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Utilizing Recycled Vegetable Plastic Bags as an Innovative and Sustainable Material for Soil Reinforcement Applications

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Abstract: Soil reinforcement techniques have become essential in geotechnical engineering to improve weak soils. This study deals with the use of waste vegetable plastic bags made of High-Density Polyethylene (HDPE) as reinforced materials for fine grained soils selected from Nizwa-Oman. Laboratory practical works were conducted to evaluate compaction and unconfined compressive strength (UCS) characteristics of soil reinforced with varying number of plastic mats. Namely, 1, 2, 3, and 4. The results indicated that reinforcing the weak soil with HDPE plastic bags significantly improved compressive strength with optimal performance observed at three reinforcement mats making four soil layers. The study not only provides an effective method for weak soil improvement but also contributes and offers an eco-friendly to sustainable waste management by repurposing non-biodegradable plastic waste. This work maps to several United Nations Sustainable Development Goals (SDGs) due to its environmental, infrastructural, and waste management implications.

Keywords: Soil reinforcement; HDPE plastic bags; Compaction; Compressive strength; Sustainable construction

1 Introduction

Throughout Reinforced soil technology has gained importance over recent decades due to its effectiveness in improving bearing capacity, reducing settlement, and enhancing shear strength. Conventional materials such as metallic strips, geotextile and synthetics fiber are commonly used, but environmental concerns and cost-consideration have prompted the exploration of alternative materials like recycled plastics [1–5]. Soil reinforcement using plastic waste has been well established practice aimed at enhancing the soft soil properties [6, 7]. A wide range of plastic waste such as plastic fibers, plastic mats, plastic strips and powder have been identified as effective reinforcement for weak soil properties enhancement. These are practically observed for their ability to improve soil mechanical properties [8–11].

Plastic waste pollution is a global issue, especially in developing countries were recycling infrastructure is limited. Waste plastic, particularly polyethene bags, possess a significant environmental threat due to its non-biodegradability. However, these materials possess high tensile strength and durability, making them suitable candidates for reinforcing weak soil structures [12–18].

Simultaneously, weak soils pose challenges in road subgrades, foundations construction, retaining structures backfilling and retaining wall construction materials [5, 19].

In the face of escalating plastic pollution and the urgent need for sustainable engineering solutions, this study explores the potential of reusing discarded plastic bags as soil reinforcement material in geotechnical applications. Traditional soil stabilization techniques often rely on non-renewable or costly materials. This research proposes an innovative, low-cost, and eco-friendly alternative by integrating shredded plastic bags into soil to enhance its mechanical properties, including shear strength and compaction behavior.

The approach directly supports SDG 9 (Industry, Innovation, and Infrastructure) by promoting the adoption of sustainable construction practices. It advances SDG 12 (Responsible Consumption and Production) by extending the lifecycle of plastic waste and reducing dependency on virgin materials. Furthermore, by diverting plastic from landfills and the natural environment, the project contributes to SDG 11 (Sustainable Cities and Communities) and SDG 15 (Life on Land), minimizing environmental degradation and land pollution. Finally, the reduction in greenhouse gas emissions associated with plastic waste disposal aligns with SDG 13 (Climate Action). Increasing the compressive strength and tensile strength of soil due to reinforcement is contributing in a higher resistance of the soil to creative exposed compressive and tensile loads in highway soil courses of subgrade and subbase, backfilling materials behind retaining walls, embankment reinforced layers, mechanical stabilized retaining walls, and soil under the construction foundations.

In this study reusing vegetable plastic bags is autolyzed as a reinforcement material for improving the properties of local fine soil from Nizwa City, Sultanate of Oman. This laboratory work aims to evaluate the effectiveness of vegetable plastic bags in improving the mechanical properties of soil namely its compressive strength and compaction characteristics. The work addresses both issues by autolyzing plastic waste as a reinforcement to stabilize poor quality soils.

2 Materials and Methodology

2.1 Soil

A fine soil is selected from Ghobrate Nizwa area located in Willayat Nizwa, 140 km south-east of Muscat—Oman. Samples were taken from a depth of 0.8–1.5 m to ensure that samples are not affected by the weathering conditions and representing the natural condition of formation.

2.2 Water

All the study experiments were implemented using the potable water to maintain consistency and to avoid any effect of water quality variation.

2.3 Vegetable Plastic Bags

The used vegetable plastic bags were considered in the study as a soil reinforcement. These waste plastic bags are labeled as High-Density Polyethylene (HDPE). These materials were procured from homes, restaurants and supermarkets of Nizwa. The waste bags have an adequate property to be used as a soil reinforcement such as weaving strips which are giving stronger interlocking and resulting an acceptable tensile strength. The arranged strips in the plastic bags can significantly enhance its strength and stability, acting as a form of reinforcement. Figure 1 shows the kind of material used. The preparation of the reinforcement used was implemented by cutting the plastic bags into a circular shaped mat of same diameter of the compaction mold used. Using the HDPE plastic bags as a mat for reinforcing the soil gives an advantage to the prior studies using different shapes of plastics that the plastic bags have appreciable rough surfaces due to the weaving process of manufacturing or the granular surfaces. These rough surfaces play an important role in increasing the friction between the soil particles and reinforcement which is considered as the main principles of the effectiveness of soil reinforcement [20].

Figure 1. Plastic bag and weaving details

2.4 Preparation of Reinforced Soil Specimens and Testing

To prepare the plastic mat-reinforced soil specimens, the soil was first thoroughly mixed with the recommended quantity of water to give the specified water content for the compaction. The plastic mats were placed in the soil in a manner to have four different cases of arrangement, one mat with two compacted soil layers, two mats with three compacted layers, three mats with four compacted soil layers and four mats with five compacted soil layers. The thickness of the compacted layers varied with the number of mats, but of equal value in each specified case. Figure 2 shows the arrangement of plastic mat reinforcement in different cases of selection. The arrangements of mats were critical to ensure an even effect of the reinforcement throughout the soil matrix [2].

The reinforced soil was compacted in a cylindrical mold with a diameter of 102 mm and height of 105 mm. The compaction was performed using the modified AASHTO compactive energy method. Accordingly, the number of standard hammers blows per layer was varied in order to give the total compactive energy. This was done using number of blows as 64 for one plastic specimen mat, 41 blows for two plastic mat specimen, 32 blows for three plastic mat specimen and 25 blows for four plastic mat specimens.

This compaction technique is widely recognized for its effectiveness in simulation field conditions [21].

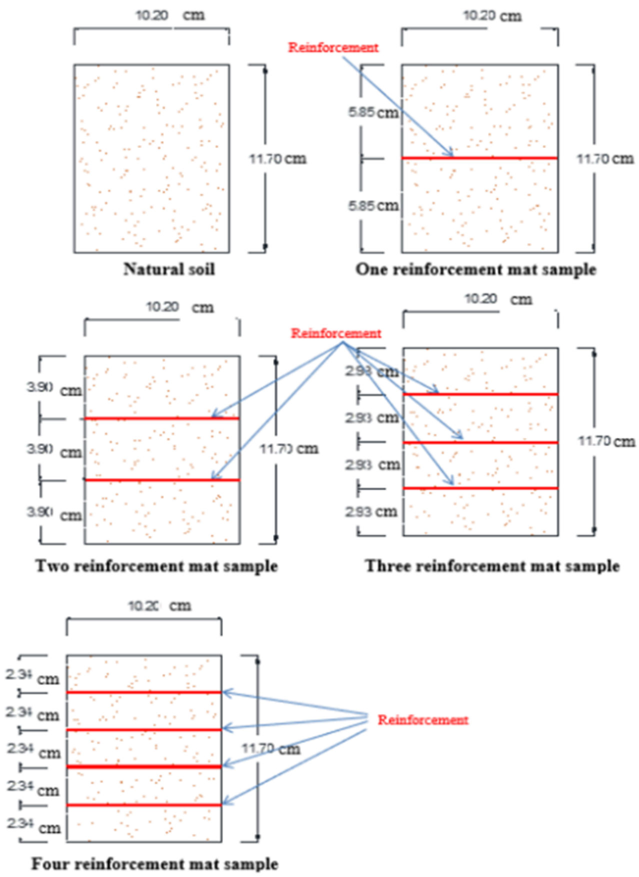

Figure 2. Arrangement of reinforcement mats in soil specimens

For each soil-mat arrangement, five molds were compacted at various moisture content in order to determine the compaction characteristic. After the completion of compaction process, the reinforced soil specimens were extruded from the molds and subjected to unconfined compressive strength testing (UCS) to failure. This test was essential to evaluate the improvement in compressive strength due to the addition of plastic mats as a reinforcement [22].

3 Results and Discussion

3.1 Index Properties of Soil

Table 1. Index properties of soil

Characteristics	Value
Liquid limit, %	39
Plastic limit, %	27
Plasticity index, %	12
Specific gravity of solid	2.68
Finer than #200 sieve, %	55
Clay content, %	12
Maximum dry unit weight, kN/m^3	19.62
Optimum moisture content, %compaction	11.21
Sulphate content, %	0.003
Organic matters, %	0.35
Unified classification	ML
AASHTO classification	A-4

Index properties of soil are shown in Table 1 and Figure 3. The soil is classified as Silt of low plasticity (ML) according to Unified Soil Classification System (USCS), and as A-4 according to AASHTO Classification System. The grain size distribution curve is shown in Figure 3.

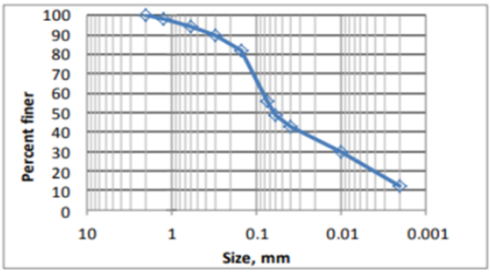

Figure 3. Grain size distribution curve of natural soil

3.2 Compaction Characteristics

3.2.1 Natural soil

The dry unit weight-water content relationship for natural soil is shown in Figure 4. The relation displays the typical behavior of soil with a maximum unit weight of 19.62 kN/m^3 and optimum water content of 11.21%.

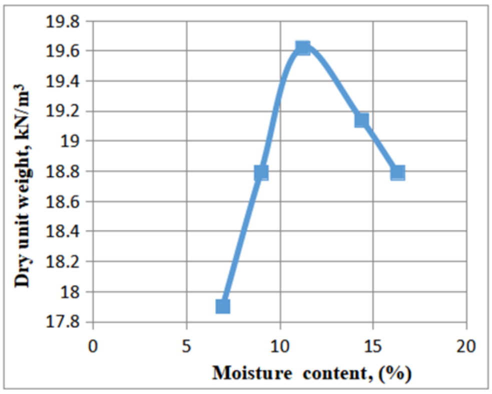

Figure 4. Compaction characteristics of natural soil

3.2.2 Reinforced soil

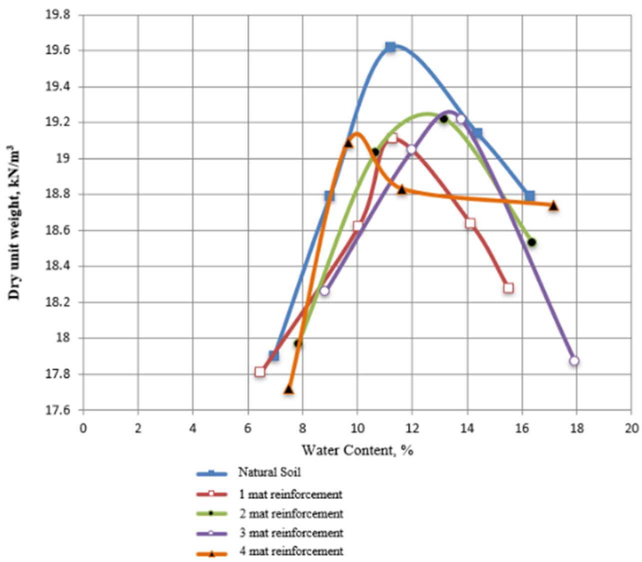

Figure 5. Compaction characteristics of soil with different mat reinforcement

The compaction characteristics of soil reinforced with different number of mats of plastic bags are shown in Figure 5. The overall behavior consistent across different number of reinforcement mats. It can be seen that the increase in dry unit weight of reinforced soil in dry side of optimum moisture content is more pronounced than the decrease on the wet side of the optimum moisture content. This behavior is indicating that the reinforced soil is more sensitive to water content change in dry side than in wet side of optimum.

The effect of varying number of reinforcing mats on the maximum unit weight is presented in Figure 6 showing a gradual decrease in maximum unit weight with increasing the number of reinforcing mats. This reduction can be related to the lower specific gravity of the material of plastic mats compared to soil solids. Figure 7 illustrates the impact of plastic reinforcement number on the optimum moisture content, showing a little decrease of the optimum moisture content with higher number of plastic mats. This is attributed to lower water absorption capacity of the plastic mats than the soil providing that the weight of the reinforcement is very small compared to the soil weight.

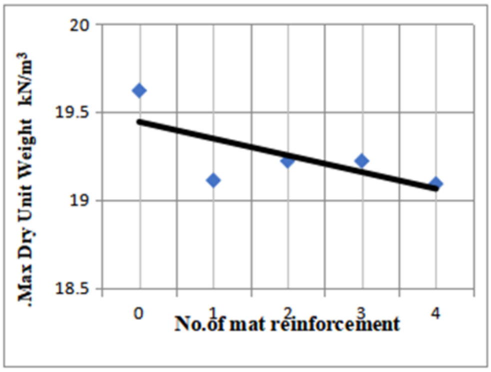

Figure 6. Effect of number of mat reinforcement on max. unit weight of soil

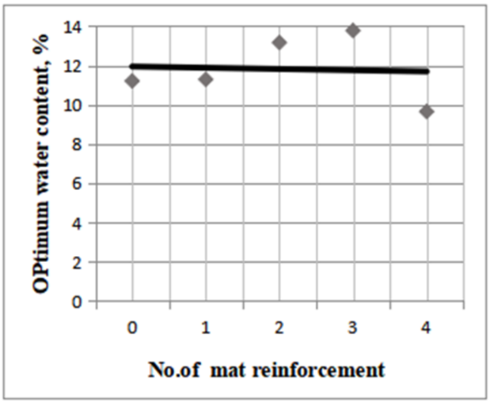

Figure 7. Effect of mat reinforcement on optimum water content

3.3 Strength Characteristics

Figure 8 presented the relationship between unconfined compressive strength (UCS) and water content for reinforced soil with various number of reinforcing mats. Or can be seen that compressive strength increases with water content up to certain level, after which it declines as water content continuous to raise. The behavior is consentient across different number of reinforcing mat soils and similar to the behavior of dry unit weight versus water content relationships.

The variation of optimum moisture content with the reinforcement number of mats in reinforced soil can be observed in Figure 8, showing a reduction in optimum moisture content with the increasing of number of reinforcing mats in general. This indicates that less water is needed to achieve maximum strength in soil with higher number of reinforcing mats.

The effect of number of reinforced mats on the compressive strength of reinforced soil is illustrated in Figure 9. The compressive strength increases with the number of reinforcements with more significant rate of increase at higher number of reinforcements, namely at 3 mats, for more than 3 mats, the rate of increase becomes lower. This is maybe due to the fact that the process of compaction in densifying the soil depends very much on the soil layer thickness and the compactive energy creative in soil. As the compacted layer thickness reduced to certain value, the compactive energy consumed may disturb the arrangement of the soil particles for densification resulting a loosening in particles interlocking and reduction in friction between the reinforcement and soil particles taken place. Accordingly, 3 reinforcement mats can be considered as an optimum value for the strength giving 4 soil layers. The developed increase in strength using the optimum soil layer thickness shown to be more than 3 folds, namely up to 980 kN/m^2. The increase in strength can be attributed to the fraction between the soil particles and surface area of plastic mat, coupled with relatively high tensile strength of plastic mat. The interaction between the plastic mat surface area and soil particle creates an indirect binding force, effectively adding cohesion to the soil. Additionally, the high tensile strength of plastic mats enhances frictional resistance, contributing to higher system failure resistance. The factors collectively result in an increase in compressive strength of the reinforced soil [23]. Vidal [20] has originated the soil reinforcement technique using the steel strips as a reinforcement, and out of his intensive study the above-mentioned justification for soil strength improvements has been indicated.

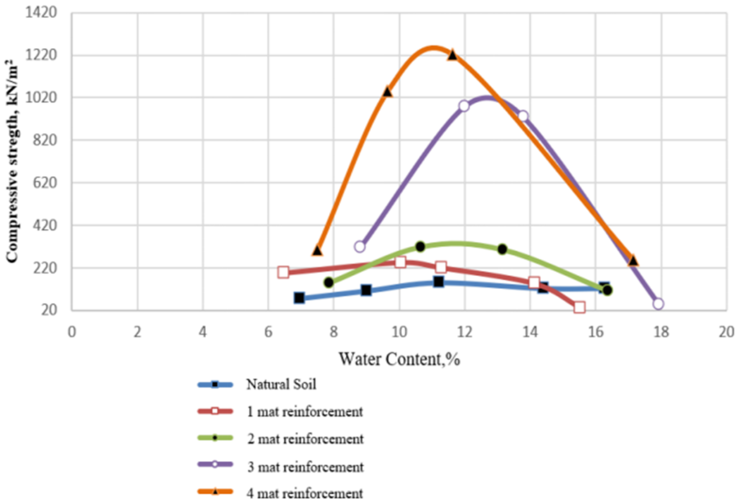

Figure 8. Strength characteristics of soil with different number of mat reinforcements

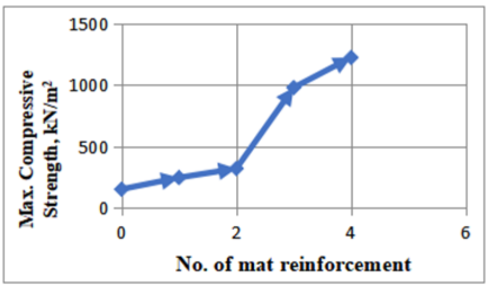

Figure 9. Effect of number of mat reinforcements on compressive strength

3.4 Field Application of Soil Reinforcement

Considering the HDPE as a soil reinforcement material in highway construction, not only to improve the mechanical properties of the subgrade layers but also provides an environmentally friendly solution to solid waste management by lowering the impact of solid waste on the environment. This approach satisfies the principles of a sustainable waste minimization. For instance, consider a project of highway subgrade construction. Taking a zone of highway subgrade 1.0 km long consist of 4 lanes with the shoulders, making a width of 19 m and having 3 reinforced soil layers using HDPE as a reinforcement. The HDEP has a density of 930 kg/m^3 and a thickness of 51 micron. Given these parameters, the total volume of HDPE for the 3 layers is calculated to 2.9 m^3 to achieve the optimal reinforcement as this study indicated, and providing 5 folds of the compressive strength approximately upon the natural soil strength. Accordingly, using the density and the volume to get 2.7 tons of plastic bags are required. This exploitation of solid waste significantly reduces the environment impact of the solid waste disposal, spotlighting the dual effect advantages of structural enhancement and environment protection. This study deals with the selected soil from Nizwa area- Sultanate of Oman and classified as Silt with low plasticity (ML). This type of soil is covering most of the flat areas and some of the coastal regions in Oman. The mountains areas of Oman mostly consist of

Granular soils, and hence the effect of such soil reinforcement will be more pronounced since the soil friction is higher and creating more interlocking effect with the reinforcement resulting higher strength.

It is still not clear what is the long-term environmental risks and effect of using HDPE mats in soil reinforcement and stabilization. Over time, exposure to UV radiation, temperature fluctuations, and mechanical stress can may cause HDPE to degrade, potentially releasing microplastics into the soil and nearby water sources. These microplastics potential to accumulate in ecosystems, posing risks to soil organisms and entering the food chain. While HDPE is generally durable and chemically inert, its long-term environmental impact raises concerns about sustainability and pollution and needs further investigation.

4 Conclusion

The study conducted on using the plastic bag mats as a soil reinforcement material has yielded significant insight into its optional benefits and effects on soil properties. The following conclusions can be drawn:

Incorporating mats of used vegetable tabplastic bags into Nizwa fine soil markedly improves its compressive strength. The study indicated that the strength of the soil increased by more than 3 folds with 3 reinforcing mats (up to 980 kN/m^2).

The maximum unit weight of reinforced soil decreases with increasing the number of reinforcing plastic mats. This can be of a benefit in the cases of reducing the load required for controlling the settlement.

As the number of the reinforcing plastic mats increasing the optimum water content needed becomes less with little influence. This has an advantage of reducing the quantity of water required for the soil compaction and reinforcement.

Overall, the study demonstrate that the used vegetable plastic bags can effectively considered as a soil reinforcement to improve the mechanical properties of fine soil.

Through laboratory testing and comparative analysis, this study demonstrates that reusing plastic bags not only addresses critical environmental concerns but also offers a scalable solution for sustainable infrastructure development in both urban and rural settings.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] F. Tanasă, M. Nechifor, M. E. Ignat, and C. A. Teacă, “Geotextiles—A versatile tool for environmental sensitive applications in geotechnical engineering,” *Textiles*, vol. 2, no. 2, pp. 189–208, 2022. https://doi.org/10.3390/textiles2020011

[2] I. Anastasopoulos, T. Georgarakos, V. Georgiannou, V. Drosos, and R. Kourkoulis, “Seismic performance of bar-mat reinforced-soil retaining wall: Shaking table testing versus numerical analysis with modified kinematic hardening constitutive model,” *Soil Dyn. Earthq. Eng.*, vol. 30, no. 10, pp. 1089–1105, 2010. https://doi.org/10.1016/j.soildyn.2010.04.020

[3] H. Chkala, S. Ighir, W. Ettahiri, M. Taleb, and N. E. EI Mansouri, “Feasibility of incorporating leaf date palm fiber in geopolymer composite made from mining waste,” *Constr. Build. Mater.*, vol. 428, p. 136188, 2024. https://doi.org/10.1016/j.conbuildmat.2024.136188

[4] L. Zhang, M. H. Zho, C. J. Shi, and H. Zhao, “Bearing capacity of geocell reinforcement in embankment engineering,” *Geotext. Geomembr.*, vol. 28, no. 5, pp. 475–482, 2010. https://doi.org/10.1016/j.geotexmem.2009.12.011

[5] A. M. George, A. Banerjee, A. J. Puppala, and M. Saladhi, “Performance evaluation of geocell-reinforced reclaimed asphalt pavement (RPA) bases in flexible pavements,” *Int. J. Pavement Eng.*, vol. 22, no. 2, pp. 181–191, 2021. https://doi.org/10.1080/10298436.2019.1587437

[6] M. Hafez, R. Mousa, A. Awed, and S. El-Badawy, “Soil reinforcement using recycled plastic waste for sustainable pavements,” in *Sustainable Solutions for Railways and Transportation Engineering*, 2018, pp. 7–20. https://doi.org/10.1007/978-3-030-01911-2_2

[7] K. Salimi and M. Ghazavi, “Soil reinforcement and slope stabilisation using recycled waste plastic sheets,” *Geomech. Geoeng.*, vol. 16, no. 6, pp. 497–508, 2021. https://doi.org/10.1080/17486025.2019.1683620

[8] S. Amena, “Experimental study on the effect of plastic waste strips and waste brick powder on strength parameters of expansive soils,” *Heliyon*, vol. 7, no. 11, p. e08278, 2021. https://doi.org/10.1016/j.heliyon.2021.e08278

[9] A. I. Dhatrak and D. K. Sunilkumar, "Laboratory performance of randomly oriented plastic waste in subgrade of flexible pavement," *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 3, no. 1, pp. 3969–3976, 2016. https://doi.org/10.15680/IJIRSET.2016.0503148

[10] A. Fauzi, Z. Djauhari, and U. J. Fauzi, "Soil engineering properties improvement by utilization of cut waste plastic and crushed waste glass as additive," *Int. J. Eng. Technol.*, vol. 8, no. 1, pp. 15–18, 2016. https://doi.org/10.7763/IJET.2016.V8.851

[11] G. Altay, C. Kayadelen, T. Taskiran, B. Bagriacik, and O. Toprak, "Frictional properties between geocell filled with granular materials," *Rev. Constr.*, vol. 20, no. 2, pp. 332–345, 2021. http://doi.org/10.7764/RDLC.20.2.332

[12] C. A. Anagnostopoulos, T. T. Papaliangas, D. Konstantinidis, and C. Patronis, "Shear strength of sand reinforced with polypropylene fiber," *Geotech. Geol. Eng.*, vol. 31, pp. 401–423, 2013. https://doi.org/10.1007/s10706-012-9593-3

[13] Z. X. Liu, D. M. Chen, and J. L. Qu, "Investigation of mechanical properties and micromechanisms of saline soil modified with synthetic fibers," *PLoS One*, vol. 20, no. 8, p. e0329941, 2025. https://doi.org/10.1371/journal.pone.0329941

[14] Y. F. Xu, J. Huang, Y. J. Du, and D. A. Sun, "Earth reinforcement using soilbags," *Geotext. Geomembr.*, vol. 26, pp. 279–289, 2008. https://doi.org/10.1016/j.geotexmem.2007.10.003

[15] G. Altay, C. Kayadelen, T. Taskiran, and Y. Z. Kaya, "A laboratory study on pull-out resistance of geogrid in clay soil," *Measurement*, vol. 139, pp. 301–307, 2019. https://doi.org/10.1016/j.measurement.2019.02.065

[16] M. Attom, S. Al-Asheh, M. Yamin, R. Vandanapu, N. Al-Lozi, A. Khalil, and A. Eltayeb, "Soil improvement using plastic waste-cement mixture to control swelling and compressibility of clay soil," *Buildings*, vol. 15, no. 8, p. 1387, 2025. https://doi.org/10.3390/buildings15081387

[17] L. Suthar, S. Meena, and V. Kumar, "Utilization using plastic waste in reinforcing sandy soil for sustainable engineering application," *J. Eng. Sci.*, vol. 11, no. 1, pp. H1–H8, 2024. https://doi.org/10.21272/jes.2024.11(1).h1

[18] F. A. A. Azam, R. bte Roslan, I. N. Z. Baharudin, and N. H. M. Muchlas, "Enhancing the soil stability using biological and plastic waste material integrated sustainable techniques," *Alex. Eng. J.*, vol. 91, pp. 321–333, 2024. https://doi.org/10.1016/j.aej.2024.02.016

[19] G. Altay, C. Kayadelen, H. Canakci, B. Bangriacik, B. Ok, and M. A. Oguzhanglu, "Experimental investigation of deformation behavior of geocell retaining walls," *Geomech. Eng.*, vol. 27, no. 5, pp. 419–431, 2021. https://doi.org/10.12989/gae.2021.27.5.419

[20] H. Vidal, "The principle of reinforced earth," *Transp. Res. Rec.*, pp. 1–16, 1969.

[21] ASTM International, "Standard test methods for laboratory compaction characteristics of soil using standard effort (12,400 ft-lbf/ft3 (600 kn-m/m3))," ASTM D698-12(2021), 2021. https://store.astm.org/d0698-12r21.html

[22] Y. Khrissi, A. Tilioua, and H. Lifi, "Experimental study of the reinforcement of unstabilized and stabilized local clay materials with date palm fibers," *Mater. Res. Proc.*, vol. 40, pp. 41–54, 2024. https://doi.org/10.21741/9781644903117-5

[23] F. M. AL-Oqla, "Evaluation and comparison of date palm fibers with other common natural fibers," in *Date Palm Fiber Composites: Processing, Properties and Applications*. Singapore: Springer, 2020, pp. 267–286. https://doi.org/10.1007/978-981-15-9339-0_10