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Research Article

Mechanical Behavior of Plastic Strips-Reinforced Expansive Soils Stabilized with Waste Marble Dust

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Expansive soil needs to undergo treatment to be used as safe foundation soil for roads and buildings. From an environmental conservation and economical point of view, the usage of agricultural and industrial wastes is the best option. In this study, the effects of utilizing plastic waste and marble waste dust on the engineering properties of expansive soils were examined. Various laboratory tests were carried out on sampled expansive soil by adding 10, 15, and 20% of marble and 0.25, 0.5, and 0.75% of $5 \times 8\ mm^2$ plastic strips. The laboratory test results showed that there are good enhancements on strength parameters due to the addition of marble dust and plastic strips. With an increase in percentages of marble dust and plastic strips, California Bearing Ratio (CBR) values rise. With the addition of marble dust, unconfined compressive strength (UCS) values increase linearly, while they increase only up to 0.5% with the addition of plastic strips. As the proportions of marble dust and plastic strips increase, the soil's free swell and CBR swell are decreased significantly. This shows that environmental pollution waste marble dust and plastic strips can be utilized to strengthen the weak subgrade soil and minimize its swelling properties. Therefore, this study found out that the expansive soil treated with polyethylene terephthalate (PET) plastic and marble dust can be used as a subgrade material since it fulfills the minimum requirement needed by standards.

1. Introduction

Expansive soils are sensitive to moisture content, which results in volume change during seasonal changes. They are present in large amounts all over the world. However, the volume changes during seasonal fluctuation, cause excessive deformation in soil, which is destructive to civil infrastructure. In Ethiopia, expansive soils are found abundantly, causing much damage to road pavements [1, 2].

In subgrade road construction, expansive soils must be replaced with other materials or treated to be used as pavement layer materials. Replacing poor soil with the selected material is unrealistic and expensive due to the massive volume of subgrade work. Therefore, treating poor soil in its in situ place is the preferable option, both economically and in reality. There are many ways by which the swelling property of expansive soils can be improved. The widely used mechanisms are stabilizing the soil mechanically and chemically. Mechanical stabilization is the physical property improvement by using techniques like compaction, dry wetting, prewetting, and reinforcement. Chemical stabilization stabilizes the soil using additives such as lime, cement, fly ash, and others [3, 4].

Recently, from an environmental conservation and economic point of view, the use of agricultural and industrial wastes as soil stabilizers has been recommended. Using waste by-products as stabilizing agents has two major advantages [5–7]. It plays an important role in reducing environmental pollution and improving the strength and swelling ability of expansive soils. Research has been conducted on the use of wastes such as plastic waste, brick waste, stone dust, fly ash, marble dust, sugar cane molasses, and other factory by-products to stabilize expansive soils [8–12].

Due to economic growth and changing consumption and production patterns, there is a rapid increase in the generation of plastic waste all over the world. In many areas, including Ethiopia, society has lack of awareness that plastic bottles and bags are thrown away in an open area, to the environment [10, 11]. Plastic waste is not biodegradable and takes time to decompose, which is why it is a common occurrence in open dumps and landfills. On the other hand, the high demand for marble products for finishing work in the construction industry generates a high accumulation of marble dust. In the process of cutting marble blocks, marble powder is mixed with water to form a suspension of marble waste, of which about 25% is powder. This accumulation of waste marble dust causes environmental pollution, and it occupies free construction area [15–17].

The reinforcement used in the study in [18] was plastic strips with 0.25, 0.5, and 1% and lengths of 10 mm, 20 mm, 30 mm, and 40 mm. They found that the strength of the stabilized soil increased by up to 0.5% with the addition of plastic strips, followed by a slight decrease in the CBR. The study was investigated in Ethiopia using plastic strips of different sizes (15×20 mm^2, 10×15 mm^2, and 5×7.5 mm^2), and 0.5, 1, and 2% additions by weight were added to the soil. The study showed that the optimum moisture content, swelling, and cracking decreased, while the maximum dry density increased slightly [8]. The experimental study conducted on an expansive soil sample having expansive behavior with 0.25, 0.5, 0.75, and 1% plastic fiber additions by weight of the soil resulted in significant improvements in swell potential, cohesion value, tensile strength, and unconfined compressive strength [19].

A study performed on the plastic fiber reinforcement in silty sand showed that significant improvement is achieved with the addition of 0.4% plastic fibers having a 15×15 mm^2 size [20]. While adding plastic strips and brick powder showed significant improvement by increasing UCS and CBR values, swelling potential decreased [21]. The study conducted by reinforcing expansive soils with plastic strips at 5% constant lime addition found that the plasticity and strength properties of the soil significantly improved at 0.75% plastic waste strips and 0.5% lime [22].

Several studies have investigated the effects of marble dust addition on the mechanical properties of expansive soils. In this study, the percentage of marble dust in the soil mass ranged from 10 to 50% proportions of the dry weight of the soil. A significant improvement in the values of the liquid limit and shrinkage limit was observed [23]. The effectiveness of this material to stabilize a weak soil has been studied by varying the percentage of addition to 5, 10, and 15% of the soil sample. The study found that the maximum dry density and optimum moisture content increased with increasing percentages of the stabilizer [24]. The study examined expansive soils mixed with percentages of waste marble dust (5, 10, 15, 20, and 25%) showed that maximum dry weight, USC, plasticity index, and CBR increased with the addition of marble powder while optimum moisture content and swelling potential decreased [25].

Several studies have shown that the addition of marble dust and other additives can increase strength characteristics while decreasing the swelling of the studied soils. An experimental study on expansive soil showed that the addition of 0, 5, 10, 10, 15, and 20% marble dust and rice husk ash reduced swelling and increased the maximum dry density, CBR, and compressive strength [26]. In another study, varying the addition percentages of the lime and marble powder resulted in a decrease in the plasticity index and OMC and an increase in UCS and MDD [27].

This study investigated the impact of the use of plastic and marble waste on the engineering properties of expansive soils. The choice of these materials was based on the observation that marble dust can improve the strength and plasticity of the soil, while plastic waste strips can improve the strength of the soil. This article describes the use of waste materials, including plastic waste and marble dust, to improve the strength and plasticity properties of soils.

2. Materials and Methods

2.1. Materials

2.1.1. Expansive Soil. The natural soil sample used for this research work was collected at a depth of 1.5 m from the ground level in Jimma town, Oromia, Ethiopia. Both undisturbed and disturbed samples were sampled and transported to the laboratory for experimental tests. An undisturbed sample was taken for the unconfined compressive strength test using the Shelby tube, and the in situ moisture content was determined by covering the sample with plastic bags. The soil is gray-black and highly plastic.

The results of laboratory tests on the index and strength properties of the soils are summarized in Table 1. The soil sample collected from the selected site was dried and sieved through the 425 microns for index property determination. The air-dried samples sieved through a 4.75 mm sieve were used for CBR and compaction tests. Laboratory soil tests such as particle size analysis (ASTM D6913), the Atterberg limits test (ASTM D4318), the compaction test (ASTM D698), unconfined compressive strength (ASTM D2166), and the CBR test (ASTM D1883) were conducted to determine soil properties [28–32]. Based on free swell and the plastic index, the soil sampled was categorized as highly expansive soil [33, 34]. The particle size analysis of the expansive soil sample is shown in Figure 1.

Gradation curves for soil and marble dust samples were obtained using wet sieve analysis. The results of the particle size analysis of the soil and marble dust are shown using gradation curves plotted in Figure 1.

2.1.2. Waste Marble. Waste marble dust (MD) was collected from construction sites, where it was left as waste during cutting, processing, and reshaping in finishing works. The dust of marble was placed in an oven for 24 hours to remove moisture and pulverized to remove agglomeration before use. The grain size analysis showed that the marble dust used in this study consists of 46% coarse-grained and 54% fine-grained from which 22% is clay and 32% is silt soils indicated in Figure 1. The specific gravity of marble is found to be 2.74.

Table 1: Summary of laboratory test results.

Parameters	Values	Units
Natural water content	42	%
Specific gravity	2.69	%
Plastic limit	35	%
Liquid limit	73	%
Maximum dry density	1.4	g/cm^3
Optimum water content	27.3	%
Unconfined compressive strength	71	kPa
CBR	1.5	%
CBR swell	8.48	%
Free swell	96.6	%

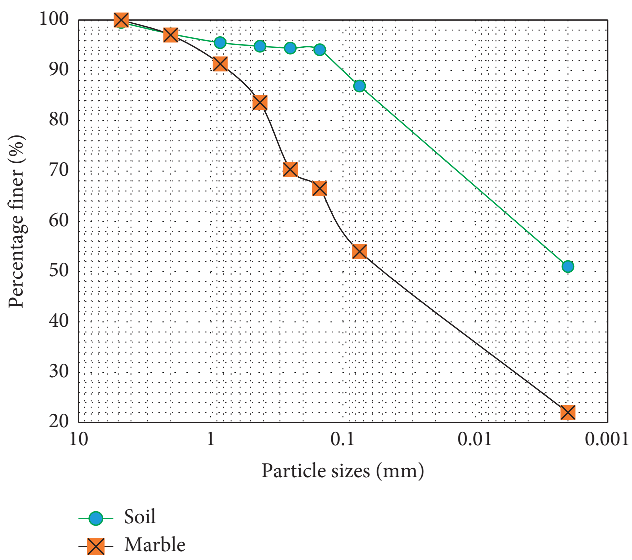

Figure 1: Gradation curves for the marble and soil.

2.1.3. Plastic Waste. As a reinforcing material, plastic waste strips (PS) made up of PET were used. Plastic waste materials, mainly water and soft drink bottles, were collected from different places in the study area. The collected PET water bottles were cut into strips of $5 \times 8\,mm^2$ manually as illustrated in Figure 2.

2.1.4. Sample Preparation. The marble waste was mixed with soil by proportions of 10, 15, and 20%. The plastic waste was cut by hand manually into 20 mm long strips. The plastic strips were mixed with the soil with marble dust at 0.25, 0.5, and 0.75% of the dry soil for determination of free swell, compaction parameters, CBR, and UCS (Figure 3).

To obtain the uniform mix soil sample, marble dust and plastic strips were mixed together carefully for each trials. The optimum moisture content and maximum dry density of the soil determined from the compaction test were used for remolding the stabilized samples for the CBR and UCS tests.

During sample preparation, as shown in Figure 3, the soil sample is allowed to air dry until it loses its moisture and dries completely. Then, the required amount of soil sample, marble dust, and plastic strips for each trial test are weighted. Marble dust and plastic strip percentages are determined by dry weight of the soil. For the specified amount of the soil sample, the required percentage of marble dust is added and thoroughly mixed until it makes the uniform mix. After that, the required percentage of plastic strips is added accordingly.

3. Results and Discussion

The addition of plastic strips and marble dust can significantly increase the strength of the treated soil. Many laboratory tests were carried out to observe the improvement in strength parameters and plasticity properties due to the addition of plastic strips and marble dust. The improvement in strength parameters was seen using the results of the compaction test, California Bearing Ratio (CBR), and unconfined compressive strength (UCS). The results of several laboratory experiments showing the effects of adding plastic sheets and marbles on the geotechnical properties of soil are discussed.

3.1. Effects of Plastic Strips and Marble Dust on Free Swell Value. For a free swell test, a $100\,cm^3$ test tube was filled with water. Then, for each trial, a total of 10 gm soil, marble dust, and plastic strips were added. Percentages of marble dust and plastic strips added to the mix were determined from a dry weight of 10 gm of soil. Figure 4 shows that the free swell of the soil decreases as the percentage of marble dust and plastic strips increases. The use of nonswelling marble dust helps keep the soil from swelling. Between the plastic strips and the soil, no chemical reactions take place.

However, the addition of plastic strips forms a gap between the particles of the soil so that it alters a free movement of soil particles. The alteration of the movement of particles due to the addition of the plastic strips resulted in the reduction of free swell. With increasing amounts of marble dust and plastic strips, the swelling potential of specimens decreased. There are no previously conducted studies using plastic strips and marble dust as a stabilizing agent for expansive soil. However, in past studies, marble powder according to [35–37] and plastic strips according to [8] were able to reduce the clay swelling.

3.2. Effects of Marble Dust and Plastic Strips on Compaction Parameters. Compaction tests were conducted on treated soils with different amounts of marble powder and plastic additives. From the results of the compaction tests shown in Figure 5, it is observed that the MDD values vary slightly with the addition of the plastic strips and marble powder. The laboratory test results showed that MDD increases with an increase in marble dust content while it decreases with increasing plastic strips as shown in Figure 5. At a fixed proportion of marble dust, increasing proportions of plastic strips resulted in a decrease in MDD. However, if the percentage of the plastic strip is constant, the MDD increases as the percentage of marble dust increases.

There are several reasons why marble dust increases the MDD. The occupation of clay soil particles in marble dust void spaces, the cementitious behavior of calcium oxide

Figure 2: Waste marble and plastic strips prepared for tests.

Figure 3: Laboratory tests: (a) compaction tests, (b) free swell, and (c) unconfined compressive strength.

(CaO) content of marble dust, and replacement of low specific gravity expansive clay particles with high specific gravity marble dust. However, plastic strips are lightweight materials compared to expansive soil particles, which decrease the density of the mix.

Figure 5 shows the variation of the optimum water content for different proportions of marble powder and plastic strips. It can be seen that the optimum water content decreases as the proportion of marble powder and plastic bars increases. The optimum water content decreases as the percentage of plastic mass increases because of the low water absorption of the plastic bars. The addition of the marble powder slightly reduces the optimum water content due to the high density of the material and its low water absorption capacity compared to natural soil.

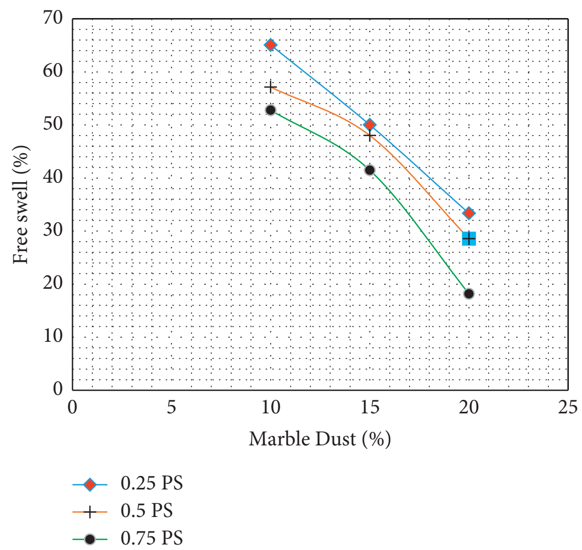

Figure 4: Variation of the free swell with marble dust and plastic strips.

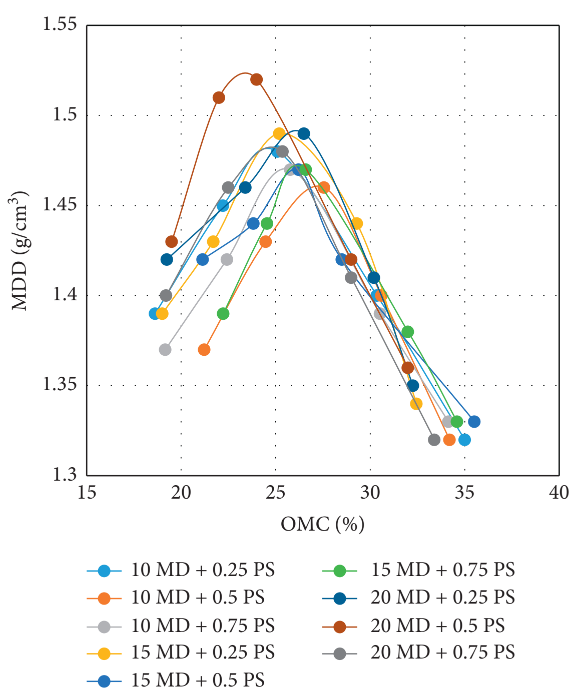

Figure 5: Variations of compaction characteristics with marble dust and plastic strip contents.

Studies have shown that the addition of marble dust and plastic strips has a significant effect on the compaction properties of expansive soils. The addition of marble dust increased the MDD and decreased the OMC, while the addition of plastic strips decreased both the MDD and OMC. Previous studies have found that exposure to plastic strips and marble dust is almost similar [5, 16, 18, 19, 21, 24]. According to [8], the greatest reduction was achieved by adding 2% plastic strips, which reduced the moisture content by 31%. The reduction in OMC may be due to the zero water absorption capacity of the plastic strips. Therefore, it was possible to compact the soil to its maximum dry density with little water addition, which is a very good improvement. A study conducted by [24] showed an improvement in OMC from 15.7% to 18.22%, which was proportional to the amount of marble powder. According to the study performed by [27], OMC reduced and MDD increased with an addition of marble dust. The addition of marble (a non-plastic material) increased the water-holding capacity of the soil mixture, which results in an increase in OMC. Deboucha et al. [39] observed a similar reduction in MDD and an increase in OMC from 10.78% to 12.96% when 5% marble dust was added to the fine-grained soil. The decrease in MDD is due to the increase in volume and the decrease in the mass-to-volume ratio [37].

3.3. Effects of Marble Dust and Plastic Strips on the California Bearing Ratio (CBR). The California Bearing Ratio (CBR) values are used as an indication of strength and bearing capacity in the design of road pavements between road base and subgrade. Soaked CBR tests were carried out with varying percentages of marble dust and plastic strips. The CBR tests were conducted at the soil's maximum dry density and optimum moisture content. Figure 6 shows the final results of the CBR when soil is treated with varying percentages of plastic strips and marble dust. The CBR value increased from 1.50% to 6.2% with the addition of plastic strips and marble dust. This shows significant improvement in treating expansive soil with plastic strips and marble dust.

This is because the addition of marble improves the soil gradation, and the addition of plastic strips alters the movement of the soil particles, reducing the change in soil volume and ensuring a high-bearing capacity. As the marble improved the soil gradation and the plastic strips changed the movement of the swollen soil particles, leading to higher CBR values. The results of this study are consistent with previous studies that were treated expansive soils with marble blocks and plastic strips [5, 15, 18, 22, 23]. An increase in the CBR by 27–55% was observed with the addition of plastic strips [37] and by 104% [8]. The study showed that an improvement of 108.4% was obtained in the CBR value from 6.19 to 12.9% when concentration of marble dust increased to 25% [25]. This improvement can be explained by the fact that marble fills the voids between particles in swollen soils, improves sorting, and increases dry density, leading to an increase in CBR values.

According to the Ethiopian Road Authority (ERA) manual [40], which is utilized in Ethiopia to build a low-volume flexible paving system. The CBR value of most clay soils is less than 15, and the soil having the CBR value less than 5 is classified as a poor subgrade material. Between 5 and 10, they are intermediate for subgrade materials. According to Schaefer et al. [41], soils with a CBR greater than 10 are suitable for the subgrade of road foundations. Natural soils have low CBR values and are therefore not suitable as untreated soil. This result is consistent with the study conducted at the same site [5, 41]. The study showed that the expansive soil stabilized with marble waste and

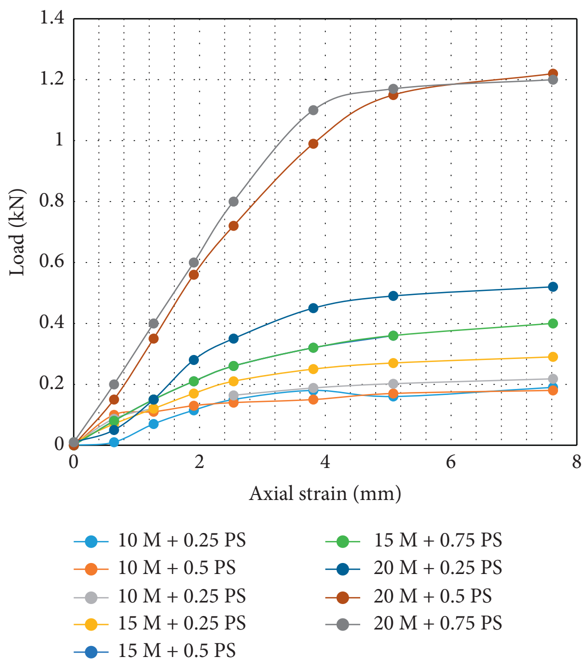

Figure 6: CBR graphs of improved soil at different percentages of marble dust and plastic strips.

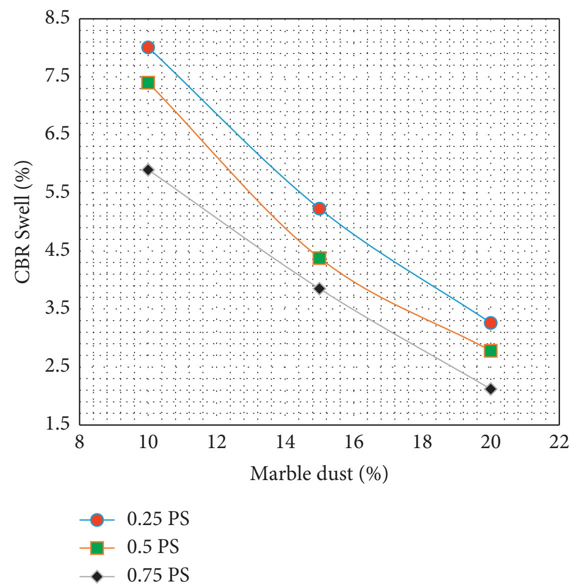

Figure 7: CBR swell variation with percentages of plastic strips and marble dust.

plastic strips met the minimum CBR of 5% required by the Ethiopian Road Administration (ERA) based on the CBR results [43].

3.4. Effects of Marble Dust and Plastic Strips on CBR Swell. Figure 7 shows the effect of PET plastic strips and marble chips on CBR soil swelling. Treatment of soil swelling with plastic strips and marble chips significantly increased the CBR of soil swelling.

The addition of nonswelling materials to swelling soil alters the change in volume of the soil. Since a mixture of plastic strips and marble dust replaces some percentage of the soil, nonswelling materials replace the swelling volume of the soil which decrease some percentage of the soil. The results show that the CBR swell values decrease with increasing plastic strips and marble powder percentages. With the addition of 0.75% plastic strips and 20% of marble dust, the highest improvement in the CBR swell value is observed. At this point, the value of CBR swell changed from 8.19 to 2.31%, which is a very significant improvement. This is because the particles of expansive clay are replaced by particles of nonexpansive marble dust particles, which act as an inert material. This study is consistent with previous investigations on the effect of plastic strips and marble fines in reducing the elasticity of expansive soils [18, 23, 24, 39, 40]. Tamiru et al. [46] measured the CBR swell of two soil samples after treating with marble dust, and the value decreased by 139 and 115%, respectively. The swelling rate of CBR expansive soils decreases as the marble dust content increases. This indicates that the swelling capacity of the samples decreases as the marble dust stabilizes. This is due to some chemical reactions between particles of expansive soils and marble dust. This is also due to the replacement of part of the volume occupied by the swollen clay minerals with marble dust.

3.5. Effects of Marble Dust and Plastic Strips on UCS Values. The unconfined compressive tests on natural and stabilized expansive soil were carried out. For plastic strips and marble dust treated expansive soil, UCS tests were carried out using the soil's MDD and OMC at varying percentages of marble dust and plastic strips.

Figure 8 shows the results of UCS tests at varying percentage additions of plastic strips and marble dust. The addition of marble dust and plastic waste strips has been shown to increase the UCS value up to 0.5% for plastic strips, but the value decreases slightly above 0.5%.

The increase in UCS comes from modification in compactness of the soil because of the addition of plastic and coarser marble dust, enhancement in gradation, the load-resisting capacity of plastic strips, and improved bonding between marble dust and soil particles. It is observed that plasticity of the soil decreased, and its strength increased with an addition of marble dust. However, plastic strips above the optimum ratio create weak layers and make the soil more susceptible to shear failures along the planes. With the addition of 20% marble dust and 0.5% plastic strips, the UCS value changed from 71.1 kPa for soil alone to 411 kPa, which is a very significant improvement. These trends on the effects of marble dust and plastic strips agree with the previously conducted studies on the effects of waste stabilizers on UCS of stabilized soils [9, 18, 42, 43]. Ashiq et al. [47] found that the unconfined compressive strength increased and reached a maximum value of 152 kPa (43.64% higher than the soil strength) when the content of marble dust content increased to 15%. The resulted high values of UCS may be due to the improvement in cementitious properties of the treated soil as the calcium content of MD

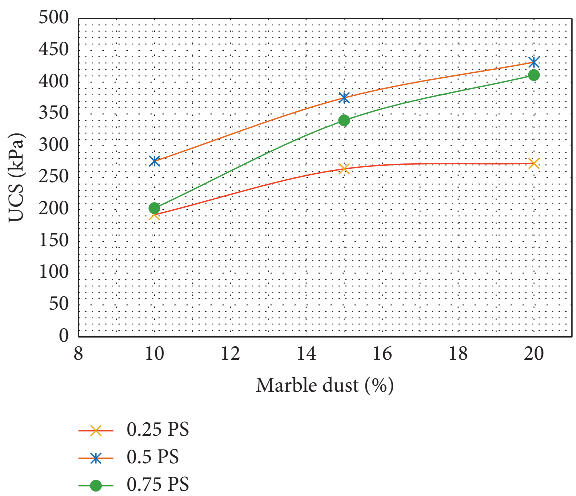

FIGURE 8: UCS value variations with percentages of marble dust and plastic strips.

and silica/alumina content of expansive soil form hydrates. As the amount of marble increases (over 15%), the soil particles are replaced by water and the soil lacks shear strength due to the higher optimum water content, resulting in lower UCS values. Mohammad [12] also found that increasing the percentage of plastic waste from 0.25 to 1.0% resulted in a gradual rise in the strength. A study conducted by [21] found that 0.75% of plastic strips are the optimum content at which a significant change in UCS (142 kPa) obtained with corresponding improvement of 90.13%. The study [48] also described the variation of UCS as a function of plastic strip percentage for three types of soil. It was found that as the UCS increased when plastic strip percentages increase up to 1% beyond which the values of UCS start declining.

4. Conclusion

This research involved the investigation on the modification of subgrade expansive soil using marble dust and plastic wastes. The following conclusions from experimental results are drawn for stabilization of expansive soils with plastic strips and marble dust:

(1) From waste management, environmental pollution reduction, and economic perspectives, using plastic wastes and waste marble dust can save the cost of construction and reduce environmental pollution.

(2) The addition of marble waste increased MDD and decreased OMC, while the addition of plastic strips decreased MDD and MOC. The addition of plastic strips and marble waste to the soil slightly increased MDD and decreased OMC.

(3) As the percentages of plastic strips and marble dust increase, an increase in values of the CBR was observed. The values of CBR change from 1.5 to 6.2% in addition to 20% marble dust and 0.75% plastic strips. The CBR swell of the expansive soil decreases with the addition of marble dust and plastic strips. It changed from 8.19 to 2.31%, with the addition of 20% marble waste dust and 0.75% plastic strips.

(4) The unconfined compressive strength value of the expansive soil increased when marble dust was added. However, when plastic strips were added, the UCS increased to 0.5% and then started to decrease.

(5) The free swell of the expansive soil is reduced by the addition of marble and plastic strips. The expansiveness of the soil changed from a highly expansive category to a low expansive category in addition to plastic strips and marble dust [6, 13, 14, 29–38, 44, 45].

Data Availability

The data used in the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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