Strength and compressibility characteristics of soil stabilized with plastic bag strips

Jayasree P K (jayasreepk@cet.ac.in)  
College of Engineering Trivandrum  
https://orcid.org/0000-0002-2229-4076

Monica Simon  
College of Engineering Trivandrum

Vismaya A  
College of Engineering Trivandrum

Vinod J S  
University of Wollongong

Research Article

Keywords: plastic bag strips, Unconfined compressive strength, compressibility, aspect ratio, thickness

DOI: https://doi.org/10.21203/rs.3.rs-730971/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

This study investigates the potential application of utilizing plastic bag strips (PBS) in improving the strength and compressibility behavior of soils. A series of unconfined compressive strength (UCS) and consolidation tests were carried out for different proportions of plastic bag strip reinforced soil. The effect of the thickness ($t$) and aspect ratio (AR) on the UCS and compressibility characteristics of PBS reinforced soil was investigated. The thicknesses of PBS used were 15 µm, 30 µm and 45 µm which were added in varying concentrations (0.1%-0.7%) at different aspect ratios 1, 2 and 2.5. The laboratory results clearly show that PBS have a significant influence on the UCS and compressibility behavior of soil. In addition, the peak value of UCS ($q_u$) increases with the thickness and AR of PBS. A significant improvement in $q_u$ has been found for 0.5% addition of PBS. Moreover, the swelling behavior of soil has significantly reduced with the addition of PBS.

1 Introduction

Plastic waste is a major concern in urban and rural areas in India. Littering of plastic waste and its by-products may lead to major health concerns for all living beings. These days plastic has become an essential part of our lives; however, the data on plastic pollution is shocking. It is produced on a gigantic scale all over the world and its global production exceeds 150 million tons per year (Peddaiah et al., 2018). Recycling of plastics is not a promising alternative for plastic waste management since it is costly. Recently many research studies have been made on the effective reuse of plastic waste in civil engineering applications (Sobhanand Manshad, 2003, Peddaiah et al., 2018). In India, it is now mandatory for all road developers to use waste plastic, along with bituminous mixes, for road construction. Therefore, in this study, an attempt has been made on the feasibility of using plastic waste in improving the properties of subgrade soil.

In the recent past, plastics were used in the form of fibers for improving the performance of both cemented (Kaniraj and Havanagi, 2001 and Correia et al., 2015) and uncedmented (Santoniet al., 2001 and Consoliet al., 2002) soils. Fiber inclusion (any type) had more influence on the cemented soils in reducing the brittleness behavior of soil by bridging the failure plane (Deb and Namaware, 2015). Further studies that have emphasized the use of fibers on uncedmented soft soil (Botero et al., 2015 and Tang et al., 2007) observed greater improvement in the compressive and shear strength of soil for fiber dosages of 0.25–1%. The addition of plastic waste in the form of fibers (0.25% and 0.5%) (Tang et al., 2007 and Chen et al., 2015) improved the unconfined compressive strength (UCS) of cemented clay by about 207%. Thomecroft et al. (2017) mixed different types of plastic waste with cement to produce sturdy and flexible concrete slabs. Plastics were used along with other additives such as lime (Muntohar et al., 2009, Muntohar et al., 2013 and Boz et al., 2018) to improve the strength of soft soil. The stability of infrastructure such as foundation and roadbeds improved with the technique of reinforcing lime stabilized or unstabilized soil with polypropylene fiber. The increase in the amount of plastic waste in the range of 0.4–0.8% improved the shear strength, compressive strength, and the CBR values of lime stabilized soft soils. Okoro et al. (2011) added fused plastic bottles to clay to improve the consolidation
characteristics of the soil. Plastic bottles heated at 275°C were mixed with the soil (plastic to soil ratio of 1) and it was found that the plastic waste stabilized specimen exhibited a lower initial void ratio. Plastic bottle strips added in various aspect ratios at plastic content ranging from 0.4–1% improved the shear strength of soil by 39–121% (Babu and Chouksey, 2011 and Peddaiah et al., 2018) whereas the compressibility reduced by 37% (Babu and Chouksey, 2011). The addition of perforated plastic strips (Kalumba et al., 2013) led to a notable improvement in the friction angle compared to the addition of solid plastic strips to sandy soil at 0.1% plastic content. Choudhary et al. (2010) observed that the use of 4%HDPE plastic bag strips on locally available sand improved the CBR values by 189%. Plastic wastes in the form of Recycled Plastic Pins (RPPs) were used by Khan et al. (2016) to provide additional resistance along the slip surface to mitigate a shallow slope failure. A new method of adding polyethylene wastes in the form of grains (passing through 4 mm sieve and retained on 0.25 mm sieve) to soil was introduced by Ilies et al. (2017) to improve the shear strength. Production of poly-ethylene grains as a stabilizing soil material has a lower carbon footprint than cement or other hydraulic binders. Recent studies conducted to analyze the potential of using shredded plastic waste in improving the properties of soil (Jegan and Salini, 2019) showed that the compressive strength of soil increased by 12% for finely shredded mixed plastic wastes. The increase in the size of the shredded plastic waste reduced the compressive strength of the soil. It was reported that the addition of plastic waste had a significant improvement in the strength as well as the compressibility characteristics of the soil. However limited studies have been conducted to analyze the performance of soil strengthened with plastic carry bags. Therefore, this study examines the influence of plastic carry bag strips of various thicknesses and aspect ratios on the strength and compressibility characteristics of subgrade soil.

2 Materials And Methodology

The soil used for the study was collected from Mangalapuram, Trivandrum (Kerala, India). Detailed laboratory tests were carried out to determine the physical properties of soil. The specific gravity of the soil is 2.56. The liquid limit, plastic limit and shrinkage limit of the soil are 53%, 37%, and 22% respectively. The particle size distribution curve highlights that the soil is composed of clay (27%), silt (32%), sand (40%), and gravel (1%). The soil was classified as MH according to the USC system. The plastic bag strips (PBS) having a thickness (t) of 15 µm, 30 µm, and 45 µm and aspect ratios (AR) of 1, 2, and 2.5 were used for testing. A wide-width tensile strength test was carried out according to ASTM D4595 to determine the tensile strength of PBS (Fig. 1). The inset of Fig. 1 shows the wide-width tensile testing of PBS and PBS having a thickness of 15µm used for the testing program. It is shown that the peak tensile strength increases with the thickness of the PBS.

The unconfined compressive strength (UCS) tests were performed to analyze the strength characteristics of PBS-soil mixtures. The specified quantity of dry soil was mixed with a different amount of PBS (χ = 0.1–0.7%) to form a homogenous mixture. The amount of PBS (χ) was determined based on the dry weight of the soil. The PBS-soil mixtures were prepared at the optimum moisture content (OMC) of the soil (i.e. OMC = 20.5%) and statically compacted in a split mold of size 38 mm in diameter and 75 mm in
height. A series of UCS tests were carried out on soil to investigate the effect of PBS, \( t \), and AR on the strength of the soil. PBS-soil samples were prepared for \( \chi = 0.1\% - 0.7\% \).

Consolidation tests were also carried out to study the compressibility behavior of PBS-soil mixtures as per ASTM D2435. Samples of PBS-soil mixtures were prepared in a standard consolidation ring (60 mm diameter x 20 mm height) having water content equal to the liquid limit of soil. All the PBS-soil specimen was loaded with a load increment ratio of 1. All specimens were loaded up to a vertical pressure of 800 kPa to capture the compression index \( (C_c) \) before unloading to determine the recompression index \( (C_r) \). The coefficient of consolidation \( (c_v) \) of PBS reinforced soil was determined using Taylor’s \( \sqrt{t} \) method.

### 3 Results And Discussion

#### 3.1 Effect of PBS on the UCS of Soil

The unconfined compressive stress-axial strain relationship of soil reinforced with PBS having a thickness 30 \( \mu \text{m} \) is presented in Fig. 2. It is evident from Fig. 2 that PBS has a significant influence on the UCS and initial tangent modulus of the soil. The UCS increases with an increase in the amount of PBS up to \( \chi = 0.5\% \). Thereafter, UCS decreases with a further addition of PBS. The initial tangent modulus also increases with an increase in \( \chi \). The increase in UCS may be due to the increased interaction between PBS and soil mobilizing the reinforcement effect of PBS. Moreover, the axial strain \( (\varepsilon) \) corresponding to the peak value of UCS \( (q_u) \) also increases with the addition of PBS up to \( \chi = 0.5\% \). A similar response on the increase of \( q_u \) with \( \chi \) is also reported on plastic bottle strips reinforced sand (e.g. Babu and Chouskey, 2011).

The performance improvement in \( q_u \) is expressed by the UCS improvement factor \( (q_{if}) \), defined as the ratio of \( q_u \) of reinforced soil to that of unreinforced soil. The values \( q_{if} \) for different percentage of PBS \( (\chi) \) are presented in Table 1. It is shown that the \( q_{if} \) for \( \chi = 0.5\% \), has increased as high as 3 times to that of untreated soil. As expected, \( q_{if} \) decreases with an increase in \( \chi \) \((\chi > 0.5\%)\).

| Thickness of plastic strips, \( t \) (\( \mu \text{m} \)) | PBS content, \( \chi \) (%) |
|---|---|---|---|---|---|---|
| | 0.3 | 0.5 | 0.7 | 0.3 | 0.5 | 0.7 |
| \( q_{if} \) | 2.4 | 2.3 | 3.1 | 2.7 | 2.5 | 1.4 |
| \( E_{if} \) | 1.2 | 1.5 | 1.6 | 1.9 | 0.9 | 1.2 |
| \( q_{if} \) | 1.4 | 1.7 | 1.9 | 2 | 0.9 | 1.3 |
3.2 Effect of Thickness of PBS on the UCS of Soil

The influence of the thickness ($t$) of PBS on $q_u$ for different proportions of PBS is shown in Fig. 3. It can be inferred that the 15 µm thickness PBS has shown significant improvement in $q_u$ compared to the thickness of 30 µm and 45 µm, irrespective of $\chi$. The $q_u$ decreases with an increase in the thickness of PBS. It is expected that an increase in $t$ may decrease the soil interaction leading to a decrease in $q_u$.

3.3 Effect of Aspect Ratio (AR) of PBS on the UCS of Soil

The effect of AR on $q_u$ for different amounts of PBS ($\chi$) is shown in Fig. 4. It is evident from Fig. 4 that AR has a significant influence on $q_u$ of the soil. It is shown that AR = 2 exhibits a higher value of $q_u$ irrespective of $\chi$. It is believed that the increase in AR contributes to an increase in the interaction between soil and PBS. Therefore, irrespective of $\chi$, an increase in $q_u$ with AR is observed in Fig. 4. As shown earlier, for all values of AR, $q_u$ increases with the addition of PBS up to $\chi \leq 0.5\%$, thereafter, $q_u$ decreases with an increase in $\chi$. In addition, the variation of $q_u$ with $\chi$ is also compared with the experimental results reported by Muntohar et al. (2013) on fiber reinforced lime treated silty soil. The results of the present study compare well with the experimental finding of Muntohar et al. (2013).

3.4 Effect of PBS on the Modulus of the Soil

The variation of $E_{50}$ with PBS for different values of $t$ is shown in Fig. 5. With the increase in PBS, $E_{50}$ increases up to $\chi \leq 0.5\%$ and then decreases with an increase in $\chi$. The increase in $E_{50}$ is due to the soil-PBS interaction. However, for $\chi > 0.5\%$ the interaction between the PBS increases compared to the soil-PBS interaction, hence, $E_{50}$ decreases. It can also be inferred from Fig. 5 that, irrespective of $\chi$, PBS having a thickness of 15 µm exhibit a higher value of $E_{50}$.

The performance improvement in $E_{50}$ of the PBS reinforced soil is determined using modulus improvement factor ($E_{if}$) defined as the ratio of $E_{50}$ of the reinforced soil to that of unreinforced soil. The values $E_{if}$ for different percentages of PBS ($\chi$) are presented in Table 1. A two-fold increase in $E_{50}$ compared to untreated soil is observed with $\chi = 0.5\%$ ($E_{if} = 2.7$).

3.5 Compressibility and Swelling Behavior of PBS Reinforced Subgrade Soil

A detailed one-dimensional consolidation test was carried out to understand the consolidation behavior of PBS reinforced soil. All the tests were conducted with PBS having AR = 2. Figure 6 presents the compression index ($C_c$) and recompression index ($C_r$) of the soil for various amounts of PBS and thickness ($t$). It is evident from Fig. 6 that PBS has a significant influence on $C_c$ and $C_r$ of the soil. A lower value of $C_c$ and $C_r$ is observed for PBS reinforced soil. The value of $C_c$ and $C_r$ decreases with $\chi$ up to a value of 0.5%. Thereafter the $C_c$ and $C_r$ increase slightly with the addition of PBS. Moreover, thickness ($t$) has a significant influence on $C_c$ and $C_r$ of the soil. Irrespective of $\chi$, $C_c$ and $C_r$ decrease with an increase in $t$. It is evident from the test results that PBS has the potential in controlling the swelling behavior of soil. The variation in $C_c$ and $C_r$ with $\chi$ is consistent with the observation made by Okoro et al. (2011).
The variation of $c_v$ value with an increase in effective normal stress for various percentages of PBS is shown in Fig. 7a. The $c_v$ values were calculated using Taylor’s $\sqrt{t}$ method. It is evident from Fig. 7a that, $c_v$ increases with an increase in $\chi$. For a particular value of $\sigma'$, $c_v$ increases with the proportion of $\chi$ up to 0.5%. For $\chi > 0.5\%$, $c_v$ decreases with the addition of PBS. Moreover, as anticipated, $c_v$ decreases with an increase in the effective normal stress. Effect of thickness of PBS ($t$) on $c_v$ value for various percentages of PBS for a particular value of $\sigma'(\sigma' = 392.4 \text{ kPa})$, is shown in Fig. 7b. It can be seen that $c_v$ increases with the increase in $t$.

4 Limitations

The laboratory experiments have captured the strength and compressibility behavior of soil reinforced with PBS. However, the laboratory tests were conducted with PBS having a maximum width of 12 mm, which is higher than $1/6$th of the specimen diameter. Therefore, the experimental data may have been affected by the sample size.

5 Conclusions

This paper reports the results of the laboratory experiments carried out to understand the strength and compressibility behavior of PBS treated soil. The UCS and consolidation tests were conducted by varying the thickness and aspect ratios of the PBS for different percentages of PBS. The following conclusions can be drawn based on the results obtained from the experimental program.

1. The inclusion of PBS had a significant influence on the $q_u$ of the soil. The strain corresponding to $q_u$ increases with $\chi$ and $q_u$ showed a higher value for $\chi = 0.5\%$.
2. The thickness, $t$, and aspect ratio, AR, of the PBS have influenced the $q_u$ of the soil. The $q_u$ decreases with an increase in $t$, but increases with AR. The variation of $q_u$ with the addition of PBS has shown a close agreement with the literature.
3. The PBS has influenced the compression index, ($C_c$) and recompression index ($C_r$) of the soil. The $C_c$ and $C_r$ were reduced with the addition of PBS. The potential prospect of the use of PBS in controlling the swelling of the soil was evident from the reduction in $C_r$. A 65% reduction in swell was observed with 0.5% addition of PBS to the soil.

Declarations

Acknowledgments

The authors wish to acknowledge the technical staff, College of Engineering Trivandrum, for their support in conducting the laboratory testing. The first author gratefully acknowledges the Clean Kerala Company Ltd (Govt. of Kerala, India) for the information on the application of plastic waste for infrastructure development.
References

Correia AAS, Oliveira PVJ, Custodio DG (2015) Effect of polypropylene fibers on the compressive and tensile strength of soft soil artificially stabilized with binders. Geotext Geomembr 43:97-106

ASTM D4595 (2011) Standard test method for tensile properties of geotextiles by the wide-width strip method D4595, West Conshohocken, PA.

Babu SGL, Chouskey SK (2011) Stress-Strain Response of Plastic Waste Mixed Soil. Waste Manag J 31(3):481-488

Botero E, Ossa A, Sherwell G, Ovando-Shelley E (2015) Stress-strain behavior of a silty soil reinforced with polyethylene terephthalate (PET). Geotext Geomembr 43(4):363-369

Boz A, Sezer A, Ozdemir T, Hızal GE, Dolmaci OA (2018) Mechanical properties of lime-treated clay reinforced with different types of randomly distributed fibers. Arab Geosci J 11(6):122

Chen M, Shen SL, Arulrajah A, Wu HN, Hou DW, Xu YS (2015) Laboratory evaluation on the effectiveness of polypropylene fibers on the strength of fiber-reinforced and cement-stabilized Shanghai soft clay. Geotext Geomembr 43:515-523

Choudhary AK, Jha JN, Gill KS (2010) Utilization of Plastic Wastes for Improving the Sub-grades in Flexible Pavements. Paving Materials and Pavement Analysis, ASCE Geotechnical special publication no. 203, Proceedings of Geo-Shanghai International conference (ASCE), Shanghai, China, pp 320-325

Consoli NC, Montardo JP, Prietto PDM, Pasa GS (2002) Engineering behavior of a sand reinforced with plastic waste. Geotech Geoenviron J 128(6):462-472

Deb K, Narnaware YK (2015) Strength and compressibility characteristics of fiber-reinforced subgrade and their effects on response of granular fill-subgrade system. Transportation in developing Economies, A Journal of the Transportation Research Group of India, Springer, 1(2):1-9

Ilies NM, Circu AP, Nagy AC, Ciubotaru VC, Kisfaludui-Bak Z (2017) Comparative study on soil stabilization with polypropylene waste materials and binders. Procedia Eng 181(2017):444-451

Jegan BKA, Salini U (2019) Use of Shredded Waste Plastic in Stabilization of Subgrade Soil. Proceedings of the international conference on geotechnics for high speed corridors, Trivandrum, pp 524-526

Kalumba D, Chebet FC (2013) Utilization of polyethylene (plastic) shopping bags waste for soil improvement in sandy soils. Proceedings of the 18th international conference on soil mechanics and geotechnical engineering, Paris, pp 3223-3226

Kaniraj SR, Havanagi VG (2001) Behavior of cement-stabilized fiber-reinforced fly ash-soil mixtures. Geotech Geoenviron J 127(7):574–584
Khan PE, Hossain PE, Kibria G (2016) Slope stabilization using recycled plastic pins. Perform Constr J 30(3)

Muntohar AS (2009) Influence of plastic waste fibers on the strength of lime-rice husk ash stabilized clay soil. Civ Eng Dimens J 11(1):32-40

Muntohar AS, Widianti A, Hartono E, Diana W (2013) Engineering properties of silty soil stabilized with lime and rice husk ash and reinforced with waste plastic fiber. Mater Civil Eng J 25(9):1260-1270 Data sets. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29MT.1943-5533.0000659

Okoro C, Vogtman J, Yousif A, Agnaou M, Khoury N (2011) Consolidation characteristics of soils stabilized with lime, coal combustion product and plastic waste. Proceedings of Geo-frontiers 2011 pp 1202-1209

Peddaiah S, Burman A, Sreedeep S (2018) Experimental study on effect of waste plastic bottle strips in soil improvement. Geotech Geol Eng J 36(5):2907-2920

Santoni RL, Tingle JS, Webster SL (2001) Engineering properties of sand-fiber mixtures for road construction. Geotech Geoenviron J 127(3):258-268

Tang CS, Shi B, Gao W, Chen FJ, Cai Y (2007) Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotext Geomembr 25(3):194-202

Thorneycroft J, Ball RJ (2017) Performance of structural concrete with recycled plastic waste as a partial replacement for sand. Construction and Building Materials. DOI: 10.1016/j.conbuildmat.2017.11.127

**Figures**
Figure 1

Wide width tensile strength response of PBS; Inset (a): wide-width tensile testing of PBS, (b): PBS of thickness, $t = 15\,$m.

Figure 2

Unconfined compressive stress- Axial strain graph for different values of $\chi$ and $t = 30\,$m.
Figure 3

Variation of qu with x for different values of t (AR=1)
Figure 4

Variation of qu with x for different values of AR (t = 15m)
Figure 5

Variation of E50 with x for different values of t (AR=1)
Figure 6

Variation of Cc and Cr for different values of $\chi$

![Graph showing variation of Cc and Cr](Image)

Figure 7

a. Variation of cv with x for different values of x
b. Variation of cv with x for different values of t

![Graph showing variation of cv with x](Image)