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Research Article

Amelioration Effect of Fly Ash and Powdered Ground Steel Slag for Improving Expansive Subgrade Soil

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The utilization of fly ash (FA) and powdered granulated steel slag (PGSS) as additives in soil stabilization plays a crucial role in environmental, economic, and weak soil property improving advantages. In this study, the combined effect of FA and PGSS in improving expansive subgrade soil was investigated. The materials used for this study were expansive soils, FA, and PGSS. The study has applied an experimental research method. For this investigation, the index properties, Free Swell Index (FSI), unconfined compressive strength (UCS), optimum moisture content (OMC), California bearing ratio (CBR), and scanning electron microscope (SEM) tests were done for treated and untreated expansive soils. The findings indicated that as the mixture of FA (0 to 12.5% at 5% increment) and PGSS (0 to 25% at 5% at 2.5% increment) is added to the untreated expansive soils, the index properties, FSI, and OMC of the soils were significantly declined. The CBR values of expansive soils containing 20% FA and 10% PGSS mixture were 13.8% and 16.21%, respectively, which improved the quality of the soils by 85.43% and 84.82%, respectively. While the untreated expansive soils have a UCS value of 0.34 kg/cm^2, the treated soil comprising 20% FA and 10% PGSS mixture has a UCS value of 13.42 kg/cm^2, indicating that the soil strength is enhanced by 97.47%. The results of the studies demonstrate that adding FA and PGSS to expansive soil improves its stability and strength. The study concluded that disposals such as FA and PGSS might be effectively used in enhancing the characteristics of construction materials and used for the construction.

1. Introduction

Most of the semiarid and arid areas are covered by expansive soil. The road construction in these areas is deteriorating before it reaches its design life. This is due to the volumetric change of the soil property with seasonal variation. The global issue of pavement failure due to the subgrade constructed on expansive soil is a prominent concern that needs a quick solution. This problem is happing in most parts of Ethiopia as it covered around 24.7 million acres. The expansive soils have clay minerals like montmorillonite which make it have variable volume. The presence of this mineral in the soil increases and decreases its volume in the wet and dry climate conditions, respectively. The infrastructures and buildings are subjected to unexpected stress applications due to the variable volume of the expansive soil which causes failure. Engineers in different parts of the world are challenged with having a large surface area and high cation alteration ability of weak soils. Therefore, these soils are hazardous to the structures if it is not properly treated and managed [1–4].

Nowadays, a huge amount of budget is invested in the maintenance and rehabilitation of pavement failure due to the behavioral change of expansive soil [5]. The subgrade is an important part of the pavement layers which creates failure to the pavement if prepared on expansive soil. The performance of the pavement is mainly affected by the property of the materials, and the construction property of subgrade. Hence, the subgrade should resist shear stresses occurring due to wheel pressure, respond elastically and reduce deflection when subjected to wheel pressure, prevents moisture susceptibility, thus keeping shear strength and modulus, and minimize swell [6].

The physical characteristics of the soils shall be enhanced through the process of treatment. This practice improves the features of the soil to a desired degree of requirement to increase its durability and applicability for construction work. The strength of the subgrade laid on expansive soil can be guaranteed by using stabilization techniques. Stabilization is the process of blending soil with economical and easily available admixtures in the construction vicinity. The properties such as plasticity, expensiveness, and permeability can be reduced by stabilizing expansive soil with locally available admixtures. Moreover, it might minimize excavation, disposal, and transporting of capable material from the quarry site. The properties of the soil and the overlying pavement thicknesses can be improved by treatment techniques [7].

The grain size distribution and plastic index properties of native soil shall be enhanced through blending with industrial wastes like FA and GGBFS [8–10]. This technique enhances the compaction characteristics of the weak soils by removing the supreme void space available within the soil particle. Because of its gradation, the expansive soil would not be affected. Treating expansive soil with PGSS and FA improve the volumetric change, swelling potential, and compressive strength of the soil [11–15].

The commonly available admixtures used in treating expansive soil are lime and cement [16]. Since they are processed materials, they are costly and highly generate carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Currently, low-cost industrial wastes such as FA and PGSS admixtures are replacing conventional additives in the construction industry [17]. Furthermore, the application of these industrial wastes as binding materials minimizes the emission of CO_2 from the factory to the environment. The advantage of stabilization is to enhance the calcium content of weak soils [18]. Also, the presence of siliceous and calcareous in fly ash and steel slag waste products makes them be used as admixtures.

The performance and the adhesion of the expansive soil can be enhanced by using geopolymer materials [7, 12, 19]. The geopolymers are produced from materials having large amount of silica (Si) and alumina (Al) [20–22]. Wastes such as FA and PGSS containing Si and Al are utilized in geopolymer for soil mixing [22–25]. The FA and PGSS containing Si and Al are easily soluble in alkaline substances to form geopolymer [20, 22, 23, 25–34].

The most economical pavement layers which adequately support the traffic load without failure before its intended life must be properly designed and constructed. The design life of the pavement is ensured by providing a thicker pavement layer over the weak subgrade. Treatment can improve the quality of expansive soil to make it efficient in road construction [1, 2, 4]. Scholars are looking for optional techniques than stabilization to enhance the quality of construction materials. Amorphous materials comprising silicon and aluminum are good in binding, treating, and enhancing pavement performance [35]. Many studies have been conducted to characterize the reused construction and demolished materials in terms of their basic properties, shear strength parameters, resilient modulus, and permanent deformation. The density results show the presence of high-quality aggregates in the reused construction and demolished materials, which gives higher density for the coarse aggregates. The characteristics of crushed brick, reclaimed asphalt pavement, and fine recycled glass can be further improved with additives or mixed in blends with high-quality aggregates to aid their utilization as subbase material [36]. Also, the utilization of construction and demolition materials are currently implementing in the applications of road pavements construction, ground improvement, engineered fills, pipe bedding, backfill and aggregates in concrete [37]. Construction and demolition materials constitute a major proportion of waste materials exists in landfills globally. With the shortage of high-quality aggregates, alternative materials, such as construction and demolition materials, are extensively being considered as a replacement for road construction materials, specifically as the sustainable usage of these materials has significant environmental advantages [38]. The reprocessing of construction materials has a high potential to protect natural resources and to reduce the energy used in production. The construction and demolished materials can be mixed with clay at specific contents for road pavement subgrade in order to reduce the environmental and economic problems globally [39, 40]. The use of waste tyres in civil engineering applications can minimize the tyre disposal challenges affects the economy and environment of an area. However, the utilization of waste tyres cannot yield the desired characteristics for some geotechnical applications always. The application of waste tyres in geotechnic could significantly improve the CBR and UCS performances of clay by creating artificial bonding with a relatively small amount of lime [41]. From an environmental perspective, the potential use of the reclaimed asphalt pavement-fly ash blend and reclaimed asphalt pavement-fly ash geopolymers as a sustainable pavement base material have high durability. Moreover, the use of these materials significantly save energy and minimizes greenhouse gas emission [42]. The reuse of computer numerical control milling waste spirals is becoming a challenging task for numerous countries because of the annual increase in steel production integrated with the computer numerical control machines. When low in plastic clay soil are mixed with computer numerical control waste, the strength and the consistency characteristics of the soil could positively improve [43]. Blending organic soils with rock powder has a significant effect on the its compressibility and behavior by converting from cohesive to cohesionless property that resulted in the substantial decrease in its index properties such as compression, swelling, and coefficient of compressibility [44].

The road constructed in Ethiopia is highly deteriorating before its intended design life due to the insufficient in strength of subgrade soil. To improve the quality of existing subgrade soil, possolonic conventional materials like cement and lime are extensively utilizing as chemical stabilization where their cost is not effective. The cost implication of such materials paved the way for searching alternative nonconventional possolonic materials which have nearly same property with cement and lime. FA and PGSS are industrial wastes which are freely and widely available. They have possolonic property which can avoid the volumetric change is soil particles. The possolonicity of these materials can also increases the binding capacity of the soil which can improve the strength of subgrade soil. Hence, the aim of this research is to examine the combined binding potential effect of FA, and PGSS in stabilizing subgrade soil.

2. Materials and Methods

Expansive soil, fly ash, and PGSS are the main materials employed in this research. The properties of these materials are described in the next section.

2.1. Materials. In this investigation, expansive soil (ES) was sampled from the Addis Ababa Bole-Sub city in Ethiopia, at depths of 0.5 to 1.5 meters beneath existing surface, and had a water content of just 38.07%, which is notable in this context. The expansive soil is dark in color. Vast trials of experiments have been also conducted to examine the geotechnical characteristics of soils, as per standard specification. FA is extracted from Reppi Thermal Power Plant found in Kolfe Keranio's, Addis Ababa. First, they were air-dried for more than a week. Then, they have mechanically grinded or pulverized to get the powder form until they passed 0.075 μm sieve size. The Reppi-waste thermal Power Plant produces FA as an industrial waste. FA possesses a teeny binding characteristic that is required for pasting. From the chemical analysis, the FA is classified as Class-*F* possolona. As a result, by the availability of smaller quantity of admixtures, a chemical reaction occurs, resulting in cementitious characteristics capable of enhancing the performance, and durability of expansive soils. PGSS is sourced from a Kalliti Iron and Steel plant stockpile in Addis Ababa, Ethiopia. It is made by quenching molten steel slag in moisture, resulting in a vitreous, grainy substance that is dried and powdered into a fine form. It has been utilized as a cement raw material, as well as gravel and a nonconductive substance. The chemical characterizations of the materials employed in this study are illustrated in Table 1.

The materials used for this research study were experimentally examined in the laboratory to evaluate their physical and chemical properties materials. The results are indicated with Table 2. As results are illustrated, the physical characteristics of materials before blending are verified. The sieve analysis of treated expansive soils provides the proportions of soil fractions as 0% gravel, 12.42% sand, 32.26% silt, and 55.32% clay. From this gradation test result, clay is the most dominant and silt is the second dominant part of soil fractions.

2.2. Particle Size Distribution. The particle size distribution of each material is analyzed using the combined results of sieve analysis and hydrometer tests. The results of the expansive soils, GPSS, and FA are shown in Figure 1. From the result, GPSS, and FA are finer than Expansive soils.

Table 1: The chemical characterization of materials used.

Composition	Expansive soil	Fly ash	GGBFS
SiO_2	58.90	39.46	46.14
Al_2O_3	18.54	14.32	18.52
Fe_2O_3	8.40	5.38	13.24
CaO	0.90	24.28	16.76
MgO	1.62	3.34	2.29
Na_2O	0.34	1.26	0.92
K_2O	0.76	2.44	1.70
MnO	0.18	0.28	4.36
P_2O_5	0.04	1.25	0.82
TiO_2	<0.01	0.04	0.07
H_2O	2.05	0.11	0.16
LOI	9.28	7.04	3.13

2.3. Methodology. In this research, the FA and PGSS admixtures have used as additives in the mixture of ES. The desired strength of the soil is attained by varying the proportion of FA and PGSS. A reasonable proportion of additives were obtained by starting with 5% of FA and 2.5% of PGSS [45]. An appropriate proportion of additives were replaced for numerous tests. The proportions of treatments replaced in the first trail are two percent of FA and one percent of PGSS; but, this practice can be varied based on the previous study [46–48]. The experiment was returned into original specimen after conducting a few dummy tests. The dummy test gave helped to know the direction of tests as it appears tedious in the beginning as the results of in adequate techniques in the experimental work. The untreated expansive soil and soil treated with FA and PGSS additives are the two methods used to separate the specimens. They were then treated with FA and PGSS admixtures. The proportion of mixing varied from 0–25% for FA and 0–12.5% for PGSS by the weight of dry expansive soil sample. Three trials have been carried out for each mixture in order to check the consistency of the specimens.

2.4. Experimental Work

2.4.1. Index Property. The plastic index of a soil is evaluated based on ASTM, standard testing method. To close a groove of the sample, a twenty-five blow is applied with Atterberg's limit testing apparatus. A logarithmic scale is used to plot the flow curve obtained from test result. The liquid limit is taken which coincides to twenty-five blows from the graph by correcting to closest integer. The PL is determined by rolling the specimen on the glass into thread like shape until it reveals cracks on its surface in most case the three-millimeter diameter obtained.

2.4.2. Density of Compacting. Compaction is the process of avoiding void spaces and moisture available among soil particles. The MDD and OMC of the materials were obtained by using modified proctor test. The modified proctor

Table 2: Characteristics of materials.

S/N	Property	Standard	Soil	Fly ash	PGSS
1	Color	—	Black	Grey	Whitish
2	Specific gravity	AASHTO T 100	2.64	2.15	2.84
3	Moisture content (%)	ASTM D-2216-90	38.07	32.00	40.00
4	Liquid limit (%)	ISO 17892-12	107.14	—	—
5	Free swell	ASTM D4546-21	118.00	—	—
6	CBR (%)	ASTM D1883	0.80	—	—
7	Plastic limit (%)	ISO 17892-12	59.83	Non-plastic	Non-plastic
8	Plasticity index (%)	AASHTO T90	47.31	Non-plastic	Non-plastic
9	OMC (%)	IS-2720	18.96	25.00	20.00
10	MDD (g/cc)	IS: 2720	1.46	1.40	2.56
11	UCS (kg/cc)	ASTM D-2166	0.34	—	—

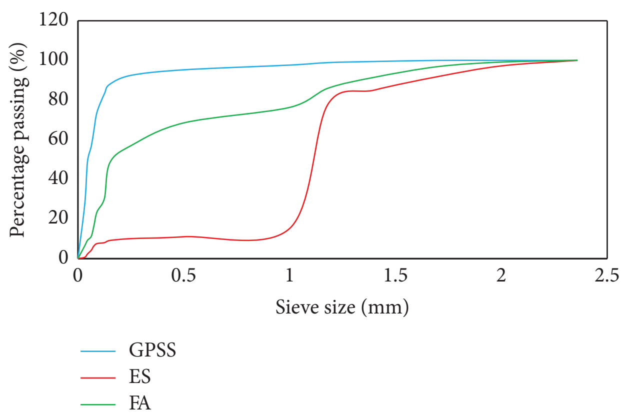


Figure 1: Particle size distribution of ES, GPSS, and FA.

density test is done following ASTM standard test method in the laboratory. Five layers of the specimen subjected to 4.5 kg compaction load are used in the compaction process. The specimen was prepared with a mold size of 105 mm and 115 mm of diameter and height, respectively.

2.4.3. Free Swell Index. The size variation of the soil containing clay subjected to wet was determined by using free swell test in accordance to Indian Standard (IS) testing method. The test illustrates a reasonable evaluation of the potential expansion of the soil. First, the dried soil passed through 425 μmm sieve size is mixed with ten-millimeter amount of water in a jar containing hundred millimeters of water. Then, the specimen is dried in oven, added to the bottle up to ten millimeters, filled by water up to the top mark, and finally the reading was taken after one-day stay.

2.4.4. Californian Bearing Ratio. The performance of the soils subjected to load under certain condition is evaluated employing CBR experiment based on ASTM standards. A specimen of six kilogram is dried, and mixed with water (OMC) acquired from compaction experiment. Soaked and unsoaked CBR experiments were performed. The soaked CBR was done by putting on the water bath for ninety-six hours subjected to 4.50 kg surcharge pressures on upper compacted specimens. Four days later, the soaked specimen with CBR mold was casted off from the curing tank, penetration of soaked specimen subjected to a pressure of twenty-eight-kilo newton circular plunger of 50 mm diameter at a speed of 1.25 millimeter per minute has conducted and the stresses obtained at 2.54- and 5.08-millimeters penetration readings was divided by the standard stress in order to get the final CBR value. And also, a tripod was fixed to the mold at the start soaking and ends of soaking (after 96 hours) in order to estimate the swell value for untreated expansive and treated soil specimens.

2.4.5. Unconfined Compressive Strength. The UCS experiment is a uniaxial compression test of the tri-axial test. The experiment was conducted following ASTM on a specimen containing a radius of 19 millimeter and a depth of 76 millimeter. All UCS experiment was carried out for removed samples applying strain at a rate of nearly one percent per minute. Throughout the computation of UCS 0.001420 N/div load factor and 0.010-millimeter deflection factor were employed and from each test result, the largest output has received as the UCS value. The specimen was prepared and compacted at variable OMC with soaking period of 24 hours, 168 hours, and 336 hours at temperature (30 ± 3).

3. Results and Discussion

3.1. Effect of FA and PGSS on the Index Property of Expansive Soil. The consistency limits (LL, PL, and PI) were examined, by which the LL and the PL were obtained. From these two consistency test results, the plasticity index (PI) is estimated. The change in consistency limits for the increasing percent of FA-GGBFS is displayed with Figure 2. Usually, clay can hold a greater amount of H_2O caused by the existence of a dispersed dual pavement [49]. The replacement amount of FA and PGSS diminishes the H_2O absorbing ability of clay. The consistencies of the soil were reduced by increasing the percentages of FA and PGSS in the mixture. Moreover, the reduction of the plastic index value illustrated that the decline with the plasticity of expansive soil by adding FA, and PGSS. Earlier study has pointed out as the declining value of PL happen a reduction of PI value correspondingly. The replacement of UES by FA and PGSS more decreased its PI showing it is highly compressible material.

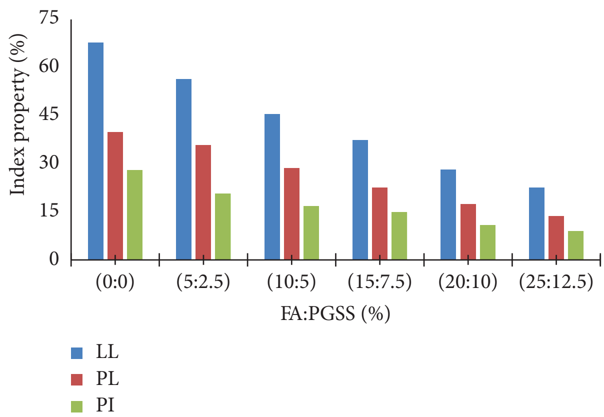


Figure 2: Index property of expansive soil mixed with FA and PGSS.

3.2. Effect of FA and PGSS on the Free Swell Index of Expansive Soil. The variation of FSI with different proportions of FA, and PGSS treatment is illustrated in Figure 3. The results of FSI declined with the application of FA and PGSS indicating that there is a failure with a tendency of expansion of UES. The authors in [50] investigated the swelling characteristics of expansive soil stabilized with PGSS and the result indicated that it has a positive influence on dropping the swelling characteristics of expansive soils. As the amount of FA and PGSS increased in the mix, the free swell is significantly decreased. This indicates that both FA and PGSS have the capacity to trap more moisture from the soils when properly added to the mix. They can also prevent the more volumetric change of the soil during seasonal variation.

3.3. Effect of FA and PGSS on Density. Figure 4 illustrates that by increasing the percentages of FA and PGSS in the mix as the OMC is reduced, the MDD is raised contrarily. From this point, it is possible to say that FA and PGSS admixtures have the capacity to improve the quality and behavior of UES through stabilization. A less capacity of particles position will occur with the existence of high clays content in the mix. Consequently, it requires a minimum pressure application at the time of compaction of earthwork [51–53]. This behavior is reversed with the application of cohesionless materials like FA and PGSS. Additionally, by increasing the amount of cohesionless materials in untreated expansive soil mixed with FA and PGSS, a few amounts of H_2O are needed at the time of compaction in the particles poisoning. Such improved behavior of UES by the addition of FA and PGSS offers to the consistency of combined soils. Therefore, it is concluded that the MDD is 1.93 at the addition of 20% FA and 10% PGSS (17.18% OMC).

3.4. Effect of FA and PGSS on CBR of Expansive Soil. Figure 5 illustrated that with the increase in the FA and PGSS percent, the CBR outcome was improved. It indicates the substitution of expansive soil by different proportions of FA and PGSS play an essential effect in enhancing the Californian bearing ratio of the soil. Moreover, it illustrated that

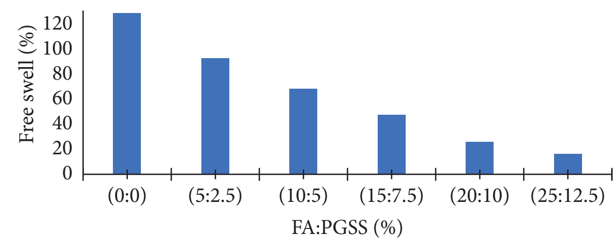


Figure 3: Swell property of expansive soil blended with FA and PGSS.

FA and PGSS act as strong materials in unsoaked conditions. When the mixture of FA and PGSS is added to expansive soil with an interval of 5–2.5% and 25–12.5%, respectively, a maximum of 16.21% of CBR value was obtained at 20% FA, and 10% PGSS mixture addition. The presence of pressure in the opening of specimen in unsoaked condition increases its compressive strength. Soaking sample continuously may fill the available openings which reduces the presence of pressure [54]. The strength is declined due to a continuous soaking and softening of specimen. As indicated on the Figure, the outcome of the CBR of cured specimen was radically declined. Moreover, the soaked and unsoaked conditions of CBR values of expansive soil are 2.010% and 2.460%, respectively, because the hydraulic conductivity of the sample in such condition is important in reducing strength at the moment of curing [55]. With the incorporation of FA and PGSS, results were further enhanced. The optimal amount of stabilization 20% FA and 10% PGSS gives the soaked and unsoaked CBR results of 13.8% and 16.21%, respectively, which is a good result for road subgrade preparation. Also, the dummy test revealed that the CBR was increased by increasing the amount of admixture in the mix which leads to improve the strength of expansive soils.

3.5. Effect by FA and PGSS on UCS. UCS experiment is rapidly aimed to determine the UCS of the materials containing much clay content to evaluate its confines. Unlike FA and PGSS blends, the UCS of untreated expansive soil is shown in Figure 6. It indicates the UCS varies as the percentages of FA and PGSS increases for estimating the shear strength of the specimen. Figure 6 indicates the compressive strength obtained at one day, seven days, and fourteen days with varying the proportions of FA and PGSS. As shown in the Figure, a significant increase in strength of mixture was observed when treated with these additives. The outcomes illustrates that the UCS of 100% expansive soil is 0.34 kg/cc after 1 day of soaking. Furthermore, the results were enhanced by replacing the soil with the admixtures. The fourteen days examination outcomes vary from that of one-day and seven days experiment with the indication of enhancing compressive strength when FA and PGSS admixtures are added to the soil. The variations of compressive strength up to a certain amount of additives are needed in order to fills the pore space in the soil. As these pore spaces were fills, the soils are more compacted. More extension might lose the strengths of the soil. The formed pozzolanic

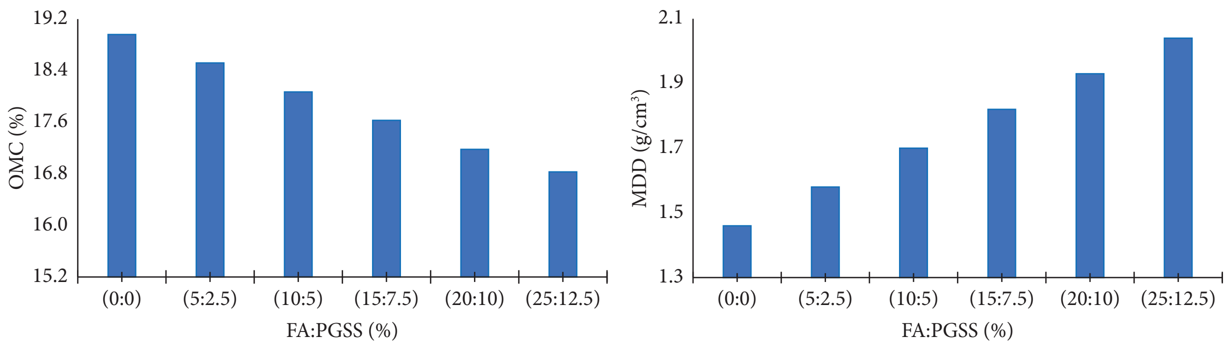


Figure 4: Compaction effect of FA and PGSS addition to expansive soil.

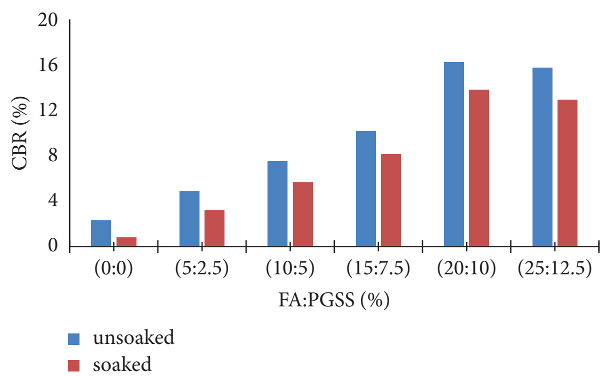


Figure 5: CBR of expansive soil mixed with FA and PGSS.

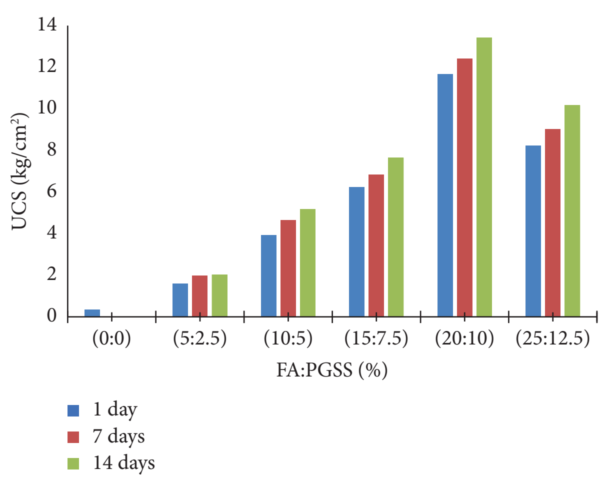
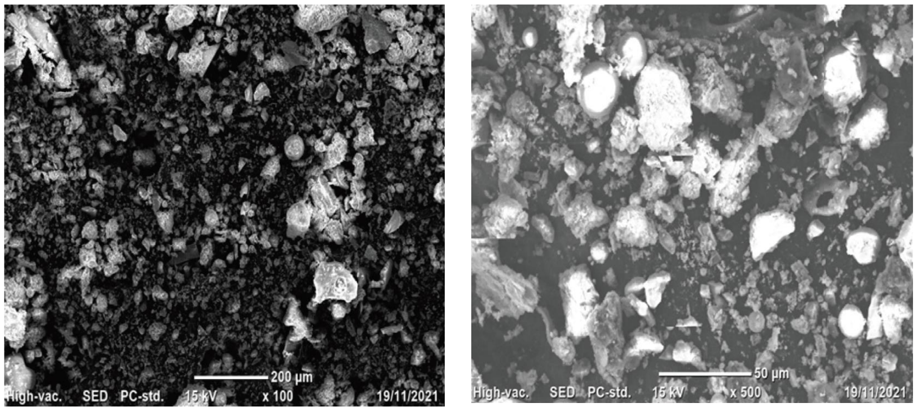


Figure 6: UCS for expansive soil with and without FA and PGSS additive.

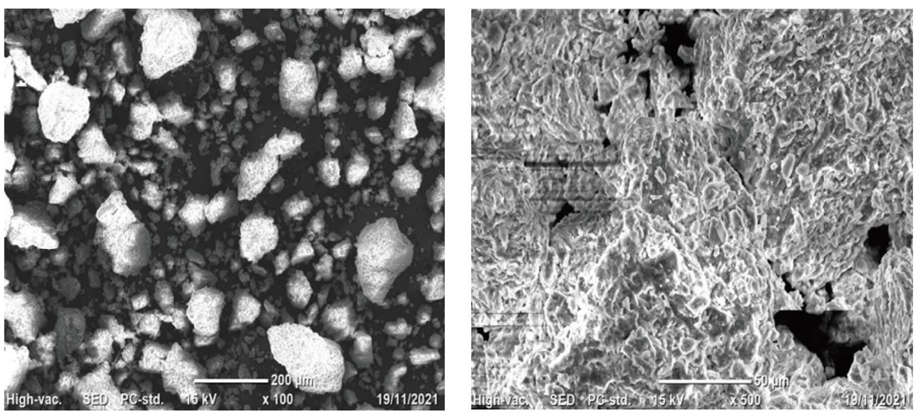
materials containing cementitious properties by the reaction of hydration enhances a binding ability of soils [48]. The percentage of pozzolanic paste material rises and strengthens with the duration of soaking time, which considerably improves the compressive strength of the soils. Further, the highest UCS result is observed at 20% FA and 10% PGSS.

3.6. Effect of FA and PGSS on SEM. Different scales of micrographs were obtained to explain the assessment of microstructures. Two scales of 200 and 50 μm has indicated with Figures 7 and 8 for the untreated and treated expansive soils. As indicated with Figure 8, the treated expansive soils particle become coarser because of the binding effect of FA and PGSS additives to pack together the fines particle, creating wider, and greater cluster of micro-micrographs. Figures 8(a) and 8(b) shows narrower scanning electronic microscope photo of the stabilized soils. In comparison to the expansive soils photo with Figure 7, novel oxides could be specified in the microstructures of stabilization soils at (a), and (b). It illustrates the creation of pasting behavior of FA and PGSS. Figures 8(a) and 8(b) indicate a micrograph of



(a) (b)

Figure 7: SEM picture of expansive soil.



(a) (b)

Figure 8: SEM picture of expansive soil containing 20% FA and 10% PGSS.

the soil blended with pasted 20% FA and 10% PGSS. From this photo, waving fragment particle could reveal. But the micro-graphs of blended soils indicated on photo (a) reveals that the micro-structures of the blended soils become thick, compressed, and consistent than expansive soils illustrated on Figure 7. Hence, it approves an advance of binding abilities which focused on enhancing the physical characteristics of expansive soil in the study. Therefore, the analysis indicated that the expansive soil mixed with FA and GPSS had lesser holes and was extremely thicker.

4. Conclusions

The investigation emphasized that the treatment of expansive soils with FA and PGSS and their effect on the soils was examined. A consistency limit of expansive soils was reduced by increasing the percentages of FA, and PGSS. In the meantime, the FSI was reduced from 118% to 23.56% which indicates it is around 80.04% less than that of the untreated expansive soil. By increasing the contents of FA, and PGSS, the OMC reduces from 18.96 to 17.18%, and the MDD rises from 1.46 to 1.93 kg/cm^3. The addition of FA and PGSS could be analogous to the enhanced compaction impact. Thus, the expansive soil comes to be stiffer. By increasing the FA and PGSS amount in the mix, the CBR result of expansive soil rises. The soaked and unsoaked CBR results of untreated expansive soils were 2.01% and 2.46%, respectively; however, by adding FA and PGSS, the CBR result was excessively raised. The optimal proportional of the combination (20% FA and 10% PGSS) gives the soaked and un-soaked CBR result of 13.8% and 16.21%, respectively, the acceptable value for subgrade materials. The substantial increases were revealed in the UCS of stabilized untreated expansive soils. UCS raised in stable rise by percentages of FA, and PGSS additive and life extension. The UCS of untreated expansive soil is 0.34 kg/cc: after fourteen-day soaking. However, the highest UCS value of 13.42 kg/cc was obtained at 20% FA and 10% PGSS showing that it has been improved the strength of the soil by 97.47%. The result indicates that the microstructure of treated expansive soil specimen varies considerably when different proportion of FA and PGSS is added. In the beginning, the particles sizes of expansive soils appeared as bigger pores than the treated one. A cementitious substance which is like the structures of FA, and PGSS was revealed, which enclosed, and stick together with the expansive soils' particle. A densified soil particle was attained as of the decrease by size of the treated expansive soils. The study summarized that industrial wastes such as FA and PGSS can be efficiently applied in improving the properties of construction materials and used for construction. Due to their possolonic property and good cementitious capacity, FA and PGSS which have similar characteristics with cement and lime is suggested to use in engineering construction.

Data Availability

All the data used to support the findings of the study are included within the research.

Conflicts of Interest

The authors declare they do not have any conflicts of interest.

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