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Strengthening the Base Course Layer of Asphalt Pavement using Shredded Plastic Water Bottles: Eco-Friendly Solutions

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Abstract The objectives of using shredded plastic water bottles in pavement industry are to combine environmental benefits with enhanced pavement performance for a more sustainable and effective infrastructure solution. This supports eco-friendly construction practices by integrating recycled materials into infrastructure, contributing to sustainable development goals. As the world faces growing concerns about plastic pollution and the need for more sustainable infrastructure solutions, the use of shredded waste plastic in pavement construction represents a significant step toward reducing waste while improving the performance of roads. In this study, plastic water bottles are processed and integrated into the base layer of pavement, potentially enhancing the durability and longevity of roads while also contributing to recycling efforts. The results show that adding 4 gm shredded plastic water bottles per kilo of soil helps improve the compressive strength as well as the California Bearing Ratio (CBR) by 23% and 28%, respectively, compared to the results of the soil sample without additives.

Keywords: Asphalt Pavement; Base Layer; Waste Plastic; CBR test.

1 Introduction

The road network forms a crucial part of a country's infrastructure, facilitating the movement of goods and people while supporting broader transportation systems. The durability and longevity of asphalt pavements are heavily dependent on the strength and stability of the base course. Water Bound Macadam (WBM) roads have been widely adopted in road construction due to their low cost and ease of construction, achieved by layering and compacting stone aggregates and binders to create a stable base. However, despite their widespread use, WBM roads are often challenged by limited load-bearing capacity, resulting in early deterioration and frequent maintenance. The strength of pavement layers is directly influenced by the subgrade soil's condition, typically assessed using the California Bearing Ratio (CBR) [1–4]. Weaker subgrades necessitate thicker pavement layers, while stronger subgrades allow for thinner layers. Both the pavement and subgrade must collectively support the expected traffic load [5]. To enhance the load-bearing capacity of WBM roads, various reinforcement methods have been proposed. One promising approach, which this study explores, involves incorporating plastic cells into the base layer to strengthen the structure. The results of this investigation will provide valuable insights into the effectiveness of this innovative technique in improving the performance of WBM roads.

Plastics are widely used across industries for their cost efficiency, lightweight properties, durability, and ease of processing compared to alternative materials [6–8]. Global plastic production surged to around 368 million metric tons in 2019, driven by increasing demand. Simultaneously, the recycling of materials, particularly for highway construction, has significantly advanced in availability and quality over the last decade. Numerous

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studies have shown that using Recycled Construction and Demolition Waste (RCDW) as a substitute for traditional aggregates in highway pavements offers significant potential. RCDW has proven particularly effective in base and sub-base layers due to its remarkable strength and durability, making it a viable alternative for enhancing the longevity of road infrastructure. It has been reported that plastic waste strips improve the tensile strength of expansive soils [9–11]. Several studies have confirmed the suitability of plastic waste as a soil stabilizer. Research has demonstrated that High-Density Polyethylene (HDPE) can effectively enhance subgrade soil properties; by incorporating varying lengths and proportions of HDPE strips derived from plastic waste into the soil, a series of CBR tests were performed. These tests revealed that adding HDPE strips to the soil significantly improves its performance, particularly for highway applications [12-13]. Further investigated the effects of plastic waste on soil reinforcement and found that mixing plastic waste with clayey and sandy soils at different ratios (0%, 2%, 4%, 6%, and 8% by weight) increased the cohesion of both soil types. However, the study also noted a reduction in the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) due to the lower specific gravity of the plastic particles [14]. A comprehensive review of the literature was conducted on the use of plastic waste in soil reinforcement. The review examined its history, benefits, applications, and challenges. It was found that the addition of plastic waste increases the dry density of lateritic soil and reduces water absorption, while also improving load-bearing capacity, as shown by the CBR value. An optimal 5% plastic waste content was found to enhance soil performance. While the use of plastic waste in soil stabilization can strengthen sub-base materials for road construction, the study also warns of potential environmental risks due to chemical leaching from the plastic [15]. A study was conducted to examine the effect of reinforcing the sub-base layer of water-bound macadam roads using plastic cells connected by plastic strips or secured with riveted joints. The results concluded that reinforcement significantly enhances the strength of the sub-base layer. Additionally, the results indicate that these interventions could help mitigate cost escalations in road construction projects. The study also lays the groundwork for future investigations into alternative jointing methods for the plastic cells [16]. The researchers addressed to use of plastic waste to reinforce expansive subgrade soils and reduce pollution. Expansive soils, which undergo significant volume changes, were treated with plastic strips at various percentages (0% to 2%). Results showed that increasing plastic content reduced swelling and compaction parameters, while CBR values improved. Unconfined compressive strength increased with plastic addition up to 0.5%, and soil cohesion improved up to 1.5% [17]. Soil stabilization using waste materials like demolished construction debris, bricks, fly ash, and factory byproducts is gaining popularity. However, plastic waste remains one of the most harmful to the environment due to its long decomposition time. This highlights the need for innovative methods for plastic waste disposal. The study concluded that incorporating plastic waste into soil stabilization enhances both soil performance and environmental sustainability. This approach not only serves as an eco-friendly solution but also strengthens the overall performance of pavement layers. Integrating plastic waste improves the permeability of the pavement and reduces water pressure accumulation within the pores. Additionally, it forms a lightweight structure, decreasing the weight of backfill materials, which helps reduce settlement rates and enhances durability by improving material adhesion [18].

2 Research Objectives

This study aims to enhance the base course layer of asphalt pavement by incorporating shredded plastic bottles, improving its load-bearing capacity and resistance to deformation under traffic loads. By repurposing plastic water bottles, the study helps reduce plastic waste in landfills, contributing to more sustainable waste management practices. The inclusion of plastic materials is expected to improve the long-term performance of asphalt pavements, increasing resistance to common issues such as cracking, rutting, and erosion. Additionally, using shredded plastic bottles can lower construction costs by partially replacing traditional aggregates with a low-cost, recycled material. This approach promotes eco-friendly construction practices, aligning with global sustainability and environmental protection goals. Furthermore, it enhances the flexibility and durability of the base course, reducing the need for frequent repairs and long-term maintenance costs.

3 Raw Materials

3.1 Soil for pavement base layer

The base layer is the layer below the asphalt surface layer and consists of gravel materials with a lower specification than the asphalt surface layer and is often untreated.

The base layer of asphalt pavement is crucial for providing structural support and ensuring the durability of the pavement. The base layer is an integral part of the road construction and has a direct and significant influence on the design and performance of the pavement. It is typically composed of various materials that offer strength, stability, and proper load distribution. The soil used for road construction should have a number of important properties such as stability, resistance to permanent deformation, good water drainage, and ease of compaction. In this research, a natural soil used in this research was supplied from Qena Governorate.

3.2 Shredded plastic water bottles

The empty water bottles produced by the same company are grouped to ensure that they have the same characteristics. These bottles were cut manually using scissors; the dimensions of one piece ranged from 90 to 100 mm in length and from 10 to 15 mm in width. The density of shredded plastic water bottles was determined, and the result was 1372 kg/m3. **Figure 1** presents the waste plastic materials used in this study.

Fig. 1 (a) Plastic water bottles and (b) Shredded plastic water bottles

4 Experimental Program

The experimental tests were designed to evaluate the effects of shredded plastic water bottles on soil properties. Different proportions of shredded plastic were incorporated into the soil to analyse their impact on soil strength and other geotechnical characteristics. Shredded plastic water bottles were added to the soil in varying percentages by weight (0%, 2%, 4%, 6%, and 8%). **Table 1** presents the experimental program that was conducted in this research. All results were compared with the results of the soil without the addition of shredded plastic water bottles to determine if there was a significant difference in performance. This comparison aimed to identify the optimal percentage of shredded plastic water bottles that could be added to the soil to improve the performance of the base layer for asphalt roads, while also addressing the environmental burden of discarded plastic bottles. Various tests were conducted, including gradation tests, Atterberg limits, compressive strength tests, and CBR.

Table 1 Soil samples with different quantities of shredded plastic water bottles and the experimental tests conducted

Shredded Plastic Water Bottles		Tests			
		Gradation Test	Atterberg Limits	Compressive Strength	CBR
0 gm per Kilo of soil	S0	√	√	√	√
2 gm per Kilo of soil	S2			√	√
4 gm per Kilo of soil	S4			√	√
6 gm per Kilo of soil	S6			√	√
8 gm per Kilo of soil	S8			√	√

4.1 Gradation test

Gradation test is essential for evaluating the particle size distribution of base course materials, ensuring they are well-graded for maximum stability and strength. A well-graded material contains a balanced mix of coarse, medium, and fine particles, which helps achieve better compaction, reduces void spaces, and enhances load-bearing capacity.

4.2 Atterberg limits

Atterberg Limits are used to determine the consistency and plasticity of fine-grained soils, helping engineers classify and assess soil behaviour under varying moisture conditions. They consist of three key parameters: Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). The Liquid Limit (LL) is the moisture content at which soil transitions from a plastic to a liquid state, measured using a Casagrande device. The Plastic Limit (PL) is the moisture content at which the soil begins to crumble when rolled into thin threads, indicating the boundary between plastic and semi-solid states. The Plasticity Index (PI) is the difference between LL and PL (PI = LL - PL), representing the range of moisture within which the soil remains plastic.

4.3 Compressive strength

The compressive strength of the base course is a critical parameter in road and pavement construction, as it determines the material's ability to withstand loads without significant deformation or failure. This strength is influenced by factors such as material composition, compaction level, moisture content, and the presence of stabilizers. **Figure 2** illustrates the different stages of preparing soil samples reinforced with shredded waste plastic during the compressive strength test.

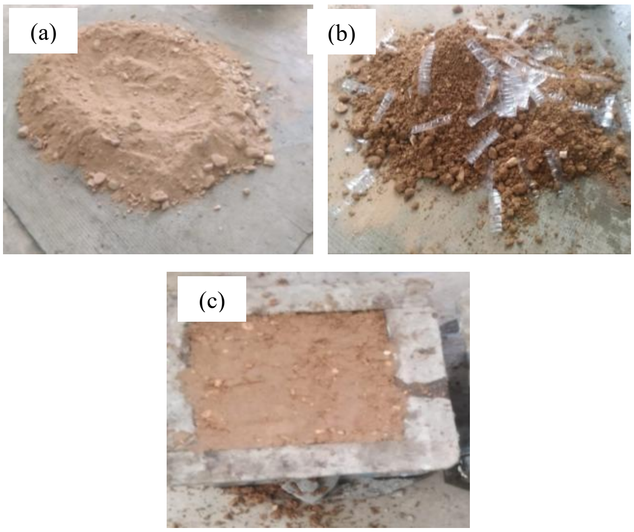

Fig. 2 Prepared samples for compressive strength test (a) Soil for base layer, (b) Mixing soil with different percentages of shredded plastic water bottles and (c) Compacted soil

4.4 California bearing ratio

The California Bearing Ratio (CBR) is a measure of the strength of soil or base material, primarily used in the design of pavement structures. It was developed by the California Division of Highways as part of their road construction design work. The CBR test is commonly used to evaluate the load-bearing capacity of subgrades, sub-bases, and base materials in road and pavement construction. The CBR test is performed by applying a standard load through a piston into a sample of soil (usually compacted to a specific density) and measuring the pressure required to achieve a given penetration depth. The test typically measures the resistance to penetration of a piston into a soil sample at 2.5 mm and 5.0 mm penetrations. The load at these penetrations is then compared to standard values to calculate the CBR value. The CBR value is expressed as a percentage of the load required to achieve the same penetration in a standard material (crushed stone). **Figure 3** shows the test sample and the apparatus used during CBR test.

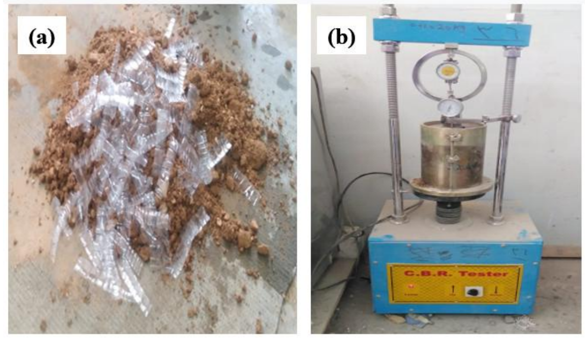

Fig. 3 CBR test set-up :(a) soil sample and (b) CBR device

5 Results

All the results from the lab tests were recorded and analysed to ensure accuracy and completeness. This section provides an overview of the findings, highlighting key observations and their significance.

5.1 Gradation test result

Gradation test result for the soil sample without shredded plastic water bottles is presented in **Fig. 4**. The gradation of the base soil of roads is an important factor in achieving the stability and durability of the road. The gradation is classified according to engineering standards to ensure good bearing capacity and effective drainage. The gradation results of the soil used were compared to the maximum gradation and minimum gradation specifications (gradation B) according to the Egyptian code. The results indicate the soil is well graded and suitable to be used as a base layer for asphalt pavement.

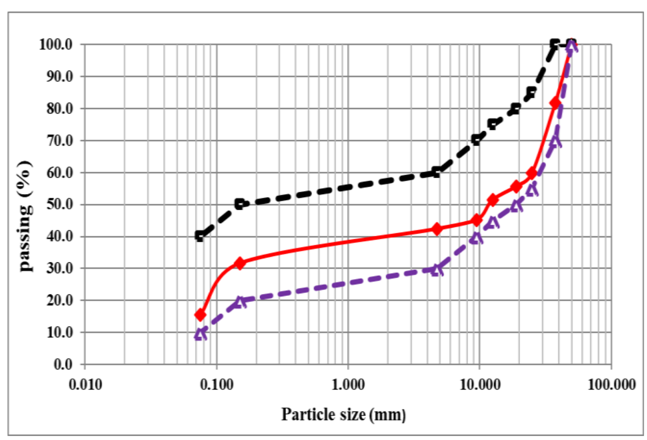

Fig. 4 Gradation test result for base layer soil and the max and min (gradation specifications (B)) according to the Egyptian code

5.2 Atterberg limits test result

The Atterberg limits test results are crucial for understanding the behaviour of fine-grained soils (clays and silts) under varying moisture conditions. The three key parameters: Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), provide insights into soil classification, engineering properties, and suitability for construction. According to the Egyptian Code, the plasticity index must not exceed 6, which makes the soil suitable for use as a base layer for roads. From **Table 2**, the Liquid Limit is equal to 38, and the Plastic Limit is equal to 32; then the difference is 6, which equals the Plasticity Index.

Table 2 Atterberg limits test result for the soil sample

Test			Plastic Limit				Liquid Limit			
Variable	No.									
	Var	Units	1	2	3	4	1	2	3	4
Number of Blows	N	blows					31	26	19	15
Can Number	---	---	14	8	19	21	34	15	7	17
Mass of Empty Can	M_C	(g)	18.5	18.6	21.3	19.0	17.5	18.5	19.5	20.2
Mass of Soil (Wet)	M_{CMS}	(g)	28.6	28.5	29.0	29.1	48.6	55.5	51.7	50.5
Mass of Soil (Dry)	M_{CDS}	(g)	24.3	27.5	27.1	28.0	41.2	46.6	41.6	41.3
Mass of Soil	M_S	(g)	5.7	9.0	5.9	9.0	23.7	28.0	22.0	21.1
Mass of Water	M_W	(g)	4.3	1.0	1.8	1.1	7.4	9.0	10.1	9.3
Water Content	w	(g)	74.6	11.2	30.9	12.2	31.3	31.9	46.0	43.9
Liquid Limit (LL or w_{ill}) (%)							38			
Plastic Limit (PL or w_P) (%)			32							
Plasticity Index (PI) (%)			6							

5.3 Compressive strength test result

The compressive strength test for soil determines the soil's ability to withstand compressive forces. The compressive strength value was calculated using the following formula:

Compressive Strength: Maximum Load / Cross-sectional Area of the sample

Figure 5 presents the results of the compressive strength test for soil samples modified with varying amounts of shredded plastic. Adding shredded plastic water bottles to a soil sample to improve its engineering properties is one of the techniques used to improve soil resistance to deformation and compression. Based on the results mentioned, the best compressive strength was achieved with the addition of 4% shredded plastic water bottles. The study concluded that the optimal addition ratio resulted in a performance improvement of 23%, surpassing that of the untreated soil sample. This ratio helps increase the bond between soil particles, and this method is considered one of the methods of soil reinforcement. As the ratio increases (6%, 8%), the plastic may begin to negatively affect the soil, as the mixture becomes uneven or causes a reduction in the soil's bearing capacity.

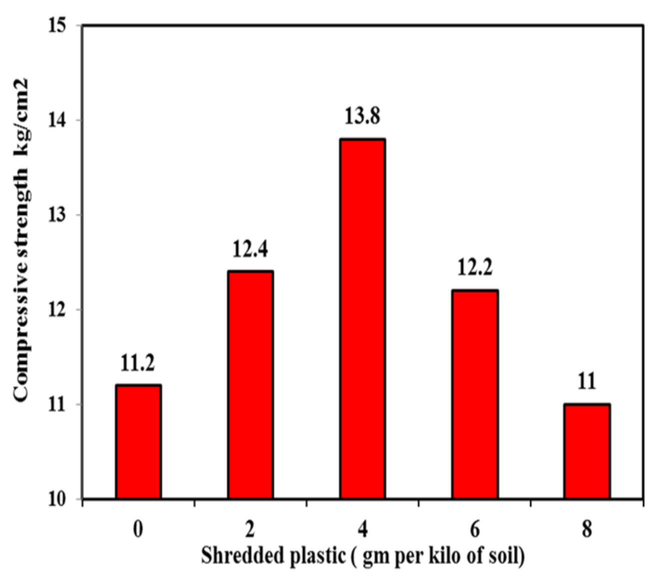

Fig. 5 Effect of shredded plastic quantity on compressive strength test results

5.4 CBR test result

Table 3 presents the load and penetration results for different soil mixtures during CBR test. The penetration values (mm) and the applied load (kN) were used to calculate the CBR values of the soil, as per the formula mentioned earlier. This was done to assess the effectiveness of adding shredded plastic to the soil samples in improving their load-bearing resistance.

The results of the CBR test showed that adding 4% shredded plastic water bottles to soil resulted in the best performance in terms of bearing capacity with an improvement of 28% compared to the untreated soil without additives., as shown in **Fig. 6**. This improvement can be explained by the fact that the plastic added at this percentage improved granular cohesion and reduced voids, enhancing the soil's resistance to compression and shear. On the other hand, increasing the shredded plastic water bottles content above this limit could have adverse effects due to the increased non-soil content, which weakens the overall structure. Therefore, 4% can be considered the optimal percentage for improving load-bearing properties using plastic.

Table 3 The applied load and penetration result for different soil mixtures during CBR test

Penetration (mm)	S0	S2	S4	S6	S8
	Load (kN)	LOAD (KN)	Load (kN)	Load (kN)	Load (kN)
0.5	0.0	0.0	0.0	0.0	0.0
0.5	2.1	2.3	2.5	2.0	1.6
1.0	4.5	3.6	3.8	3.1	2.4
1.5	5.6	5.9	6.4	5.4	3.5
2.0	7.6	8.1	8.7	7.1	5.8
2.5	8.2	8.4	10.5	9.4	8.4
3.0	9.2	9.6	11.5	10.5	9.0
3.5	10.5	10.8	12.5	11.2	9.6
4.5	11.6	11.4	13.5	12.1	10.7
5.0	12.3	12.4	14.5	13.8	12.4
6.0	13.2	12.9	15.2	14.7	13.5
7.0	14.5	13.8	16.4	15.8	14.5
8.0	15.6	14.8	17.4	16.4	16.4
9.0	19.5	16.8	18.6	17.2	17.2
10.0	20.0	17.8	19.4	18.2	18.2
11.0	21.6	19.4	20.5	18.9	19.1
12.0	22.4	20.9	23.6	19.7	20.1

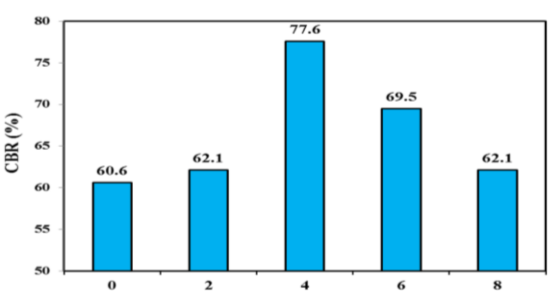

Fig. 6 Effect of shredded plastic quantity on CBR test results

6 Conclusion

The results indicate that incorporating 4% shredded plastic water bottles into the material significantly enhances its mechanical properties. Specifically, the compressive strength improved by 23%, while the CBR increased by 28 % compared to soil results without plastic additives. These findings suggest that recycled plastic waste can be effectively utilized to strengthen construction materials, promoting both performance improvement and environmental sustainability. Based on the results, a trial section incorporating shredded plastic water bottles into the road base layer is recommended. This would allow for practical evaluation of the material's performance under real traffic and environmental conditions before full-scale implementation.

References

[1] M. Akhtar Hossain, ‘Application of Jute Fiber for the Improvement of Subgrade Characteristics’, *Am. J. Civ. Eng.*, vol. 3, no. 2, pp. 26–30, 2015.

[2] A. Sawangsuriya and T. B. Edil, ‘Evaluating stiffness and strength of pavement materials’, in *Proceedings of the Institution of Civil Engineers: Geotechnical Engineering, 158*, pp. 217–230, 2005.

[3] D. Joseph and C. Vipulanandan, ‘Characterization of Field Compacted Soils (Unsoaked) Using the California Bearing Ratio (CBR) Test’, in *Geo-Frontiers 2011: Advances in Geotechnical Engineering*, 2011, pp. 2719–2728.

[4] E. H. Davis, ‘The california bearing ratio method for the design of flexible roads and runways’, *Geotechnique*, vol. 1, no. 4, pp. 249–263, 1949.

[5] W. Chimoye, ‘Strength Characteristic of Lateritic Soil Replaced by Recycled Asphalt Pavement’, *Int. J. Eng. Res. Technol.*, vol. 8, no. 05, pp. 596–599, 2019.

[6] M. Machsus *et al.*, ‘IMPROVEMENT FOR ASPHALT MIXTURE PERFORMANCE USING PLASTIC BOTTLE WASTE’, *Int. J. GEOMATE*, vol. 20, no. 79, pp. 139–146, 2021.

[7] S. Hassan and N. Sharma, ‘Strength Improvement of Clayey Soil with Waste Plastic Strips and Cement Kiln Dust’, *Int. Res. J. Eng. Technol.*, vol. 6, no. 11, pp. 2216–2222, 2019.

[8] C. Engineering, S. V. R. E. College, and M. T. Student, ‘UTILISATION OF WASTE BOTTLE PLASTIC STRIPS AND LIME AS A SOIL’, *Int. Res. J. Eng. Technol.*, vol. 4, no. 4, pp. 1046–1051, 2017.

[9] F. B. Teshome, ‘Municipal solid waste management in Ethiopia ; the gaps and ways for improvement’, *J. Mater. Cycles Waste Manag.*, vol. 23, no. 1, pp. 18–31, 2021.

[10] R. Saravanan, P. Murthi, KPoongodi, and D. Raju, ‘A study on the effect of waste plastic strips in the stabilization of clay soil’, in *IOP Conference Series: Materials Science and Engineering*, 2020, pp. 1–8.

[11] S. Amena, 'Experimental study on the effect of plastic waste strips and waste brick powder on strength parameters of expansive soils', *Heliyon*, vol. 7, pp. 1–6, 2021.

[12] A. Gupta, V. Saxena, V. Gaur, V. Kumar, and T. Kumar, 'A Review paper on Stabilization of Soil using Plastic waste as an additive', *Int. Res. J. Eng. Technol.*, vol. 6, no. 5, pp. 6435–6440, 2019.

[13] M. H. Nsaif, 'Behavior of Soils Strengthened By Plastic Waste Materials', *J. Eng. Dev.*, vol. 17, no. 4, pp. 182–194, 2013.

[14] A. I. Dhatrak, S. D. Konmare, and S. P. Tatewar, 'Performance of Randomly Oriented Plastic', *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 5, no. 12, pp. 20529–20537, 2016.

[15] A. B. Shehu, A. A. Bala, H. Aliyu, and I. Z. Ishaq, 'EFFECT OF PLASTIC WASTE ON THE STRENGTH CHARACTERISTIC OF NIGERIAN LATERITIC SOIL USED AS SUB BASE MATERIAL IN ROAD CONSTRUCTION : A SYSTEMATIC REVIEW APPROACH', *Int. J. Adv. Res. Innov. Ideas Educ.*, vol. 10, no. 5, pp. 292–303, 2024.

[16] M. D. Bandaru, D. vara prasad Bokka, S. Kyle, V. V. S. Sarma, and P. Rohith, 'Increasing the Bearing Strength of Base Layer (WBM Roads) by Using Plastic Cells and Analysis Through Staad Pro', in *IOP Conference Series: Earth and Environmental Science*, 2023, pp. 1–12.

[17] S. Amena, 'Utilizing solid plastic wastes in subgrade pavement layers to reduce plastic environmental pollution', *Clean. Eng. Technol.*, vol. 7, pp. 1–6, 2022.

[18] M. B. ASGEDOM , Abraha Gebrekidan DESTA, 'The Environmental Impacts of the Disposal of Plastic Bags and Water Bottles', *Sacha J. Environ. Stud.*, vol. 2, no. 1, pp. 81–94, 2012.