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Research Article

Strength Improvement of Black Cotton Soil Using Plastic Bottles and Crushed Glass Wastes

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The aim of this study was to improve the strength of black cotton soil for its suitability for road subgrade construction using wastes from plastic bottles and glass waste powders. Currently, nondecomposable wastes from plastic and glasses have become threats to the human health and the environment. This study used the wastes to replace cement, since the cost of cement raised due to energy and raw material to use as stabilizer in weak soil. The glass powder (WGP) and the plastic chips were mixed with the soil sample with a percentage by dry weight of 6%, 12%, 18%, and 24% of WGP and 2%, 4%, 6%, and 8% of plastic chips, respectively. The glass waste can be prepared similar to the soil as the requirement of test standards and plastic wastes was used as reinforcement for the soil-glass-mix; hence, its purpose was geomechanical. Laboratory tests for soil-mix physical properties and strength parameters were conducted. Soil laboratory test results proved that the natural soils were classified to A-7-5 as per the AASHTO Soil Classification System and CH as per the Unified Soil Classification System (USCS). The Unconfined Compressive Strength (UCS) improved from 91.92 kPa to 688.83 kPa, and the California Bearing Ratio (CBR) improved from 2.64 to 17.5. The improvement of subgrade soil properties was increased with increased ratios of powder glass and plastic strips. The result indicated that the two stabilizers were very effective in improving strength parameters and index parameters.

1. Introduction

Soil property plays a big role in the construction world. Most of the structures are constructed on soil or use soil as a construction element. In light of this, the type of soil present on the construction site affects the project's cost and safety. Black cotton (BC) soils are a particular kind of clay soil that has undesirable properties for the construction industry and a high degree of expansion. The sort of soils that fluctuate in volume in response to changes in water content is called expansive clay soils. A severe risk to structures placed over them is posed by their behavior of swelling and contracting. During the dry season, these soils are extremely hard and absorb water, becoming sticky. Due to ground heave and structural settlements brought on by the soil's erratic behavior, it is less desirable for construction. The presence of swelling clay minerals gives expansive soils their unique properties. These minerals, which may contain montmorillonite, absorb water when they are moist, and as they dry out, they shrink, leaving deep holes and fractures in the soil. Emphasis is constantly needed on foundations in expansive soil to ensure the structural integrity and safety of the building that is built upon them. In some high terrains, unstable soils can cause landslides. If the clay content is greater than 5% by weight, swelling clays can dominate the qualities of any type of soil [1–4].

Soils are called highly expansive when the free swell index exceeds 50%, and such soils undergo volumetric changes leading to pavement distortion, cracking, and general unevenness due to seasonal wetting and drying. The type and proportion of the clay mineral found in the soil can determine the soil's engineering properties. The montmorillonite clay mineral has high contribution for the swelling properties of the black cotton soil [5, 6]. For many years, buildings, roads, and houses have been constructed without the knowledge of the existence of expansive soils as a consequence of the structural damages on buildings, roads, and other similar structures; problems associated with expansive soils have been recognized and preventive measures are being incorporated in to new designs and construction works [7–10].

Soil stabilization increases the shear strength of a soil, reduces its swelling properties, and improves its load-bearing capacity. Stabilization mainly consists of mechanical and chemical methods. Mechanical stabilization is achieved by compaction of interlocks of soil-aggregate particles with higher density material. The mechanical stabilization is mainly associated with strength improvement through reinforcement and density increment. Chemical stabilization is done by adding a material which can alter the chemical property of the existing soil. The chemical stabilizer avoids or reduces the poor-quality mineral by undergoing a chemical reaction. The chemical reaction is done by exchanging ions. This enhances the stabilized soil's non-expansive or less expansive material [11–17].

Plastic wastes are found abundantly in most part of the world. As revealed by the United Nations environment program [18], currently, about 400 million tons of plastic wastes are produced every year and less than 10% of them have been recycled. According to [19], an estimated amount of 60 to 99 million metric tons of mismanaged plastic wastes were produced globally in 2015. Jimma City produced approximately 88,000 kg of garbage per day, with an average per-capita generation rate of 0.55 kg/day [20]. In addition, there is a lot of glass trash in the globe, and the recycling rate is still much lower than the rate of production [21]. Although Ethiopia has implemented environmental policy, municipal solid waste management proclamations, and other related rules, the country has poor enforcement and implementation practices [22].

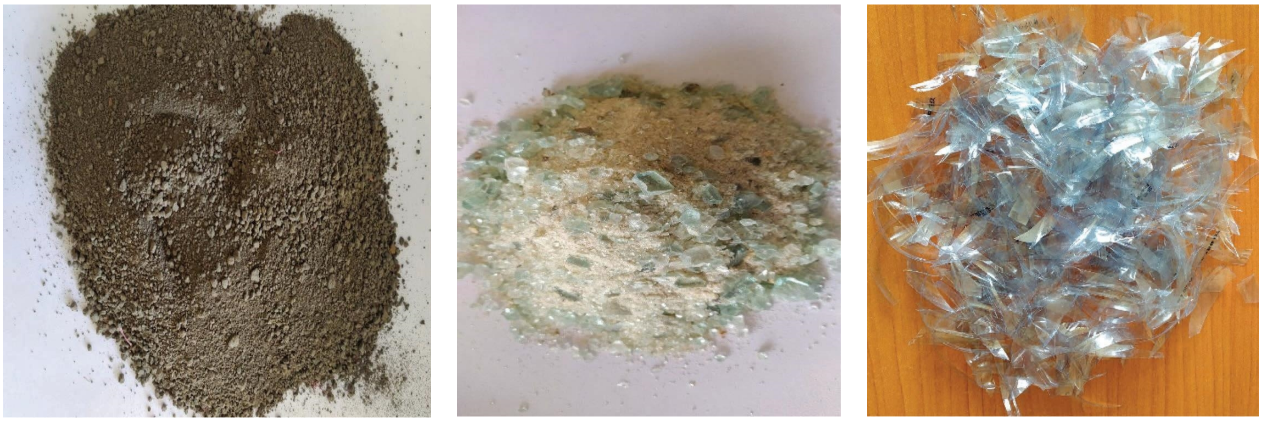
Industry wastes such as plastic bottles are associated with environment pollution. Glasses from residential house, hotels, and construction sites may be crushed and remain as a solid waste material. Solid waste recycling or reusing is one of the sustainable technologies that get attention in most parts of the world. Plastic and glass wastes are non-decomposable wastes that have an adverse effect on the soil fertility and the environment. In addition, these materials are not environment friendly. When they are burnt, large amount of smoke and nonpleasant odor has been noticed [23–25]. According to the review of [26], waste plastic can effectively be used as a reinforcing material and it is an ecofriendly solution. Utilization of such materials as a construction input enhances achieving a dual purpose. The first one is cleaning the environment in a safe way, and the other one is substituting costly stabilizer materials such as cement and lime.

There are many literatures that encourage the use of industrial, agricultural, and construction wastes as stabilizer materials. However, there is no direct evidence to apply the blend of plastic and glass wastes for weak soil stabilization. Therefore, the main concern of this study is to prove the possibility of these materials as an alternative type of stabilizers where they abundantly existed. Expansive soils are abundantly existing soil types in Ethiopia, particularly in Jimma. In order to manage this problem, this research was carried out to evaluate the engineering properties of expansive clays found in Jimma town which was stabilized with plastic chips and glass powders as admixture. This study contributes a safe way of removing decomposable wastes through recycling as a construction material and can replace the expensive way of soil stabilization.

2. Materials and Methods

2.1. Materials and Preparation of Samples. The materials used in carrying out this project were black cotton soil, plastic bottles, and crushed glass wastes. A soil sample was taken from a road side of newly constructed road around Merkato, Jimma. A clayey subgrade is reported to exist on the study area according to previous researchers [15]. Plastic bottles and waste glass were collected and prepared from a neighboring garbage disposal location. Cleaning the waste glass to eliminate dirt and then crushing it were part of the preparation. The plastic chips are prepared and glass wastes are powdered enough to get finer materials for mixing with the expansive soil, as shown in Figure 1. These wastes can be collected from household goods, crushed or deformed materials, from bar and restaurants, cafés, construction sites, and waste disposal places. Glass is an amorphous noncrystalline material which is typically brittle and optically transparent. The familiar type of waste glass materials found around are drinking vessel and windows, and most of the readily available waste glass materials are soda-lime glass, composed of about 75% silica (SiO_2) with Na_2O, CaO, and several additives [27, 28]. This material is added to clay soil in its powdered form for soil stabilization. In order to investigate the utilizing of this material to improve the subgrade of weak soil, laboratory tests were conducted by the researcher on samples that were collected from Jimma town. Plastic wastes were observed in many places including the side of streets, drainage diches, hotels, and other similar locations. These plastic bottle wastes are nonbiodegradable and do not decompose through time, thus it has an advert effect on the soil fertilization as well as the agriculture center in general. These wastes can pollute the environment, seas, oceans, rivers, and land as reported by previous researchers [29, 30]. The plastic is prepared by cutting into strips and used as reinforcement on the soil. Thus, the plastic strip would have the mechanical strength enhancement with the glass powder on the expansive soil.

2.2. Research Design. The study included laboratory experiments to examine particle size distribution, consistency, moisture density relationship, and mechanical strength of soil and soil-stabilizer mixes. The investigation was carried out experimentally and was backed by evidence from the literature. A qualitative and quantitative study had been carried out. The qualitative investigation conveys an impression of the findings, whereas the quantitative study describes the numerical components of the findings. The flowchart depicted in Figure 2 describes the research study.



(a) (b) (c)

Figure 1: Materials: (a) air dried soil, (b) crushed glass, and (c) plastic chips.

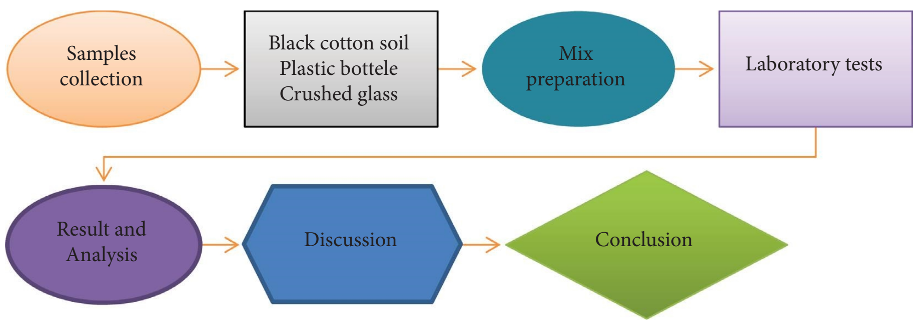


Figure 2: Study design.

2.3. Mix Preparation. The laboratory tests were performed by mixing according to the size and grain requirements of each test type. The black cotton (BC) soil was mixed with different percentage of the stabilizers. The stabilizers were prepared in a ratio of 3 : 1 (glass waste powder to plastic waste chips) by mass of the total mix. The amounts of the stabilizer added are presented in Table 1. Since the density of the plastic strips weighed a smaller value, the mass is reduced during the mixing process. The waste glass powder can be fined enough to be mixed with the test requirement of the soil. However, the plastic is used as strips that reinforce the mix of soil and waste glass powder with the provided percentage by weight.

Table 1: Soil-stabilizer compositions.

BC soil (%)	Stabilizers	
	Glass (GWP) (%)	Plastic (PW) (%)
92	6	2
84	12	4
76	18	6
68	24	8

Table 2: Tests and the corresponding test methods.

Tests	Methods
Water content	ASTM D2216
Specific gravity	ASTM D854
Grain size analysis	ASTM D422-63
Atterberg's limit	ASTM D4318-17
Unconfined compression strength	ASTM D2166
California Bearing Ratio (CBR)	AASHTO T193-93
CBR swell	AASHTO T193-93
Free swell	Holtz and Gibbs (1956)
Modified compaction	ASTM D-18

2.4. Testing Procedures and Methods. Soil samples along the road section from different location were collected to conduct this study. The collected samples were disturbed and taken from 1.5–3.0 m depth. The soil samples were first exposed to air for up to 21 days and well dried. The tests were performed by adopting standard laboratory test specification and procedures of the American Society of Testing and Material (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) [31–35]. Table 2 shows the tests with the corresponding test methods. In addition to the geomechanical tests, the mineralogical characterization of the materials was examined by the X-ray diffraction (XRD) method. The graphical analysis Microsoft 2016 and Origin 2022 software were used. For mineral identifications and characterization of the samples from XRD tests, match and X'pert high score software were used.

3. Results and Discussion

3.1. Material Properties

3.1.1. Geotechnical Properties of Soil. Geotechnical properties of soil are important to identify the soil density index, consistency limits, particle size analysis, settlement behaviors, compaction properties, and shear strength behaviors. These properties can control that either the soil is used as a construction material or not. If the soil encountered on the construction site is a problematic soil, there can be possible damages on the structure and the environment associated with the weak soil, and remedial measures should be implemented. The properties of the natural soil were determined before the stabilizers were added. The natural moisture content, specific gravity, free swell, grain size, the Unconfined Compressive Strength, the Atterberg's limits, the California Bearing Ratio, and CBR swell are determined by laboratory tests, as presented in Table 3. According to the laboratory results, it is proved that the native soil is highly expansive with free swell of 128%, UCS of 53 kPa, CBR of 2.6, and 94.7% of clays and silts. For classification of the soil from its index properties and grain size analysis, the American Association of State Highway (AASHTO) Classification System and the Unified Classification System were used. Therefore, according to the AASHTO and Unified Soil Classification System, the study was classified as A-7-5 and CH, respectively. The geotechnical properties of this soil indicate that it is a weak and soft soil that cannot resist loads and may cause settlements, cracks, and expansions.

Table 3: Geotechnical properties of the natural soil.

Geotechnical properties		Values
Grain analysis	Gravel (%)	2.4
	Sand (%)	2.9
	Silt (%)	38.6
	Clay (%)	56.1
Natural moisture content (%)		44
Average specific gravity (g/cm^3)		2.67
Free swell (%)		128
Linear shrinkage (%)		25
Liquid limit (%)		87
Plastic limit (%)		34.4
Plasticity index (%)		52.6
Maximum dry density (g/cm^3)		1.4
Optimum moisture content (%)		25.1
California Bearing Ratio		2.6
Unconfined Compressive Strength (kPa)	Native soil	53
	Remolded	91.2

3.1.2. Particle Characterization of Soil and the Stabilizers. The mineral characterization of the materials was done using X-ray diffraction (XRD). The natural soil had higher peaks at 26°. As analyzed from match software's and high score expert, the soil was highly dominated by montmorillonite clay. The XRD of the glass powder shows amorphous mineral microstructure. The glass powder is highly dominated by silicon dioxide (SiO_2), as shown in Table 4. When the soil particles are mixed with the glass powder particles, they reacted and mineral change occurred as studied by previous researchers [15, 36–39]. However, the plastic chips are mixed as a mechanical stabilizer; hence, its effect is only geomechanical. Plastic chips were used as soil reinforcement, and they increased the bondage and strength of the weak soil. According to researchers, plastic strips can modify a weak soil and their effect is mechanical [40–42]. Figure 3 provides the XRD output graphs for individual materials. As characterized by [1], the soil owes expansive property. The native soil was dominated with the expansive clay minerals (see Table 4).

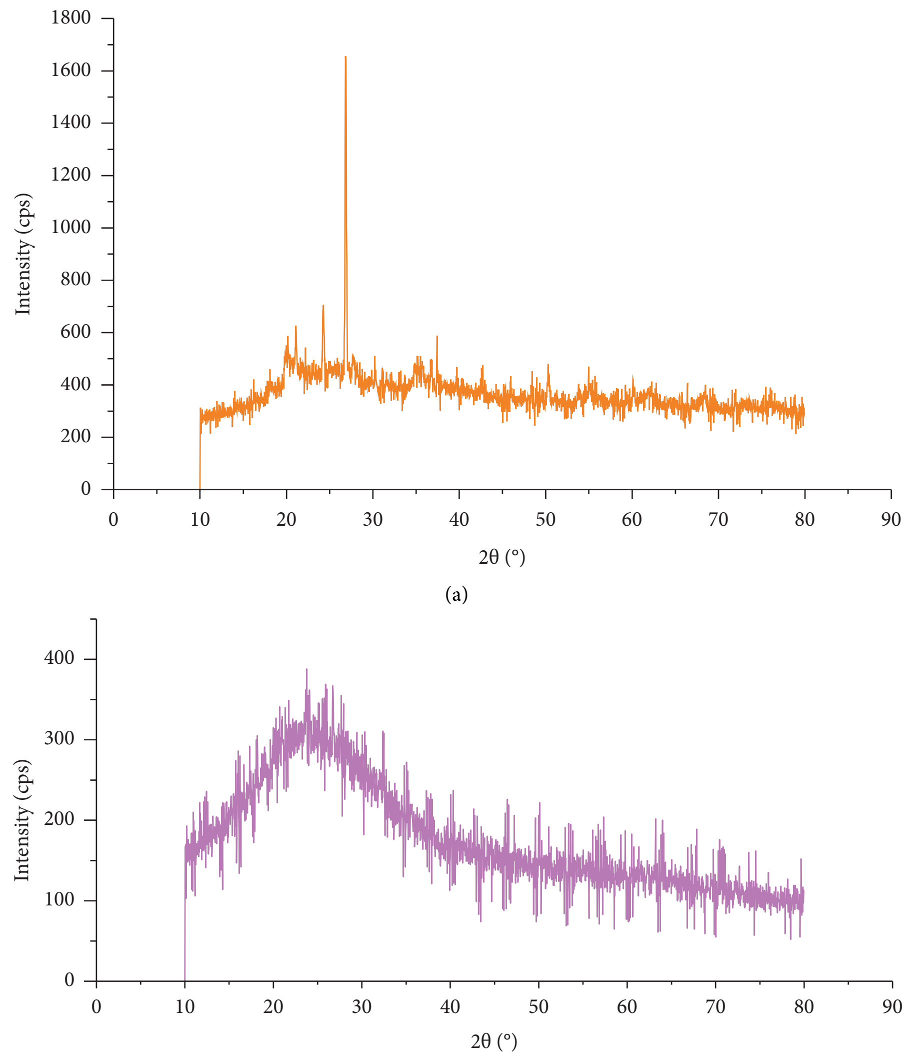
3.2. Improvement on Consistency. Atterberg's limits are determined by the soil moisture content. The moisture content at which the soil transitions from semisolid to plastic (flexible) is the plastic limit. The liquid limit is the point at which the soil transitions from a plastic to a viscous fluid state. Atterberg's limits are used to classify fine-grained soils according to the Unified Soil Classification System or the AASHTO method. Soil sample pass through #40 sieve (425 micron) and stabilizers with different percentage being mixed and soaked for 24 hours. The output of this laboratory test is shown in Figure 4. Liquid limit is the moisture content at which the soil suspension passes from no strength to a very small strength. Plastic limit is the moisture content at which the sample, when it is rolled into a thread, starts to crumble rather than distort plastically. From this consistency limit test, the effect of stabilizer on improving Atterberg's limit is observed. The liquid limit, plastic limit, and plasticity index are improved in each addition of the stabilizer. Therefore, it is concluded that the admixture controls the expansiveness and reduced water absorption of the soil since the stabilizers are not water absorbent.

The result of Atterberg's limit tests showed that there is a reduction in the plasticity index as there is an increasing percentage of stabilizers. The liquid limit decreases as there is an increase in the addition of stabilizers, and the plastic limit increases as the percentage addition of stabilizers increases.

3.3. Improvements on Free Swell and Linear Shrinkage. According to Holtz and Gibbs (1956), ten grams (10 cm^3) of oven-dried soil and soil-stabilizer mix samples that pass through #40 sieve (0.425-micron sieve) are placed in two different graduated cylinders and filled with water and kerosene until it reaches 100 ml. The bottle is shacked by hand and rod then placed in a protected area for about 24 hr until all the sample completely settles on the bottom of the cylinders. Then, the results are compared and the percent swell of each sample was calculated. The soil had high value of percent swell (128%), and the addition of 8% of the stabilizers reduces the range to 84.3%. The sample is still expansive. Addition of 16% and 24% of the stabilizers brought the percent swells to 55.7% and 32.5%, respectively (see Figure 5). However, at 32% addition of the stabilizer,

Table 4: Chemical composition.

	Compound name	Chemical formula	Percentage (%)
Soil	Montmorillonite	$Na_{0.3}(Al, Mg)_2Si_4O_{10}(OH)_{21}\cdot 6H_2O$	40.4
	Illite	$Al_2H_2KO_{12}Si_4$	26.3
	Quartz	SiO_2	21.8
	Others	—	11.5
Glass	Sodium oxide	Na_2O	11.1
	Calcite	$CaCO_3$	39.4
	Silicon dioxide	SiO_2	49.5



(b)

Figure 3: XRD graphs of the materials: (a) native soil and (b) glass powder.

a significant value was achieved. The percent swell became only 18.4%. On a similar study by [43], the effectiveness of fiber reinforcement on strength, swell, and shrinkage characteristics of expansive clays is proved.

Linear shrinkage value is a method of obtaining the amount of shrinkage experienced by clay soils. This test is done by taking a soil sample that passes 425 μm sieve and using the liquid limit previously determined for each proportion of the mix. Initially, the linear shrinkage for native soil was 25%. As the percentage of stabilizers added increased, the linear shrinkage is observed reducing. At 8%, 16%, 24%, and 32% addition of the stabilizer on the blend, the linear shrinkage values were improved to 17.2%, 11.4%, 7.7%, and 3.5%, respectively. The degree of expansion of the

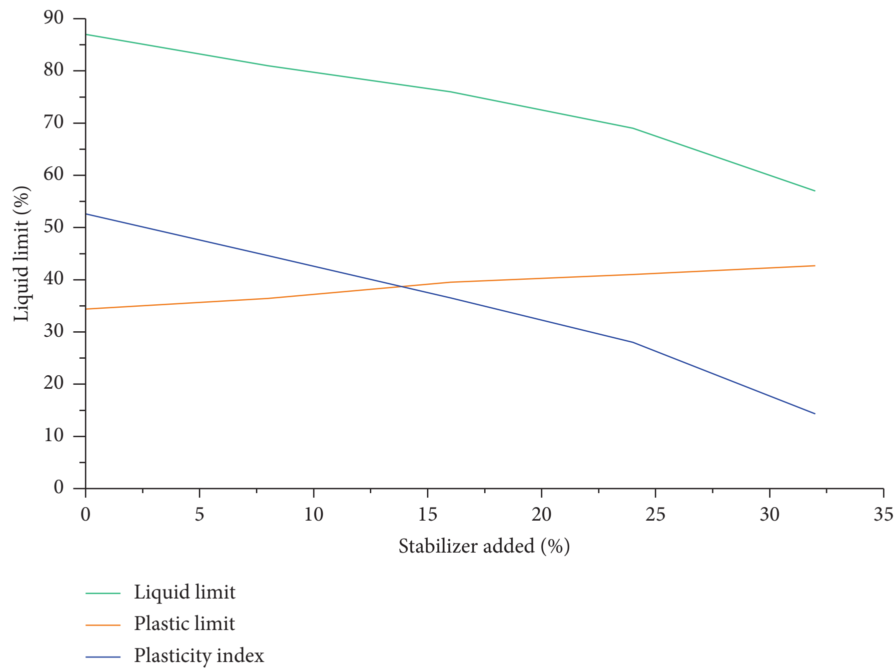


Figure 4: Improvements on consistency.

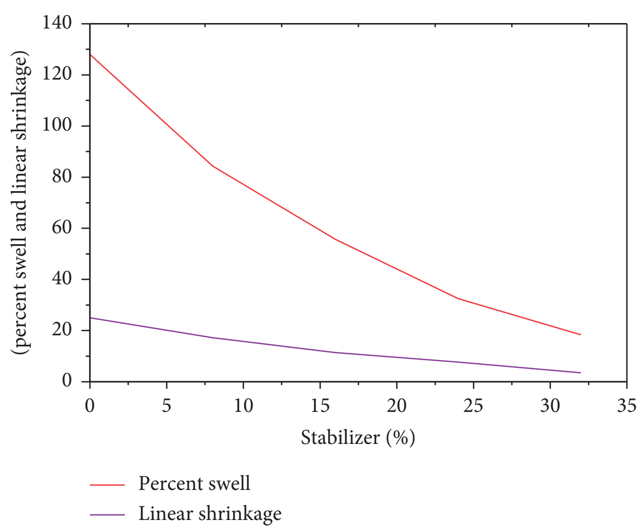


Figure 5: Improvements on free swell and linear shrinkage.

natural soils was critical. 24% and 32% addition of this stabilizer brought the blend to a noncritical stage of expansion (see Figure 5). Experimental studies by Dang et al. [44] revealed that the linear shrinkage of stabilized expansive soils decreased with increasing hydrated lime and bagasse fiber proportions.

3.4. Improvement on Compaction. The optimum moisture content and the maximum dry density for the natural soil and different combinations of soil-stabilizer mixes were determined in the laboratory using the compaction test. Compaction can increase the density of the soil and the load-bearing capacity as well (see Figure 6). The stabilizers improved the density of the weak soil. The natural soil had a maximum dry density of 1.4 g/cm^3 with an optimum moisture content of 25.1%. After that, the addition of 8%, 16%, and 24% of the stabilizers changed the maximum dry density value to 1.43 g/cm^3, 1.46 g/cm^3, and 1.5 g/cm^3, respectively. With the maximum addition of the stabilizer (32%), the maximum dry density improved to 1.54 g/cm^3. The main reason associated with this improvement is the increase in density of the soil-stabilizer mix for treated soil due to stabilizers [13, 15].

The study by Shah et al. [45] revealed that soil strength can be improved by addition of stabilizer at an optimum level of compaction energy. Similarly, a review by Afrin [46] shows that stabilization can alter the value of maximum dry density and optimum moisture content. However, when the soil is stabilized by low density and cementitious materials, they may show a reduction in their maximum dry density. According to [47], the correlation between optimum degree of saturation and optimum water content shows that OWC is lower for soils with larger maximum dry density. Besides, with optimum water content being less than 40%, the relationship between optimum degree of saturation and OWC depends very much on soil type and particle size.

3.5. Unconfined Compressive Strength (UCS). The test is an undrained (quick) test and is based on the assumption that there is no moisture loss during the test. The value of $\sigma 1$ at failure is known as the Unconfined Compressive Strength and is designated by the ASTM D 2166 standard test method for the Unconfined Compressive Strength of cohesive soil. Since the sample is laterally unconfined, only cohesive soils can be tested. The sample is tested quickly and there is no drainage. In this simple test, a cylindrical cohesive specimen

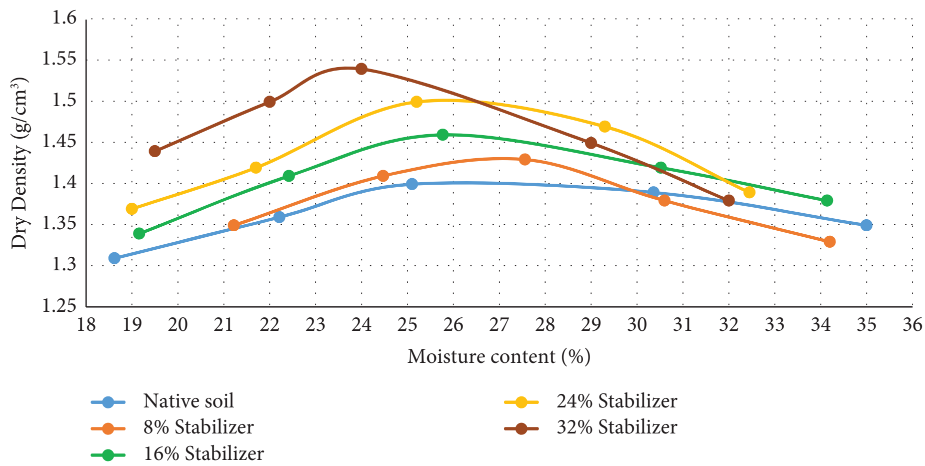


Figure 6: Improvement on compaction.

without any lateral support is subjected to axial loading, till the sample fails either due to shear along a diagonal plane or by the lateral bulging [1, 2]. According to the ASTM standard, the Unconfined Compressive Strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. The UCS tests are performed at 7 days of curing period for the remolded and the soil stabilizer mixes. Curing can increase the UCS according to previous researchers [15, 48]. The result of this UCS tests shows that as the stabilizer increased through process or trial, its compressive strength of the expansive soil had increased. Natural soil or the soil without any treatment has a cohesion (cu) value of 45.96 kPa, but after an improvement, its cu value increased to 154.3 kPa, 186.8 kPa, 262.52 kPa, and 344.41 kPa for 8%, 16%, 24%, and 32% addition of stabilizers, respectively. A study by Zha et al. [49] on behavior of fly ash stabilized soil at 7 days curing of the fly ash-treated soils, and the Unconfined Compressive Strength increased significantly. Similar study by Abdelkader et al. [50] on the influence of waste marble dust shows similar improvement on the Unconfined Compressive Strength of the stabilized soil. This improvement is due to the higher bondage between the stabilizers and the natural soil after treatment. Stabilization can develop a brittle material. As proved by [51], stabilization causes a decrease in deformability of soil samples and gives more brittle materials. The strain versus the stress is graphically presented in Figure 7.

3.6. Improvements on CBR and Swell. The California Bearing Ratio (CBR) test is the most important test to determine the load-bearing strength of the subgrade soil. Three-point CBR tests at 10, 30, and 65 blows were conducted according to AASHTO T193-93, and the CBR at 95% MDD was determined and results are presented in Figure 8. The study area is characterized by high annual rainfall and tropical rainforest climate, and to consider the worst effect in humidity, the CBR test is conducted under samples prepared with heavy energy of compaction under soaked condition for 96 hours. Both during soaking and penetration tests, the specimens are covered with equal surcharge weights to simulate the effect of overlying pavement or the particular layer under construction.

From the CBR test result, the CBR value is increased when the mix percentage of the stabilizer is increased. Initially, the CBR value of the natural soil was 2.6 only. Each percentage addition of the stabilizer significantly increased the CBR value, as observed in Table 5. Addition of 8%, 16%, and 24% of the stabilizer improved the CBR value to 4.2, 11.4, and 15, respectively. Later, when the soil is stabilized by 32%, the stabilizer changed the CBR further to 17.5. Therefore, the stabilizer improved the CBR of the weak soil by 673%. The stabilizer was successful in reducing the water absorption tendency of the soil and increased the density of the weak soil, hence the CBR value increased.

The glass-plastic-soil mixtures compacted in CBR molds at optimum moisture content with maximum dry density gauged for swelling characteristics before and after soaking for four days to evaluate the percent of swell. For each soil-glass powdered and plastic chips mix a sample that passes sieve #9.5 is prepared for three-point CBR test using the optimum moisture content and maximum dry density from standard compaction test. From the CBR swell record, the swell is significantly decreased for each increment of the stabilizer. For natural soil, the CBR swell is determined as 7.48%. The addition of 8% mix percentage of stabilizers has shown 4.7% improvement. Also, the 16%, 24%, and 32% additions of stabilizers improved the CBR swell value to 1.25%, 0.82%, and 0.52%, respectively (see Table 5). This reduction is acceptable according to many specifications of subgrade soil strength requirements. The main reasons corresponding to CBR and swell improvements were decreased in water absorption during soaking period and increasing interlocking between particles due to admixtures. Figure 8 shows the load versus penetration of the natural soil and the stabilized mixes at 10, 30, and 65 blows.

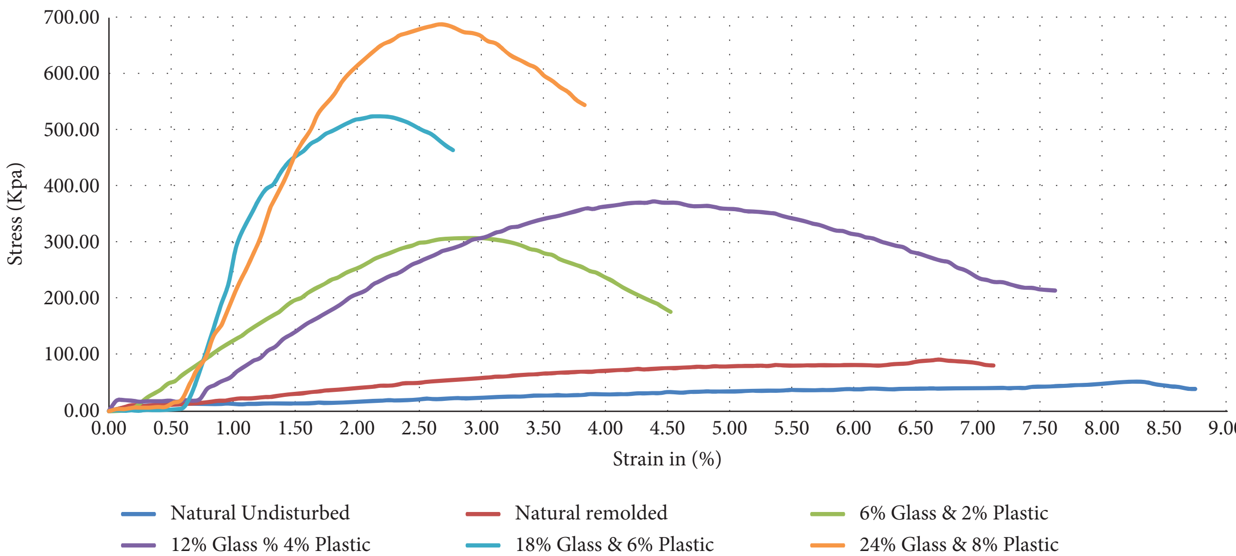


FIGURE 7: UCS results of natural and stabilized mixes.

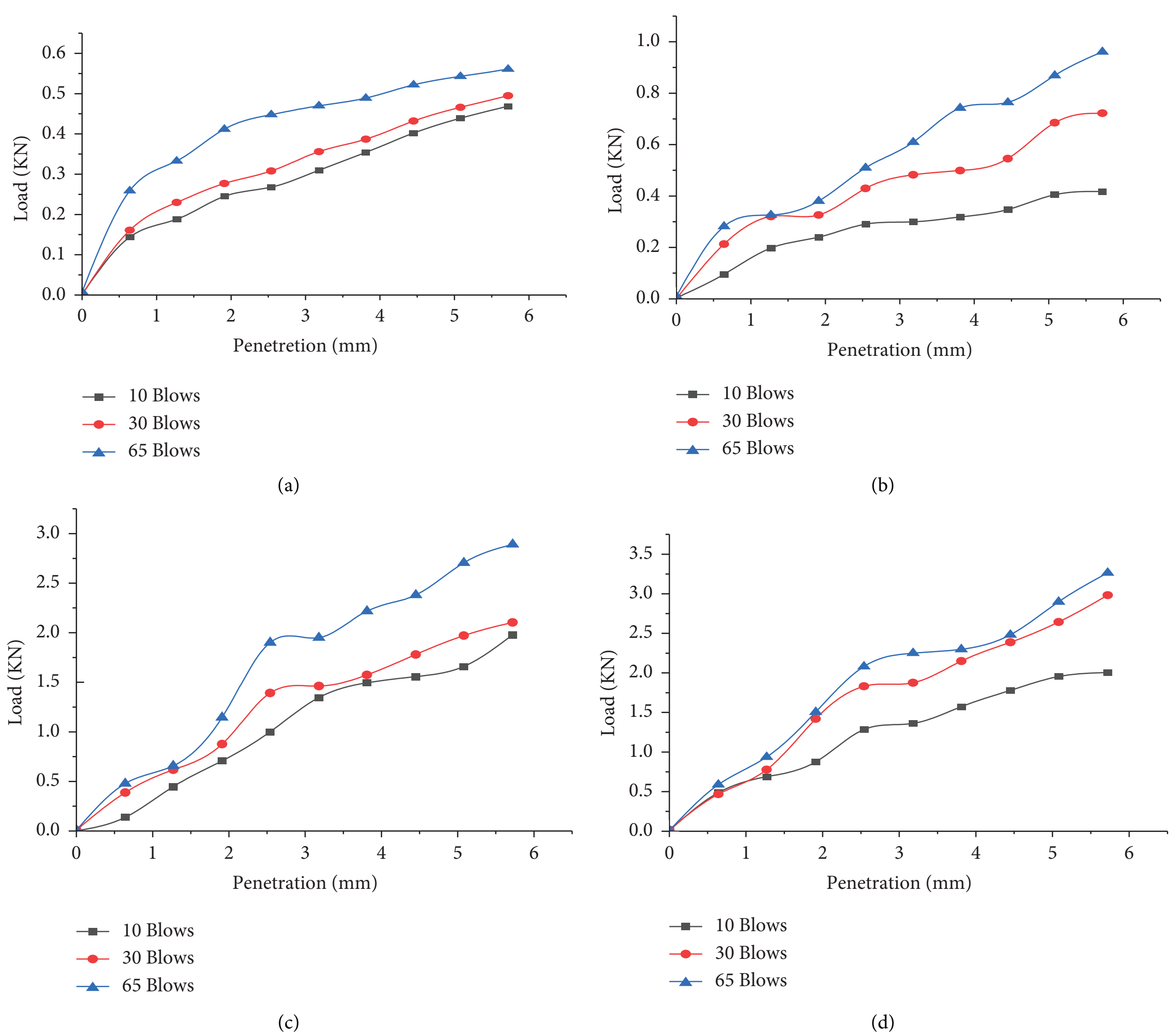
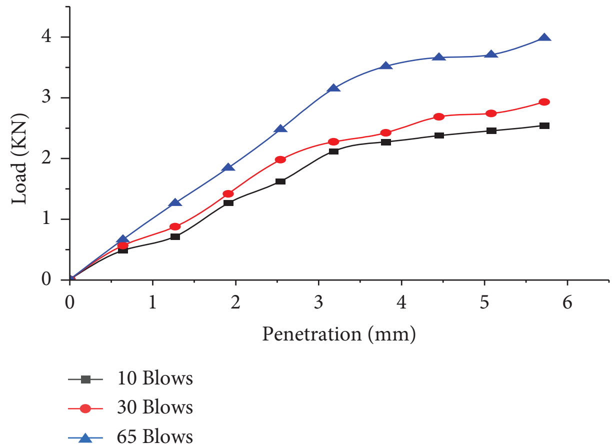


FIGURE 8: Continued.



(e)

Figure 8: CBR results of natural soil and stabilizers: (a) natural soil, (b) 8% stabilizer, (c) 16% stabilizer, (d) 24% stabilizer, and (e) 32% stabilizer.

Table 5: The effect of stabilizers on CBR and CBR swell.

Mix percentage	CBR (%)	Swell (%)
Natural soil	2.6	7.48
8% stabilizer (6% Gwp, 2% Pw)	4.2	4.7
16% stabilizer (12% Gwp, 4% Pw)	11.4	1.25
24% stabilizer (18% Gwp, 6% Pw)	15	0.82
32% stabilizer (24% Gwp, 8% Pw)	17.5	0.52

According to the Ethiopian Road Authority manual [52], a soil with a CBR value less than 3% needs treatment to use as a subgrade material. The manual classifies the strength of the subgrade soil, in terms of the CBR value, into six classes (S-1 to S-6). The addition of 24% to 32% stabilizers brings the subgrade strength class to S-5 subgrade strength class from S-1 for natural soil. To be economical for the stabilization, 24% of the stabilizer is preferred since both amount of addition brings the soil to the same subgrade strength class (S-5). This shows that the stabilizers were highly successful in improving load-bearing strength. The strength of the black cotton soil has been increased with the addition of the stabilizer [53–55].

4. Conclusion

The paper describes how to use plastic bottle chips and powdered glasses to improve low quality subgrade soil, such as black cotton soils with high expansive properties, and turn it into a suitable material for subgrade construction. The study transforms poor soil into a dense, impermeable media. Laboratory tests for this study included moisture content, specific gravity, particle size analysis, Atterberg's limits, Unconfined Compressive Strength, proctor test, free swell test, California Bearing Ratio, and CBR swell tests. The laboratory testing was carried out in line with AASHTO and ASTM standards. The subgrade soils chosen for this study were not suitable due to high expansiveness and weak shear strength, according to the test results on engineering parameters of the natural soil. The soil under research was categorized under A-7-5 and CH by AASHTO and the Unified Soil Classification System, respectively. Soil type falls under the category of "weak soil" for the use in construction. Following treatment, the soils gained a high bearing capacity and a low expansion tendency. The two stabilizers, glass powder, and plastic chips were found to be effective in the laboratory. The soil consistency and maximum dry density have been enhanced. After treatment, the strength parameters, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) were dramatically altered.

Generally, proper stabilizer type and the amount of stabilizer ratio to be used in future construction on expansive clay soil were investigated. The use of glass powder and plastic strip wastes increases the strength of expansive soil by filling void space of soil particles and reducing plasticity index. The soil samples stabilized with an optimum ratio of powdered glass and plastic chips met all the standard for subgrade soils. Based on soil parameters and required strength, the findings can be utilized to pick an appropriate stabilizer type and amount. The laboratory results obtained from this study will be expected to be useful in designing better subgrade strength of road pavements for areas that are occupied by poor soil. The improved soils can be used for subgrades, sub-bases, bases, and in some rare occasions for surface courses. The finding can be used as a guide to select an appropriate stabilizer type and amount based on soil properties and the desired strength.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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References

[1] M. Budhu, *Soil Mechanics and Foundations*, University of Arizona, Arizona, 3rd edition, 2010.
[2] M. Alemayehu Tefera and, *Leykun, Principles of Soil Mechanics*, Addis Ababa: Addis Ababa University, Addis Ababa, Ethiopia, 1999.
[3] M. Mokhtari and M. Dehghani, "Swell-shrink behavior of expansive soils, damage and control," *Electronic Journal of Geotechnical Engineering*, vol. 17, pp. 2673–2682, 2012.
[4] G. Haile Fekadu, D. T. Melese, and T. T. Woldesenbet, "Landslide Susceptibility Assessment Using GIS on Rock-Soil Slope along Zabidar Mountain Road Corridors, Ethiopia," *Geopersia*, vol. 12, no. 2, pp. 201–222, 2022.
[5] L. D. Jones and I. Jefferson, *Expansive Soils*, Institution of Civil Engineers, London, UK, 2012.
[6] J. Nelson and D. J. Miller, *Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*, John Wiley & Sons, Hoboken, NJ, USA, 1997.
[7] F. H. Chen, *Foundations on expansive soils*, Vol. 12, Elsevier, Amsterdam, Netherlands, 2012.
[8] R. Kishor, V. P. Singh, and R. K. Srivastava, "Mitigation of expansive soil by liquid alkaline activator using rice husk ash, sugarcane bagasse ash for Highway subgrade," *International Journal of Pavement Research and Technology*, vol. 15, no. 4, pp. 915–930, 2022.
[9] A. J. Puppala, T. Manosuthikij, and B. C. Chittoori, "Swell and shrinkage characterizations of unsaturated expansive clays from Texas," *Engineering Geology*, vol. 164, pp. 187–194, 2013.
[10] A. Sorsa, *Engineering Properties of Expansive Clay Stabilized with Cement and Lime for Subgrade in Road Construction: A Case Study of Jimma Town*, Jimma University, Jimma, Ethiopia, 2014.
[11] A. Seco, F. Ramírez, L. Miqueleiz, and B. García, "Stabilization of expansive soils for use in construction," *Applied Clay Science*, vol. 51, no. 3, pp. 348–352, 2011.
[12] S. D. Khadka, P. W. Jayawickrama, S. Senadheera, and B. Segvic, "Stabilization of highly expansive soils containing sulfate using metakaolin and fly ash based geopolymer modified with lime and gypsum," *Transportation Geotechnics*, vol. 23, Article ID 100327, 2020.
[13] J. R. Prusinski and S. Bhattacharja, "Effectiveness of portland cement and lime in stabilizing clay soils," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1652, no. 1, pp. 215–227, 1999.
[14] S. Amena, "Utilizing solid plastic wastes in subgrade pavement layers to reduce plastic environmental pollution," *Cleaner Engineering and Technology*, vol. 7, no. 2022, Article ID 100438, 2022.
[15] T. T. Woldesenbet, "Experimental study on stabilized expansive soil by blending parts of the soil kilned and powdered glass wastes," *Advances in Civil Engineering*, vol. 2022, Article ID 9645589, 12 pages, 2022.
[16] J. Olufowobi, A. Ogundoju, B. Michael, and O. Aderinlewo, "Clay soil stabilisation using powdered glass," *Journal of Engineering Science & Technology*, vol. 9, no. 5, pp. 541–558, 2014.
[17] A. Sorsa and E. C. Agon, "Lime stabilization of expansive clay soil of Jimma town, Ethiopia," *Civil Engineering Infrastructures Journal*, vol. 55, no. 2, pp. 211–222, 2022.
[18] United Nations Environment Programme, "World Environment Day brings solutions to plastic pollution into focus," 2023, https://www.unep.org/interactives/beat-plastic-pollution/.
[19] L. Lebreton and A. Andrady, "Future scenarios of global plastic waste generation and disposal," *Palgrave Communications*, vol. 5, no. 1, p. 6, 2019.
[20] T. Getahun, E. Mengistie, A. Haddis et al., "Municipal solid waste generation in growing urban areas in Africa: current practices and relation to socioeconomic factors in Jimma, Ethiopia," *Environmental Monitoring and Assessment*, vol. 184, no. 10, pp. 6337–6345, 2012.
[21] J. H. Butler and P. D. Hooper, "Glass waste," in *A Handbook for Management*, pp. 307–322, Academic Press, Cambridge, MA, USA, 2019.
[22] L. Hirpe and C. Yeom, "Municipal solid waste management policies, practices, and challenges in Ethiopia: a systematic review," *Sustainability*, vol. 13, no. 20, Article ID 11241, 2021.
[23] M. MacLeod, H. P. H. Arp, M. B. Tekman, and A. Jahnke, "The global threat from plastic pollution," *Science*, vol. 373, no. 6550, pp. 61–65, 2021.
[24] P. Li, X. Wang, M. Su, X. Zou, L. Duan, and H. Zhang, "Characteristics of plastic pollution in the environment: a review," *Bulletin of Environmental Contamination and Toxicology*, vol. 107, no. 4, pp. 577–584, 2020.
[25] T. T. Woldesenbet, B. T. Wodajo, and D. T. Melese, "Assessment of pedestrian's road crossing behaviors and developing a model to predict road crossing speed on zebra-marked crossings," *Innovative Infrastructure Solutions*, vol. 8, no. 1, p. 14, 2023.
[26] S. Kumar, M. Mishra, and J. Singh, "A review on soil stabilization using waste plastic materials," *Gradiva Review Journal*, vol. 7, no. 7, pp. 372–376, 2021.
[27] R. G. Beerkens, "Sulfate decomposition and sodium oxide activity in soda–lime–silica glass melts," *Journal of the American Ceramic Society*, vol. 86, no. 11, pp. 1893–1899, 2003.
[28] A. Fluegel, "Glass viscosity calculation based on a global statistical modelling approach," *Glass Technology: European Journal of Glass Science and Technology, Part A*, vol. 48, no. 1, pp. 13–30, 2007.
[29] H. Ritchie and M. Roser, "Plastic Pollution," 2018, https://ourworldindata.org/plastic-pollution?utm_source=newsletter.
[30] E. M. Duncan, A. Davies, A. Brooks et al., "Message in a bottle: open source technology to track the movement of plastic pollution," *Plos One*, vol. 15, no. 12, Article ID e0242459, 2020.
[31] ASTM International, *ASTM-D-18, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 Ft-Lbf/Ft3 (2,700 KN-M/M^3))*, Vol. 1, ASTM International, West Conshohocken, PA, USA, 2009.
[32] ASTM, "ASTM-D2166 Standard test method for unconfined compressive strength of cohesive soil," in *American Society for*

Testing and Materials, ASTM, West Conshohocken, PA, USA, 2013.

[33] ASTM International, *ASTM-D4318-17 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity index of Soils*, ASTM International, West, Conshohocken, PA, 2017.

[34] T. Aashto, *Standard Method of Test for the California Bearing Ratio*, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, USA, 2013.

[35] American Society for Testing and Materials, "Standard test method for particle-size analysis of soils," 2007, http://coal-ash.co.il/docs/Bottom_Ash_2006.pdf.

[36] A. K. Jain, A. K. Jha, and Shivanshi, "Geotechnical behaviour and micro-analyses of expansive soil amended with marble dust," *Soils and Foundations*, vol. 60, no. 4, pp. 737–751, 2020.

[37] Y. Ma and W. Chen, "Study on the mechanism of stabilizing loess with lime: analysis of mineral and microstructure evolution," *Advances in Civil Engineering*, vol. 2021, Article ID 6641496, 11 pages, 2021.

[38] V. S. Shrivastava, "X- ray diffraction and mineralogical study of soil: a review," *Journal of Applied Chemical Research*, vol. 9, pp. 41–51, 2009.

[39] J. C. Ruge, X. Palacios, F. M. G´omez, and J. P. R. Su´arez, "Mineralogical, microstructural and porosimetry analysis in three different clayey soils," *Journal of physics: conference series*, vol. 1388, no. 1, Article ID 12014, 2019.

[40] S. Peddaiah, A. Burman, and S. Sreedeep, "Experimental study on effect of waste plastic bottle strips in soil improvement," *Geotechnical & Geological Engineering*, vol. 36, no. 5, pp. 2907–2920, 2018.

[41] I. Bozyigit, F. Bulbul, C. Alp, and S. Altun, "Effect of randomly distributed pet bottle strips on mechanical properties of cement stabilized kaolin clay," *Engineering Science and Technology, an International Journal*, vol. 24, no. 5, pp. 1090–1101, 2021.

[42] R. K. Mai, P. Sarathkumar, V. Dinesh, and N. Sathish, "PET as soil stabilization material," *International Journal of ChemTech Research*, vol. 10, no. 11, pp. 127–130, 2017.

[43] A. J. Puppala and C. Musenda, "Effects of fiber reinforcement on strength and volume change in expansive soils," *Transportation Research Record*, vol. 1736, no. 1, pp. 134–140, 2000.

[44] L. C. Dang, B. Fatahi, and H. Khabbaz, "Behaviour of expansive soils stabilized with hydrated lime and bagasse fibres," *Procedia Engineering*, vol. 143, pp. 658–665, 2016.

[45] S. A. R. Shah, Z. Mahmood, A. Nisar, M. Aamir, A. Farid, and M. Waseem, "Compaction performance analysis of alum sludge waste modified soil," *Construction and Building Materials*, vol. 230, Article ID 116953, 2020.

[46] H. Afrin, "A review on different types soil stabilization techniques," *International Journal of Transportation Engineering and Technology*, vol. 3, no. 2, pp. 19–24, 2017.

[47] G. Spagnoli and S. Shimobe, "An overview on the compaction characteristics of soils by laboratory tests," *Engineering Geology*, vol. 278, Article ID 105830, 2020.

[48] S. Firat, J. M. Khatib, G. Yilmaz, and A. Comert, "Effect of curing time on selected properties of soil stabilized with fly ash, marble dust and waste sand for road sub-base materials," *Waste Management & Research*, vol. 35, no. 7, pp. 747–756, 2017.

[49] F. Zha, S. Liu, Y. Du, and K. Cui, "Behavior of expansive soils stabilized with fly ash," *Natural Hazards*, vol. 47, no. 3, pp. 509–523, 2008.

[50] H. A. M. Abdelkader, M. M. A. Hussein, and H. Ye, "Influence of waste marble dust on the improvement of expansive clay soils," *Advances in Civil Engineering*, vol. 2021, Article ID 3192122, 13 pages, 2021.

[51] A. J. Choobbasti, H. Ghodrat, M. J. Vahdatirad et al., "Influence of using rice husk ash in soil stabilization method with lime," *Frontiers of Earth Science in China*, vol. 4, no. 4, pp. 471–480, 2010.

[52] Wyoming, "Road Design Manuals," 2013, https://www.dot.state.wy.us/home/engineering_technical_programs/manuals_publications/road_design_manual.html.

[53] C. Ikeagwuani, I. Obeta, and J. Agunwamba, "Stabilization of black cotton soil subgrade using sawdust ash and lime," *Soils and Foundations*, vol. 59, no. 1, pp. 162–175, 2019.

[54] M. A. Rahgozar, M. Saberian, and J. Li, "Soil stabilization with non-conventional eco-friendly agricultural waste materials: an experimental study," *Transportation Geotechnics*, vol. 14, pp. 52–60, 2018.

[55] A. Fauzi, W. M. N. W. A. Rahman, and Z. Jauhari, "Utilization waste material as stabilizer on kuantan clayey soil stabilization," *Procedia Engineering*, vol. 53, pp. 42–47, 2013.