

Research Article

Experimental Study on Stabilized Expansive Soil by Blending Parts of the Soil Kilned and Powdered Glass Wastes

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This experimental study explores the utilization of glass wastes mixed with kilned soil for weak soil improvement. Expansive soil remains a reason for a lot of road and building damage through settlement and cyclic volume change. Replacing or stabilizing the soil can minimize the risks associated with the soil type. Cement and lime have been the major stabilizers. However, the cost of these materials is raised. Among many stabilizing materials, parts of the expansive soil burned and mixed with glass powder are investigated to fulfill the major requirements. It is proved that the soil sample taken requires improvement. Parts of the soil kilned and mixed with powdered glass waste have 75% of expansive soil kilned and 25% of glass waste powder, which are then added in expansive soil with percentages of 5%, 15%, and 25% to test the change that occurred on liquid limit, plastic limit, free swell, unconfined compression, compaction, California bearing ratio (CBR), and mineral composition. Maximum dry density (MDD) improved from 1.33 g/cm^3 to 1.61 g/cm^3 , optimum moisture content (OMC) reduced from 40% to 21.3%, plastic index reduced from 58.79% to 19.91%, California bearing ratio (CBR) increased from 0.95% to 12.08%, and unconfined compressive strength (UCS) changed from 216 kPa to 910 kPa on 14 days of curing period. Similarly, the addition of 15% and 25% of the stabilizer improved the free swell of expansive soil to 36% and 14%, respectively. CBR swell values significantly improved from 7.16% to 0.22%. Changes in mineral contents from X-ray diffraction (XRD) test are observed: montmorillonite and illite minerals disappeared, and the nonexpansive minerals are observed abundantly in stabilized soil. The addition of 15% to 25% of the stabilizer in expansive soil improved the physical and chemical properties as to be in the appropriate range for road subgrade construction use.

1. Introduction

Soil characteristics play a vital role for construction of structures. Expansive soils are types of high plasticity clay soils and experience seasonal volume changes. The soil would require a special approach during the construction. The parent materials associated with expansive soils are either basic igneous rocks or sedimentary rocks. Expansive soil is dominated by silty clay or clayey with grey to black color. Expansive soil clay minerals generally consist of montmorillonite, illite, and quartz. Montmorillonite belongs to the smectite clay family and aluminum smectite with a small amount of Al^{+3} replaced by Mg^{2+} . This causes a charge inequity that is balanced by exchangeable cations Na^+ or Ca^{2+} and oriented water. During the wet period, this type of

soil absorbs water and swelling occurs, while during the subsequent dry period, the soil loses moisture by evaporation, and volume reduction occurs [1–3].

Expansive soil has been the major problem of the construction environment. The swell-shrink behavior, settling, and compressive behavior of this soil make it less preferable for the construction industry. Civil engineering projects like roads located in areas with expansive soils need improvement of soil properties by using various methods. If the special treatment is not done, the structure will be damaged and structural failure will occur. Expansive soils remain a reason for damage of structures, particularly pavements, gravel roads, cobble stone roads, and light buildings compared to any other natural hazard, including earthquakes and floods. It has been reported that the damage

caused by these soils contributes significantly to the burden that the natural hazard poses on the economy of countries where the occurrence of these soils is significant. At dry state, the expansive soils are very difficult to compact since their consistency varies from hard to very hard. At wet state, they are very sticky. The volume changes exhibited by expansive soils are related to the interactions of various intrinsic and external factors [4–8].

Expansive soils exist all over the world and cause damage to foundations and associated structures. Expansive soils are widespread also in Africa, in particular in South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, and Nigeria. Furthermore, expansive soil is found in the central, North-Western, and eastern highlands of Ethiopia, in the western lowlands around Gambella, and in some parts of the rift valley. Expansive soils, mainly black cotton soils, cover nearly 40% of surface area of Ethiopia. Local deposits of this soil are also present throughout the country near rivers, water logged areas, and in drainage restricted localities [3, 9]. This soil may trigger landslides in some mountainous terrains and endanger human life and resources, since many houses are in the areas of land slide susceptible locations [10].

During subgrade construction, the soil encountered will be expansive soil. If the encountered soil is expansive, it may be removed and replaced or stabilized with other materials to increase the shear strength. Soil stabilization has been used for the construction of many structures, roads, dams, and small buildings. Soil stabilization is the alteration physical and chemical properties of the soils to enhance their shear strength properties and to control its shrink-swell properties. There are many methods of stabilization with chemical, mechanical, and thermal stabilization [11]. Stabilization improves soil's load bearing capacity. Stabilization with cement and lime was the primary methods of soil improvement for long time. However, their cost is raising from time to time. Thus, looking for alternative stabilizer by locally available material can reduce the cost of the stabilizer. Agricultural, industrial, and environmental wastes are observed to improve the properties of expansive soil. This can reduce the hazard of the natural environment. Solid wastes are among the alternatives for stabilizing expansive soils, and most of those materials have been observed improving weak and expansive soils [12–19].

Utilization of solid wastes for construction purpose can minimize the amount of waste to be disposed to the environment and has contribution for green environment. There is a lot of research encouraging the use of industrial, agricultural, and construction wastes as stabilizer materials. However, there is no direct evidence to apply the blend of soil kiln and glass wastes for weak soil stabilization. Therefore, the stabilization of expansive soil using parts of the soil kiln and blended with powdered glass has been investigated by experimental study.

2. Materials and Research Methodology

2.1. Sample Collection and Sampling Techniques. The sampling technique used for the study is purposive sampling,

which is based on the objective and information to determine the properties of the expansive soil. Thus, the sample is taken based on visual inspection and engineering judgement. The research is conducted by using expansive soil and glass wastes to stabilize the nature of expansive properties of the soil. For this particular study, the samples are collected from the place with high abundance of expansive soil. The soil sample is collected from Jimma town, kebele 05 on a side of road under construction. The soil was blackish brown in color which is highly plastic clay soil. Glass wastes were collected from hotels since there were a lot of glass bottles crushed and thrown. The glasses were collected and deposited on some area; hence, they occupy land spaces, and they are difficult to dispose. Additionally, crushed glasses are observed as a household waste from residential buildings and construction residue materials during finishing works.

2.2. Materials and Samples Preparation. Soil samples were prepared on the basis of methods: expose the soil sample as received from the field to the air at room temperature until dried thoroughly, break up the aggregations thoroughly in the mortar with a rubber-covered pestle, and select a representative sample of the amount required to perform the desired tests by the method of quartering or using a sampler. The expansiveness and plasticity of the soil are known by conducting free swell and Atterberg's limit tests. The natural properties of the soil are presented in Table 1.

The soil is burned/kilned on high temperature in a furnace at 700°C for 2 hours. Then, the cooling process took 24 hours to process for further tests. The kilned soil showed different physical change (color change), chemical change (became sandy), and loss of weight about 10%. The natural air-dried soil and the burned soils of the same type of soil are shown in Figures 1(a) and 1(b), respectively. When the soil is burned above a temperature 550°C, it loses chemical properties as proved by pervious researchers [20, 21].

Glasses were collected and powdered enough to be mixed with soil. Glass is totally inert and nonbiodegradable. Glass is an amorphous noncrystalline material which is typically brittle and optically transparent. After crushing, it is sieved with a #200-micron sieve which has 0.0075 mm opening as shown in Figure 2(a). Crushed or powdered glass was observed to improve the expansive soil by previous researchers, and it is proved that crushed glass can be used as a stabilizer [22–24]. The long-term effect (up to 1500 days) of glass-treated soil as studied by Bilgen proved that the glass powder effectively improves the clayey soil [25]. The percent of mixing of the stabilizer was specified as 75% soil kilned and 25% powdered glass waste, which has a ratio of 3 : 1. The mixing percentage of the stabilizers was 5%, 15%, and 25% of the total weight of the sample. Figure 2(b) shows the prepared mix for 25% stabilizer and the natural soil before blend.

2.3. Laboratory Tests. The laboratory tests performed are as follows: natural moisture content determination, unconfined compressive strength (UCS), grain size analysis/sieve analysis and Atterberg's limit test, specific gravity, free swell

TABLE 1: Native soil geotechnical properties.

Geotechnical properties		Values
Grain analysis	Gravel (%)	1.96
	Sand (%)	2.68
	Silt (%)	35.36
	Clay (%)	60
Natural moisture content (%)		14.1
Average specific gravity (g/cm^3)		2.01
Liquid limit (%)		93.84
Plastic limit (%)		35.05
Plasticity index (%)		58.79
Free swell (%)		135



FIGURE 1: Soil sample: (a) air dried and (b) kilned/burned.



FIGURE 2: Prepared sample: (a) powdered glass and (b) soil and stabilizers.

index test, modified compaction test, California bearing ratio (CBR), CBR swell value, and X-ray diffraction test (XRD). The stabilizer is prepared as per the test requirements of American Society of Testing and Material (ASTM) and American Association of State Highway and Transportation

Officials (AASHTO) [26–30]. The methods used for each test are presented in Table 2.

The mineralogical characterization of the natural clay soil and the stabilized soil is analyzed using X-ray diffraction (XRD) method. XRD is one of the most widely used

TABLE 2: Tests and methods.

Test performed	Method used
Free swell	Holtz and Gibbs (1956)
Grain size analysis	ASTM D422-63
Consistency limits	ASTM D4318-17
Modified compaction	ASTM D-18
Unconfined compressive strength (UCS)	ASTM D 2166
California bearing ratio (CBR)	AASHTO T193-93
CBR swell	AASHTO T193-93

techniques for chemical analysis and material characterization. For mineral composition analysis of the samples, X'pert high score and Match software are used. Similar studies proved that this technique is the reliable method for mineralogical and crystalline characterization of powders study [25, 31–36].

3. Results and Discussion

3.1. Grain Size Analysis. Grain size analysis is performed in two stages. The first stage was performing sieve analysis (wet sieve) for coarse grained soils, and the second stage was hydrometer analysis for fine grained soil. Wet sieve analysis is done to determine the distribution of soils by taking 500 gm of soil, soaked for 24 hrs and then washed on 75-micrometer sieve, and the retained soil is oven-dried and sieved on dry sieving. Soil particle sizes smaller than 0.075 mm (passing 200 mesh sieve) are determined by hydrometer method. From the result of wet sieve and hydrometer analysis, it is shown that the natural soil has a high amount of clay percentage, as presented in Figure 3. The result shows that the soil contains 1.96% gravel, 2.68% sand, 35.36% silt, and 60% clay. Based on the laboratory identification, the soil is classified under USCS and AASHTO classification. According to Jim Stevens of USCS classification system, the soil type was classified under high plasticity clays, CH [37]. According to AASHTO classification system using the plasticity chart, the soil was under the category A-7-5 [1, 38].

3.2. Specific Gravity. This test is used in the phase relationship of air, water, and solids in a given volume of soil. Specific gravity is defined as the ratio of the unit weight of a given material to the unit weight of water [39]. The average specific gravity of the natural soil is reported as the specific gravity of the soil, and it is 2.65. The specific gravity of a soil is used in calculating the phase relationships of soils (that is, the relative volumes of solids to water and air in a given volume of soil). According to previous researchers, the obtained value of specific gravity indicates that the soil is clay soil [1, 40].

3.3. Improvements on Free Swell Index. The expansive soil had high present swell (135%), and after treatment, the value reduced significantly. For each addition of the stabilizer, the reduction in swelling is observed. The free swell values should be less than 50% to be in the range of nonexpansive

soil. Addition of 15% and 25% of the stabilizer improves the expansive soil to 36% and 14%, respectively. Therefore, stabilizing the expansive soil by these materials improves the swelling property significantly based on the recommended values. The obtained value shows much better improvement when it reduces the value below 20%, a recommended value for engineering use according to Alemayehu et al. [3, 40]. The reason behind this improvement is the less tendency of the stabilizer for absorbing water when exposed for humidity. The more the stabilizer is added, the lesser the percent of swelling is recorded.

3.4. Improvements on Consistency. The addition of the stabilizer decreases the liquid limit significantly and increases the plastic limit. The plastic index of the soil decreases to an effective range to be used as a subgrade material. As observed in Figure 4, the liquid limit reduces from 93.84% of native soil to 72.58% after addition of 15% of the stabilizer. After treatment, the plastic limit increases from 35.05% to 52.67%. Plastic index decreases from 58.79% to 19.91%. This improvement of plastic index brings the nonusable expansive soil to a range of important construction materials as a subgrade soil. Previous researchers proved the improvement of consistency limits in a similar way [16, 23]. The main reason for improvement on the consistency of the soil is that the stabilizer can reduce the water absorption and becomes nonplastic soil.

3.5. Improvements on Compaction. The optimum moisture content and the maximum dry density for natural soil and soil stabilizer can be determined in the laboratory using the compaction test. The purpose of compaction is generally to enhance the strength of a soil by increasing density. Compaction also increases stiffness, decreases the sensitivity of the subgrade soil to changes in moisture content, minimizes long-term settlement, and reduces the swelling potential of expansive soils [41, 42]. As shown in Figure 5, the natural soil has a maximum dry density (MDD) of 1.33 g/cm³, and the addition of 5%, 15%, and 25% stabilizer improves the MDD to 1.4 g/cm³, 1.51 g/cm³, and 1.61 g/cm³, respectively. The OMC reduces from 40% to 21.3% at 25% stabilizer addition. This indicates that the stabilizer has high density compared to the native soil. According to the study by Jian et al., the increase in MDD is due to the improvement in the gradation of soil and the decrease in void ratio, and the decrease in OMC is due to the decrease in porosity. A similar study by Javed and Sudipta showed reduction in OMC and increase in MDD [23].

3.6. Improvements on CBR and CBR Swell. Strength of subgrade soil is highly dependent on the CBR value. The subgrade strength affects the pavement thickness selection. The CBR value of the natural soil is very low, and the addition of the stabilizer increases the CBR value to a remarkable level to be used as a subgrade material. The obtained CBR value for natural soil is 0.95%. This CBR value is too low to be used in road subgrade construction works.

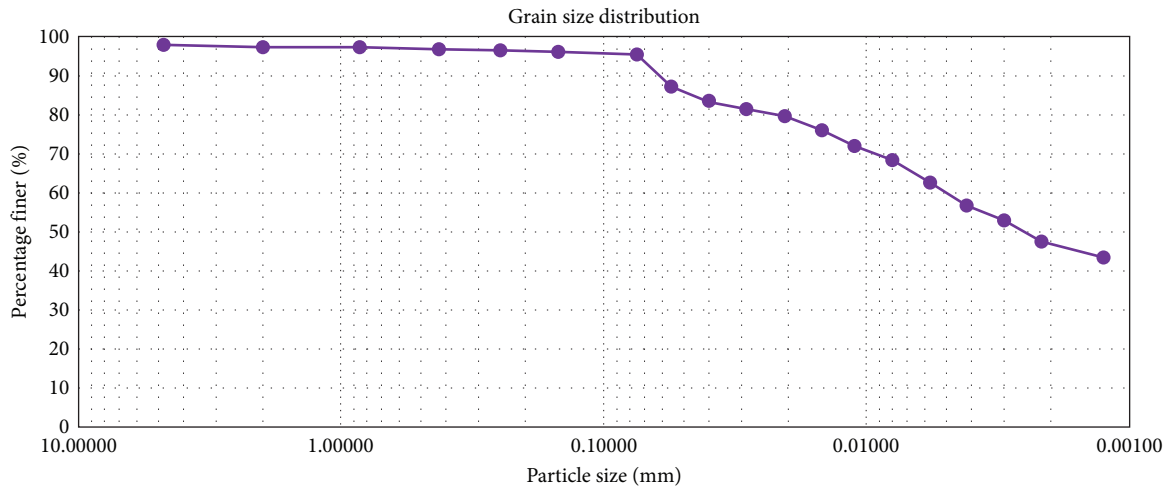


FIGURE 3: Grain size analysis curve.

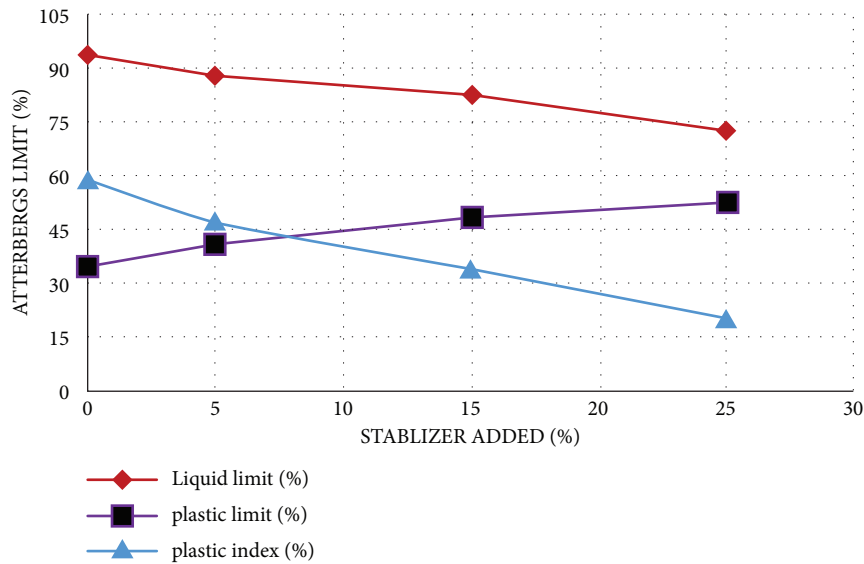


FIGURE 4: Improvement on consistency.

Addition of 5% stabilizer improves the CBR to 2.34%, and again this stabilized soil has low strength. For 15%, stabilizer addition improves the subgrade strength to be used in low volume roads and the recorded CBR value is 10.56%. At 25%, the addition of the stabilizer shows improvement to be in the range of good subgrade strength with a CBR value of 12.08%. Figure 6 shows the stress versus penetration graph of the CBR test results. The main reason for the increase in CBR value is that the stabilizer has high strength and load resisting capacity compared to the natural soil. Additionally, in 96 hours of soaking period, the stabilized soil absorbs less amount of water and shows smaller swell in the mold.

The CBR swell was taken after soaking of native soil and different percentages of soil-stabilizer mixes. During the soaking period, the sample absorbed water and expanded. The effect of addition of the stabilizer decreased the swelling. As shown in Figure 7, the CBR swell was significantly

decreased. For natural soil, the CBR swell was determined as 7.16%. The addition of 5% of the stabilizer has shown an improvement to 4.05%. Moreover, the 12% and 15% additions of the stabilizer improved the CBR swell value to 2.83% and 0.73%, respectively. As presented in Figure 5, at 25% addition of the stabilizer, the CBR swell is recorded as 0.22%. This enhancement is due to increase in density and reduction of moisture absorption relative to the original soil. The improvement showed better increase in CBR and reduction in CBR swell when compared to similar studies [16, 17, 23]. This improvement is acceptable according to the standards and specifications of Ethiopian Road Authority (ERA), which is classified under subgrade class 4. According to Ethiopian Road Authority (ERA) manual, a soil with CBR value less than 2% needs treatment to be used as a subgrade material. The manual classifies the strength of subgrade soil using CBR value into six classes, subgrade class 1 to subgrade

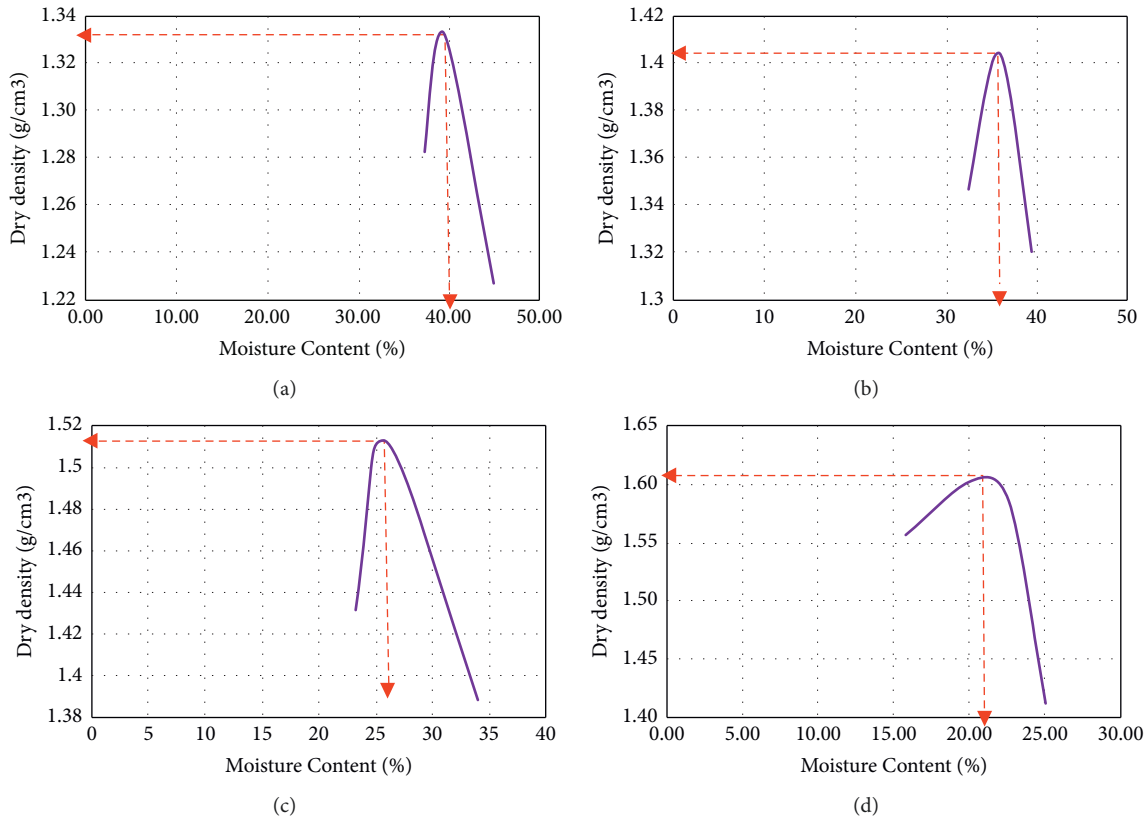


FIGURE 5: Density-moisture content relationship for untreated and treated soil samples. (a) Natural compaction, (b) 5% stabilization, (c) 15% stabilization, and (d) 25% stabilization.

class 6 for various depths of water table, assuming that the subgrade is compacted to not less than 95% of the maximum dry density attainable in the ASTM Test Method D 698 [43].

3.7. Improvements on Unconfined Compressive Strength (UCS). The improvement on UCS after mixing different percentages of stabilizer is known after the laboratory test. The effects of curing the sample for 7 and 14 days on unconfined compressive strength are identified. From the stress-strain relationship, it is observed that the UCS value improves for noncured and cured mix samples, as shown in Figure 8. The improvement on UCS value is due to active participation of the stabilizer and the expansive soil. Moreover, UCS value increases with decrease in the amount of water absorbed. The reason is that the presence of more water prevents the bonding of particles [44]. The UCS increment shows remarkable increase in value when compared to other stabilization techniques as studied by [15, 17, 22].

For the remolded samples, UCS of the noncured sample is performed immediately after the sample preparation. The stress-strain relationship of the noncured sample shows that the failure stress varies from natural soil to different mix contents. The failure stress for the natural soil is determined as 108 kPa. The addition of 5% of the stabilizer improves the failure stress to 536 kPa, and 25% addition of the stabilizer gives the maximum failure stress. After curing the samples

for 7 days, the UCS test result obtained indicates that the failure stress is improved by adding the stabilizer. Native soil had a failure stress of 188 kPa. The addition of 5%, 15, and 25% stabilizers improves the failure stress to 483 kPa, 662 kPa, and 818 kPa, respectively. The 25% stabilizer addition is the content that gives the maximum failure stress value, and it improves the failure stress of the natural soil by 4.35 times. From the 14 days of cured sample test for UCS, the effects of the stabilizer are observed. Similarly, the 25% stabilizer addition shows the best improvement on failure stress, and the value recorded is 910 kPa. This amount of stabilizer addition improves the UCS by 4.21 times the UCS of the natural soil of the same curing period. The UCS of the natural soil is 216 kPa, and by adding 5% and 15% of the stabilizer, the failure stresses recorded are 496 kPa and 697 kPa, respectively. Generally, for all cases, the 25% addition of the stabilizer is observed to give the maximum failure stress. The increase in UCS value is due to the formation of cementitious compounds between the expansive soil and the stabilizer. The effect of curing is observed, and the UCS value is improved with increasing curing days. Thus, curing gives the brittle material for these soil stabilizer mixes.

3.8. Improvements on Chemical Properties. From the XRD microstructure analysis, the chemical compositions formed and altered are examined. The samples are

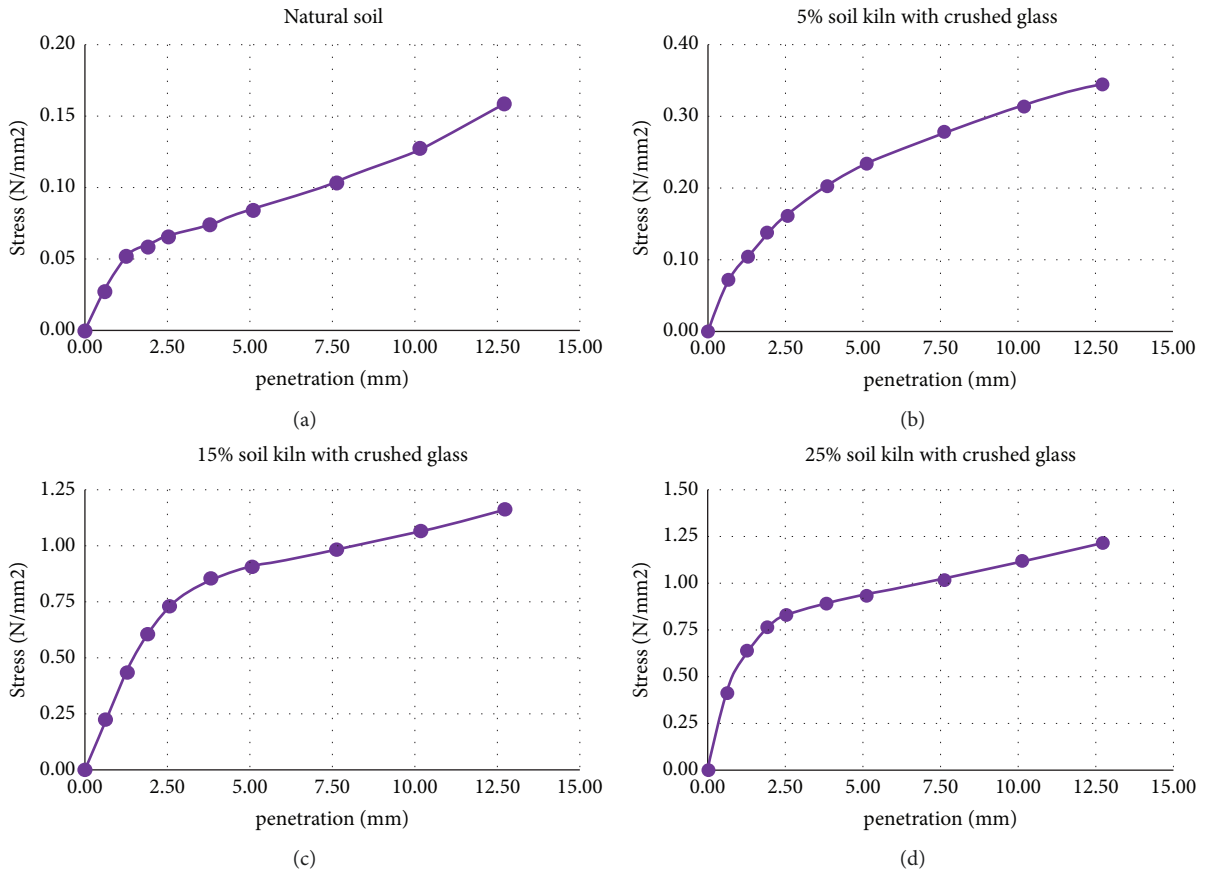


FIGURE 6: Stress versus penetration of CBR test.

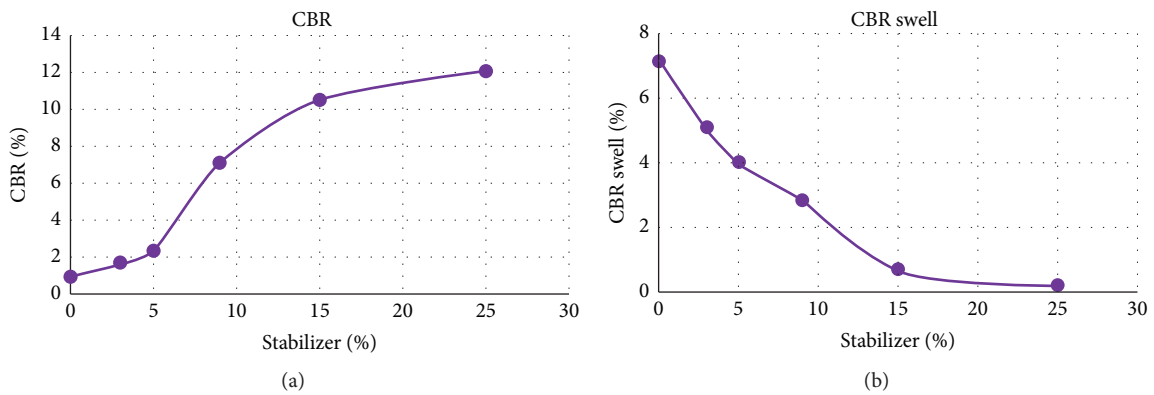


FIGURE 7: The effect of stabilizer on CBR and CBR swell.

uniformly ground to be fine particles, which are less than 45 μm . The mix has cured for seven days and then scanned at a speed of 1° per minute for Bragg’s angle (2θ) ranging from 10° to 80° by using $\text{Cu-K}\alpha$ radiation. The XRD outputs are drawn in graphs as shown in Figure 9, for the natural soil and the soil sample mixed with 5%, 15%, and 25% of stabilizers by weight.

The mineral composition analysis from XRD test results of samples has performed using X’pert high score and Match

software. The elements and compounds present in the native clay soil and the different soil-stabilizer mixes are shown in Tables 3 and 4. Hydrogen (H), iron (Fe), silicon (Si), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), carbon (C), and oxygen (O) are the main types of element minerals and gases in the native soil. Addition of 5% stabilizer does not show significant difference in elemental composition except in the presence of some aluminum (Al) element. However, addition of 15% and 25% stabilizer in the soil

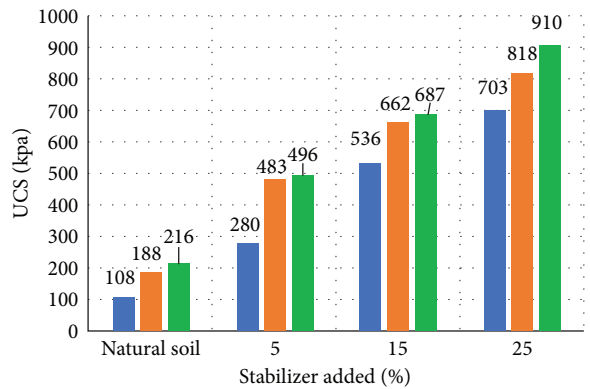
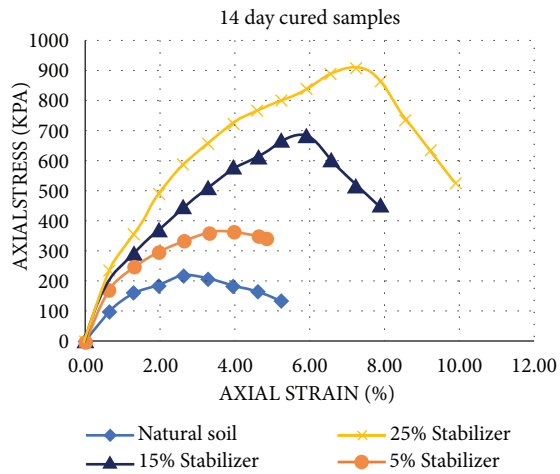
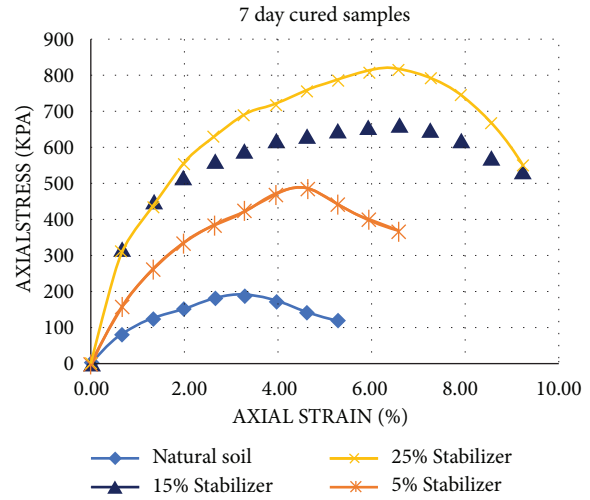
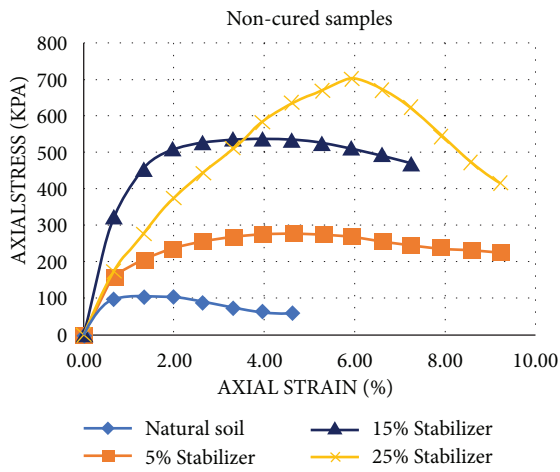
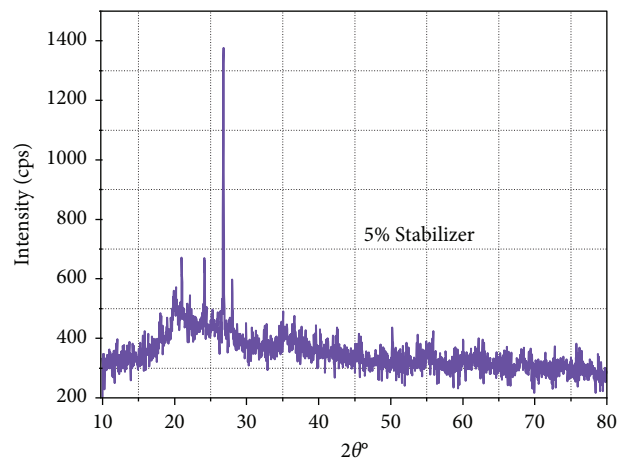
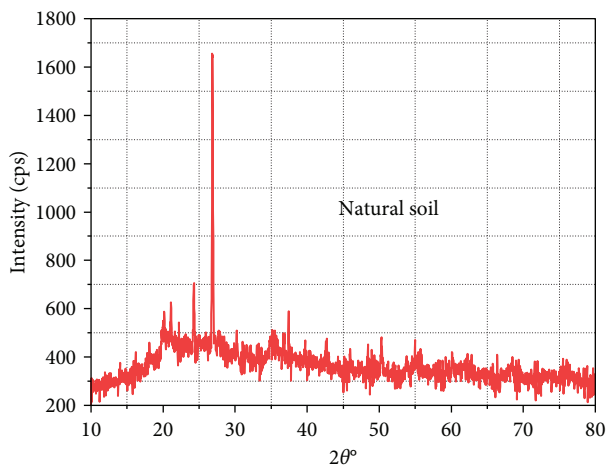


FIGURE 8: Effects of the stabilizer on UCS for cured and noncured sample.



(a)

(b)

FIGURE 9: Continued.

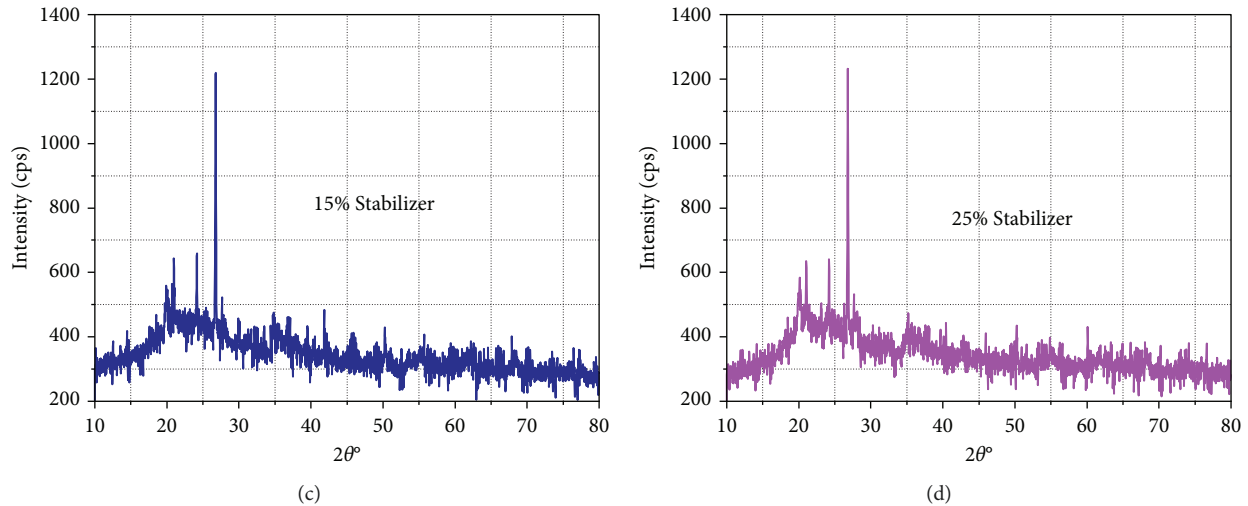


FIGURE 9: XRD graphs for natural soil and different mixes of stabilizers.

TABLE 3: Percentage of elements in native and stabilized soil.

Elements	Al	H	Fe	K	Na	Si	Mg	Ca	O	C
Natural soil	—	48.6	6.7	2.4	6.5	8.2	5.8	3.3	4.2	14.3
5% stabilizer	4.8	49.2	2.1	2.4	3.4	5.4	7.5	3.6	9.2	12.4
15% stabilizer	2.2	61.5	0.8	1.1	3.8	2.1	3.9	1.9	3.3	19.1
25% stabilizer	4.0	55.8	1.5	3.2	6.1	3.3	5.7	1.9	7.4	11.1

TABLE 4: Percentages of compounds in native and stabilized soil.

Compounds	Montmorillonite	Muscovite	Illite	Quartz	Goethite	Gibbsite	Kaolinite
Natural soil	34.1	20.7	18.4	12.2	5.3	9.3	—
5% stabilizer	31.2	27.6	22.1	2.8	4.7	11.7	—
15% stabilizer	—	48.5	—	5.6	11.7	15.4	18.9
25% stabilizer	—	46.8	—	5.6	11.3	15.2	21.1

shows significant reduction in iron (Fe), silicon (Si), calcium (Ca), and carbon (C) elements while magnesium (Mg), sodium (Na), potassium (K), and aluminum (Al) keep nearly constant amount. On the other hand, hydrogen (H) and oxygen (O) gases are observed to be increasing slightly.

Addition of the stabilizer causes alteration of compounds in the blend. The untreated soil was dominated by montmorillonite ($\text{Na}_{0.3}(\text{Al}, \text{Mg})_2\text{Si}_4\text{O}_{10}(\text{OH})_{21}\cdot 6\text{H}_2\text{O}$) and illite ($\text{Al}_2\text{H}_2\text{KO}_{12}\text{Si}_4$). Addition of 5% stabilizer does not show significant change in the composition. However, stabilizing the weak soil by 15% and 25% changed the compound contents in the blend. At these percentage additions of stabilizers, the montmorillonite and illite disappear while a new nonexpanding clay, kaolinite ($\text{Al}_2\text{H}_4\text{O}_9\text{Si}_2$), is formed. Similar studies by Jian et al., Y Ma, and W Chen observed similar improvements on the treated soil samples [31, 33]. The compounds muscovite ($\text{Al}_3\text{KO}_{12}\text{Si}_3$), goethite (FeHO_2), and gibbsite (AlH_3O_3) are observed as increasing their values. The compound quartz (SiO_2) is also observed to decrease. The reduction in contents of

SiO_2 is due to active participation of the compound with the additives to form kaolinite and muscovite.

Figure 10 indicates the positions of minerals on XRD analysis graphs. The peaks are observed going constant, changing, and totally disappearing. The change in peak corresponds to active minerals that exchange ions with the stabilizers and then forms new compositions with different chemical properties. At the positions $2\theta = 21^\circ - 23^\circ$, goethite is observed in all mixes of stabilization. Quartz is observed at $2\theta = 24.3^\circ$ and 26.7° . The montmorillonite is found in the natural soil and 5% stabilization at $2\theta = 37.5^\circ$, 43.5° , and 55° . Illite is observed at $2\theta = 48^\circ$, 66° , and 73° . Muscovite is found in all soil mixes at $2\theta = 28.5^\circ$ and 78° .

The changes in peaks are observed in combined simulation as presented in Figure 11 for the position from $2\theta = 23^\circ$ to 29° . The sample position indicates alteration in the mineral contents of the untreated and treated soil. The position is mainly for quartz and muscovite peaks, which are found in all soil-stabilizer mixes. The reduction in

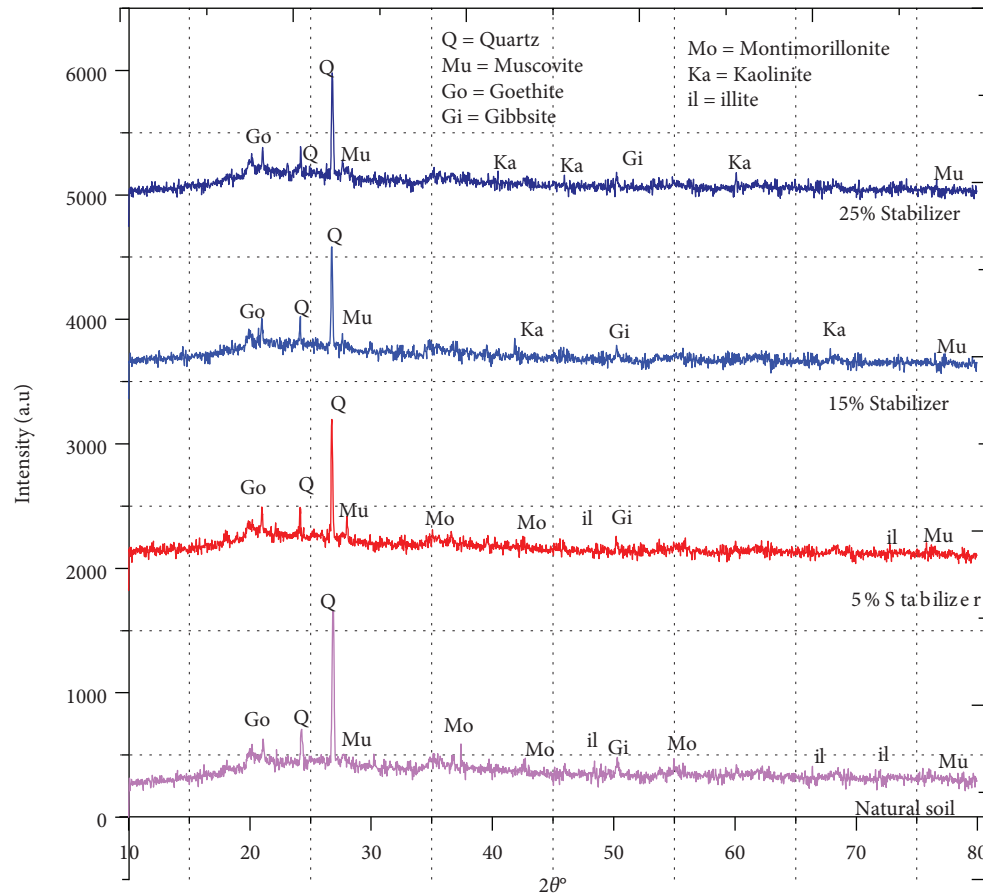


FIGURE 10: Stacked XRD graph with chemical composition.

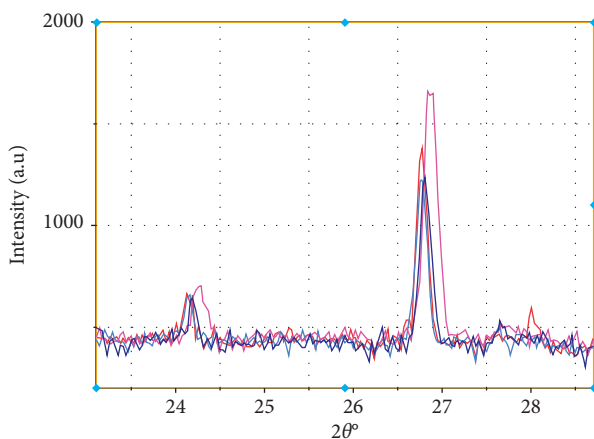


FIGURE 11: Peaks comparison with combined XRD curves.

peaks is related to the addition of glass because glass is an amorphous and noncrystalline material which is typically brittle and optically transparent.

4. Conclusion

This study presents the improvement of engineering properties of expansive soil by parts of the same soil kilned and mixed with

powdered glass. The soil type was highly expansive and had high degree of expansion, high plastic index, and weak strength, and the stabilizer was nonexpansive and truly requires stabilization. Laboratory tests are conducted, and the results are obtained and compared to the untreated soil.

The liquid limit (LL) is reduced from 93.84% to 72.58%, and plastic limit (PL) is improved from 35.05% to 52.67%. Additionally, the plastic index (PI) is improved from 58.79% to 19.91%, to be in the range of acceptable subgrade material. Addition of 15% and 25% of the stabilizers improved the free swell of the expansive soil to 36% and 14%, respectively, from 135%. CBR swell value is significantly improved from 7.16% to 0.22%. Addition of the stabilizer reduces the OMC and increased MDD. UCS values showed improvement by the stabilizer from 108 kPa to 703 kPa on uncured sample, 188 kPa to 818 kPa on 7 days of curing period, and 216 kPa to 910 kPa on 14 days of curing time. The effect of curing on the UCS value is observed that curing increases the UCS. The strength parameters such as CBR showed significant improvement. The CBR value (0.95%) of the natural soil was a nonapplicable material but after the addition of stabilizer the CBR value (12.08%) is improved to favourable subgrade material strength. The natural soil was highly dominated by active and water absorbent minerals when examined by X-ray diffraction (XRD) test. The stabilized soil is free from expansive minerals like montmorillonite and illite.

Generally, the physical, chemical, and engineering properties of expansive soil are significantly improved by the stabilizer addition of 15% to 25%. This method of stabilization can be used as cost-effective stabilization by consuming waste from industries and helps to keep the environment clean from unwanted materials. Therefore, the researcher recommends using the alternative stabilizer where the materials abundantly exist and replacing the costly materials like cement and lime.

Data Availability

All information provided in the conclusion is presented in the full document.

Conflicts of Interest

The author declares there are no conflicts of interest.

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