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Research Article

A Novel Technique to Utilize Second Waste of Plastic Bottle as Soil Reinforcement: A Comparative Study on Mechanical Properties with Natural Black Cotton Soil

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Black cotton soils, which are expansive, are present in abundance in Ethiopia. This type of soil possesses expansion when saturated with water and contraction during hot seasons, due to which it is labelled as "weak soil." They may remain a threat to the structures if they are constructed over them without precautions. The quality of such soils can be improved by treating them with suitable stabilizers or soil reinforcers. This paper discusses the chances of using the second waste of plastic bottles as a reinforcer to strengthen weak black cotton soils in Ethiopia. Second, plastic bottle waste was added at 1%, 2%, 3%, 5%, 7%, and 9% to the soil, and numerous trials were conducted to ensure the reliability of the results. The effects were analyzed based on the results from the Atterberg limit tests, compaction tests, unconfined compression strength (UCS) tests, and the California bearing ratio test (CBR) for soaked and unsoaked conditions. The results were compared against the natural soil results, and the optimum usage percentage of second waste plastic required to reinforce the soil was reported. The results indicate that among the various properties used, the mix with 2% second waste plastic is effective with numerous trials being conducted to ensure the reliability of the results and decreased values of OMC by 18.5%, increased MDD by 1.9%, increased CBR by 50.9%, and increased UCS by 10.1%. Thus, the research provides a novel technique to recycle plastic waste once again as soil reinforcement, thereby saving the environment from dumped waste.

1. Introduction

Soil particles containing clay particles possess severe strength loss, especially during the rainy season, and will show signs of shrinkage in summer. Black cotton soil is an excellent example, with the characteristics mentioned above. In Ethiopia, the major portion of the country's roadways, lightly loaded residential and commercial buildings, airfields, and planned railway systems, as well as a significant portion of the country's newly planned railway systems, are built on expansive soils. Uba [1] reported that expansive soils are the major cause of the destruction in Ethiopia as they are not suitable to carry heavy loads. They cause large volume changes, causing severe slope and foundation damage [2]. These types of soils can be made suitable to bear heavy loads by performing certain techniques such as stabilization and soil reinforcement involving the use of admixtures, waste materials, or with natural plant fibers such as coir waste, which can improve the physical characteristics of the soil [3, 4].

1.1. Literature Review

1.1.1. General Materials Used for Soil Stabilization. Many minerals and supplementary cementitious materials are used for soil stabilisation, such as lime [5], Bagasse flies ash [6], bottom ash [7], concrete slurry [8], and stabilizers like ordinary Portland cement, which is frequently used as an individual or in combination with any supplementary cementitious material like Metakaolin, as it leads to forming hydration products essential for soil stabilization effect [9–11]. However, the use of such alternative cementitious materials may be required in larger quantities and, depending on the circumstances, may be uneconomical. This can be made economical by blending weak soils with industrial waste and other possible waste materials that will be used in minimal quantity.

1.1.2. The Use of Waste Materials such as Soil Stabilizers. Solid waste reuse has gained popularity in recent years as a method of addressing long-term waste management. Soil stabilisation with recycled byproducts of manufacturing operations has a lower environmental impact and reduces the cost of reinforcing the soil before construction. E-waste, glass, and plastic waste are among those wastes which are great sources of land pollution, causing severe dumping problems globally. They are less likely to harm the environment when used as a soil stabiliser or reinforcer [12]. One of the main advantage of using plastic wastes in the soil as stabilisers to the environment is reducing the danger of blocking water bodies due to dumped plastic wastes [13]. Earlier researchers invested a significant amount of time and effort into using waste to stabilise soil. Malkanthi et al. [14] discussed using crushed concrete waste along with river sand in order to optimise the particle packing and certified that compressed stabilised earth blocks contribute to the reduction of pollution caused by building waste. Sivakumar et al. [15] utilised concrete slurry waste generated from ready-mix concrete as a soil stabilising agent and identified that slurry waste helps in stabilising soil by calcium ion exchange and reported that the use of such waste improved the soil stabilisation effect by 38% greater than that in which ordinary Portland cement was used. Pateriya et al. [16] tried stabilising weak soil using marble waste blended with fly ash, cement, and nanomaterials, and the outcomes revealed that such a blended mix acts as a potential source for stabilising weak soil. There has been a lot of research done on other waste items like granite waste, oxygen furnace slag, and fly ash [17, 18]. Because of the presence of silica, glass wastes can be utilised in multiple ways in the construction industry: as fine aggregate in the form of glass powder [19, 20], as glass fibres in fibre reinforced concrete [21], and even as a stabilising agent in weak soil [22, 23]. Similarly, e-waste can also be utilised as a different resource in construction activities as a partial replacement for fine aggregate.

1.1.3. The Use of Plastic Waste in Soil Stabilization. Plastic bottle overuse, on the other hand, can be found all over the world [24] , and there is limited usage of the disposed of plastic waste in construction industries. Oyinlola et al. [25] had tried to construct plastic bottle brick houses with water plastic filled with earth. They are utilised in various forms in construction works even then the disposed plastics are available in plenty. Plastic consumption and production are increasing in Ethiopia. According to EUROMAP (European plastics and rubber machinery), Ethiopia will produce 386,000 tonnes of plastic by 2022, with per capita consumption reaching 3.8 kg. Plastic consumption per capita in Ethiopia has increased by approximately 13.1 percent per year in recent years, rising from 0.6 kilograms in 2007 to 2.8 kilograms in 2018, and is expected to reach 3.8 kilograms in 2020. Use of plastic waste has already been tried by earlier researchers in many forms, Farah, and Nalbantoglu [26], discussed the performance of plastic waste for improving soil properties. Peddaiah, et al. [27] tried using plastic waste in the form of strips and improving the soil characteristics. Ferriera et al. [28] used polyethylene terepthalate bottles in fibre form in the sand and reported that the mixed sand showed better performance.

According to the above literature review, even though much works is done with plastic waste, it continues to be a major problem in terms of disposal. In this study, second waste of plastic material is used to reduce the aforementioned problems, with the specific goals of improving the plastic index as well as the strength values of black cotton soil and minimising environmental pollution by reducing the amount of plastic waste going to landfills.

1.2. The Scope and Significance of the Research. This paper discusses the use of various waste materials as soil reinforcement and compares them with that of second-hand plastic bottles in enhancing soil properties. Though many studies have been published on strengthening weak soils with plastic waste [29, 30] and ultrafine cementitious materials, few studies have been conducted on the second waste of plastic material. In the present study, the use of the second waste of plastic material as a soil reinforcer and its effect in strengthening the soil structure was studied by performing various tests such as Atterberg limit tests, proctor compaction tests, unconfined compressive strength tests, california bearing ratio tests, and undrained shear strength tests.

2. Materials and Methods

2.1. Materials under Consideration. Natural black cotton soil and waste plastic bottles were the basic materials considered for the current study. The samples of natural black cotton soil were collected in Addis Ababa, Ethiopia, from the bole subcity. Waste plastic bottles were processed (grinding, washing, and drying) by a plastic recycling machine at the Coba Impact plastic recycler company. The second type of plastic material is different from the other types of plastic materials by their size, shape, and strength, as well as this

Table 1: Laboratory result of a natural soil sample.

Test categories	Laboratory tests	List of description	Results
Index properties	Particle-size distribution (PSD)	Gravel	0%
		Sand	20.62%
		Silt	26.46%
		Clay	52.92%
	Atterberg limit (Casagrande cup method)	LL	102%
		PL	36%
		PI	66%
	Natural moisture content	W	38.23%
	Specific gravity	G_S	2.66
Swelling properties	Free swell index	Free swell (S_f)	110%
		Differential free swell (S_{df})	90.9%
	Swelling potential	S	12.06
Compaction tests	Standard compaction	Maximum dry density (MDD)	1.13 g/cm^3
		Optimum moisture content (OMC)	37.78%
Strength tests	Soaked California bearing ratio (CBR)	CBR	2.14%
	Unconfined compression strength (UCS)	UCS	246.54 kPa
		ε_f	8.68%
A unified soil classification system (USCS)		CH (highly plastic clay) black cotton soil	

material does not have any purpose, rather it engaged the dumping areas with too much space and contribute to the pollution of the environment.

2.1.1. Natural Soil. Using a combined sieving and hydrometer test process, a continuous particle-size distribution curve of soil can be plotted from the size of fine sand particles down to the size of clay particles. Table 1 presents the laboratory results of natural soil tests, which include the details obtained from the particle size distribution as per ASTMD6913M-17 [31], the Atterberg limits for the Casagrande cup method of liquid limit (LL), plastic limit (PL), and plastic index (PI) values as per ASTMD4318-17 [32] and CBR tests as per ASTMD1883-16 [33], Based on the results from the unified soil classification system (USCS) done as per ASTMD2166-16 [34], it is inferred that the soil sample could be categorized as highly plastic clay (CH).

2.1.2. Second Waste of Plastic Bottle Stabilized Black Cotton Soil. The waste plastic materials or bottles collected were crushed in a plastic crusher machine. The crushed materials were collected, washed, and dried. Figure 1 shows the material used in the current research. Earlier, Preethi [35] had used plastic strips such that they passed through a 4.75 mm sieve for soil stabilisation in the present work, the second waste plastics passing through a 4.75 mm sieve size and retained at 0.075 mm were segregated and considered for mixing with black cotton soil. Moreover, in the present work, the crushed pieces and the process was done as per ASTM D6913M-17, 2017 [34].

2.2. Mix Proportions, Methodology, and Testing. A total of 7 mixes, including one control mix (C) and 6 random mixtures (M1, M2, M3, M4, M5, M6) consisting of second waste

Figure 1: Second waste of plastic bottles.

of plastic bottles added (by weight) with natural black cotton soil in 1%, 2%, 3%, 5%, 7%, and 9% were made. Amena [3, 36] has used plastic stripes in 0.5%, 0.75%, 1%, 1.5%, and 2% and reported that increasing the percentage of plastic strips increased the CBR values and cohesion of soil by up to 1.5%. Gangwar and Tiwari [35] used waste plastic bottles for soil stabilisation in 0.5%, 1%, 1.5%, and 2%. Because the second waste of plastic is smaller in size and is used to implement a large usage of waste in the current work, the proportion began with 1%. Two types of laboratory tests, namely, tests for natural soil classification and analysis of the strength of black cotton soil stabilised by second-hand waste plastic bottles, were performed. Atterberg limit tests, particle size distribution, specific gravity, compaction parameters, unconfined compressive strength (UCS), CBR (soaked and unsoaked) tests, and soil swelling characteristics were performed to determine the soil samples' features. The cone penetration method was also used to check the potential of the plastic material. All the tests were done as per ASTM standards.

Figure 2: Casagrande cup for performing Atterberg limits.

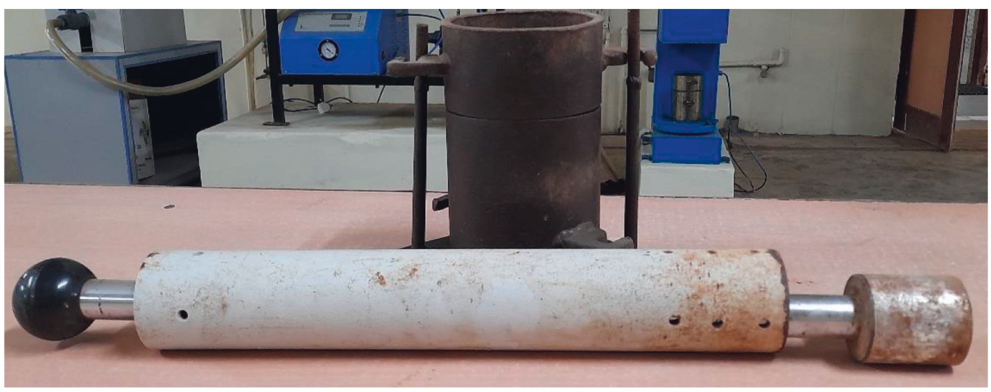

Figure 3: Set up for performing standard compaction tests.

2.2.1. Atterberg Limit. The Atterberg limit test is used to determine a soil's plasticity qualities and utilizes them as input index parameters for soil classification. The Casagrande method was used to determine the soil's liquid limit. Figure 2 shows the setup utilised for the present research. The Atterberg limits that are used to measure the distinctive features of soils in terms of water content are liquid limits (LL), plastic limits (PL), and plastic index (PI). The test was performed as per ASTMD4318-17 [32] requirements.

2.2.2. Standard Compaction Test. ASTM D698-12, 2012 [37] was used to calculate the maximum dry density (MDD) and optimal moisture content (OMC). Three layers of air-dried soil samples were crushed with 25 blows. After compaction, the mold is trimmed and the compacted dirt mass is measured. The soil moisture content is also determined. From the densities and moisture contents of the compacted soil experiments, a graph between dry density and moisture content is generated. Figure 3 depicts the test setup, and the properties are already listed in Table 1.

2.2.3. California Bearing Ratio. The CBR test was used to find the strength of the mixed soil based on the guidelines of ASTM D1883-16, 2016 [33]. The homogeneous mixture of samples was compacted in the California Bearing Ratio (CBR) test molds for both the soaked and unsoaked conditions, and CBR values of the soil with varying amounts of plastic were found. In the soaked CBR test, the samples were immersed in water for four days to investigate the environmental and climatic effects of natural and plastic stabilised black cotton soils. Figure 4 displays the CBR apparatus used for current research.

Figure 4: CBR test setup.

Figure 5: UCS test setup.

Table 2: Variations of the Atterberg limit value of stabilised soils with different percentages of the waste plastic bottles.

Mix ID	LL (%)		PL (%)	PI (%)	PI (%)
	Casagrande cup	Cone penetration	Conventional method	Casagrande cup	Cone penetration
C	102	83	36	66	47
M1	102	83	36	66	47
M2	99	82	35	64	47
M3	93	81	34	59	47
M4	91	80	34	57	46
M5	93	77	33	60	44
M6	96	74	32	64	42

2.2.4. Unconfined Compressive Strength. Unconfined compressive strength as specified in ASTM D2166-16, 2016 [34] was done for the samples collected. As a consequence of this test, the soil's maximal strength has been confirmed to be 135.72 kPa. With this UCS value, the soil is classified as stiff clay soil. The test set up is displayed in Figure 5.

3. Results and Discussion

3.1. Atterberg Limit Result. The Atterberg limits for the Casagrande cup method of liquid limit (LL), plastic limit (PL), and plastic index (PI) values are presented in Table 2.

The LL of 5 percent plastic stabilised soil is reduced by 10.8 percent for the Casagrande cup method, and the LL of 9 percent plastic stabilized soil is reduced by 10.8 percent for the cone penetration method, compared to natural black cotton soil, while the PL of 9 percent plastic reinforced soil is reduced by 11.1 percent. With coefficients of determination of $R^2 = 0.999$ (at 5% in the Casagrande cup method) and 0.98 (at 9% in the cone penetration method), it is clear that the second waste plastic reinforcement resulted in a progressive decrease in LL value. As a result, the plastic reinforcer aids the black cotton soil in lowering its moisture content in both methods.

The PI value of natural soil is reduced by 13.6 percent when stabilised by 5 percent plastic material for the Casagrande cup method, and by 10.6 percent when reinforced by 9 percent plastic material for the cone penetration method. As a result, 5 percent plastic reinforcer is the ideal content for the Casagrande cup method.

3.2. Standard Compaction Test Results. Table 3 presents the OMC and MDD results of waste plastic reinforced black cotton soil improvement using the standard compaction method.

Table 3: OMC and MDD values.

% of plastic waste	OMC (%)	MDD (g/cm^3)
C	37.78	1.130
M1	36.1	1.146
M2	30.8	1.151
M3	36	1.144
M4	37.47	1.143
M5	38	1.112
M6	38	1.092

Adding a second plastic waste resulted in a progressive increase in MDD and a roughly linear decrease in OMC until the reinforcer content reached its optimum, i.e., at 2%. The OMC is reduced by 18.5 percent for the replacement of waste plastic reinforcer with 2%, the reason is due to the poor water absorption capacity of the plastic reinforces, which is an important property to be considered when using it on road pavements. The same trend was reported by other researchers that plastic waste stabilizer were used [3, 38]. Also the MDD of soil increases up to 2% replacement levels and decreases thereafter as the percentage of replacement is increased. This is due to the fact that density decreases when the same volume of soil is replaced by lighter materials. The increase in MDD value indicates that the strength of black cotton soil improves as more solids might have been filled in the given volume. In terms of percentages of dry weight of soil, the moisture content of reinforced soil was reduced by replacing black cotton soil with waste plastic material. Furthermore, when a compaction force is applied, the stabilised soil becomes interlocked with one another due to the roughness of the surface of the small plastic material. The

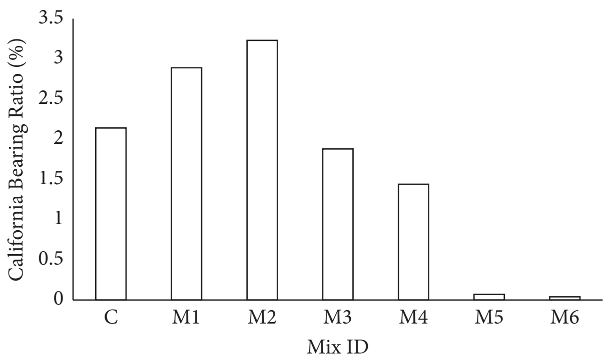

Figure 6: CBR values of soaked soil samples.

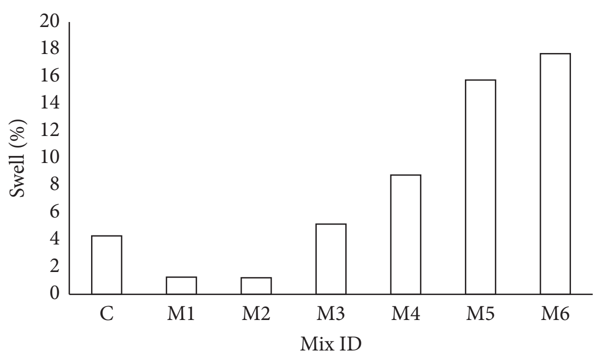

Figure 7: Swell percentage of various soil samples.

results showed that the use of second waste of plastic as a reinforcer reduced the negative effects of soils with high OMC values to some extent.

3.3. California Bearing Ratio Results. According to the study, CBR values increased for a replacement level of 2% plastic reinforcer and showed an improvement of 50.9 percent, while the percentage swell of the 2% plastic reinforced soil decreased by 71.6 percent when compared to natural black cotton soil. This indicates that the CBR of the optimum plastic stabiliser, at 2%, increased by half the amount of the natural soil. Furthermore, the results of unsoaked CBR tests with 0%, 2%, and 3% plastic reinforcer were 9, 12, and 9.31 without swell. The friction action between plastic and black cotton soil at OMC and MDD is responsible for this improvement. According to the results of the tests, the CBR values of the reinforced soil increased significantly under unsoaked and soaked conditions. As a result, the strength of the black cotton soil was enhanced by the use of a low-cost, economical waste reinforcer. In a soaked condition, however, CBR values of waste plastic reinforced soil greater than the optimum content decrease due to high swelling characteristics. The reason for such a decrease in CBR after 2% replacement of second waste of plastic was that mixture showed low resistance to penetration and mixtures may not have possessed proper interlocking as the presence of smooth plastic particles exceeded the optimum limit. Amena [3], who had been using plastic strips for enhancing the subgrade properties, also mentioned that there was an increase in CBR values up to 1.5% and the values decreased

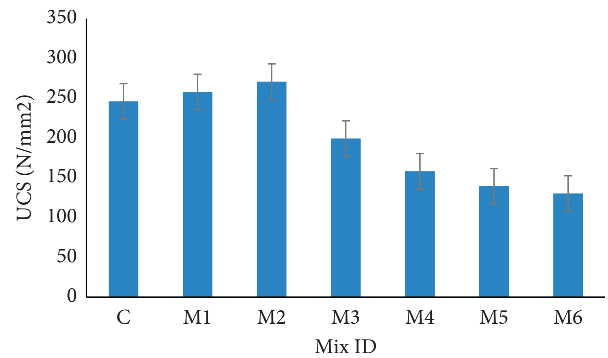

Figure 8: Values from the unconfined compressive strength test.

Figure 9: UCS failure of 2% waste plastic stabilized black cotton soil.

thereafter. Also, earlier reports state that when plastic waste is used in the form of trips, the optimum CBR values were obtained at 1% [39], so it is comparatively better as there are chances for adding plastic waste at a slightly increased level by recycling and using the second waste. Figures 6 and 7 display the CBR and percent swell values.

3.4. Unconfined Compressive Strength Results. The unconfined compressive strength (UCS) result is presented in Figure 8. It is also known that as the MDD of the soil rises, the UCS parameters of the soil also rise, eventually reaching the optimum percentage of second-waste plastic stabilizer. The UCS value at 2% optimum plastic stabilizer is 271.43 kPa, which is greater by 10.1% than natural black cotton soil. The reason for such a decrease in UCS may be due to the smoothness of the plastic reinforcer. When more p-second waste of plastic was added, the strength decreased due to the low resistance offered by the samples, as proper packing is not ensured between the soil particles and the smooth plastic waste. Amena [3] found the same pattern in their study of waste plastic bottles. So, from the results, it is inferred that when the proportion exceeds 2%, the soil begins to form weak shear lines along which it can fail quickly. Hence, the most optimal percentage of waste plastic that should be used to increase the strength of black cotton soil is 2%. The inclined failure line at failure strain is 7.37% of the unconfined compressive strength after the application of compressive load is shown in Figure 9.

4. Conclusion

By suggesting the use of second waste of plastic along with black cotton soil for reinforcing processes, this project intends to improve the strength of expanding soils while also reducing the environmental pollution. Thus, the research could serve three goals. The first is to develop a good way of disposing of plastic waste; the second is to enhance the performance of black cotton soil; and the third, and most importantly, is to make the process economical by using waste.

The following findings are obtained based on the analysis and interpretations: The second waste of plastic bottle material proved to be a good reinforcement when used in different proportions for the replacement of dry weight of soil by improving the engineering properties of black cotton soil; use of second plastic waste in 5% has led to a considerable decrease of 13.6% compared to the natural black cotton soil as presented in the Casagrande cup method; the plastic as a reinforcer had increased the MDD values up to an optimum level of 2% usage, beyond which the values started decreasing; and the OMC values were seen decreasing up to 2% replacement level and thereafter an increase in moisture content was noticed. So, it is inferred that the M2 soil mix with a 2% effective amount of plastic waste, remained as the optimum mix based on the analysis of the results from tests such as compaction, CBR, and possessing less swelling percentage and registering a higher value for UCS than the natural black cotton soil.

Thus, according to the findings, using the second waste of plastic bottles as reinforcement of black cotton soil can allow for proper plastic waste disposal and soil enhancement.

Data Availability

All the data used to support the findings of this study are included in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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