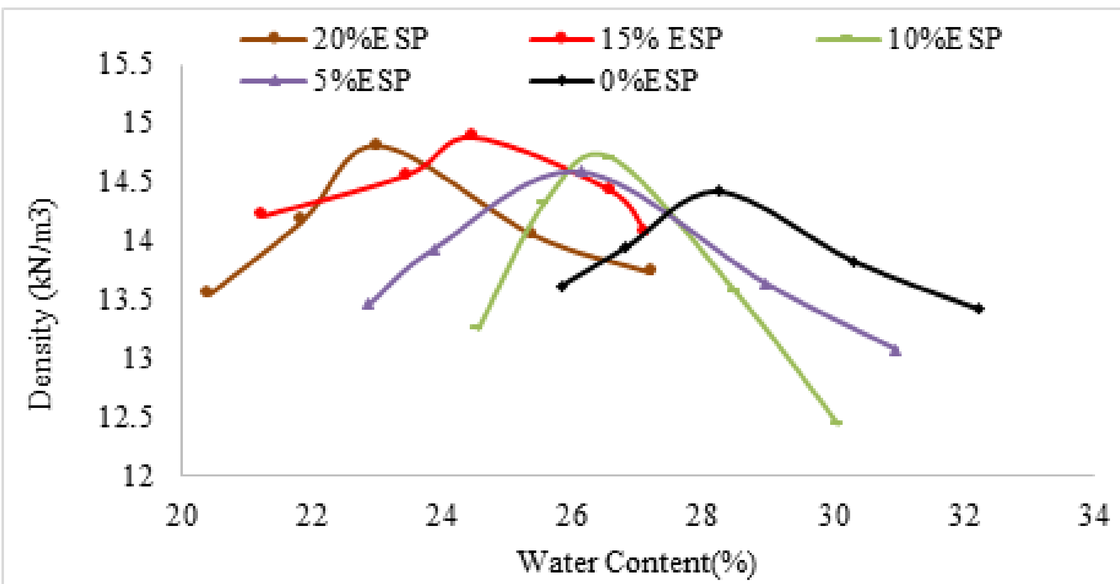

Fig 9. OMC Vs MDD values variations in expansive soil when treated with different percentages of Egg Shell Powder (ESP)

of 135.37 kN/m^2, 154.66 kN/m^2, 196.32 kN/m^2 and 248.02 kN/m^2 respectively was attained at I,7,14 and curing period of 28 days as compared to other percentages used in this investigation.

6 Discussions

In this study, various percentages of ESP in the quantity of 5%, 10%, 15% and 20% were mixed with expansive soil so as to find out the optimal percentage of ESP mixing with expansive soil so as to bring an effective solution for construction works. As per the laboratory test results, the liquid limit values get decreased for soil blending of various percentages of ESP from 81.12%, 73.34%, 66.53%, 59.61% and 53.76%. Starting with 130%, 121%, 109%, 85% and 64% with addition to the variation in ESP from 0% to 20%, there is a decrease in the outcome of differential free swell in expansive soil when treated with different ratios of ESPs. The

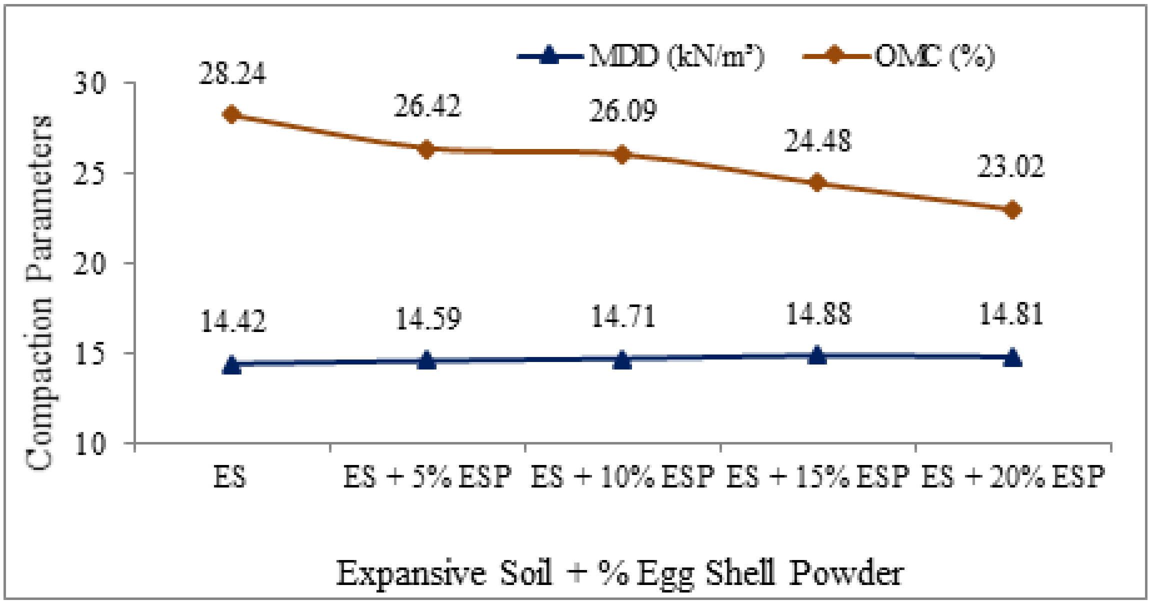

Fig 10. Variation in compaction parameters of expansive soil treats with diverse percentages egg shell powder

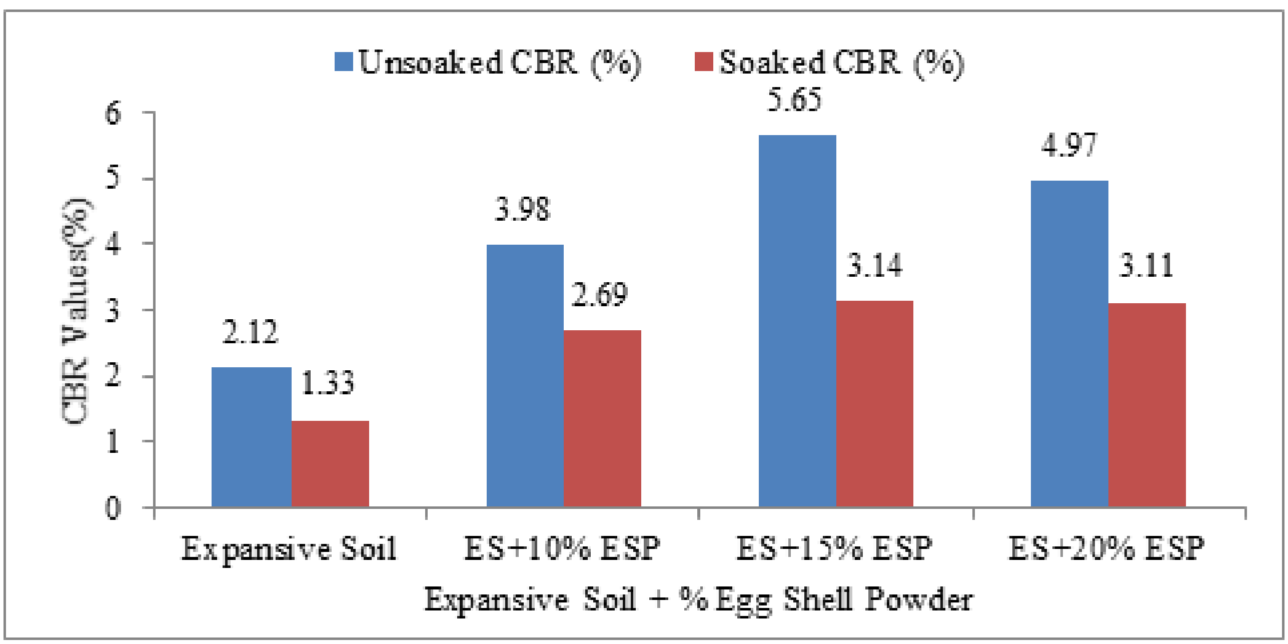

Fig 11. CBR values variation in expansive soil when treated with uneven % of Egg Shell Powder

Table 3. Variation in properties of untreated expansive soil and treated expansive soil with 15% eggshell powder

S.NO	Property	Symbol	Expansive Soil	Expansive Soil + 15% Egg Shell Powder
1	Liquid Limit (%)	W_L	80.32	59.61
2	Plastic Limit (%)	W_P	32.15	36.38
3	Plasticity Index (%)	I_P	48.17	23.23
4	Soil Classification	—	CH	CH
5	Specific Gravity	G	2.65	2.71
6	Differential Free Swell (%)	DFS	130	85
7	Optimum Moisture Content (%)	OMC	28.24	24.48
8	Maximum Dry Density (kN/m^2)	MDD	14.41	14.88
9	CBR (%)	—	1.33	3.14
10	Unconfined compressive strength (kN/m^2)	UCS	136.7	248.02

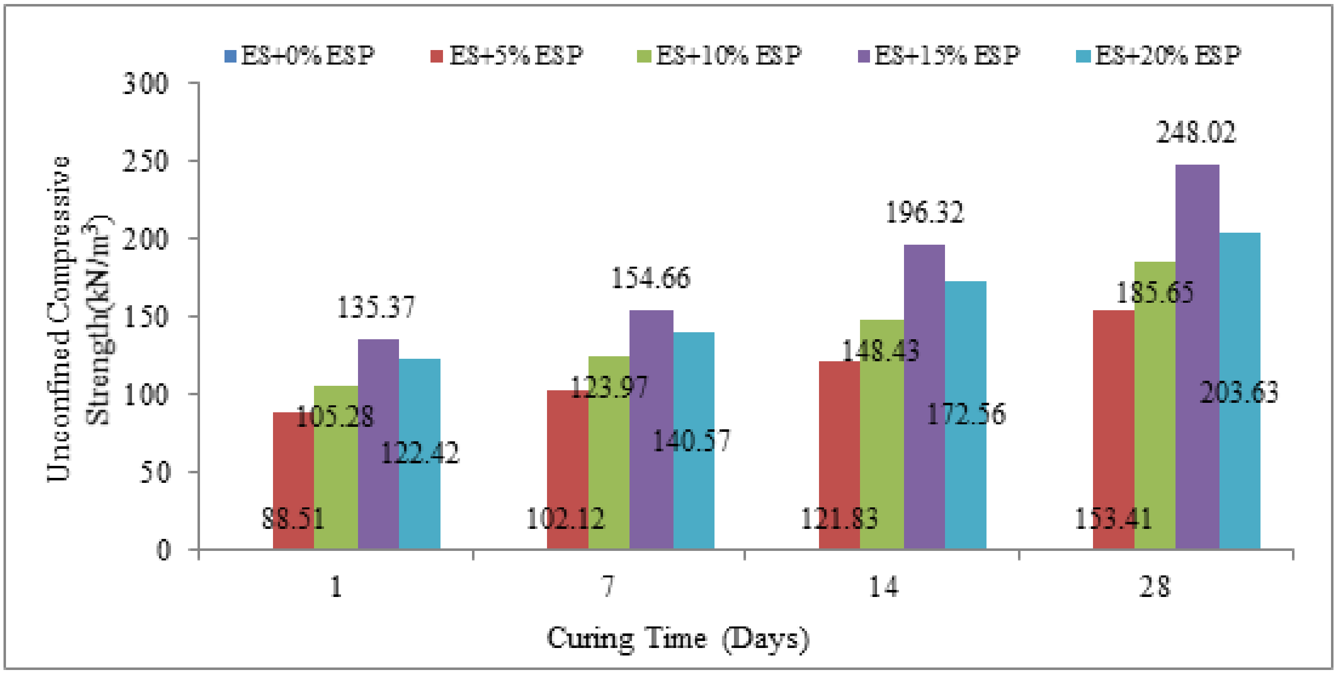

Fig 12. Unconfined compressive strength values variation of expansive soil when treated with variable % of egg shell powder

maximum dried density of the soil has been increased from 14.42 kN/m^3, 14.59 kN/m^3, 14.71 kN/m^3, 14.88 kN/m^3 and 14.81 kN/m^3,and optimum moisture content was decreasing from 28.24 %, 26.42%, 26.09%, 24.48% and 23.02% respectively when 0% to 20% of eggshell powder was blended ES with the subsequent addition of 5% ESP. The addition of different percentages of ESP to expansive soil, the unsoaked and soaked CBR values are increased from 2.12%, 1.33%, 3.98%, 2.69%; 5.65%, 3.14% and 4.97%, 3.11% in addition of ESP. Ultimately, in view of 15% ESP as an optimal percentage, larger UCS of 135.37 kN/m^2, 154.66 kN/m^2, 196.32 kN/m^2 and 248.02 kN/m^2 respectively was attained for a period of 28 days of curing. Hence, it could be finalized that 15% ESP mixing with expansive soil will be an excellent construction material for raising foundations.

7 Conclusions

The ESP results on an index and the swelling soils' engineering properties were satisfied by the enhanced geotechnical properties of expansive soils with the domination of eggshell powder. Sample expansive soil from Katreni Kona near Amalapuram was selected for this study. ESP was mixed with the sample expansive soil in different percentages of 5%, 10%, 15% and 20% so as to find out the optimal percentage of ESP mixing with expansive soil. Considering different percentages of ESP, different experimental results in this study demonstrated that the optimal percentage of ESP was 15%. Therefore, the properties of expansive soil improve significantly by the addition of ESP, and their use in stabilization of black cotton soil can further reduce the construction costs and also provides a better environmental solution for their disposal. Especially in the rural areas of developing countries, an alternative way to reduce the road construction costs could be accomplished by using this ESP waste.

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