Ecological Applications of Polyethylene Terephthalate Plastic in Producing Modified Subbase Soil

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Abstract: Plastic materials can now be intelligently and creatively utilised in civil engineering applications such as the creation of soil improvement materials to accomplish economic goals while diminishing the environmental impact of plastic waste. In this study, the influence of adding recycled polyethylene terephthalate granules (PET) to the strength properties of subbase soil was investigated. The adopted fractions of waste plastic granules ranged between 2.5% and 12.5% by volume, and optimum moisture content (OMC) and maximum dry density (MDD) were measured in modified subbase soil with these various waste plastic contents. The California bearing ratio test (CBR) was then implemented for each alternative. The outcomes illustrated that the modified subbase properties were significantly enhanced by the addition of waste plastic granules and that, for best results, the optimal percentage of recycled polyethylene terephthalate granules to be added was 10% by the volume of the subbase material. The increment in the California bearing ratio value for modified subbase as compared with the subbase without waste plastic reached as high as 36%, suggesting that this method can provide a potential practical use for waste plastic as well as achieving enhancement of subbase soil layers for flexible pavement.

1. Introduction
The principal intention of waste recycling is to diminish the amount of waste that must be disposed of with environmental impacts. Recycling of waste also, however, offers a source of alternative materials that reduces natural materials’ depletion rates, mitigating current overexploitation [1, 6]. Flexible pavement is the preferred pavement structure for highways and roads in most areas, and a huge quantity of industrial products and non-renewable materials such as subbase, bitumen, aggregates, lime, cement, and other additives are expended in the construction and maintenance processes of such structures. This excessive extraction and fabrication of such virgin construction materials is unsustainable [7, 8]. Depletion of resources, waste of materials, environmental deterioration, and a spike in the cost of materials have all motivated researchers to find alternative materials that can be utilised in the creation of flexible pavement.

Similarly, plastics production has increased noticeably over the last 60 years, and the current levels of utilisation and disposal of such items produces several environmental problems [9]. Landfill is the conventional method for the management of waste, but space for landfills is becoming scarce as non-degradable waste volume increases. Plastics recycling can thus help decrease the industry’s environmental impact as well as mitigating resource depletion. Polyethylene terephthalate is one of most widely used plastics for packaging food, resulting in multiple short lifecycle products that convert to waste when users discard them. Non-recycled plastic materials of this type end up in landfills or distributed in the environment, causing a range of environmental problems due to slow polymer degradation [10, 12].
Arulrajah et al. [13] assessed the effect of adding plastic waste on the performance of subbase layers. Two types of waste plastic (low density polyethylene and high-density polyethylene) were used as replacement materials in subbase layer at ratios of 3% and 5%. The study utilised a modified Proctor test to determine the optimum moisture content and maximum dry density; California bearing ratio testing was also undertaken. The experimental results indicated that the insertion of plastic waste increased the optimum moisture content and reduced the maximum dry density and California bearing ratio; modified subbase layer also satisfied the requirements of applicable standards codes. Based on these outcomes, it was recommended that use of plastic waste in subbase layers is feasible for practical work.

Mishra and Gupta [14] researched the strength properties of subgrade soil reinforced with recycled polyethylene terephthalate fibres in combination with fly ash. The California bearing ratios and shear strengths of subgrade soils with various percentages of recycled polyethylene terephthalate fibres (up to 1.6%) with different percentages of fly ash (up to 20%) were examined. The experimental results revealed that there was an enhancement in the California bearing ratio and the shear strength and a decrease in the plasticity index with such additions. The optimal properties of subgrade soil were measured at 1.2% recycled Polyethylene terephthalate fibres and 15% fly ash.

Farah and Nalbantoglu [15] investigated the possibility of recycling waste plastic water bottles fabricated from polyethylene terephthalate thermoplastic polymer to reinforce sandy soil. Polyethylene terephthalate chips were inserted into the soil at three different aspect ratios (2, 4, and 8) at up to 1% for each aspect ratio. The experimental outcomes revealed that the insertion of waste bottle plastic chips into sand improved the California bearing ratio and the shear strength of the soil.

Mir [16] researched the engineering characteristics of subgrade soil reinforced with low density polyethylene waste plastic chips of various aspect ratios and proportions up to 1.5% by weight of soil. The California bearing ratio test and shear strength test were implemented on the composite samples. The test results showed that the addition of 1% by weight of chips of waste plastic improved the shear strength and California bearing ratio of subgrade soil. The necessary base layer thickness of flexible pavement was also found to be considerably reduced where plastic waste chips were utilised as soil stabilising material for subgrade soil in construction of highway subbases.

Alvarez et al. [17] conducted an experimental study to analyse the utilisation of waste plastic materials in reinforcing high plasticity clay soil. Four percentages of recycled polyethylene terephthalate chips, ranging from 0.5% to 3.5%, with dimensions of 3 to 5 mm were adopted. Based on standard Proctor and direct shear tests, the optimum fraction of waste plastic added in this manner was found to be 1%.

Panda and Rath [18] implemented an experimental study to examine the effect of utilisation of strips of polyethylene terephthalate obtained from waste plastic bottles on the engineering properties of expansive soil. The waste plastic strips ranged from 10 to 30 mm in length and were introduced as fractions of between 0 and 4%. The test outcomes indicated that the California bearing ratio of the expansive soil increased as the fraction and aspect ratio of the waste plastic strips increased to up to 4% and 3, respectively.

Oke et al. [19] studied the effect of adding shredded plastic waste to both sandy soil and clayey soil, adding proportions of 0%, 5%, 10% and 15% of soil weight in shredded plastic waste. They concluded that the engineering properties for both soils were enhanced by addition of waste plastic. The cutting process required to turn waste plastic bottles into chips or fibres is time consuming and makes it very difficult to achieve the required shape and size of additive. The major goal of the current experimental investigation was thus to examine the influence of the utilisation of recycled polyethylene terephthalate granules obtained from an automatic waste plastic recycling machine on subbase soil engineering properties. This objective was achieved by examining the effects of using various fractions of recycled plastic granules as a volumetric replacement within subbase soil by using modified Proctor and California bearing ratio tests, with subbase soil without plastic used as a comparator. The optimum supplementary fraction of recycled plastic granules to subbase soil for the enhancement of the latter’s engineering properties was thus also identified.
2. Materials and methodology.

2.1 Materials
The materials used in this study were subbase soil, which was mixed with waste plastic granules of recycled polyethylene terephthalate (PET) as a reinforcing material. The PET plastic waste granules were of cylindrical shape, being 2.5 mm in diameter and 4 mm high. This material, shown in Figure 1, was manufactured using an automatic waste plastic recycling machine at a locally plastic recycling factory. The subbase soil was collected from a quarry located in Karbala city, which was tested for its physical properties and gradation before the addition of any PET. The strength properties of the subbase soil were also tested both with and without the addition of plastic waste materials. The subbase used in this study was of class B according to Iraqi Standard Specifications for Roads and Bridges (SORB/R6). The grain size distribution curve is shown in Figure 2.

![PET plastic waste granules](image1.png)

**Figure 1.** PET plastic waste granules.

![Grain size distribution curve for subbase](image2.png)

**Figure 2.** Grain size distribution curve for subbase.
2.2 Compaction Test (Procter Test):

This study used a modified Proctor’s test to determine the dry density and moisture content of the subbase samples. In this test, a standard mould was filled with subbase soil in five layers. Each layer was compacted using 56 blows of a modified hammer of weight 4.5 kg. This process allows the maximum dry unit weight of the subbase soil and its optimum moisture content to be determined based on the wet weight of the compacted soil and its water content. This test was performed in accordance with ASTM D-1557 [20] specifications. A set of compaction tests were carried out on subbase soil samples and the samples of subbase with various percentages of PET plastic waste granule inclusions (2.5%, 5%, 7.5%, 10% and 12.5%) by volume. The aim was to determine the optimum moisture content (OMC) and the maximum dry density (MDD) at different percentages of added PET and to investigate how the addition of waste plastic as a volumetric percentage affected the moisture content and the density of the subbase.

2.3 California Bearing Ratio (CBR):

The California bearing ratio (CBR) is defined as the ratio of the force needed for a circular plunger of 50 mm diameter to penetrate into a soil sample at a rate of 1.27 mm/min to the force required for the same penetration into a sample of crushed rock [21]. CBR values are calculated at both 2.5mm and 5mm penetration, and the higher value is used. CBR testing was carried out on a series of subbase samples with different percentages of PET plastic waste granules inclusion (0%, 2.5%, 5%, 7.5%, 10% and 12.5% by volume) to determine the optimum amount of PET in soil for penetrative purposes. The specimens were prepared for CBR testing with the optimum water contents and densities as obtained from the compaction tests conducted previously. The prepared samples were compacted in standard moulds and immersed in a water tank for four days each to obtain their soaked CBR values. CBR tests were performed in accordance with ASTM D-1883 [22].

3. Discussion of results

Within the implemented experimental works, six mixes of subbase containing PET plastic waste granules were prepared and tested using compaction testing with subsequent CBR testing. All results of this experimental work are shown in Table 1.

| No. | Polyethylene Terephthalate (PET) waste (%) | Optimum Moisture Content (OMC) (%) | Maximum Dry Density (MDD) (g/cm³) | California Bearing Ratio (CBR) Value (%) |
|-----|------------------------------------------|----------------------------------|-----------------------------------|----------------------------------------|
| 1   | 0.0                                      | 7.3                              | 2.196                             | 50                                     |
| 2   | 2.5                                      | 7.1                              | 2.169                             | 53                                     |
| 3   | 5.0                                      | 6.8                              | 2.093                             | 56.7                                   |
| 4   | 7.5                                      | 6.3                              | 2.088                             | 59.3                                   |
| 5   | 10.0                                     | 5.9                              | 2.083                             | 67.9                                   |
| 6   | 12.5                                     | 7.3                              | 1.978                             | 34.7                                   |

3.1 Compaction test (Modified Procter test)

A modified Proctor’s test was carried out to determine the optimum moisture content and maximum dry density of the soil samples for all percentages of PET wastes (0%, 2.5%, 5%, 7.5%, 10%, and 12.5%). Figure 3 shows the optimum moisture value’s relationship with the maximum dry density at varying percentages of PET waste plastic, while Figure 4 shows the effect of different PET waste percentages on the MDD. The values of OMC for PET wastes at 0%, 2.5%, 5%, 7.5%, 10%, and 12.5% were 7.3%, 7.1%, 6.8%, 6.3%, 5.9%, and 7.3%, respectively. However, the values of MDD were 2.196, 2.169, 2.093, 2.088, 2.083, and 1.978 g/cm³, respectively. The effect of increasing the percentage of PET wastes
on compaction properties, optimum moisture content (OMC), and maximum dry density (MDD) results is clearly significant. The value of OMC decreases as the percentage of plastic wastes increases, with the reduction rate reaching 20% as compared to the subbase without waste plastic. The value of MDD also decreases as the PET waste plastic content increases, as shown in Figure 4. This percentage reduction rate is up to 10% as compared to the subbase without PET plastic waste, which can be attributed to the PET plastic having a lighter weight than soil, so that increases in its volume within the soil mass decrease the density of the mix. Moreover, the presence of the plastic granules may provide a high resistance to compaction, thus reducing density further [23, 24]. As the plastic percentage in the subbase increases, the energy absorption capacity of the adjusted subbase is also increased. This result is in agreement with the work of other researchers [25, 26].

![Figure 3](image_url)

**Figure 3.** Optimum moisture relationship with maximum dry density results at a different plastic percentages.
3.2 California Bearing Ratio (CBR):

CBR tests were carried out for all subbase mixtures with different percentages of PET plastic inclusions. As shown in Table 1, the value of CBR% is significantly affected by adding PET plastic waste to the subbase. The CBR% value increases as the percentage of PET plastic wastes increases to the 10% level, as shown in Figure 5. The resulting percentage increases are 6%, 13.4%, 18.6%, and 35.8 for 2.5%, 5%, 7.5%, and 10% plastic content, respectively, as compared to subbase without PET plastic waste additions, though adding 12.5% plastic waste created a 30.6% decrease in CBR% value. The maximum value of CBR was observed at 10% PET plastic by weight. This may be attributed to the high interaction between soil particles and plastic granules, which can increase resistance to plunger penetration into the soil sample, thus increasing CBR values. The reduction in CBR value for a PET percentage of 12% may be associated with the high quantity of plastic affecting the compaction energy, though this requires further study to distinguish the effects of addition of PET plastics on compaction energy from other factors. The load-penetration curves shown in Figure 6 demonstrate that the subbase resistance to
penetration increases significantly as the percent of added PET waste increases until that point. The maximum resistant load is noted at 10% PET addition, with load values of 27 kN and 35 kN for 25 and 56 knocks, respectively, at 10% PET, while the minimum resistant load values are observed with 12.5% of PET plastic at 18 kN and 20 kN for 25 and 56 knocks, respectively. A different trend is occurs for load-penetration curve at 10 knocks, however, where the 12.5% curve shows higher values of load resistance, in agreement with the findings of other researchers [27, 28].

Figure 5. Relationship between PET plastic waste (%) and CBR (%).

Figure 6. Relationship between Load and penetration at 10, 25, and 56 blows.
4. Conclusions

1. The maximum dry density (MDD) of subbase decreases as PET plastic waste granule content increases. The decrements of MDD are 1.22%, 4.69%, 4.91%, 5.15%, and 9.92% for waste plastic contents of 2.5%, 5.0%, 7.5%, 10.0%, and 12.5%, respectively, as compared with the reference mix without plastic waste.

2. The optimum moisture content (OMC) for modified subbase decreases as the content of PET plastic waste granules increases up to the 10% point, though the 12.5% plastic waste content restores the optimum moisture content to the same value as that found in the subbase mix. The reduction percentages of the OMC are 2.74%, 6.85%, 13.69%, and 19.18% for PET plastic waste granules content of 2.5%, 5.0%, 7.5%, and 10.0%, respectively, as compared with reference mix.

3. CBR value is increased when the percentage content of the PET plastic waste granules increases, reaching a maximum for at 10% PET content. The increments of CBR values are 6%, 13.4%, 18.6%, and 35.8% for waste plastic contents of 2.5%, 5.0%, 7.5%, and 10.0%, respectively, as compared with the reference mix without plastic waste.
4. The optimum value of the PET plastic waste granules to be used to reinforce the studied subbase soil was 10% (OMC of 5.9% with a CBR value of 67.9%).

5. This method produces effective stabilisation and can thus be utilised as an effective means of both disposing of waste plastic materials and decreasing virgin material use.

5. References

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