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Sustainable Soil Stabilisation Using Plastic Waste

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Abstract. The practice of soil stabilisation is popular to increase the bearing capacity and strength of weak subgrade soils. Traditional stabilisers like lime and cement enhance soil performance, but their sole use can result in higher costs and environmental impacts. This research paper examines the synergy effect of using recycled polyethene terephthalate (PET) bottle fibres with lime and cement in subgrade stabilisation. Two systems were tested: lime-PET (LP) and cement-PET (CP). The content of total stabiliser (binder and PET) was adjusted between 2% and 10% by dry mass of soil with a ratio of 1:1 binder to fibre. The soil samples were collected in Pokhara, Nepal, and subjected to compaction tests, including California Bearing Ratio (CBR) at 95% maximum dry density (MDD), and unconfined compressive strength (UCS) according to IS standards. The highest CBR at 95% MDD was 12.03% for LP6 and 13.20% for CP8, compared to 4.11% for untreated soil, corresponding to increases of approximately 192.7% and 211.16%, respectively. UCS improved by 143.07% for LP6 and 162.98% for CP8 relative to untreated soil. The results indicate that a regulated use of PET fibres that are chemically stabilised improves the performance of subgrades and can be used to reuse plastic waste in pavements.

1 Introduction

Subgrade soils that have a high level of fines are often associated with low bearing capacities, increased compressibility, and sensitivity to changes in moisture. These characteristics lead to rutting, differential settlement, and premature distress of flexible pavements [1]. The use of chemical stabilisation using lime or cement has been a popular methodology in increasing the strength and reducing the plasticity of such soils. Lime causes flocculation and pozzolanic reactions, and cement produces cementitious bonds, as a result of hydration, thus enhancing stiffness and load-bearing capacity[1, 2]. However, binder-only stabilisation can increase construction costs and even give brittle behaviour when subjected to repetitive loading or seasonal shrink-swell cycles.

At the same time, the piling up of plastic bottle debris, especially Polyethene Terephthalate (PET), is a major environmental issue. Even though the PET bottles are widely recycled, some portion of the shredded or contaminated material is not suitable to be reused in high-grade products and is often discarded in landfills [3]. The reuse of this waste in civil

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engineering projects is a possibility to overcome the environmental and infrastructural issues [4].

It has been proven that fibre reinforcement enhances soil ductility, tensile resistance and crack control through offering mechanical interlocking and bridging action in the soil matrix. Empirical research has indicated the enhancement of strength parameters in the event of incorporation of industrial by-products like copper slag, fly ash, and biopolymers to stabilise soils. As an example, the addition of copper slag has been demonstrated to have a substantial positive effect on unconfined compressive strength and inhibition of swell potential [1, 4]. Similarly, the biopolymer-based methods of stabilisation have demonstrated compaction and strength behaviour improvements [1, 5]. It is also widely documented that lime and cement stabilisation of expansive soils to be used as subgrades is done[1, 6]. Plastic strips and synthetic fibres have been found to strengthen CBR and shear strength when used in low percentages through reinforcement effects [7, 8].

In spite of such developments, the literature that remains has a number of limitations. In numerous studies, the type of polymer used (PET or other plastics) is not clearly stated, no specific proportions of binder to fibres are given, and the process of interaction between chemical stabilisation and fibre reinforcement is not clarified. Moreover, the lack of consistency in reporting standards and units often affects the reproducibility and technical transparency.

The stabilisation of fine-grained subgrade soil was tested in the current research through the use of PET bottle fibres along with lime or cement. Stabiliser percentage was adjusted to 2%-10 % dry mass of soil, with a constant ratio of binder to fibre. This research will seek to present a technically sound and experimentally proven evaluation of PET-enhanced chemical stabilisation in subgrade applications.

The goals of the investigation are:

- To determine the variation in index properties and compaction characteristics with an increase in stabiliser content.
- To find the best lime -PET (LP) and cement -PET (CP) dosages in terms of California Bearing Ratio (CBR) of 95% of the Maximum Dry Density (MDD), and on Unconfined Compressive Strength (UCS).
- The analysis aimed to determine how the use of PET fibres affects the performance of chemically stabilised soil.

2 Material and Methods

2.1 Soil Sampling and Initial Characterisation

The samples of disturbed soils were taken at a depth of about 0.30m below the ground level in Pokhara, Nepal. The soil collected was air-dried under laboratory conditions, crushed by hand to loosen clods, and sieved (4.75mm) before testing.

2.2 Stabilising Materials

Chemical stabilisers used were hydrated lime and Ordinary Portland Cement (OPC). The type of cement used was OPC 43. The values of specific gravity of lime and cement were obtained by means of laboratory tests or manufacturer information and are given in the results section. The plastic fibres were made of post-consumer beverage bottles that were characterised as Polyethene Terephthalate (PET). PET verification was done by verifying the presence of the resin identification code marking (Code 1) on the base of the bottle, and the recycling facility providing the waste material confirmed the presence of the material. The bottles were washed, dried, and shredded by machinery. Fig. 1(a) presents the test soil. The cement and lime were used in the study and are shown in Fig. 1(b) and 1(d). The fibres were shredded to a length of less than 3mm to make sure that the fibres were evenly distributed in the soil matrix. Fig. 1(c) represents a representative picture of PET fibres.

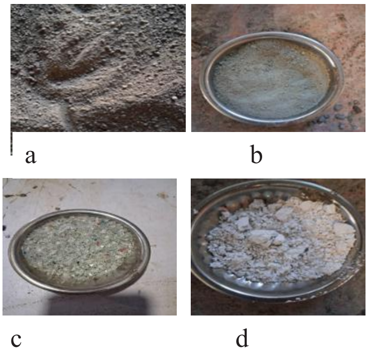

Fig. 1. (a) Soil Sample, (b) Cement, (c) PET shred, and (d) Lime.

2.3 Mix Proportioning and Sample Preparation

Two stabilisation systems were explored: Lime-PET system (LP) and Cement-PET system (CP). Dry mass of soil was varied in total stabiliser content (lime + PET or cement + PET) 2%, 4%, 6%, 8%, and 10%. The ratio of binder to fibre within each stabiliser dosage was kept at 1:1 by dry mass. As an illustration, 6 % total stabiliser in the LP6 mix was made of 3 % lime and 3 % PET fibre by dry soil mass. On the same note, CP8 bore 4 % cement and 4 % PET fibre. The untreated soil was designated S0. Table 1 gives the entire mix matrix used in the study. Dry mixing was initially conducted to bring about equal distribution of lime/cement and PET fibres in the soil. The water required according to the estimated moisture content was then added in bits, and the mixture was well mixed to become homogeneous, and then compaction was done.

Table 1. Mix identification and testing program.

Mix ID	Stabilizer Content (% by dry soil mass)	Tests Conducted
S0	0% (Untreated soil)	Grain size analysis, Specific gravity, Atterberg limits, Modified Proctor compaction, CBR, UCS
LP2, LP4, LP6, LP8, LP10	2%, 4%, 6%, 8%, 10% (Lime–PET; 1:1 ratio within stabilizer)	Atterberg limits, Modified Proctor compaction, CBR, UCS
CP2, CP4, CP6, CP8, CP10	2%, 4%, 6%, 8%, 10% (Cement–PET; 1:1 ratio within stabilizer)	Atterberg limits, Modified Proctor compaction, CBR, UCS

2.4 Compaction Characteristics

The compaction properties were established based on the Modified Proctor method, as provided in the IS 2720 Part 8[12]. The typical compaction energy, which is a regime of 56 blows per layer, was used, with a prescribed rammer weight and drop height. After compaction, the MDD and optimum moisture content (OMC) were derived from the compaction curves obtained.

2.5 California Bearing Ratio (CBR) Testing

A mix proportion was prepared at each mix proportion, and each mix proportion was prepared at its OMC and compacted at Modified Proctor energy to obtain a density of 95 % of the MDD. The specimens were then soaked in water for the four days given in the standard after compaction. The specimens during testing and soaking were subjected to surcharge weights to replicate the overburden pressure of the pavement layers. After the soaking period, the penetration test was conducted at a constant rate of 1.25 mm/min with the standard plunger, and the load-penetration data were obtained. CBR values were calculated from the measured loads at 2.5mm penetration and presented as percentages. Besides absolute CBR values, the percentage change over untreated soil (S0) was computed to show the stabilisation effect without falsely presenting CBR as an absolute percent change.

2.6 Unconfined Compressive Strength (UCS) Testing

For the UCS tests, specimens of each mix were made at their respective OMC and compacted to attain the corresponding MDD as obtained through Modified Proctor tests. The samples were properly extruded and covered to prevent loss of moisture. After preparation, specimens were allowed to cure for seven days under controlled laboratory conditions at ambient temperature before being tested. This curing time was chosen to allow sufficient hydration and the pozzolanic reaction to develop in lime- and cement-treated soils and to provide a similarity with the soaked CBR testing conditions. After the curing, an axial loading was imposed at a constant rate of strain in the vertical direction until failure. Load deformation behaviour was measured, and the maximum axial stress was determined as the UCS value.

2.7 Testing Conditions and Data Reporting

As shown in Table 2, the laboratory tests were carried out under indoor controlled conditions with an average temperature of about 27 ± 2°C. In each mix proportion, which was outlined, several specimens were prepared and put to test; the reported values are the arithmetic mean of the observed values.

Table 2. Laboratory tests and relevant Indian Standards

Test	**Equipment**	**IS Standard**
Grain Size Analysis	Sieve set	IS 2720 (Part 4): 1985
Specific Gravity	Pycnometer	IS 2720 (Part 3/Sec 1): 1980
Liquid Limit and Plastic Limit	Casagrande apparatus	IS 2720 (Part 5): 1985
Modified Proctor Compaction	Modified Proctor mold and rammer	IS 2720 (Part 8): 1983
California Bearing Ratio (CBR)	CBR testing apparatus	IS 2720 (Part 16): 1987
Unconfined Compressive Strength (UCS)	UCS compression apparatus	IS 2720 (Part 10): 1985

3 Results and Discussion

Laboratory investigations were carried out on untreated soil (S0) and stabilised mixes listed in Table 1. The results of index properties, compaction characteristics, CBR, and UCS are presented and discussed in the following sections.

3.1 Soil Identification and Classification

The natural soil used in this study was identified as a fine-grained, low-plasticity material. The test soil is classified as CL (low-plasticity clay) according to the Unified Soil Classification System (USCS). The low plasticity index indicates limited shrink–swell potential and predominance of non-expansive silt-sized particles. Table 3 shows the liquid limit, plastic limit, and plasticity index of the sampled soil for various percentages of stabiliser material.

Table 3. Liquid limit, Plastic Limit, and Plasticity Index of sampled soil for various percentages of stabiliser material.

Lime–PET (LP) mixes			
Mix ID	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**
S0	33.18	21.64	11.54
LP2	32.82	21.69	11.13
LP4	31.15	22.24	8.91
LP6	30.69	22.46	8.23
LP8	30.37	23.81	6.56
LP10	29.72	24.20	5.42
Cement–PET (CP) mixes			
Mix ID	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**
S0	33.18	21.64	11.54
CP2	33.04	21.71	11.33
CP4	32.85	22.15	10.70
CP6	32.11	22.31	9.80
CP8	31.83	23.60	8.23
CP10	31.17	24.08	7.09

3.2 Specific Gravity

The specific gravity (G_s) of the untreated and stabilised soils is indicated in Table 4**.** The G_s of untreated soil were 2.632. G_s in the LP (lime-PET) mixes declined gradually, with the stabiliser content reaching 2.418 at the LP10 proportion. In the case of the CP (cement-PET) mixes, there was only a minor change in G_s at lower percentages of stabilizer, but thereafter it decreased at higher percentages of stabilizer. The given reduction in specific gravity with the increase in the content of PET is expected, as the density of PET (1.12) is lower than the densities of soil minerals, cement (3.15), and lime (2.48). The difference in G_s is therefore a result of the composition of the composite material and not a sign of inconsistency in the procedure of the test.

Table 4. Specific gravity of untreated and stabilised soil mixes

Mix ID	**S0**	**LP2**	**LP4**	**LP6**	**LP8**	**LP10**
Gs (Lime–PET)	2.632	2.616	2.602	2.585	2.455	2.418
Mix ID	**S0**	**CP2**	**CP4**	**CP6**	**CP8**	**CP10**
Gs (Cement–PET)	2.632	2.667	2.634	2.650	2.541	2.444

3.3 Compaction Characteristics

The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) values obtained from Modified Proctor testing are presented in Table 5**.** For untreated soil (S0), the MDD was 1.62 g/cm³ with an OMC of 16.5%. With stabiliser addition, MDD initially increased for both LP and CP mixes. The highest MDD values were observed at LP6 (1.40 g/cm³) and CP8 (1.37 g/cm³). Beyond these dosages, MDD decreased, particularly at 10% stabilizer content. The initial increase in MDD may be attributed to improved particle packing and cementation effects from lime and cement. However, at higher stabiliser contents, the increasing proportion of low-density PET fibres disrupts soil particle continuity, resulting in reduced dry density. OMC generally decreased with stabiliser addition. This reduction can be associated with decreased clay activity and improved particle aggregation, reducing the amount of water required for lubrication during compaction. The earlier contradictory interpretation has been clarified: MDD increases up to an optimum stabiliser content and decreases beyond that threshold. MDD increased up to LP6 and CP8 due to improved particle interlocking and binder reaction, while a further increase in stabiliser content reduced density because of the higher proportion of low-density PET fibres.

Table 5. Compaction characteristics of untreated and stabilised soil

Lime–PET (LP) mixes		
Mix ID	**MDD (g/cm³)**	**OMC (%)**
S0	1.62	16.5
LP2	1.57	17.5
LP4	1.53	18.21
LP6	1.40	18.42
LP8	1.31	19.25
LP10	1.21	19.68
Cement–PET (CP) mixes		
Mix ID	**MDD (g/cm³)**	**OMC (%)**
S0	1.62	16.5
CP2	1.60	17.51
CP4	1.55	18.43
CP6	1.42	18.94
CP8	1.37	19.72
CP10	1.30	19.90

3.4 California Bearing Ratio (CBR)

Fig. 2 summarizes the findings of the California Bearing Ratio (CBR) tests. At the 95 % of maximum dynamic density, the untreated soil (designated S0) had a soaked CBR of 4.11 %. In the case of lime-prepared (LP) mixtures, the CBR rose gradually with the proportion of lime, reaching a peak of 12.03 % at the LP6 formulation, after which a minor decrease was detected with the addition of more lime. Conversely, cement prepared (CP) mixtures showed optimum CBR values at the CP8 mix, with a value of 13.20 % at the 95% MDD. As compared to the untreated soil, the LP6 and CP8 formulations showed an increase of about 192.70 % and 221.16 % in CBR, respectively. These values are given as percentages of the change relative to S0 and are not to be interpreted as absolute values of CBR. The increase in CBR can be attributed to:

- cementation and pozzolanic processes in lime and cement-treated soils;
- The fibre reinforcement effect of polyethene terephthalate (PET), which enhances load transfer and prevents localised deformation.
- enhanced compaction properties at the optimum stabiliser dosage.

At stabiliser levels more than optimum, the loss in continuity of the matrix and bonding efficiency leads to a slight decrease in CBR. These achieved CBR values are above the minimum requirements of subgrade materials used in the flexible pavement applications.

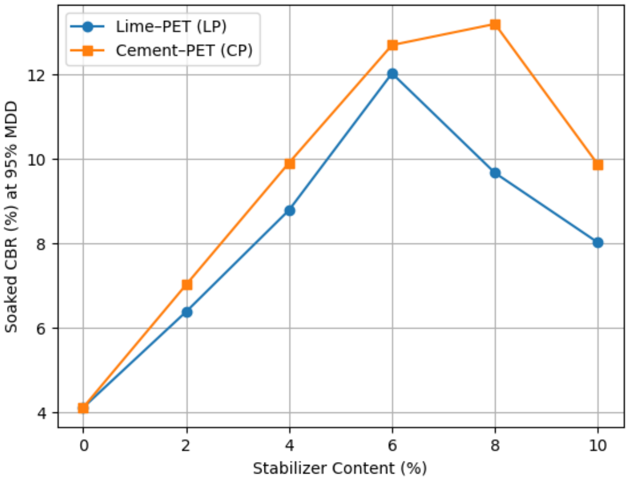

Fig. 2. Soaked CBR results at 95% MDD

3.4 Unconfined Compressive Strength

The UCS results are presented in Fig 3**.** For untreated soil, UCS was 110.5 kPa. All UCS values have been converted and interpreted in SI units for consistency. For LP mixes, UCS increased up to LP6 (268.6 kPa), representing an improvement of approximately 143.07% compared to untreated soil. For CP mixes, the highest UCS was recorded at CP8 (290.6 kPa), corresponding to approximately 162.98% improvement relative to S0. The increase in UCS is primarily due to:

- Formation of cementitious bonds through hydration and pozzolanic reactions
- Mechanical interlocking and crack-bridging provided by PET fibres
- Enhanced confinement and reduced crack propagation under axial loading

At 10% stabilizer content, UCS decreased slightly. This reduction is attributed to fibre clustering and disruption of soil–binder matrix continuity at higher dosages. Overall, the results indicate that optimum stabiliser content lies at 6% for lime–PET and 8% for cement–PET blends. Beyond these levels, the marginal benefit reduces due to excess fibre content interfering with matrix integrity.

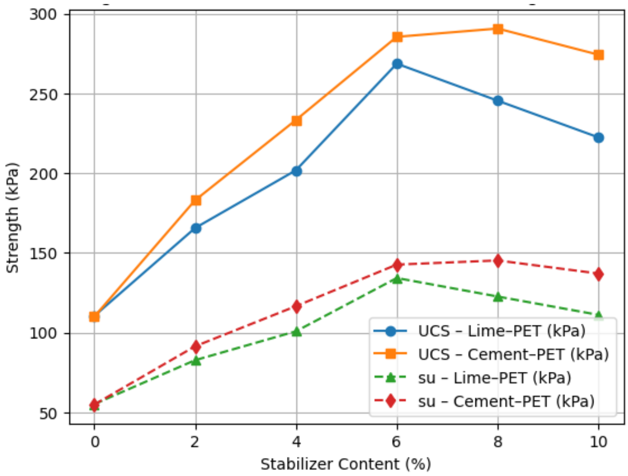

Fig. 3. Unconfined compressive strength and derived undrained shear strength (su) after 7-day curing

4 Conclusion

This study evaluated the stabilisation of a fine-grained subgrade soil using combined lime–PET (LP) and cement–PET (CP) systems. Based on laboratory testing conducted in accordance with relevant IS standards, the following conclusions are drawn:

- The untreated soil exhibited low bearing capacity, with a soaked CBR of 4.11% and UCS of 110.5 kPa.
- Both LP and CP systems improved strength characteristics up to an optimum stabiliser content. The maximum soaked CBR at 95% MDD was observed at LP6 (12.03%) and CP8 (13.2%), representing approximately 192.70% and 221.16% improvement over untreated soil, respectively.
- UCS increased to 268.6 kPa for LP6 and 290.6 kPa for CP8, corresponding to strength gains of approximately 143.07% and 162.98%, respectively.
- Compaction characteristics indicated that MDD decreased due to low-density PET fibres.
- Stabiliser contents beyond the optimum level resulted in a marginal reduction in strength parameters, indicating the existence of a performance threshold.

Overall, the results demonstrate that controlled incorporation of PET fibres with lime or cement enhances subgrade performance through combined cementation and fibre-reinforcement mechanisms.

5 Recommendations

The findings suggest that PET-assisted chemical stabilisation can be considered for subgrade improvement applications where plastic waste reuse is desirable. However, for practical implementation, further investigation is recommended on:

- Long-term durability under cyclic wet–dry and traffic loading conditions
- Field-scale validation studies
- Microstructural analysis to better understand bonding mechanisms
- Performance comparison under different soil types

Such investigations would strengthen the applicability of PET-based stabilisation in sustainable pavement engineering.

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Conflict of Interest

The authors of this manuscript have nothing to disclose. There is no conflict of interest.

References

[1] Y. Zhao, Y. Yang, X. Ling, G. Li, W. Gong, Mechanical behaviours of natural sand soils and modified soils in heavy-haul railway embankment. Adv. Civ. Eng. **2020**, 8843164 (2020). https://doi.org/10.1155/2020/8843164

[2] B. Ahmed, S. Islam, Md.T. Hossen, H. Ahmed, Md.R. Islam, Eco-friendly and cost-effective design of concrete pavement using used foundry sand and tiles dust. Nano Hybrids Compos. **23**, 46–54 (2018). https://doi.org/10.4028/www.scientific.net/NHC.23.46

[3] F.I. Shalabi, et al., Cement-stabilised waste sand as sustainable construction materials for foundations and highway roads. Materials **12**(4), 600 (2019). https://doi.org/10.3390/ma12040600

[4] C.K. Purchase, et al., Circular economy of construction and demolition waste: a literature review on lessons, challenges, and benefits. Materials **15**, 76 (2022). https://doi.org/10.3390/ma15010076

[5] C. Küpfer, M. Bastien-Masse, J. Devènes, C. Fivet, Environmental and economic analysis of new construction techniques reusing existing concrete elements: two case studies. IOP Conf. Ser.: Earth Environ. Sci. **1078**(1), 012013 (2022). https://doi.org/10.1088/1755-1315/1078/1/012013

[6] B.D.O. Ayibiowu, O.G. Fadugba, Strength characteristics of lateritic soil stabilized with Terrasil. Int. J. Sci. Technoledge **7**(10), 2019. https://doi.org/10.24940/theijst/2019/v7/i1/141500-33996

[7] M. Upshaw, C.S. Cai, Feasibility study of MK-based geopolymer binder for RAC applications: effects of silica fume and added CaO on compressive strength of mortar samples. Case Stud. Constr. Mater. **14**, e00500 (2021). https://doi.org/10.1016/j.cscm.2021.e00500

[8] B.Y.F. Wong, K.S. Wong, I.R.K. Phang, A review on geopolymerisation in soil stabilization. IOP Conf. Ser.: Mater. Sci. Eng. **495**(1), 012070 (2019). https://doi.org/10.1088/1757-899X/495/1/012070