Effect Of Waste Plastic Strip On The Shear Strength And Permeability Characteristics Of Black Cotton Soil

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The use of plastic bottles is on the rise, causing lots of new environmental issues. It is now extremely difficult to dispose of plastic waste without damaging the ecosystem. As black cotton soil for embankments and foundations has limited use due to its swelling and shrinkage property as well as its bearing capacity, utilizing plastic bottles to enhance soil strength parameters can be a cost-effective solution. This study investigates the possibility of improving the characteristics of soil by using leftover strips of plastic that have been cut from plastic water bottles. The black cotton soil is amended with about 0%, 5%, 6%, 7%, 8%, 9%, and 10% plastic strips. On the black cotton soil that had been strengthened with plastic waste, direct shear and falling head water permeability tests were executed as part of the experiment. The test results under the circumstances are provided to evaluate the change in soil strength characteristics. In the aspects of shear strength, friction angle, and cohesiveness, it was determined that soil samples containing 5-9% plastic strips performed better than soil samples containing no plastic strips. Therefore, shear strength can assist in resisting deformation under stress caused by the weight of an embankment. Moreover, the friction angle determines the embankment slope stability and the material's ability to withstand deformation caused by water flow, freeze-thaw cycles, or other environmental factors.. On the other hand, the inclusion of the plastic strip enhanced the permeability of black cotton-reinforced soil. This innovative approach may be utilized to successfully address socioeconomic issues, such as recycling waste materials.

Keywords: Soil improvement, Waste plastic, Permeability, Shear strength, Geotechnical engineering.

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1. Introduction

Plastic items have turned out to be an indispensable component of our daily lives. It is generated in a massive amount worldwide, with annual production exceeding 150 million tons [1]. As a result, proper disposal of these waste products is required. In recent years, the practice of using recycling materials has emerged more than before due to the large availability and disposal problems of the materials [1–4]. Therefore, it is a deliberate, productive, and cost-effective method of recycling these materials to use discarded plastic as reinforcing materials for soft soil in order to strengthen the soil. Waste plastic can use in soil since it is cheaper than cement and lime. Modak et al. [5] suggested to use the additives for the improvement of soil qualities when it cannot support design loads. Waste plastic fibers can increase earth embankment subgrade and stability, and plastic strips can contribute to the stabilization of the soil and enhance its drainage capabilities. This innovative soil stabilizing approach can be used to efficiently tackle societal concerns and reduce the amount of waste plastic, resulting in an environmentally friendly and safe situation.

Polyethylene Terephthalate (PET), Low-Density Polyethylene, High-Density Polyethylene (HDPE), Poly Propylene (PP), Poly Vinyl Chloride, and Polystyrene are all examples of plastic waste [1, 6]. It is vital to investigate these compounds as another possibility to enhance the engineering features of soils with the purpose of minimizing plastic waste and protecting the environment.

For several years, soil stabilization or reinforcement has been used to advance geotechnical materials and meet design requirements. Previously, a number of researchers examined the mechanical characteristics of low-strength soils and attempted to strengthen them to modify their function as construction materials [7–13]. However, partial researchers investigated the practice of plastic waste as a strengthening substantial for soil. Researchers have employed plastic bottle debris as a reinforcing element in the sand [14, 15] In various amounts, plastic waste has been incorporated as chips. The shear strength of sandy soil was improved by including plastic waste particles, which resulted in the soil being more resistant to shearing. An increase in the amount of friction that took place between the sand grains and the plastic waste chips was the root cause of this phenomenon [14]. Botero et al. [16] explored the impact of plastic waste on silty soil shear strength. The test findings exhibited that the rising quantity of recycled plastic material reduced the inner friction angle, even though it increased the cohesion value. Researchers have shown that including waste plastic in soils increases both the soil's strength and its stability [17].

Recent research has shown that plastic waste can be used to reinforce the strength of soil in embankment designs. Plastic waste has been used as a reinforcing material in embankment construction to improve the strength and stability of the soil. Several studies have investigated the effect of plastic waste on various strength parameters, such as shear strength, compressive strength, and tensile strength. A study conducted by Farah and Nalbantoglu [18] investigated the effect of plastic waste on the shear strength of soil. The study found that the addition of plastic waste improved the shear strength upto 9% with the addition of 0.75% plastic waste. These strength parameters are critical in the design of embankments, as they determine the stability and performance of the embankment under different loading conditions. Majji Gowri et al. [19] investigated the lime stabilization of soil with 0%, 2%, 4%, and 6% recycled plastic bottle strips. They obtained that waste plastic strips enhanced the shear strength and decreased the falling head permeability of the samples. Farah and Nalbantoglu [18] examined the possibilities of reutilizing scrap plastic bottles manufactured from the thermoplastic polymer polyethylene terephthalate (PET) and used to strengthen sandy soil. At up to 1% for each aspect ratio, PET strips were incorporated into the soil at three distinct ratios. The addition of discarded plastic particles into sand enhanced the soil's shear strength parameter. In an experimental investigation, Alvarez et al. (2020) considered the use of discarded plastic components to strengthen the high plasticity clay soil. Therefore, four different proportions of recycled PET strips with dimensions of 3 to 5 mm have been used, ranging from 0.5 percent to 3.5 percent. Based on conventional direct shear testing, it was determined that 1% of waste plastic was included in this method. Conversely, black cotton soils present a challenging environment for engineers worldwide, especially in tropical nations like Bangladesh. This is due to the fact that tropical nations experience a greater range of temperature levels as well as different dry and wet seasons, both of which contribute to a greater range of moisture content in the soil [20]. Therefore, this study brings much interest by remembering the conditions of the tropical nation.

Furthermore, relatively limited investigations have been carried out on using plastic waste to stabilize subgrade soil. Moreover, there is a limitation of the previous studies that deal with the incorporation of plastic waste in the black cotton soil of Bangladesh. The novelty of the study lies in its focus on the use of scrap plastic bottles for improving black cotton soil, and its investigation of the optimum percentage of the plastic waste strip to be added for soil improvement in the construction industry of Bangladesh. Additionally, the study contributes to the existing literature by providing insights into the use of plastic waste for soil stabilization in the South Asian context, which is an important and underexplored area of research. In addition, the study presents a novel and valuable contribution to the field of earth embankments and the utilization of plastic waste for sustainable construction practices. Therefore, the investigation was carried out using a direct shear test and falling head water permeability test considering 0%, 5%, 6%, 7%, 8%, 9%, and 10% accumulation of plastic waste strip into the soil. Furthermore, the optimum percentage was obtained for the soil stabilization process in the construction industry of Bangladesh, which added extra value to the research in the south Asian context.

2. Materials and methods

2.1. Materials

In this study, black cotton soil served as the raw material, which was combined with recycled PET plastic waste particles. The PET plastic waste was extracted from a local plastic recycling plant utilizing an automatic waste plastic recycling system. The plastic wastes were incorporated at 5%, 6%, 7%, 8%, 9% of the volume of soil. Fig. 1 depicts the grain size characteristics of waste PET. The coefficient of uniformity C_u is 7.10, and the coefficient of gradation C_c is found at 1.099 for PET. Before adding any PET, the soil was obtained from an excavation at Khulna city of Bangladesh and examined for its physical qualities. Table 1 presents the characteristics of black cotton soil.

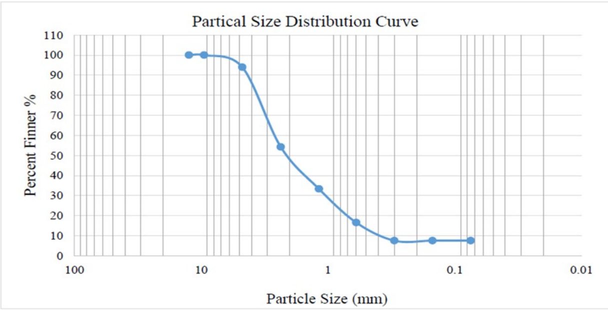


Fig. 1. Gradation curve of waste plastic.

Table 1. Characteristics of black cotton soil.

Characteristics	Quantity (%)
Passing from No.200 sieve	76
Plastic limit	34.4
Liquid limit	66.7
Shrinkage limit	14.2
Moisture Content	21.42

2.2. Specimen Preparation

Plastic waste was collected from water bottles, which is a consumer-based product. This is PET-type plastic waste which was extracted from a local plastic recycling plant utilizing an automatic waste plastic recycling system. After that, the plastic waste was sorted by type and cleaning it to remove any contaminants. The plastic waste is then shredded or ground into small pieces to create a consistent particle size that can be mixed with the soil. It is important to segregate the plastic waste from other types of waste and to ensure that only clean plastic waste is used for soil improvement. Contaminants in the plastic waste can have negative effects on the engineering properties of the soil and may also have negative environmental impacts. The soil was first kept in an oven at around 105°C for an overnight period. Subsequently, those samples were completely mixed with the recycled plastic components at the prescribed optimum moisture content. The mixing process was completed in an automatic mixer for around 7 minutes to ensure complete water dispersion in the soil. The mixing technique was checked visually to make sure it was adequate and comprehensive. In order to prevent evaporation, specimens were kept in a sealed container for 24 hours prior to any additional testing. The specimen preparation was conducted by following ASTM D 3080-04 [21]. According to this standard, the specimen for direct shear test of soil was prepared by trimming a soil sample to a square or circular shape of desired dimensions and then consolidating it to the desired stress level in a consolidation device. The specimen is then trimmed and placed in a direct shear apparatus, and loaded to failure. The length of the specimen was 1.5 times the width, and the height was equal to the width. The authors of this study have prepared 63 specimens for the direct shear test and 21 specimens for the permeability test. After that, the mean value of the 3 specimens was taken for the measurement of each mix. For embankment construction, the soil was compacted to achieve the desired density and strength. This involved additional steps such as moistening the soil, placing it in layers, and using a compactor to apply pressure to each layer. The reason for using a specific preparation method for a direct shear test is to ensure that the test accurately measures the shear strength properties of the soil being tested. Similarly, the reason for using a specific preparation method for embankment construction is to achieve the desired engineering properties of the soil for the project's requirements.

2.3. Testing

The direct shear test is conducted in order to get information on the consolidated-drained shear strength of the soil. The test was conducted by following ASTM D 3080 [21]. The ASTM D 3080 standard also specifies the testing conditions, including the normal stress and the rate of shear displacement. During the test, the black cotton soil specimen was subjected to a constant normal stress and a shear stress that was applied at a constant rate of displacement. The shear stress will cause the specimen to deform and eventually fail along a shear plane. The final specimen in the direct shear test of black cotton soil following ASTM D 3080 has a rectangular parallelepiped geometry, which is not a cubic shape. The shear stress drives the specimen to deform and eventually fail along a shear plane. Total 63 specimens were prepared for the direct shear test and 21 specimens for the permeability test. After that, the mean value of the 3 specimens was taken for the measurement of the each mix. The cohesiveness and internal friction angle of black cotton soil can be determined using a direct shear test. By plotting the shear stress vs. horizontal displacement and establishing the maximum shear stress for a given vertical confining force, a direct shear device was implemented to measure the shear strength of the soil. Furthermore, the friction angle and cohesion were also obtained by plotting the correlation between the normal and shear stress.

The specimens were also examined using a falling head permeability device in accordance with BS 1377-5:1990 to determine their coefficients of permeability. The falling head test is mostly used for soils with low permeability (k $<10^{-4}$ cm/s), such as black cotton soil.

3. Experimental results and discussion

3.1. Direct Shear Test

Based on the field test results, Fig. 2(a) shows the shear stress vs. horizontal displacement curve of black cotton soil. Fig. 2(a) shows that black cotton soil with zero PET achieved 83.45 KPa shear stress with respect to 5 mm horizontal displacement under 30 kg load. As the horizontal displacement expanded, the shear stress ascended as well. In Table 2, maximum shear strength was found as a function of normal stress. With a linear function, shear and normal stress were highly connected. The cohesion value is obtained at about 22.57, and a friction angle is 53.08°.

Experimental observation of black cotton soil with 5% plastic waste incorporation was plotted in Fig. 2(b). From Fig. 2(b), it is obtained that the peak shear stress achieved 84.06 KPa shear stress with respect to 5 mm horizontal displacement under a 30 kg load. The behavior of the curve was more ductile type, and enhancement of stress was observed for the control specimen. A similar fashion of shear stress trend was also observed for 10 kg and 20 kg. The cohesion value is obtained at about 26.12, and a friction angle is 53.21° from Table 2.

In terms of shear stress vs horizontal displacement, the findings of black cotton soil with plastic debris indicate high reproducibility. As a consequence, consistent shear strength values can be obtained. The plastic chip's peak and critical friction angles reinforced black cotton soil increased as the frictional strength between the soil particles increased. Additionally, the higher shear strength of reinforced soil with plastic waste can be represented by the tension that was produced in the shear zone as a result of the anchoring that took place outside the shear region at the interface of the soil reinforcement. The shear strength of the soil is amplified by the tension induced by the PET strip. Furthermore, even after reaching maximal strength, the PET remained under tension. Consequently, the post-peak shear strength reduction is less noticeable than in unreinforced specimens.

Fig. 2(c)-Fig. 2(g) show the shear stress response with the horizontal displacement of black cotton soil and shear stress behavior with the normal stress profile of the plastic waste-replaced soil. Fig. 2(c), Fig. 2(d), Fig. 2(e), and Fig. 2(f) presented a similar pattern of shear stress and horizontal displacement diagram, whereas Fig. 2(g) showed significant improvement of shear stress of 10% plastic waste-based soil under 20 kg load. However, 10 kg and 30 kg showed a similar trend of shear stress regarding horizontal displacement. The soil at the interaction seems to dilate from the start to the finish of the shear process under low normal stresses. A linear function was used to link the peak shear stress with the normal stress. Therefore, the cohesion and angle of friction can be obtained as presented in Table 2.

It was also noted that when waste PET strips are added, the friction angle rises. The friction angle of reinforced samples with 9% plastic waste was roughly 61.3% higher than that of unreinforced materials, as presented in Table 2. Similarly, unreinforced black cotton soil materials had 10.57% less cohesion than the 9% plastic waste inclusive mix. A probable explanation is that PET strengthens the interface between granular by reducing lateral distortion and shortening the failure path, leading to a significant increase in the friction angle and cohesiveness of black cotton soils. Furthermore, the plastic strips' surfaces are naturally ribbed and contorted. Plastic strip surfaces have a greater cohesiveness and internal friction angle due to their nature [1, 22, 23]. At the 10% PET mix, the specimen deviates from the increasing nature due to the excessive amount of PET in the sample. The excessive amount of PET hinders the interlocking behavior of soil. The frictional interaction between soil particles and PET waste with a content of more than 9% has started to weaken. The internal friction angle was reduced due to weaker adhesion between the soil particles and the PET [18].

Table 2. Characteristics of black cotton soil.

Plastic waste replacement replacement	Cohesion	Angle of friction
0%	22.57	53.08°
5%	26.12	53.21°
6%	28.58	54.83°
7%	29.46	54.83°
8%	32.80	55.64°
9%	35.68	55.69°
10%	33.28	26.76°

In addition, the cohesion value is obtained about 28.58, 29.46, 32.80, 35.68, and 33.28 for 6%, 7%, 8%, 9%, and 10% replacement of plastic waste. The increasing value of cohesion was observed with the upsurge of plastic waste; however, at the 10% replacement of plastic waste in soil,

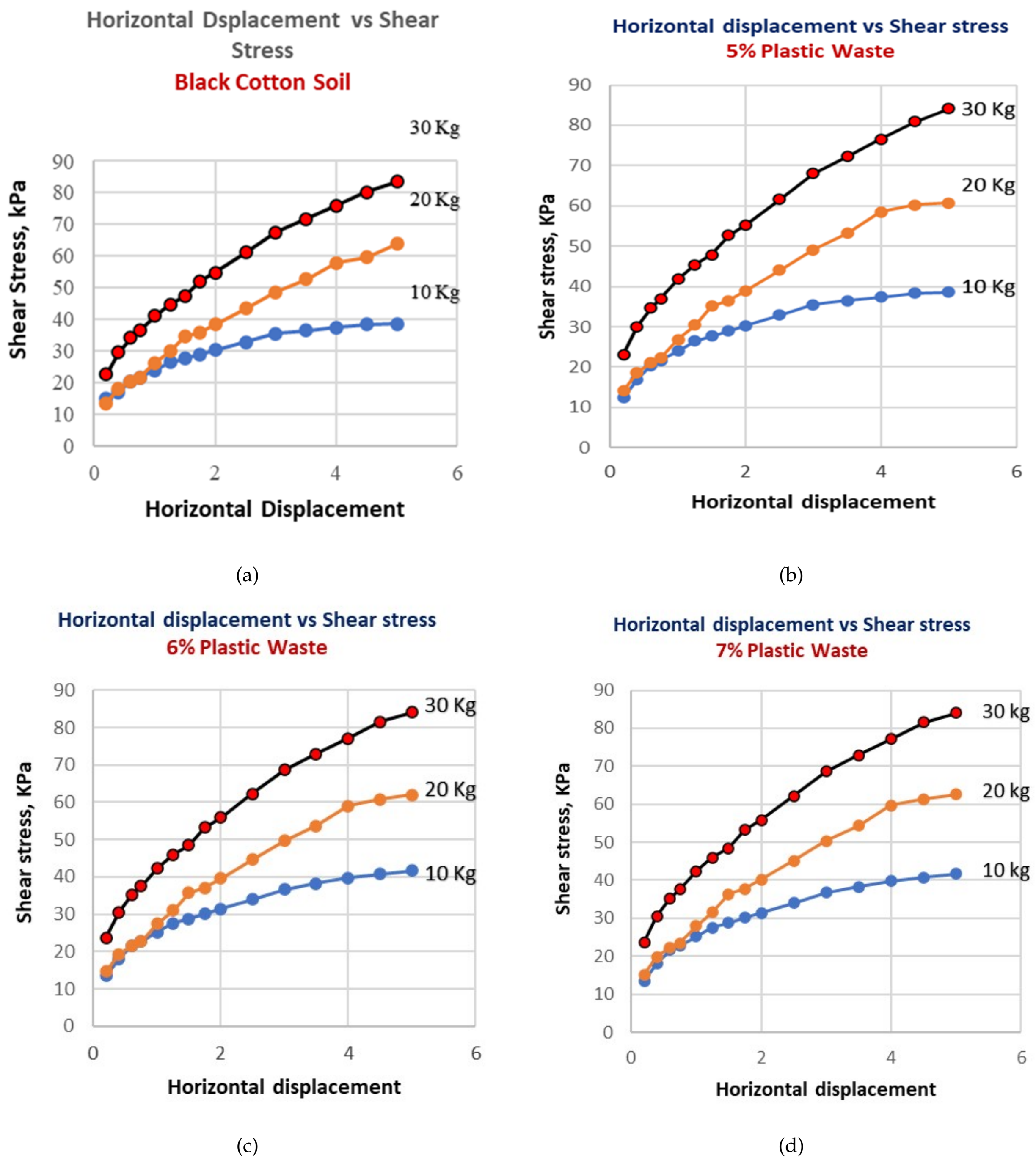
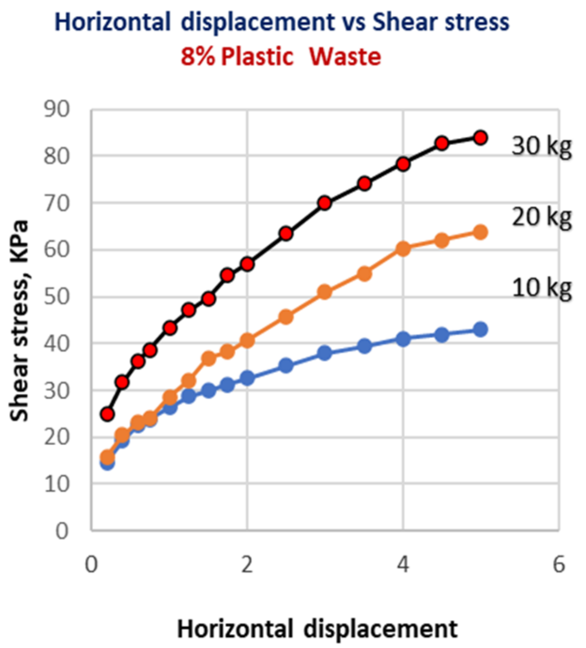


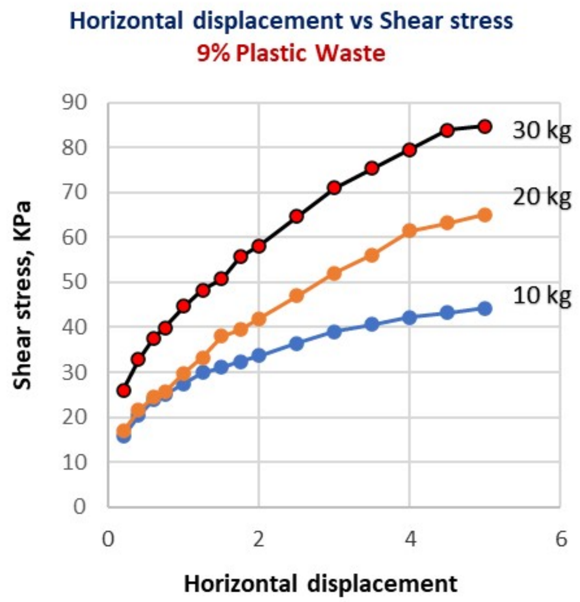
Fig. 2. Horizontal displacement and shear stress of black cotton soil with (a) 0% plastic waste strip; (b) 5% plastic waste strip; (c) 6% plastic waste strip; (d) 7% plastic waste strip.

the cohesion value decreased drastically. On the other hand, the increase of friction angle is observed with the upsurge of waste plastic percentage in black cotton soil. The friction angle for 6%, 7%, 8%, 9%, and 10% of plastic waste contain soil were about 54.83°, 54.83°, 55.64°, 55.69°, and 56.76°.

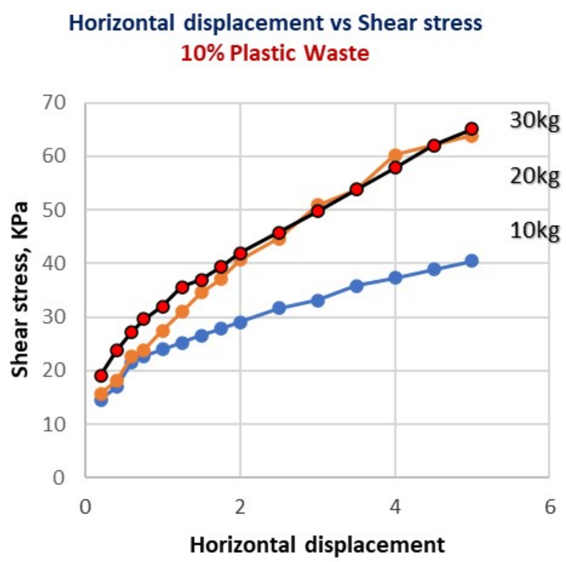
In the study of Al-Taie et al. [24], the addition of depolymerized recycled PET (DRPET) raised the internal friction angle and decreased the peak vertical contractive dislocation of the soil when it was treated with 1.5 and 2.0 percent DRPET. The surface of the particles was covered with DRPET, which improved the resistance between soil particles. In this study, similar kind of behavior was also observed in



(e)



(f)



(g)

Fig. 2. (continued) Horizontal displacement and shear stress of black cotton soil with (e) 8% plastic waste strip; (f) 9% plastic waste strip; (g) 10% plastic waste strip.

black cotton soil for 5-9% PET inclusion. However, Hossain et al. [25] have obtained that 15% inclusion of waste plastic strip increased the shear stress of the soil under different load condition. Due to the different property of soil and plastic waste, the variability in the percentage is observed. According to Kassa et al. [26] and Alzaidy [27], the application of plastic strip in soil significantly decreased soil swelling and desiccation fracturing characteristics. The behavior was observed in this research while testing the direct shear test. Moreover, less brittle behavior is also observed in the plastic waste strip reinforced soil specimen which are corelated with the research of Muntohar et al. [28].

In order to investigate the effect that waste plastic has on the shear strength parameters, Fig. 3 illustrates the correlation between friction angle and the cohesiveness of the soil. When the cohesiveness of the soil rises, there is a corresponding increase in the angle of friction. However, the rate of increase accelerated significantly to the point where there was 10% of the plastic waste strip deposited in the soil.

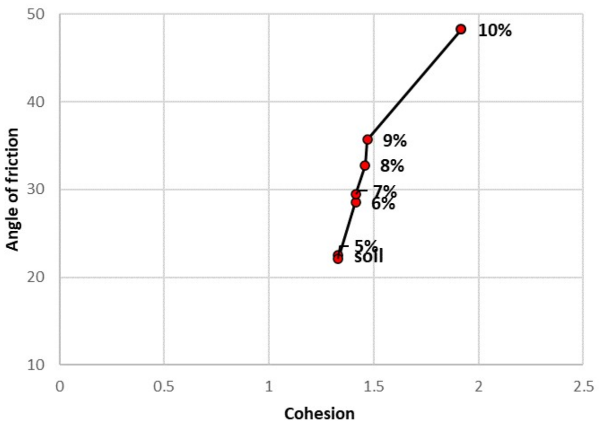


Fig. 3. Gradation curve of waste plastic.

3.2. Permeability

The results of the falling head permeability test of black cotton soil and plastic waste-reinforced soil are shown in Fig. 4. The permeability coefficient of the soil samples rose as the proportion of the waste plastic strips increased. Subsequently, with the incorporation of 10% plastic waste strip in the soil, the coefficient of permeability improved by 128.57%. The findings of the permeability of the black cotton plastic strip reinforced soil in this investigation is similar to the study of Gobinath et al. [29]. As the PET concentration in the treated soil amplified, the platy structure of the soil was distorted, resulting in more linked macropores within the soil, allowing water to flow more easily through the soil. The percentage at which treated black cotton soil compresses increases along with the interconnected pore space in the prepared black cotton soil as waste PET content rises. As the waste PET content of the treated soil grew, this allowed water to drain at a faster pace. This means that as the waste PET content rises, the settlement rate induced by water drainage from the pore space will rise as well. Fig. 4 shows that by using the appropriate amount and kind of plastic, the permeability of the tested soils could be enhanced. This would improve the performance and preservation of the pavement. Moreover, surface leakage as well as other sources of water raises pavement maintenance costs and reduces pavement life [30]. Therefore, it is better to have a greater permeability coefficient of unbound materials in pavement applications [31, 32]. This can improve water drainage system of the soil and prevent water from accumulating inside the soil.

The long-term durability of plastic in black cotton soil depends on several factors, including the type of plastic used, the environmental conditions of the soil, and the duration of use. Generally, plastic mixed with black cotton soil can improve the durability of the soil and prevent erosion. Additionally, the plastic was well mixed with the soil to ensure proper distribution and minimize the risk of damage due to exposure to the elements. Proper maintenance and regular inspection can also help detect any damage or degradation of the plastic and prevent further deterioration.

On the other hand, when considering the use of new plastic versus plastic waste in black cotton soil, there are a few potential results that could arise. Black cotton soil has a high clay content, which can make it prone to cracking and shrinking when it dries out. Adding new plastic or plastic waste could potentially help to stabilize the soil structure and prevent cracking, but this would depend on the type of plastic used and how it is incorporated into the soil. Using new plastic can have a significant environmental impact due to the resources required to produce it and the potential for plastic pollution. On the other hand, using plastic waste can be seen as a form of recycling and can help to reduce waste in landfills or the environment. However, there may be concerns about the potential leaching of chemicals from plastic into the soil. The cost of using new plastic versus plastic waste could also be a consideration. New plastic may be more expensive than recycled plastic, but the cost of processing and incorporating the plastic waste into the soil could also be a factor.

There are several potential applications and implementations of plastic-mixed black cotton soil products. The plastic mixed black cotton soil can be used as a building material for various purposes, such as constructing walls, floors, and roofs. The plastic mixed black cotton soil can be used as a base material for road construction. The plastic content in the soil improves its strength and durability, which can reduce the need for frequent maintenance and repair of roads. The plastic-mixed black cotton soil can be used to control soil erosion in areas prone to erosion. The plastic content in the soil can help bind the soil particles together and reduce the risk of soil erosion. The plastic content can improve the water retention capacity of the soil and reduce the need for frequent watering. In addition, the plastic mixed black cotton soil can be used for land reclamation purposes. The plastic content in the soil can help stabilize the soil and improve its fertility, which can make the land suitable for agriculture and other purposes. The use of plastic mixed black cotton soil can help reduce greenhouse gas emissions. The plastic content in the soil can help sequester carbon, which can help reduce the amount of carbon dioxide in the atmosphere.

The authors would like to suggest analyzing the effect of using waste plastic and different types of admixtures on the behavior of black cotton soil. In addition, the thermal properties of plastic waste in the soil improvement technique can be investigated. Moreover, the water absorption behavior of plastic waste should be investigated, which might affect the soil improvement.

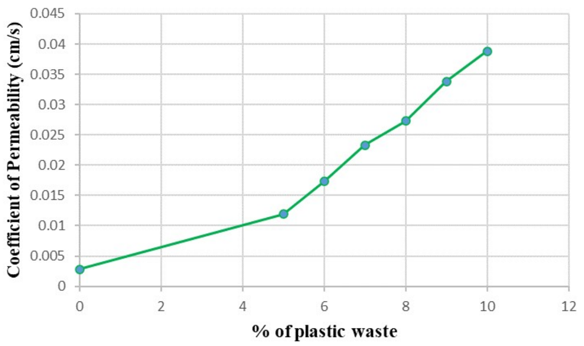


Fig. 4. Gradation curve of waste plastic.

4. Conclusion

The study examined the potential uses of discarded plastic strips to enhance the soil of black cotton. A direct shear test and a falling head water permeability test were used to conduct the investigation while accounting for the addition of 5% to 10% of the plastic waste strip to the soil. Following the testing of the black cotton soil reinforced with plastic, the relevant conclusion can be made: Black cotton soil's shear stress behaviour was greatly enhanced by the use of plastic waste as a reinforcing material. The post-peak shear strength reduction was less noticeable than in unreinforced specimens, indicating that PET strips remained under tension even after reaching maximal strength. The 5-9% plastic strip replacement showed substantial enhancement in cohesion and angle of friction, while the 10% addition of the PET strip showed degrading cohesion between the soil particles. The permeability of the soil rises with the inclusion of the plastic waste strip, and the growing rate greatly upsurges after the 10% addition of the plastic strip. The 9% inclusion of plastic waste strip in black cotton soil provided greater shear strength, cohesion, and angle of friction which can be designated as an optimum condition for using the black cotton soil. The use of a large amount of plastic strip in soil saved the cost and embodied CO_2 emission, which leads to a sustainable solution of the plastic waste.

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