Hindawi
Advances in Civil Engineering
Volume 2022, Article ID 7716921, 11 pages
https://doi.org/10.1155/2022/7716921

Research Article

Utilization of Waste Incineration Bottom Ash to Enhance Engineering Properties of Expansive Subgrade Soils

Damtew Tsige Melese

Department of Civil Engineering, Jimma Institute of Technology, P.O. Box 378, Jimma 47, Ethiopia

Correspondence should be addressed to Damtew Tsige Melese; melese0510@gmail.com

Received 6 June 2022; Revised 12 November 2022; Accepted 26 November 2022; Published 6 December 2022

Academic Editor: Zhiguo Zhang

Expansive soils are a type of soil that exhibits the ability to swell and shrink with the variation of moisture content. Lightweight structures such as pavements, sidewalks, and driveways face failures due to the swelling and shrinkage behavior of expansive soils. Therefore, the aim of this study is to investigate the effect of waste incineration bottom ash on the engineering properties of expansive subgrade soils. To investigate the waste incineration bottom ash, tests such as specific gravity, Atterberg limit, free swell test, compaction characteristics, unconfined compression strength, and Californian bearing ratio (CBR) were conducted. The soil was stabilized by waste incineration bottom ash with proportions of 10%, 15%, 20%, 25%, and 30% by dry weight. From the laboratory test results, the soil under this category has poor engineering properties which include high plastic index, high free swell index, low UCS, and low CBR. The performance of soil improved as waste incineration bottom ash content increased with respect to curing time. The curing time of the sample has a significant effect on the performance of the weak subgrade soil.

1. Introduction

Incinerators are used worldwide to process industrial, municipal, clinical, and medical wastes. Energy can be utilized through incineration waste to minimize landfill area without energy recovery. In the presence of oxygen at high pressure in a furnace, the waste that comprises of organic materials is burnt. The byproducts produced in the combustion process include CO_2 and H_2O, N_2, oxygen and noncombustible residues, and flue gas. Finally, the steam turbine is used to generate electricity. Nowadays, many countries contribute for the development of incenerators technology. The energy recovery in Europe and Japan is 23% and 70%, respectively [1].

Soil is an unconsolidated material comprised of resilient debris produced via the breakdown of rocks. Soils comprise void areas between particles which include air, water, or both. Natural matters might also include soil particles. The soil particles can be separated by the mechanical approach such as agitation and water. The soil can bear the load imposed by the structures constructed on it. However, there might be weak soils used as construction materials, like expansive soil, in which the engineering properties are highly influenced by moisture content variation. The swelling and expansiveness of clay soils are governed by the presence of clay mineralogy, namely, montmorillonite, kaolinite, and illite. But excess amount of montmorillonite in soil causes the soil to have excessive swelling potential [2]. Infrastructures constructed on expansive soil face distinct types of damages. Some of those damages are settlement of buildings and roads, cracks on buildings, and heaving and swelling. The damage of expansive soil on the structure is due to variation of water content, and an increase in moisture content causes swelling of clay which ends up in vertical deformation of soil layers, hence, controling moisture content flactuation can reduces vertical deformation of structures [3–5]. The montmorillonites are dominant clay mineral present in expansive soil, which are octahedral sheets sandwiched between silica sheets. Water is absorbed by silica sheets when montmorillonites is exposed to moisture. When this mineral is exposed to moisture, water is absorbed by interlayer lattice systems and exerts upward pressure. This pressure is referred to as swelling pressure, which imposes the maximum damage on the structure built on expansive soil. The version of moisture content material is especially due to modifications inside the area of surroundings from herbal situations, adjustments associated with creation and exploitation outcomes at the moisture below the shape [5, 6].

One of the strategies in improving susceptible subgrade soil, primarily expansive soils, is removing and replacing it with a better subgrade material that allows bearing the load coming from the pavement structure. Therefore, the cost of stabilization of weak subgrade soil has brought the highway organization to evaluate opportunities for techniques to assemble over the weak subgrade soil. As a result, subgrade stabilization is the most suitable solution which is widely used in pavement [7]. Subgrade soil stabilization is a modification of original soil properties to satisfy specific engineering properties. There are two major methods of soil stabilization which are mechanical stabilization and chemical stabilization [8, 9]. Mechanical soil stabilization improves the properties of soil by of mixing two or more soils [10]. Chemical stabilization changes the characteristics of weak soil by adding some chemicals into weak soil. The soil engineering properties can be enhanced by chemical stabilizing agents like cement, lime, and bitumen. Although they are common additives, their production manufactured in the industry kept a financially high cost [11, 12].

In order to improve the properties of soil, recycled slugged ash hydrated lime to improve soft cohesive soil, cohesive clay soil, and five ratios of sludge and hydrated lime were mixed with cohesive soil, and the result showed that the swelling behavior of treated clay soil effectively decreased and unconfined compressive strength of soil increased to three to seven times better than untreated soil. The researchers proposed that sewage sludge and hydrated lime could particularly improve the properties of soft clay subgrade soil. This result revealed that the unconfined compression strength of treated soil was improved. Furthermore, the CBR value of treated soil is up to 30 times the CBR value of untreated soil, concluding that sewage sludge and cement may be useful for many potential geotechnical applications [13, 14].

Fly ash is the byproduct of coal-fired power plants and is collected by electrostatic precipitators, which is noncementous compared to lime and cement. About 85% of the ash is fly ash. Most fly ash belongs to the secondary binder. These binders alone cannot achieve the desired effect. However, in the presence of a small amount of activator, it chemically reacts to form a cementitious compound, which contributes to the improvement of the strength of the soft soil. According to estimates from a survey by the world coal association (WCA), there are more than 850 giga tons of proven coal reserves worldwide. The annual production of fly ash in India is approximately 10 million tones [15–17]. Fly ash is a byproduct of coal-fired electric power generation facilities; it has lesser cementitious properties compared to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot generate the desired effect by themselves. However, in the presence of a small amount of activator, it can react chemically to form a cementitious compound that contributes to improved strength of soft soil. Fly ashes are readily available, and they are cheaper and environmentally friendly [16–18]. Fly ash has been shown to decrease the plasticity of heavy clay soils, which decreases the swelling potential. The plasticity and swelling potential decreases with increasing fly ash contents. The plasticity index of expansive soil-fly ash mixtures shows a drop in value of as quantity of fly ash increases. The reason is that fly ash does not have any plastic characteristics that are associated with plastic. The addition of fly ash alters particle size and colloidal reaction, which leads to decrease in plasticity of expansive soil [8, 19–23]. The effect of fly ash on the engineering properties of expansive soils is thoroughly investigated by different scholars. With the addition of fly ash, the optimum moisture content (OMC) and maximum dry density (MDD) of expansive soil-fly ash mixed samples are increased and decreased, respectively, with the increase of fly ash content. Similarly, the CBR of soil-fly ash mixed samples increases with the increase in fly ash content [24–26].

Portland cement clinker production is a major source of CO_2 and other greenhouse gases, accounting for 5% of the world's annual atmospheric CO_2 emissions. Cement kiln dust (CKD) is a byproduct of the cement manufacturing process and has traditionally been considered as industrial waste. Global cement production capacity in 2017 was ~4.99 billion tons per year. While the CKD production rate ranged from 54 to 200 kg per ton of produced cement clinker. CKD is composed of fine, powdery solids and highly alkaline particulate material, and it is similar in appearance to Portland cement [27–29].

Previously, when the soils have weak engineering properties and bearing capacity, the route of site should be changed to a suitable location. Otherwise, weak soils are removed and replaced by materials with better strength and more compactness, and then they obtain the required design specification [30–34]. Soil stabilization is a way to alter and enhance the stability of soil mass and mechanical and chemical alteration of soil to enhance their engineering characteristics. Soil stabilization results in higher soil strength by decreasing plasticity and increase or decrease of permeability, hence resulting in higher soil strength, lower volume fluctuation due to moisture and temperature variation, and higher workability of soil. The soils available for the construction of any civil engineering structure often do not meet requirements of the construction [35–37]. The main aim of soil stabilization is cost minimization and the efficient use of locally available materials. The most common application of soil stabilization is seen in the construction of roads and airfields pavement. Thus, one has to look for a better, appropriate, economical soil stabilization method to minimize additional project costs and time required for the removal and replacement of problematic soil. The procedure includes the combination of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation sizes, texture, or plasticity or act as a binder for the cementation of the soil [38].

Municipal solid waste ash is incinerated as a byproduct of combustion of municipal solid waste, and the management of municipal solid waste ash has posed problems such as occupying a large area of landfill and environmental issues. This study suggests the utilization of waste incineration bottom ash in reducing the enormous increase in the amount of municipal solid waste deposited in the area. Therefore, the use of such technology tends to reduce construction material consumption thereby reducing greenhouse emission imposed by municipal solid waste ash and improving the strength of weak subgrade.

2. Materials and Methods

2.1. Study Design. The research design was based on purposive sampling. Selection processing of representative sampling focused on the area affected by expansive soil. The research methodologies that were used are quantitative and experimental approaches so as to achieve the desired objective. The purpose of the research is to determine the effect of modifying expansive soil by waste incineration bottom ash to improve its engineering properties. The selection of sites for excavation is based on visual identification, and data collection is done based on the investigation of engineering properties of soil along Jimma to Sekoru road corridor, Ethiopia. Prior to the test, sample preparation is basically made in accordance with the method described in AASHTO T8786. Then, by spreading the material out for seven days and breaking up the soil aggregates with a rubber-covered hammer, the natural soil samples got air dried. Waste incineration bottom ash samples were sieved to separate the dust from granular waste. The content of waste incineration bottom ash used in improving the engineering property of expansive soil in various studies varied from 10% to 50%. In case of this study, the by product of waste incineration bottom increased in an alarming rate due to rapid urbanization. Therefore, the use of waste incineration bottom ash for soil improvement is identified as an effective utilization option for a large quantity of bottom ash consumption Thus, for this study, 10%–30% of waste incineration bottom ash is selected with increasing 5 percent. Then, the sieved soil sample was mixed manually with 10%, 15%, 20%, 25% and 30% of waste incineration bottom ash until a uniform mix is obtained. Finally, we treated the soil samples with waste incineration bottom ash mix cured for 3, 7, and 14 days by sealing the samples with a plastic bag and keeping them in a humidity chamber/water bath.

2.2. Initial Moisture Content. The initial moisture content of expansive soil was determined by the test method AASHTOT265. The water content of the disturbed soil sample was measured using the oven-drying method. Small typical natural soil samples taken from large numbers of samples from the site are placed in plastic bags. The sample was then weighed as received and oven-dried in a 105°C moisture can for 24 hours. The final dry weight was decisive, and the weight difference was taken as the weight of the water expelled during drying. The weight difference was divided by the weight of the dry soil.

2.3. Particle Size Analysis. Particle size analysis is a method of separating the soil into different fractions based on the size of the particles present in the soil. Particle size analysis was performed by mechanical (sieving) analysis and sedimentation analysis. Sieve analysis is used to separate coarse-grained soil fractions. Soil fractions with particle sizes larger than # 200 (75 μm) are based on the ASTM D422 standard. Sediment analysis is used to analyze fine-grained soil (silt and clay) with a particle size smaller than # 200 (0.075 mm). It is performed by hydrometer analysis as per the ASTM D1140 standard. For this study, both wet sieve analysis and hydrometer analysis was done according to ASTM D42263.

2.4. Specific Gravity. The specific gravity of soil is the ratio of weight of the air of a given volume of soil particles at a stated temperature to the weight of the air of an equal volume of distilled water at a stated temperature. The heaviness of soil particles was determined by the pycnometer method using a soil sample passing the #40 (0.425 mm) sieve as per ASTM D 854 standards.

2.5. Atterberg Limits. This was performed on a reshaped soil sample with a fraction passing through sieve No. 40 (0.425 mm). In the Casagrande cup method, the soil paste is placed in the Casagrande cup, and a groove is made at the center of it. The limit is defined as the moisture content, in percent, required to close a distance of 0.5 inches along the bottom of a groove after 25 blows in a liquid limit device. The test follows ASTM D431398 procedures.

2.6. Soil Classification. The most widely used soil classification system for engineering purposes is the American Unified Soil with National Highway and Transport Authority Association (AASHTO) classification system and # 40. The AASHTO system for soil classification contains seven "A" group of inorganic soils from Al to A7 with a total of 12 subgroups. This system is based on soil particle size distribution, liquid limit, and plasticity index. For uniform soil, the classification system is based on species detection and prevalence of a component that considers particle size, gradation, plasticity, and compressibility. It divides soil into three major divisions: coarse-grained soils, fine-grained soils, and highly organic soils.

2.7. Linear Shrinkage. The linear shrinkage is defined as the decrease in one dimension of a soil mass, expressed as a percentage of the original dimension, when the water content is reduced from a given value to the shrinkage limit. Linear shrinkage is determined by IS 2720-part-20-1966. A sample weighing 150 g from thoroughly mixed portion of bulk material passed through 425 micron IS sieve is prepared. The linear shrinkage of the soil is to be calculated as a percentage of the original length of the specimen from the following formula:

$$\mathrm{LS\%} = \frac{\mathrm{Ls}}{L} * 100, \tag{1}$$

where L is the length of the mold (mm) and Ls is the longitudinal shrinkage of the specimen (mm).

2.8. Free Swell Test (IS 2720). The test was conducted in accordance with the United States Bureau of Reclamation (USBR) method (Holtz and Gibbs, 1956). About 10 g of soil passed through the BS No. 4 sieve (0.425 mm) was oven dried and allowed to cool in a desiccator. The sample was slowly poured into a 100 cm^3 measuring cylinder to which water was added in order to fill the cylinder. The cylinder was then agitated in order to obtain a homogenous mixture of soil and water after which it could settle for 2 hours or more before the initial volume was recorded. The final volume was recorded after 24 hours.

2.9. Proctor Compaction Test (AASHTO T 180-95). This test was done by modified (heavy) compaction to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the material. It was done on the natural expansive soil on the mixture, and various percentages of waste incineration bottom ash added into the expansive clay soil and its MDD and OMC were determined.

The apparatus set-up consists of (i) cylindrical metal mold (with internal diameter 15.24 cm and internal height 11.7 cm), (ii) detachable base plate, (iii) collar (with 5 cm effective height), and (iv) rammer (4.54 kg). The compaction process helps in increasing the bulk density by driving out the air from the voids. The theory used in the experiment is that for any compaction effort, the dry density depends upon the moisture content in the soil. The maximum dry density (MDD) is achieved when the soil is compacted at relatively high moisture content and almost all the air is driven out, and this moisture content is called optimum moisture content (OMC).

2.10. California Bearing Ratio (CBR) (AASHTO T 193-93). The CBR test measures the shearing resistance of soil under controlled moisture and density conditions. It is a major laboratory test conducted on the subgrade and other pavement layers of roads. CBR value is the ratio of load required to affect a certain depth of penetration into a soil specimen compacted at given moisture content and dry density to the load required to obtain the same depth of penetration on a standard sample of crushed stones.

For this research three-point, the CBR test (10, 30, 65 blows) was conducted. As per the AASHTO T 193-93 test procedure, the CBR test with curing durations of 3, 7, and 14 days was conducted for the waste incineration bottom ash mixture. To make a general evaluation of the effect of applying the mixture of waste incineration bottom ash on strength development, CBR samples were prepared using soil passed through the No. 19 sieve, and treated samples were compacted using moisture content at maximum dry density obtained from compaction results. The swelling potential of the soil sample was measured. No surcharge loads have been applied to compacted samples during curing durations assuming that no traffic flow is allowed during construction. Hence, the curing process is undertaken by using a plastic bag immersed into water bath to obtain uniform temperature inside and outside the plastic bag. When the allocated curing period is finished, the compacted soil in the CBR mold was then soaked in water for four days to simulate the saturated condition of the site. Table 1 shows Ethiopian road authority manual standard rating of pavement layer based on the CBR value.

According to the ERA site investigation manual (2002), a subgrade soil should have a maximum swell of 2%. Hence, this material has the high potential to swell and cannot be used as a subgrade material.

2.11. Unconfined Compressive Test. The unconfined compressive strength (qu) is defined as the compressive stress at which unconfined cylindrical specimen of soil will fail in a simple compression test. This test was conducted to determine the UCS of the natural soil, soil waste incineration bottom ash specimens prepared by mixing, compacting, and curing. For stabilized subgrade, a minimum 30 psi (207 kPa) increase from untreated natural soil is required.

The prepared specimens were molded in the standard compaction mold, extracted using Shelby tube samplers, and cut to size with a height-to-diameter ratio of 2. The diameter and height of the specimen tube were 38 mm and 80 mm, respectively. The extracted specimens were placed in an airtight plastic bag and allowed to cure in the bath for 3, 7, and 14 days to avoid any moisture loss from the sample. At the end of the curing period, the specimen was carefully placed in the compression device. Finally, the UCS of the sample was determined at the point on the stress-strain curve at which failure occurred.

3. Results and Discussion

3.1. Laboratory Test Results

3.1.1. Chemical and Physical Properties of Subgrade Soil. In order to determine the mineralogical phases present in the clay soil samples, X-ray diffraction analyses were carried out. Representative oven-dried soft clay samples were crushed until a powder passing the No. 200 (0.075 mm opening) sieve was attained. The powder samples were step-scanned from 10° to 75° (2θ) with a time step of 1 second, and scanning speed is continuous. The software program Match! 3 was also used to help identify the minerals present in the samples. Testing and analysis were conducted by setting a voltage of 30 kV with 25 mA and a scanning time 0.02°/sec for XRD. According to the findings, waste incineration bottom ash powder has the highest proportion of silicon dioxide (53.7%), followed by ferric oxide and calcium oxide, with 11.1% and 6.1%, respectively. Table 2 shows the chemical properties of subgrade soil.

3.1.2. Chemical Properties of Waste Incineration Bottom Ash. Waste incineration bottom ash used for the study was collected from Addis Abeba, Ethiopia. An incineration plant

Table 1: ERA manual-2002 rating of subgrade, subbase, and base-course materials based on the CBR value.

CBR (%)	General rating	Uses
0–3	Very poor	Subgrade
3–7	Poor to fair	Subgrade
7–20	Fair	Subbase
20–50	Good	Base coarse/base
>50	Excellent	Base coarse

Table 2: Chemical properties of subgrade soil.

Chemical composition		Weight
Name	Chemical formula	(%)
Silicon dioxide	O_2Si	51.98
Aluminum oxide	Al_2O_3	1.91
Ferric oxide	Fe_2O_3	11.1
Calcium oxide	CaO	6.1
Phosphorus pentoxide	O_5P_2	3.8
Magnesium oxide	MgO	4.1
Dipotassium oxide	K_2O	3.3
Titanium oxide	O_2Ti	1.2
Disodium oxide	Na_2O	1.4
Barium oxide	BaO	1.3
Strontium oxide	OSr	0.9
Manganese oxide	MnO	0.8

has been established in the city. This waste input to electricity plant with a capacity of 50 MW is built on a landfill site called "Koshe" which lies on 5.3 Ha of land. The total cost of this project was around US$ 118.5 million, and it has an annual processing capacity of 350,000 tons of waste. The technology is advantageous in increasing the reduction of waste volume producing energy and distracting toxic organic compounds. The plant is 350 km far from Jimma town, and its chemical composition is shown in Table 3. According to the findings, waste incineration bottom ash powder has the highest proportion of calcium dioxide (42.62%), followed by silicon oxide and iron dioxide, with 15.22% and 3.98%, respectively.

3.1.3. Effect of Waste Incineration Bottom Ash on Atterberg Limit and Linear Shrinkage. Figure 1 shows basic Atterberg limit laboratory test results like liquid limit, plastic limit, and linear shrinkage, which were conducted to study the effect of waste incineration bottom ash on expansive subgrade soil. Soil passed through the on #40 sieve was mixed with different proportions of waste incineration bottom ash. Chemical additives at optimum moisture content was cured for 1 day by the dissector to protect against loss of moisture. The proportion of waste incineration bottom ash used was 10%, 15%, 20%, 25%, and 30%. As the test result indicated, the plastic limit, liquid limit, and linear shrinkage rate of expansive soil decreased after adding the waste incineration bottom ash. Consequently, the plastic index slightly decreases. As the percentage of waste incineration bottom ash varies from 10% to30%, the plastic index decreases from 46.4% to 42.5% and the linear shrinkage also decreases from 15.54% to 7.63%. When the water content of cohesive soil is reduced below the plastic limit, the shrinkage of soil continues until the shrinkage limit is reached. At this point, the solid particles are in close contact and water contained in soil is just sufficient to fill the voids between them. Below the shrinkage limit, the soil is considered to be solid in which the particles remain in contact. In cohesive soil, the shrinkage limit is below the plastic limit (Figure 1).

The probable reason beyond to this result, the content of silica, and aluminum and iron ions in waste incineration bottom ash was high, that are used to reduce the surface area and water affinity of expansive soil by promoting cation exchange, pozzolanic reaction, agglomeration, and flocculation of dispersed clay particle.

3.1.4. Effect of Waste Incineration Bottom Ash on Specific Gravity. A specific gravity value of expansive subgrade soil with different percentages of waste incineration bottom ash has shown in Figure 2. Decreases of specific gravity values of expansive soil with increasing of waste incineration bottom ash content is a result of increasing lightweight materials due to the lower density of waste incineration bottom ash. The specific gravity values decreased from 2.72 to 2.5 when treated by waste incineration bottom ash from a percentage 0–30%.

3.1.5. Effect of Waste Incineration Bottom Ash on the Free Swell Index. Figure 3 shows the effect of the addition of waste incineration bottom ash on a free swell index of expansive subgrade soil. Untreated free swell values determined in the laboratory was 52.01%. The sample has free swell values > 50%, which is categorized as problematic soil. When the soil is treated with 10%, 15%, 20%, and 30% of waste incineration bottom ash, the free swell index decreased to 46.87%, 41.66%, 36.46%, 31.25%, and 30.62%,

Table 3: Chemical composition of waste incineration bottom ash.

Parameters	Chemical composition of waste incineration bottom ash (%)
SiO_2	15.22
Al_2O_3	3.98
Fe_2O_3	2.24
CaO	42.62
MgO	0.72
Na_2O	0.36
K_2O	<0.01
MnO	0.04
P_2O_5	0.17
TiO_2	0.05
H_2O	0.86
LOI	33.88

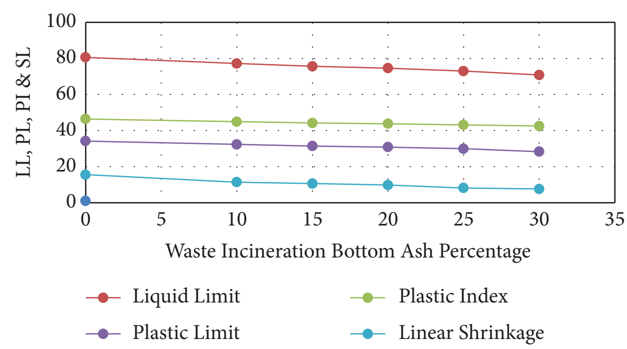

Figure 1: Effect of waste incineration bottom ash liquid limit, plastic limit, plastic index, and linear shrinkage.

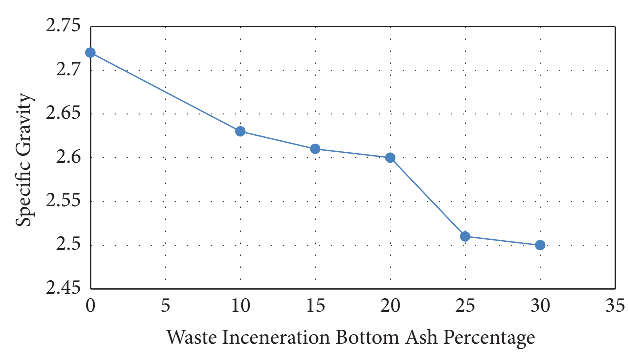

Figure 2: Effect of waste incineration bottom ash on specific gravity of soil.

respectively. This result shows that the swelling potential of virgin soil improved when waste incineration bottom ash is mixed with soil at different percentages.

3.1.6. Effect of Waste Incineration Bottom Ash on Compaction Characteristics. The variation in optimum moisture content with waste incineration bottom ash content with different curing time is shown Figure 4. The optimum dry density decreases with an increase in waste incineration bottom ash content. The optimum moisture content of untreated subgrade soil is 23.62%. The optimum moisture content of the mixture decreased as the percentage of waste incineration bottom ash increased. The optimum moisture content of the treated soil was less when compared with the untreated soil. This result ascribed the waste incineration bottom ash filling pores among soil particles, creating small pores between soil and waste incineration bottom ash that can prevent space for water. Maximum dry density values of all samples with different percentages of waste incineration bottom ash were clearly reduced after being cured within 14 days. This indicates that with an increase in time with the application of admixture to stabilize the soil, a more significant result is obtained.

Figure 5 illustrates the results of dry density values for samples modified with waste incineration bottom ash that were cured for 3, 7, and 14 days, respectively. The test result depicted that waste incineration bottom ash mixture activates the maximum dry density (MDD) of expansive subgrade soil. Maximum dry density (MDD) of soil modified

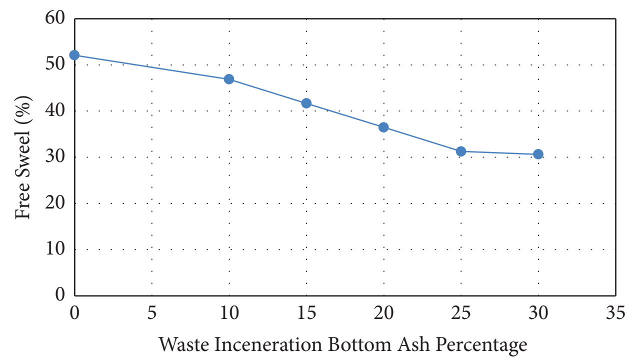

Figure 3: Effect of waste incineration bottom ash on the free swell index of soil.

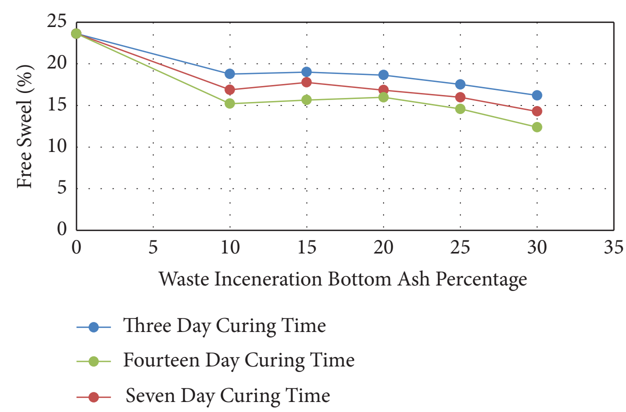

Figure 4: Effect of waste incineration bottom ash content and curing period on optimum moisture content of subgrade soil.

with waste incineration bottom ash increased up to 25% mixture of waste incineration bottom ash, but at 30% waste incineration bottom ash, the value decreased. It is noted that the MDD increased with an increase in waste incineration bottom ash percentage of unmodified soil with different curing times. As the waste incineration bottom ash content increased, the maximum dry density of the mixture increased from 1.42 g/cm^3 to 1.47 g/cm^3 with 3-day curing period, 1.41 g/cm^3 to 1.45 g/cm^3 with 7-day curing period, and 1.4 g/cm^3 to 1.42 g/cm^3 with 14-day curing period.

3.1.7. Effect Waste Incineration Bottom Ash on Californian Bearing Ratio (CBR). The effect of waste incineration bottom ash percentage and curing time on subgrade CBR values are illustrated in Figure 6. To estimate the significance of waste incineration bottom ash in the improvement of weak subgrade soil, waste incineration bottom ash was added to soil with 10, 15, 20, 25, and 30% of the dry weight of soil and tested for soil stabilization. The curing was made on samples for a period of 3, 7, and 14 days to estimate the influence of curing period on the CBR value. For this study, three-point CBR with 10, 30, and 65 blows soaked for 3 days (72 hours) was used after curing periods to simulate the worst condition of the site in the rainy season. During this time, the samples were stored within nylon bags to keep the moisture content unchanged. According to the Ethiopian road authority pavement design specification, the soil changed from poor subgrade soil to medium subgrade soil. This improvement in CBR with respect to curing time may be attributed to the change of soil structure from dispersed to flocculate, or interparticle bond was made over time. From the figure, as the percentage of waste incineration bottom ash increased, the CBR value increased up to 25% of waste incineration bottom ash mix; however, there is a trend to decrease to 30 percent of waste incineration bottom ash.

3.1.8. Effect of Addition of Waste Incineration Bottom Ash on the UCS Test. Figures 7–9 show stress-strain for untreated and treated expansive subgrade soil with waste incineration bottom ash by 10%, 15%, 20%, 25%, and 30% with curing time 3, 7, and 14 days, respectively. In this study, the stress-strain behavior of waste incineration bottom ash specimens treated with soil, with different proportions and curing times has been investigated based on an unconfined compression test. At its natural state, the maximum UCS of untreated expansive soil has reached 136 kPa with the strain rate of 5.644%. Upon treatment with a considerable amount of 10%, 15%, 20%, 25%, and 30% of waste incineration bottom ash, unconfined compressive strength of soil has increased to 242 kPa, 256 kPa, 260 kPa, 276 kPa, and 273 kPa respectively, with a corresponding strain of 7.21, 6.81, 6.87, 7.03, and 7.62% for 3-days curing time. Similarly, an increase in the amount of waste incineration bottom ash causes an increase in strength for both curing

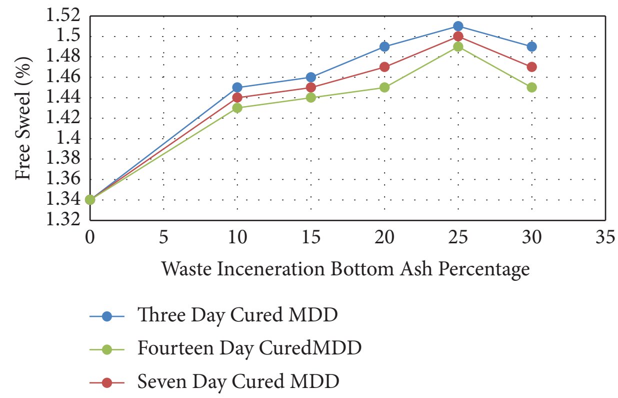

Figure 5: Effect of waste incineration bottom ash content and curing period on maximum dry density of subgrade soil.

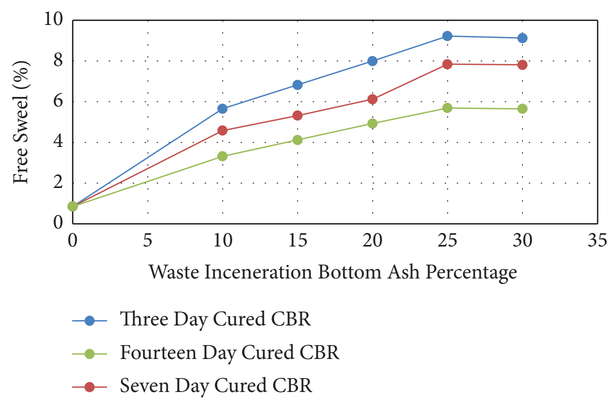

Figure 6: Effect of waste incineration bottom ash content and curing period on Californian Bearing Ratio (CBR) of subgrade soil.

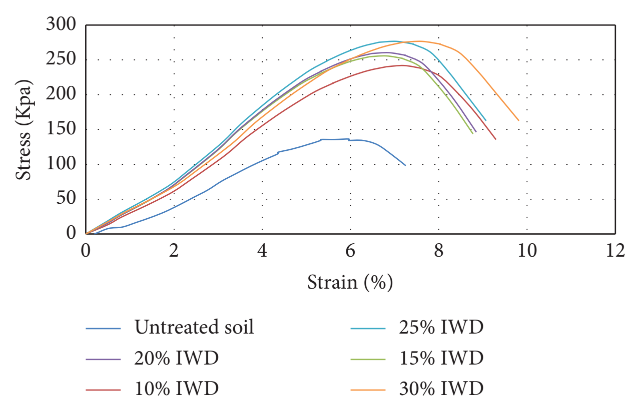

Figure 7: Effect of waste incineration bottom ash (WIBA) variation and 3-day curing time on weak subgrade soil.

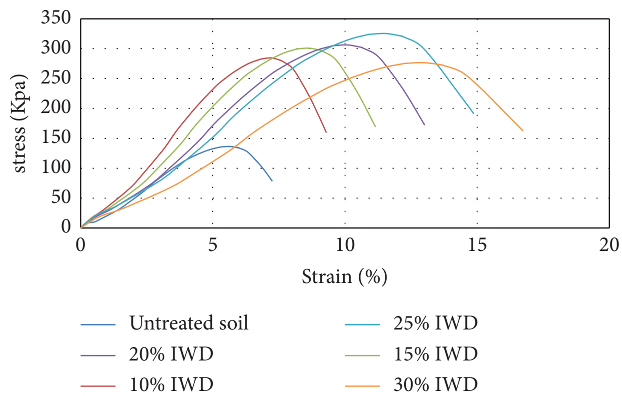

Figure 8: Effect of waste incineration bottom ash variation and 7-day curing time on weak subgrade soil.

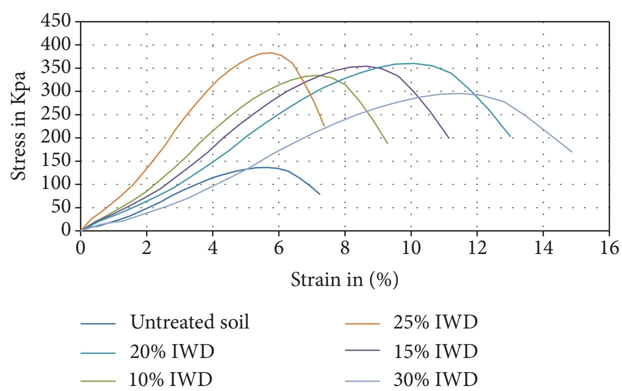

Figure 9: Effect of waste incineration bottom ash variation and 14-day curing time on weak subgrade soil.

time (7 and 14 days). There is a decrease in the absorption of water by samples by increasing the curing times, with the absorption of water with increasing waste incineration bottom ash. It is evident that the development of cracks in samples before failure decreases with increasing the percent of waste incineration bottom ash and curing time. When curing time is 14 days, the unconfined compression strength is at a maximum of 383.77 kPa for soil with 25% of waste incineration bottom ash, which is taken as the optimum. The strength increase may be credited to the pozzolanic reactions of waste incineration bottom ash to form the cementious products between pozzolona presents in waste incineration bottom ash and calcium hydroxide present in the soil.

4. Conclusion

Based on the result presented in this study from a laboratory that is conducted on soil samples blended with different percentages of waste incineration bottom ash, the following conclusion can be drawn:

(1) In this study, the stabilization of expansive soil with waste incineration bottom ash was investigated, and the effect of stabilization on engineering properties of expansive clay soil was studied. Various percentages of waste incineration bottom ash were utilized to investigate its effect on plasticity index, linear shrinkage, free swell, specific gravity, compaction characteristics, UCS, and CBR of soil. From the result, as the waste incineration bottom ash content increases from 10 to 30%, the plasticity index, linear shrinkage, free swell index, and specific gravity decreased from 45.4 to 41.5%, 14.54% to 6.63%, 52.01% to 30.62%, and 2.72 to 2.5%, respectively. It was observed that all listed test results decreases with the increase in waste incineration bottom ash content.

(2) Based on the experimental data, the performance of waste incineration bottom ash on compaction characteristics (OMC and MDD) was evaluated. The maximum dry density (MDD) of the soil increased with increasing waste incineration bottom ash content. The optimum moisture content of the mixture decreased as the percentage of waste incineration bottom ash increased. This result confirmed that the waste incineration bottom ash filling pores among soil particles can prevent space for water. The CBR increased with an increase in waste incineration bottom ash till about 25% and then decreased. The CBR representative value of 14 days could fulfil the strength requirement of subgrade construction according to Ethiopian road authority standards. Unconfined compressive strength of waste incineration bottom ash-treated

expansive soil increases with curing time and the failure strain decreases with curing time. Longer curing period has a significant effect on the strength test of both CBR and UCS of expansive soil.

(3) It is concluded that significant strength improvements were observed for soil treated with waste incineration bottom ash admixture with respect to curing time.

Data Availability

The datasets produced during this study are accessible from the author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

[1] X. G. Li, Y. Lv, B. G. Ma, Q. B. Chen, X. B. Yin, and S. W. Jian, "Utilization of municipal solid waste incineration bottom ash in blended cement," *Journal of Cleaner Production*, vol. 32, pp. 96–100, 2012.

[2] N. K. Vishwas, K. D. Rakesh, and K. Sampan, "Shear strength, bearing ratio and settlement behavior of clay reinforced with chemically treated coir fibers," *Jordan Journal of Civil Engineering*, vol. 11, no. 4, pp. 657–679, 2017.

[3] B. Adamu, T. Yada, T. Damtew et al., "Experimental study on potential suitability of natural lime and waste ceramic dust in modifying properties of highly plastic clay," *Heliyon*, vol. 8, no. 10, 2022.

[4] D. Melese, "Improvement of engineering properties of expansive soil modified with scoria," *Jordan Journal of Civil Engineering*, vol. 16, no. 2, 2022.

[5] T. Damtew, K. Meaza, and B. Adamu, "Deformation analysis of cement modified soft clay soil using finite element method (FEM)," *Heliyon*, vol. 8, no. 6, 2022.

[6] O. Enkhtur, D. Dalai, O. Enkhtur, and D. Dalai, *The Distribution and Characterization of Expansive Soils in Mongolia*, Mongolia University of Science and Technology, Bator, Mongolia, 2011.

[7] I. Yilmaz, "Relationships between liquid limit, cation exchange capacity, and swelling potentials of clayey soils," *Eurasian Soil Science*, vol. 5, 2004.

[8] M. Magdi and E. Zumrawi, "Stabilization of pavement subgrade by using fly ash activated by cement," *American Journal of Civil Engineering and Architecture*, vol. 3, pp. 218–224, 2015.

[9] Q. Tang, F. Gu, H. Chen, C. Lu, and Y. Zhang, "Mechanical evaluation of bottom ash from municipal solid waste incineration used in roadbase," *Advances in Civil Engineering*, vol. 2018, Article ID 5694908, 8 pages, 2018.

[10] D. Abhishek, N. Manish, and M. Rahul, "Effect of fly ash geotechnical properties of soil," *IJETMR*, vol. 3, 2016.

[11] S. N Bhavsar, H. B. Joshi, P. k. Shrof, and A. J. Patel, "Effect of burnt brick dust on engineering properties on expansive soil," *International Journal of Renewable Energy Technology*, vol. 03, no. 04, pp. 433–441, 2014.

[12] H. A. H. Ismaiel, "Cement kiln dust chemical stabilization of expansive soil exposed at el-kawther quarter, sohag region, Egypt," *International Journal of Geosciences*, vol. 04, no. 10, pp. 1416–1424, 2013.

[13] W. McCoy and A. Kriner, *Use of Waste Kiln Dust for Soil Consoildation*, Lehigh Portland Cement Coorporation, Allentown, PA, USA, 1971.

[14] K. Deepdarshan, "Effect of fly-ash and geo-polymer in the stabilization of pavement foundation soil at nekempt-gudar road Ethiopia," *International Journal of Creative Research Toughts (IJCRT)*, vol. 8, no. 5, 2020.

[15] W. A. Tasong, S. Wild, and R. J. Tilley, "Mechanisms by which ground granulated blastfurnace slag prevents sulphate attack of lime-stabilised kaolinite," *Cement and Concrete Research*, vol. 29, no. 7, pp. 975–982, 1999.

[16] L. Coppola, D. Coffetti, and E. Crotti, "Plain and ultrafine fly ashes mortars for environmentally friendly construction materials," *Sustainability*, vol. 10, no. 3, p. 874, 2018.

[17] M. K. Mohanty, *Stabilization of Expansive Soil Using Fly Ash*, National Institute of Technology, Rourkela, India, 2015.

[18] T. L. Ramadas, N. D. Kumar, and G. Yesuratnam, "A study on strength and swelling characteristics of three expansive soils treated with fly ash," in *Proceedings of the International Symposium on Ground Improvement*, Brussels, Belgium, June 2012.

[19] M. S. Chauhan, S. Mittal, and B. Mohanty, "Performance evaluation of silty sand subgrade reinforced with fly ash and fibre," *Geotextiles and Geomembranes*, vol. 26, no. 5, pp. 429–435, 2008.

[20] Y. Sanjeev and D. Devi, "Stabilization of expansive soils employing activated fly ash," *International Journal of Scientific Research and Engineering Development*, vol. 5, no. 5, 2022.

[21] X. Kang, L. Ge, G. C. Kang, and C. Mathews, "Laboratory investigation of the strength, stiffness, and thermal conductivity of fly ash and lime kiln dust stabilised clay sub grade materials," *Road Materials and Pavement Design*, vol. 16, no. 4, pp. 928–945, 2015.

[22] S. K. Mohanty, P. K. Pradhan, and C. R. Mohanty, "Stabilization of expansive soil using industrial waste fly ash," *Civil Engineering Research Journal*, vol. 3, no. 2, 2017.

[23] P. Gireesh Kumar and S. Harika, "Stabilization of expansive subgrade soil by using fly ash," *Materials Today Proceedings*, vol. 45, no. 7, pp. 6558–6562, 2021.

[24] P. Solanki, M. M. Zaman, and J. Dean, "Resilient modulus of clay subgrades stabilized with lime, class C fly ash, and cement kiln dust for pavement design," *Transportation Research Record*, vol. 2186, no. 1, pp. 101–110, 2010.

[25] D. Barnat-Hunek, J. Góra, Z. Suchorab, and G. Łagód, "Cement kiln dust," in *Waste and Supplementary Cementitious Materials in Concrete*, pp. 149–180, Woodhead Publishing, Sawston, UK, 2018.

[26] S. Wayne, P. E. Adaska, and D. H. Taubert, "Beneficial uses of cement kiln dust," in *Proceedings of the IEEE/PCA 50th Cement Industry Technical Conference*, Miami, FL, USA, May 2008.

[27] D. Abebe and M. Tadesse, "Tobacco production practice of smallholder in bilate, wolaita and hawassa tobacco farms, Ethiopia," *Advances in Biological Research*, vol. 1, no. 1, pp. 23–28, 2020.

[28] D. B. Rama, P. V. Satyanarayana, M. A. Surya, and K. T. Rama, "Impact of rice husk ashe on expansive soils in road construction," *International Journal of Engineering Science and Innovative Technology (IJESIT)*, vol. 5, no. 3, 2016.

[29] M. Y. Fattah and M. M. Jaber, "Consolidation properties of compacted soft soil stabilized with lime-silica fume mix,"

International Journal of Science and Engineering Research, vol. 5, pp. 1675–1682, 2014.
[30] H. Chen and Q. Wang, "The behaviour of organic matter in the process of soft soil stabilization using cement," *Bulletin of Engineering Geology and the Environment*, vol. 65, no. 4, pp. 445–448, 2006.
[31] S. Topolinski, "Unconfined compressive strength properties of a cement- organic soil composite," *IOP Conference Series: Materials Science and Engineering*, vol. 471, Article ID 042018, 8 pages, 2019.
[32] S. Por, S. Nishimura, and S. Likitlersuang, "Deformation characteristics and stress responses of cement-treated expansive clay under confined one-dimensional swelling," *Applied Clay Science*, vol. 146, pp. 316–324, 2017.
[33] Z. M. D Ghazaly, Z. A. Muhammed, and A. R. Mustaqqim, "Deformation characteristics of lime stabilized peat," *International Journal of Mechanical and Production Engineering*, vol. 6, pp. 2320–2092, 2018.
[34] B. Depaa, "Stabilization of pavement material using waste brick kiln dust," *International Journal of Engineering Rsearch and Technology*, vol. 2, pp. 1684–1691, 2013.
[35] D. N. Lakshman Teja and S. Kumar, "Stabilization of expansive soil using brick dust," *International Journal of Pure Applied Mathematics*, vol. 17, pp. 903–910, 2017.
[36] A. Arulrajah, J. Piratheepan, T. Aatheesan, and M. W. Bo, "Geotechnical properties of recycled crushed brick in pavement applications," *Journal of Materials in Civil Engineering*, vol. 23, no. 10, pp. 1444–1452, 2011.
[37] A. Arulrajah, J. Piratheepan, M. M. Disfani, and M. W. Bo, "Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications," *Journal of Materials in Civil Engineering*, vol. 25, no. 8, pp. 1077–1088, 2013.
[38] S. Por, S. Nishimura, and S. Likitlersuang, "Deformation characteristics and stress responses of cement-treated expansive clay under confined one-dimensional swelling," *Applied Clay Science*, vol. 146, pp. 316–324, 2017.