Soil stabilization using Eggshell powder,Fly ash,Alccofine,Sodium silicate (Na_2SiO3) and sodium hydroxide (NaOH) solution

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Abstract

In construction projects worldwide, especially in areas with weak or problematic soil conditions, soil instability poses significant challenges in construction. In order to tackle this challenge, traditional stabilization techniques such as cement or lime stabilization have been used which along with being costly are also environmentally harmful. This has led to an increased emphasis towards exploring cost-effective and eco-friendly alternatives for soil stabilization. Waste products such as Eggshell powder, Fly ash, and Alccofine serve dual purposes of waste disposal as well as soil stabilization making their combined effect worth investigating. Through this research, we incorporate these materials as soil stabilizers and investigate their effectiveness to enhance soil strength. Three different mixtures were prepared by using varying proportions of these stabilizers. Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests were conducted on these specimens as well as untreated soil. Comparative analysis highlighted significant enhancements in both UCS and CBR values for stabilized soil mixtures, indicating strength enhancement as compared to untreated soil.

Keywords: Soil stabilization,Eggshell Powder,Fly Ash, Alccofine,UCS test,CBR test,Geopolymer.

1 Introduction

Properties of soft soil change dramatically when soil gets wet and pose challenges for engineers. Dry soft soil easily supports heavy load but when moisture content increases the stability gets compromised,which leads to problems like swelling and shrinking. Movement due to swelling and shrinkage can damage the structure built on the soil. Owing to population increase and rapid development in urban areas, structures are being constructed on weak ground conditions. Traditionally , non eco friendly soil stabilization materials such as cement are used, which contributes to global greenhouse gas emission of around 7%[1].Geopolymer as an environment friendly binding material alternative have emerged.When aluminosilicate material hardens at below 100°C a three-dimensional hardened material is formed which is a Geopolymer[2].Geopolymerization requires a material containing alumina and silicate and an alkaline reagent and heat to form a geopolymer binder . Geopolymers significantly reduce carbon emission, from 40-90% as compared to traditional OPC [3].

2 Literature Review

According to published research fly ash-based geopolymer improves the properties of challenging silty clays [4].Silty clay soil stabilized using class C fly ash improved and used as stabilized subgrade material [5]. Similarly, class C fly ash based stabilized clay soil performed better in stability and strength as compared to lime-treated clay [6].Plasticity of kaolin clay was also reduced when treated with fly ash and GGBS which lead to polymerization and reduced plasticity state from high to low [7]. Kaolin clay also saw a significant increase in the early strength due to formation of calcium aluminum silicate hydrate gel (CASH) at ambient temperature [7].Soil reinforcement with fly ash has been widely studied in geotechnical and materials engineering.Fly ash has been shown to be effective in stabilizing soft inorganic soils [8].Research has shown that the addition of fly ash can help improve compressive strength and soil water content [8].Various studies have investigated the impact of different types of fly ash on the sustainability of organic soils, with results showing the effectiveness of fly ash in soil stabilization [9].Additionally, the use of Class C and Class F fly ash has been shown to successfully stabilize clay soils, demonstrating the potential of fly ash in soil stabilization applications [10]. Studies also highlight the importance of optimizing the soil/fly ash mixture ratio to improve the technical properties of clay sand used as a base layer [11].Fly ash, alone or in combination with other materials such as lime, has been shown to significantly reduce the plasticity index and swelling rate of expansive soils, thereby eliminating their swelling [12].

One of the notable materials used for stabilizing soil is Alcofine, which shows promising results in improving various soil properties [13] Alcofine can significantly improve the stability and durability of various soils. Research studied the effects of different additives combined with Alcofine on soil stabilization.For example, addition of coconut fiber, polypropylene fiber [14] geogrids as well as Alcofine have been explored to improve soil properties.Additionally, the combination of Alccofine with materials such as finely ground blast furnace slag (GGBFS) has been studied for soil stabilization.These studies highlight the potential of Alcofine when combined with other materials to effectively improve soil properties.In addition, the effectiveness of Alccofine in stabilizing various soil types has been proven.Research has shown successful stabilization of black cotton soils [15], sedimentary soils, laterite soils [16] with the help of Alcofin.

Eggshell powder has been studied for its potential to improve the engineering properties of expansive soils, with studies showing that its composition is similar to lime, leading to better soil stabilization [17].Eggshell powder has been explored as a filler in various materials to improve their physical and mechanical properties [18].Studies have shown that eggshells can improve not only the physical properties but also the mechanical properties of soil, making it a cost-effective alternative [19].Furthermore, research has demonstrated that eggshell powder can be used to stabilize soil during road construction, demonstrating its applicability in civil engineering projects [20].By partially replacing cement with eggshell powder, pollution from eggshell waste and cement production can be reduced, highlighting its environmental benefits [21].Eggshell powder has been studied in combination with other materials such as sodium chloride and polypropylene fibers for soil stabilization, showing promising results in soil stabilization applications [22].Supplementing eggshell powder with alkaline soil stabilizers has been shown to improve the durability of clay soils, further highlighting its role in soil stabilization [23].Characterization of soil stabilized with eggshells and natural chlorides using geophysical techniques.Improving the technical properties of expansive soil by adding eggshell powder and fly ash .Kumar and Soni's study on the mechanical properties of clay under normal and freezing conditions .

3 Scope of the study

Considering the aforementioned literature, the present research was strategized to study the trend of strength characteristics of fly ash,eggshell powder and alccofine geopolymer-treated clay with varying proportions of fly ash and eggshell.The three different ratios of FA:ESP used in this study were 1:2,1:1 and 2:1 respectively. The strength characteristics of geopolymer-stabilized soil composites, cured at ambient temperature, were studied systematically by conducting an unconfined compressive strength test, California bearing ratio test. The results of the study are critically examined to evaluate the potential use of the aforementioned waste materials based geopolymer in pavements.

4 Materials and Methodology

In this study, the geopolymer binder is developed using a combination of low-calcium fly ash (FA), eggshell powder (ESP), alccofine along with an alkaline reagent (a solution of sodium silicate and sodium hydroxide). The presence of alkaline reagent is pivotal to initiate the reaction among the precursor materials to produce the geopolymer. Different combinations of precursor materials were chosen to observe the trend of UCS and CBR values with varying proportions of ESP and FA.

4.1 Soil

The soil was obtained from Delhi Technological University, Delhi, India and was classified in accordance with Indian Standard Soil classification system(ISSCS) by conducting the preliminary tests on the soil according to IS 2720. The properties and classification thus found out are mentioned in Table 1. Further Unconfined Compression Test (UCS) and California Bearing Ratio (CBR) was conducted for the untreated soil and their values were noted. The UCS for the soil was observed as 45.4 KN/m^2 and

CBR values were found to be 6.4 % for unsoaked condition and 4.71% for soaked condition.

Table 1: Properties of soil

Property of Soil	**Value/ Remarks**
Specific Gravity	2.74
Natural Moisture Content (NMC)	1.83 %
Optimum Moisture Content (OMC)	14.25 %
Maximum Dry Density (MDD)	15.49 KN/m^3
Plastic Limit	16.83 %
Liquid Limit	30.69 %
Plasticity Index	13.86 %
Classification	Clay with Low Compressibility (CL)

4.2 Geopolymer Ingredients

The precursor material fly ash (FA) of class F category conferring to ASTM C618-12a, (2012) was obtained from Concrete Lab, Delhi Technological University. The specific gravity of the precursor FA was found out to be 2.2. For the production of another precursor material, eggshell powder (ESP), discarded eggshells were acquired from local roll shops and omelet vendors. Eggshells were cleaned and adequately rinsed with water. The washed eggshells were subsequently dried for one day. After drying, the eggshells were crushed into powder. The Eggshell powder was sieved through 300 mm and 75mm sieves. The part of the eggshell passing through the 300 mm sieve and retained on a 75 mm sieve was put to use in this study. The specific gravity of the precursor ESP was reported as 1.89. Alccofine 1203 available in 25kg packaging was obtained from a vendor for the purpose of this study.The specific gravity of Alccofine 1203 was 2.86 A mixture of sodium silicate (Na_2SiO3) and sodium hydroxide (NaOH) solution, was prepared as recommended in the literature[7] having the ratio of Na2SiO3/NaOH fixed at 2. The concentration of the alkaline reagent was kept at 10 M, conferring the earlier literature[24-27].

5 Methodology

From the existing literature on fly ash and eggshell based geopolymer treated clay, the optimum content of geopolymer content in terms of mechanical strength as well as economical consideration was found out to be 30% of the total sample material. [4].Building on this we fixed the percentage of soil at 70% by weight of the total sample. Another research paper found out that addition of 3% alccofine significantly increased the early strength of clayey soil.[28].Hence in this study, we took soil 70% by weight and 3% alccofine by total weight of the sample. To further study the trend when alccofine is incorporated in the geopolymer and ratio of FA:ESP is varied, we adopted three ratios namely 1:2,1:1,2:1 respectively in 3 specimens. The proportions of each material in the samples are tabulated in Table 2 for the three specimens.

Table 2 : Specimen Details

Mixture	Soil (%)	Eggshell Powder (%)	Fly Ash (%)	Alccofine (%)
Normal Soil	100	0	0	0
S1	70	9	18	3
S2	70	13.5	13.5	3
S3	70	18	9	3

5.1 Sample Preparation

The geopolymer-treated clay mixtures were prepared by dry mixing the precursor materials of geopolymer(fly ash,eggshell powder and alccofine) with oven-dried and sieved down soil. This ensured that all the dry materials were thoroughly mixed and

a uniform mixture was formed. Following dry mixing, the alkaline reagent (with a ratio of $Na_2SiO_3/NaOH - 2$) was gradually added to prepare samples. The specimen of untreated clay (without geopolymer mix) was implied as Normal Soil and was considered a reference mixture.
All geopolymer-treated clay mixtures were prepared with the optimum activator content (OAC) keeping in mind the in situ application, determined from modified Proctor tests (IS: 2720 (Part 8) 1983). OAC is equivalent to the optimum moisture content (OMC) excluding the fact that alkali reagent was utilized in place of water. For determining the unconfined compression strength (UCS), the geopolymer clay mixture was compacted into cylindrical molds of 76.2 mm length and 38.1 mm. The samples obtained through this process were extracted from the mold with the help of a sample extractor. To avoid the loss of moisture, composites were subsequently kept in desiccators for a period of 14 days for ambient curing. With respect to California Bearing Ratio (CBR) tests, the samples were prepared according to the MDU and OAC of the mixtures. The mold having a 150 mm diameter and 175 mm height with a detachable collar of 50 mm in height was used. The samples were cured for fourteen days in ambient conditions prior to testing in unsoaked and soaked situations.

6 Tests conducted

6.1 Unconfined Compressive Strength (UCS)

Unconfined compression strength (UCS) test is a great tool to examine the mechanical strength of samples. Hence UCS tests were conducted conferring to IS: 2720 (Part 10), (1991) after a curing period of 14 days. The samples were placed axially sandwiched between the bearing plates in the compression measurement machine by placing the specimen. From the load frame and proving ring, the load was exerted on composites at 1 mm/min of strain rate axially. The readings of the dial gauge were noted at a period of 30 secs until the failure point. The mean of three experiments was computed for each different composite and the variation of UCS values was analyzed.

6.2 California bearing ratio (CBR)

California bearing ratio (CBR) experiments on geopolymer treated clay for soaked and unsoaked situations were conducted according to the procedures proposed in IS: 2720 (Part 16), (1987) (IS: 2720 (Part 16) 1987). The load was exerted at a rate of 1 mm/min on the sample by means of the penetration piston, and load evaluations were noted at each 0.5 mm penetration up to a total of 6 mm penetration . The %CBR of samples was acquired by dividing the loads conforming to 2.5 mm and 5.0 mm penetration to the standard loads of 1370 kg and 2055 kg, correspondingly.

7 Results and Discussion

7.1 Unconfined compressive strength performance of stabilized soil

Compressive strength of the treated soil was analyzed after a curing period of 14 days at ambient temperature.The untreated soil sample had a UCS of 45.4 KN/m^2 while the UCS as observed for the samples S1, S2, S3 were 53.19 KN/m^2, 67.29 KN/m^2 and 88.3 KN/m^2 respectively. Comparing the UCS values of the treated soil samples to the UCS of the untreated soil sample , a significant increase in the unconfined compressive strength of soil is observed. This increase is non-linear and increases in accordance with the increase in the eggshell powder content in the soil samples S1,S2,S3. The percentage increase in the UCS for samples S1,S2,S3 were 17.16% ,48.22% ,94.49% respectively as compared to the normal untreated soil.

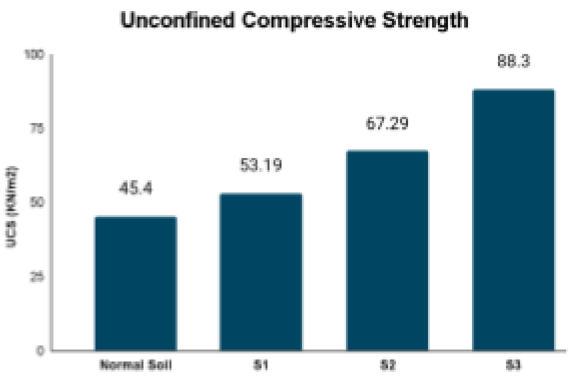

Fig 1: UCS for different samples

7.2 California bearing ratio values of the stabilized soil

California bearing ratio(CBR) values at 2.5mm penetration for normal untreated soil for unsoaked and soaked condition was 6.40% and 4.71% respectively.while the CBR as observed for samples S1, S2, S3 in unsoaked condition was 7.34%,8.66%,14.88% and for soaked condition was 5.65%,7.06%,10.36% at 2.5mm penetration. Comparing the CBR values for untreated soil and treated soil,a significant increase in the CBR value is observed where the increase is in accordance with the increase in the eggshell powder content in the samples S1,S2,S3 the percentage increase in CBR value is 14% ,35%,132% for unsoaked condition and 19%,67%,120% for soaked condition respectively as compared to the untreated normal soil.

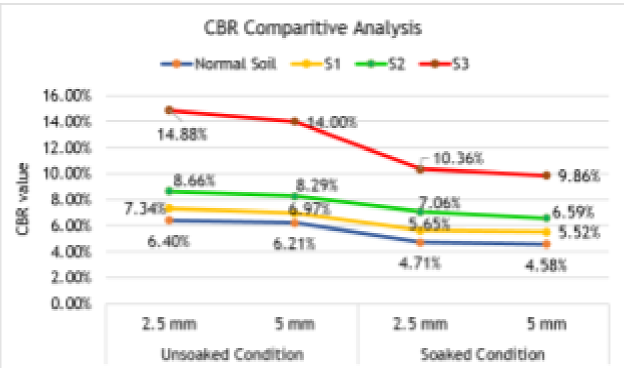

Fig 2: UCS for different samples

Conclusion:

In this investigation, the application of Fly ash-Eggshell Powder and alccofine geopolymer as a binding agent for clay stabilization at ambient conditions was explored. The mechanical strength improvement of geopolymer-stabilized clay after a curing period of 14 days was assessed. Moreover, an investigation was carried out on the CBR of the geopolymer-stabilized clay in both soaked as well as unsoaked conditions. The constituents of geopolymer were varied as explained in Table 2. The outcomes of soil-geopolymer mixes were also equated with clayey soil without any treatment. Subsequent important deductions were observed from the investigation:

- A significant increase in the mechanical strength can be observed with the addition of geopolymer by analyzing the UCS values of the different samples.
- As the content of the eggshell powder increases within the contents of the geopolymer mix, there is a non linear increase in the UCS value. Out of the samples prepared the maximum UCS observed was in the case of S3 having the maximum ESP%. When compared to the UCS value of untreated soil, the UCS value increases by 94.49% which significantly improves the strength of the soil.
- A similar trend can be observed in case of CBR wherein the sample S3 containing the maximum percentage of ESP exhibits the maximum increase in the CBR value in both soaked as well as unsoaked conditions. The percentage increase in the CBR value for unsoaked condition was 132% while in the case of soaked condition there was a 120% increase for S3 as compared to untreated soil.

Hence it can be concluded that the geopolymer mix containing ESP and FA in the ratio of 2:1 with alccofine yielded the best results within the samples used in this study on both parameters being used, namely UCS and CBR. This could lead to a decreased environmental impact of these waste products and significant increase in the properties of the soil which could have positive impacts on various kinds of construction projects.

Declarations

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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