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Research Article

Black Cotton Soil Improvement Techniques by Waste Plastic

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Abstract

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 good quality soil for embankments is limited, utilizing plastic bottles to enhance soil strength parameters is a cost-effective solution. This study explores the potential application of discarded plastic strips from plastic bottles for soil property enhancement. The black cotton soil is amended with about 0%, 5%, 6%, 7%, 8%, 9%, and 10% plastic strips. On 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. The composition of discarded plastic bottle strips has a considerable influence on the development of soil strength. On the other hand, the inclusion of the plastic strip enhanced the permeability of black cotton-reinforced soil. In addition, this innovative approach may be utilized to successfully address socioeconomic issues, such as the recycling of waste materials.

Keywords: Soil improvement, Waste plastic, Permeability, Shear strength, Angle of friction

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 (Abukhettala M et al., 2021). 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 (Al-Taie AJ et al., 2020). 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. Their use in civil engineering includes soil stabilization at the base or subbase course of pavement, earthen embankment reinforcements, and reducing soil settlement in foundations (Alzaidy MNJ, 2019). As waste plastic is a less expensive alternative to other costly admixtures like cement and lime, it can be used in soil improvement. According to Modak et al. (2012), when the existing soil is insufficient to sustain maximum design loads, soil improvement techniques can be applied to enhance the properties by including appropriate additives. Therefore, soil stabilization with waste plastic fibers is a way to increase earth embankment subgrade and stability (Amena S et al., 2022). This innovative soil stabilizing approach may be utilized 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 (Bayewu O et al., 2013). 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. (Botero E et al., 2022). 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 (Bozyigit I et al., 2013). 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 (Chebet FC et al., 2015).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 (Datta SD et al., 2021). The study of Iravanian and Ahmed (2021) obtained that combining plastic scraps with moderate plasticity clay enhances the engineering capabilities of the mixture to the point that it can be utilized as a subgrade soil in roadways, low-cost pavements, and possibly even village and temporary roadways (Dutta RK et al., 2015). To stabilize two distinct types of sandy soils (Farah RE et al., 2014). Used strips of plastic from shopping bags made of HDPE. The researchers examined strip holes of various sizes as a way to strengthen sandy soils. The two types of sand with HDPE strips were put through a series of direct shear tests at weight percentages ranging from 0.1 to 0.3 percent. They also examined the effects of various strip spans and breadths, ranging from 15-45 mm and 6-18 mm. At a strip content of 0.1 percent, the maximum angle of friction can only be obtained with a punching diameter of 2 mm and a breadth of 6 mm, according to their findings. The longer and broader strips result in a loss of strength at certain thresholds. Due to their high tensile resistance, even minor additions of HDPE strips have a significant influence on the shear strength of sandy soils (Fathi H et al., 2018) 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 (2019) 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 (Gobinath R 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 (Hafez M et al., 2014). 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 (Hossain A et al., 2019). Therefore, this study investigates the probable utilization of scrap plastic bottles for black cotton soil improvement. 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 (Huang YH et al., 2014). 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.

MATERIALS AND METHODS

Materials

In this study, black cotton soil served as the raw material, which was combined with recycled PET plastic waste particles (Jha JN et al., 2014). 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. Figure 1 depicts the grain size characteristics of waste PET. The coefficient of uniformity Cu is 7.10 the coefficients of gradation Cc are 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 (Figure 1).

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

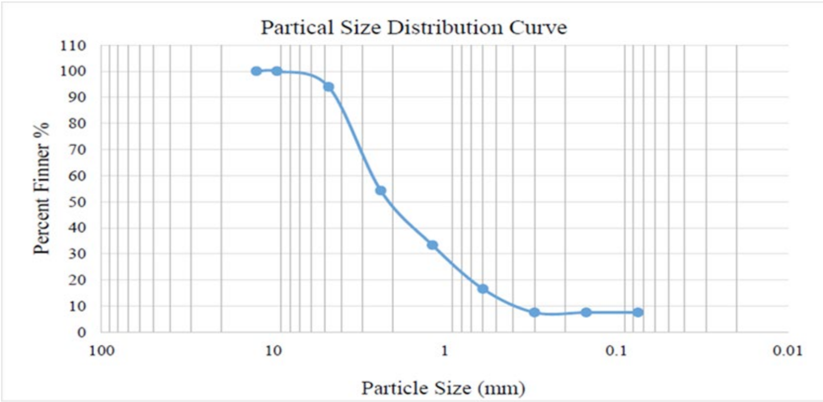


Figure 1. Gradation curve of waste plastic.

Specimen Preparation: 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 (Kar RK et al., 2012). 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.

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. 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.

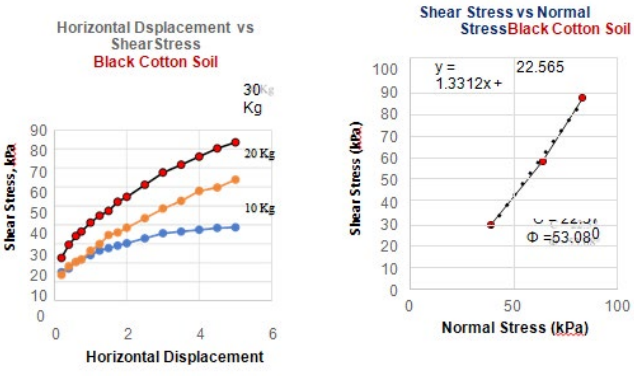
EXPERIMENTAL RESULTS

Direct Shear Test

Based on the field test results, Figure 2 shows the shear stress vs. horizontal displacement curve of black cotton soil. Figure 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 Figure 2(b), 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 Figure 3. From Figure 3(a), 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 behaviour 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 Figure 3(b). Figure 4-8 shows the shear stress response with the horizontal displacement of black cotton soil and shear stress behaviour with the normal stress profile of the plastic waste-replaced soil. Figures 4(a), 5(a), 6(a), and 7(a) presented a similar pattern of shear stress and horizontal displacement diagram, whereas Figure 8(a) 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 (Kassa RB et al., 2020). 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 as presented in Figures 4(b), 5(b), 6(b), 7(b), 8 (b). (Figure 2-5).

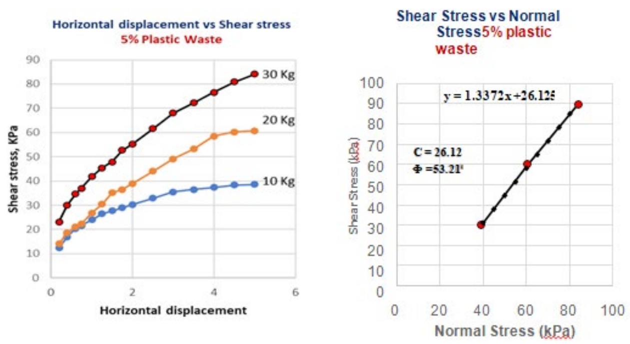
In addition, the cohesion value is obtained about 28.58, 29.46, 32.80, and 35.68, and33.28 for 6%, 7%, 8%, 9%, and 10% replacement of plastic waste. The increasing value of cohesion was observed with the upsurge of plastic waste; however, at the 10% replacement of plastic waste in soil, the cohesion 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° (Figure 6-8).

In order to investigate the effect that waste plastic has on the shear strength parameters, Figure 9 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



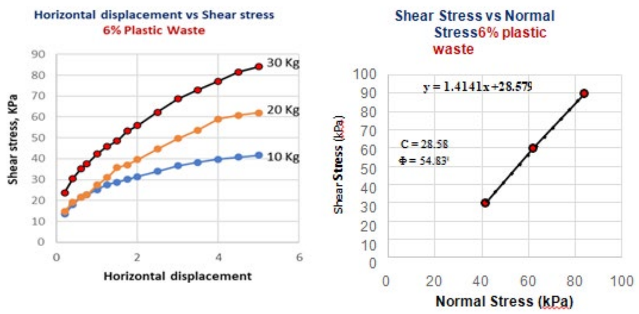
(a) (b)

Figure 2. Black cotton soil with 0% plastic waste strip **(a)** Horizontal displacement and shear stress of soil; **(b)** Correlation between shear and normal stress of soil.



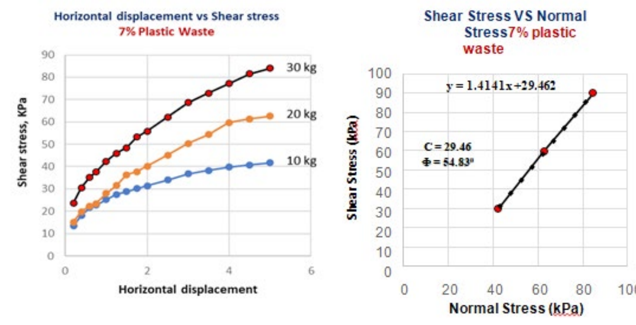
(a) (b)

Figure 3. Black cotton soil with 5% plastic waste strip; **(a)** Horizontal displacement and shear stress of soil; **(b)** Correlation between shear and normal stress of soil.



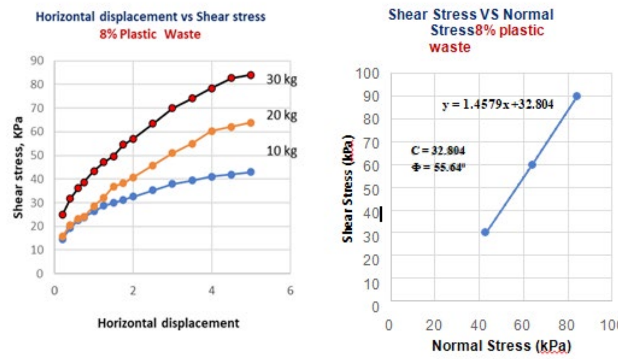
(a) (b)

Figure 4. Black cotton soil with 6% plastic waste; **(a)** Horizontal displacement and shear stress of soil; **(b)** Correlation between shear and normal stress of soil.



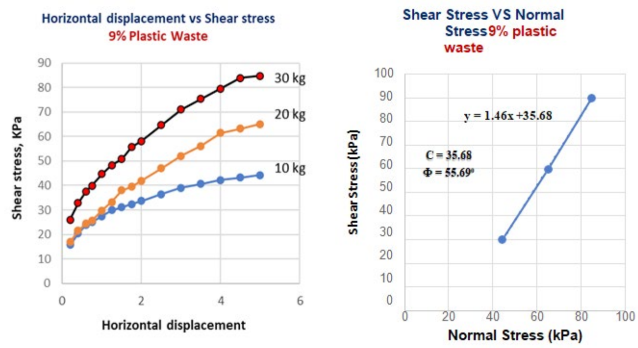
(a) (b)

Figure 5. Black cotton soil with 7% plastic waste; **(a)** Horizontal displacement and shear stress of soil; **(b)** Correlation between shear and normal stress of soil.



(a) (b)

Figure 6. Black cotton soil with 8% plastic waste; **(a)** Horizontal displacement andshear stress of soil; **(b)** Correlation between shear and normal stress of soil.



(a) (b)

Figure 7. Black cotton soil with 9% plastic waste; **(a)** Horizontal displacement and shear stress of soil; **(b)** Correlation between shear and normal stress of soil .

where there was 10% of the plastic waste strip deposited in the soil (Figure 9).

Permeability: The results of the falling head permeability test of black cotton soil and plastic waste-reinforced soil are shown in Figure 10. 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% (Figure 10).

DISCUSSION

In terms of shear stress vs horizontal displacement, the findings of black cotton soil with plastic debris indicate

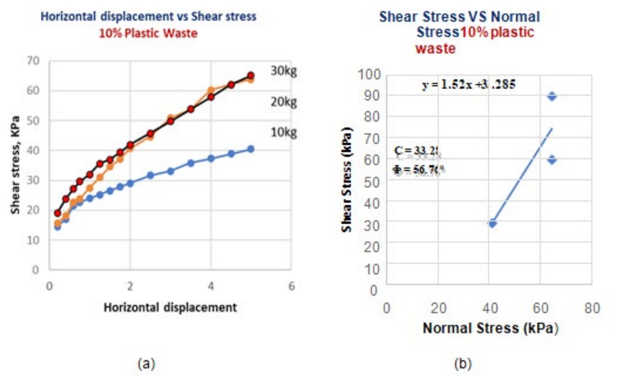


Figure 8. Black cotton soil with 10% plastic waste; **(a)** Horizontal displacement and shear stress of soil; **(b)** Correlation between shear and normal stress of soil.

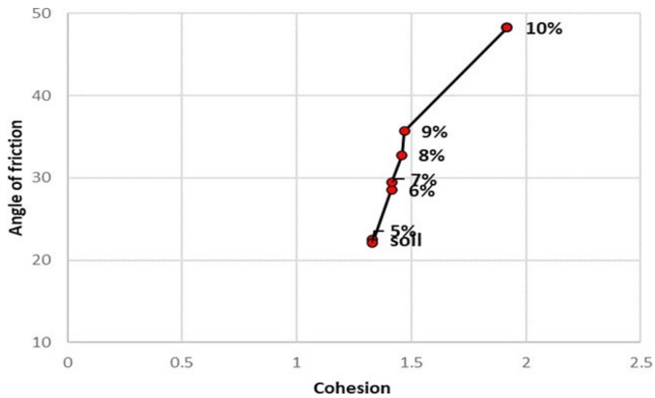


Figure 9. Variation in cohesion and angle of friction due to plastic content.

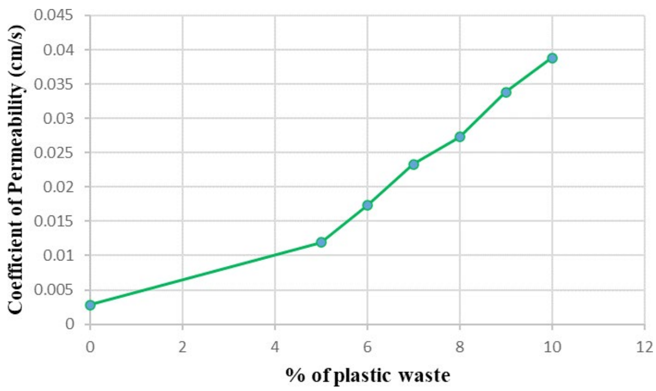


Figure 10. Coefficient of permeability variation of black cotton soil with the increasing of plastic waste percentage in soil.

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 soils particles increased (Khazaei J et al., 2019). 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 has remained under tension. Consequently, the post-peak shear strength reduction is less noticeable than in unreinforced specimens (Majji Gowri DNC et al., 2018). 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 Figure 7 (b). 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 (Modak PR et al., 2012). At the 10% PET mix, the specimen deviates from the increasing nature due to the excessive amount of PET in the sample (Modak PR et al., 2012). The excessive amount of PET hinders the interlocking behavior of soil. The frictional interaction between soil particles and PET waste with 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 (Moharir RV et al., 2019). In the study of Al-Taie et al. (2020), 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 black cotton soil for 5-9% PET inclusion. (Muntohar AS et al., 2019) 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. (Nath AD., 2021). The application of plastic strip in soil significantly decreased soil swelling and desiccation fracturing characteristics (O'Kelly BC et al., 2022).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 who is corelated with the research of (Peddaiah S et al., 2018).

The findings of the permeability of the black cotton plastic strip reinforced soil in this investigation are similar to the study of (Sahoo K et al., 2022). 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. Figure 10 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 raise pavement maintenance costs and reduce pavement life (Salimi K et al., 2021). Therefore, it is better to have a greater permeability coefficient of unbound materials in pavement applications (Singh S et al., 2013). This can improve water drainage system of the soil and prevent water from accumulating inside the soil.

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 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 behavior was greatly enhanced by the use of plastic waste as a reinforcing material (Sivakumar Babu GL et al., 2012). 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 (Sobuz MHR et al., 2022). The use of a large amount of plastic strip in soil saves the cost and embodied CO_2 emission, which leads to a sustainable solution of the plastic waste.

RECOMMENDATIONS FOR FURTHER STUDIES

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.

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