VOCATECH: Vocational Education and Technology Journal 7, 1 (2025): 16-21
Website: http://ojs.aknacehbarat.ac.id/index.php/vocatech/index
ISSN 2716-5183 (online) ISSN 2686-4770 (print)

PLASTIC WASTE CHIPS FOR ENVIRONMENTALLY FRIENDLY SOIL STABILIZATION: EXPERIMENTAL STUDY ON CLAY SOIL IMPROVEMENT USING CBR METHOD

Andrian Kaifan[1]*
Irham[2]
Aiyub[3]
Fauzi A. Gani[4]
Munardy[5]
Ruhana[6]

[1]Program Studi Teknologi Rekayasa Jalan dan Jembatan, Politeknik Negeri Lhokseumawe
Jl. Banda Aceh - Medan Km. 280 3, Dusun Buketrata, Gampong Mesjid Punteut, Kecamatan Blang Mangat, Kota Lhokseumawe, Provinsi Aceh 24301, INDONESIA
[2,4] Program Studi Teknologi Konstruksi Bangunan Air, Politeknik Negeri Lhokseumawe
Jl. Banda Aceh - Medan Km. 280 3, Dusun Buketrata, Gampong Mesjid Punteut, Kecamatan Blang Mangat, Kota Lhokseumawe, Provinsi Aceh 24301, INDONESIA
[3,5,6] Program Studi Teknologi Rekayasa Konstruksi Bangunan Gedung, Politeknik Negeri Lhokseumawe
Jl. Banda Aceh - Medan Km. 280 3, Dusun Buketrata, Gampong Mesjid Punteut, Kecamatan Blang Mangat, Kota Lhokseumawe, Provinsi Aceh 24301, INDONESIA

Abstract

Clay soils are widely recognized for their poor engineering characteristics, particularly their low bearing capacity and high shrink-swell potential. These limitations make them unsuitable for use as foundation material in road construction and other geotechnical applications. This study aims to evaluate the potential of plastic waste chipping as an additive to improve the geotechnical properties of clay soil. The research was conducted using the California Bearing Ratio (CBR) method to assess bearing capacity. The experimental program involved mixing clay soil—sourced from Blang Pala Village, North Aceh—with varying contents of plastic waste chips (1%, 1.5%, and 2%) and different chip sizes (0.5×0.5 cm, 0.75×0.75 cm, and 1×1 cm). A series of laboratory tests were conducted, including specific gravity, Atterberg limits, standard proctor compaction, and CBR tests in both unsoaked and soaked conditions. The results revealed that the addition of plastic waste chips consistently improved the CBR values, with the most significant enhancement observed at 2% plastic content and 1×1 cm chip size. The unsoaked and soaked CBR values increased from 6.8% to 8.1% and from 3.8% to 5.9%, respectively. These findings suggest that plastic waste chips offers a promising, sustainable construction method for enhancing the performance of clay soils while contributing to plastic waste management.

Keywords:
California bearing ratio; Clay soil; Plastic waste; Soil stabilization; Sustainable construction

Abstrak

Tanah lempung dikenal secara luas karena memiliki sifat-sifat teknik yang kurang baik, terutama daya dukungnya yang rendah dan potensi kembang susut yang tinggi. Keterbatasan ini menjadikan tanah lempung tidak sesuai untuk digunakan sebagai bahan dasar pondasi dalam pembangunan jalan dan aplikasi geoteknik lainnya. Penelitian ini bertujuan untuk mengevaluasi potensi cacahan limbah plastik sebagai bahan tambahan guna meningkatkan sifat geoteknik tanah lempung. Penelitian dilakukan menggunakan metode California Bearing Ratio (CBR) untuk menghitung daya dukung tanah. Penelitian ini dimulai dari pencampuran tanah lempung yang bersumber dari Desa Blang Pala, Aceh Utara dengan variasi jumlah cacahan limbah plastik (1%, 1,5%, dan 2%) dan ukuran cacahan yang berbeda (0,5×0,5 cm, 0,75×0,75 cm, dan 1×1 cm). Serangkaian uji laboratorium yang dilakukan meliputi berat jenis, batas Atterberg, uji proctor standar, dan uji CBR dalam kondisi tidak direndam dan direndam. Hasil penelitian menunjukkan bahwa penambahan cacahan limbah plastik secara konsisten meningkatkan nilai CBR, dengan peningkatan paling signifikan pada kandungan plastik 2% dan ukuran cacahan 1×1 cm. Nilai CBR tidak direndam meningkat dari 6,8% menjadi 8,1% dan nilai CBR direndam meningkat dari 3,8% menjadi 5,9%. Hasil ini menunjukkan bahwa cacahan limbah plastik merupakan metode yang menjanjikan untuk konstruksi berkelanjutan untuk meningkatkan kinerja tanah lempung sekaligus turut berkontribusi dalam pengelolaan limbah plastik.

Kata Kunci:
California bearing ratio; Tanah lempung; Limbah plastik; Stabilisasi tanah; Konstruksi berkelanjutan

DOI: 10.38038/vocatech.v7i1.226
Received: 03 July 2025; Accepted: 31 July 2025; Published: 01 August 2025

Citation in APA Style: Kaifan, A., Irham, I., Aiyub, A., Gani, F. A., Munardy, M., & Ruhana, R. (2025). Plastic waste chips for environmentally friendly soil stabilization: Experimental study on clay soil improvement using CBR method. *VOCATECH: Vocational Education and Technology Journal, 7*(1), 16-21.

*Corresponding author:
Andrian Kaifan, Politeknik Negeri Lhokseumawe, Jl. Banda Aceh - Medan Km. 280 3, Dusun Buketrata, Gampong Mesjid Punteut, Kecamatan Blang Mangat, Kota Lhokseumawe, Provinsi Aceh 24301, Indonesia
Email: andriankaifan@pnl.ac.id

1. INTRODUCTION

The engineering behavior of clay soil — characterized by low shear strength, high plasticity, and significant volumetric changes due to moisture variations — presents persistent challenges in the design and durability of civil infrastructure (Hardiyatmo, 2002; Bowles, 1992; Alqaisi et al., 2020). These challenges are especially pronounced in regions with tropical climates, where seasonal wetting and drying exacerbate soil instability. Traditionally, stabilization techniques have involved the application of binders such as lime, cement, or fly ash to improve load-bearing capacity and reduce settlement. However, the widespread use of these conventional materials raises environmental concerns due to their high carbon footprint and energy-intensive production processes (Basha et al., 2005; Subha Pradha & Saranya, 2023).

In response to these environmental implications, recent research has explored sustainable alternatives, including the incorporation of plastic waste into soil stabilization. This approach not only addresses the critical issue of plastic pollution but also provides a circular economy solution for construction engineering (Renaningsih et al., 2022; Khalid & Alshawmar, 2024; Kumar et al., 2024). Plastic waste, particularly in forms such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polypropylene (PP), has shown potential to enhance soil strength, reduce brittleness, and improve ductility when used as reinforcement or additive in geotechnical applications (Hoque et al., 2023; Radhi, 2021).

Empirical studies have reported favorable outcomes when plastic waste is incorporated into cohesive soils. For instance, Herman et al. (2021) and Endaryanta & Wibowo (2016) demonstrated that plastic chips could significantly improve the unconfined compressive strength (UCS) and California Bearing Ratio (CBR) of clay soils. However, these studies often lacked region-specific analysis and comprehensive investigation into the influence of particle size and dosage variations. Moreover, research in the context of Aceh's unique geotechnical environment remains scarce.

This study addresses this gap by evaluating the performance of clay soil stabilized with recycled plastic chips sourced locally and applied in varying proportions and sizes. The soil samples were obtained from Blang Pala Village, Aceh, and tested using the CBR method to assess the enhancement in load-bearing capacity. By doing so, the research contributes to the development of sustainable, low-cost stabilization strategies tailored to local materials and environmental conditions.

2. LITERATURE REVIEW

2.1. Fundamental concept of soil stabilization

Soil stabilization is an essential technique in geotechnical and pavement engineering aimed at enhancing the engineering properties of problematic soils. By altering the physical and mechanical characteristics—such as strength, stiffness, plasticity, and durability—soil stabilization improves the reliability and load-bearing capacity of foundations, subgrades, embankments, and roadways (Subha Pradha & Saranya, 2023; Renaningsih et al., 2022). The process typically involves either mechanical methods (compaction and densification) or chemical and physical modifications through the addition of stabilizing agents such as lime, cement, or industrial and municipal waste materials.

The growing emphasis on sustainability has motivated engineers to explore alternative stabilizing materials that align with circular economy principles. Reusing waste materials in soil stabilization not only reduces dependency on conventional binders but also addresses environmental challenges associated with waste management (Kaifan et al., 2025; Malkanthi et al., 2021).

2.2. Utilization of non-degradable materials as stabilizing agents

An innovative approach in recent soil stabilization research involves the incorporation of non-degradable materials, particularly polyethylene terephthalate (PET) plastic chips. These materials improve soil behavior mainly by increasing internal friction and restraining deformation, acting as reinforcing elements within the soil matrix (Pujiastuti & Ngudiyono, 2013; Subha Pradha & Saranya, 2023). The interlocking and bridging effects between plastic chips and soil particles contribute to enhanced structural integrity in compacted soil layers.

2.3. Influence of plastic type and geometry on soil properties

Khalid & Alshawmar (2024) reported that adding 0.5% of polypropylene (PP) plastic waste to clay soils can significantly reduce swelling pressure and improve dimensional stability—key concerns in expansive soils. Additionally, Endaryanta & Wibowo (2016) emphasized the importance of chip size and shape, revealing that larger plastic particles tend to deliver more effective reinforcement. This is due to their greater surface area and improved contact with surrounding soil particles, which enhance cohesion and the internal angle of friction—two critical parameters for shear strength.

2.4. CBR test in soil evaluation

Among the various methods used to assess the effectiveness of soil stabilization, the CBR test remains one of the most widely adopted. The test measures the penetration resistance of compacted soils under standardized loading conditions, providing a reliable indicator of subgrade strength and bearing capacity (Wesley, 1977; AASHTO, 2020). CBR testing is especially relevant in pavement and roadway design, as it evaluates performance under both soaked and unsoaked conditions to simulate field moisture variations. The ability of stabilized soils to maintain structural integrity despite changes in moisture content is essential for the long-term durability of transportation infrastructure (Raza et al., 2021).

3. METHOD

This study utilized an experimental quantitative research method carried out at the Soil Mechanics Laboratory of Politeknik Negeri Lhokseumawe. The primary objective was to investigate the effect of polyethylene terephthalate (PET) plastic waste on the mechanical properties of clay soil. The clay samples were collected from Blang Pala Village, which is known for its high-plasticity soils, while the plastic waste—originating from used mineral water bottles—was gathered from Uteun Geulinggang Village. These waste bottles were thoroughly cleaned, dried, and manually cut into small square chips to serve as stabilization additives, as shown in Figure 1.

The materials used in the study consisted of two main components: natural clay soil and recycled plastic chips. Based on the AASHTO soil classification system, the clay soil was identified as type A-7-6, indicating high plasticity and low bearing capacity—characteristics typical of poor subgrade materials. The plastic waste was processed into three different chip sizes: 0.5 × 0.5 cm, 0.75 × 0.75 cm, and 1 × 1 cm. These dimensions were chosen to evaluate the effect of plastic geometry on soil stabilization performance.

A series of laboratory tests were conducted to evaluate the physical and mechanical properties of the untreated and treated soil samples. The testing procedures included determination of specific gravity, Atterberg limits (liquid limit, plastic limit, and plasticity index), and compaction characteristics using the standard proctor test. The primary performance indicator in this research was the CBR, which was measured under both soaked and unsoaked conditions. The CBR tests were conducted on soil samples with varying plastic contents: 0% (control group), 1%, 1.5%, and 2% by weight of dry soil.

For data analysis, statistical methods were applied to assess the significance of changes in CBR values between the control and treated specimens. Independent sample t-tests were employed to determine whether the inclusion of PET chips led to statistically significant improvements in soil strength. This analysis provided a quantitative basis for evaluating the effectiveness of plastic waste as a stabilizing agent in clay soils with poor engineering properties.

Figure 1. The plastic waste chips and the soil used

4. RESULTS AND DISCUSSION

The specific gravity of the clay soil used in this study was found to be 2.70, which is typical for mineral soils composed predominantly of fine particles. The Atterberg limits test revealed that the soil exhibits high plasticity, characterized by a liquid limit (LL) of 52.44%, a plastic limit (PL) of 32.61%, and a plasticity index

(PI) of 19.83%. The complete data of physical properties of the soil used in the study are presented in Table 1. These values confirm that the soil belongs to the high-plasticity category, which generally correlates with poor engineering performance in terms of strength and stability. Such soils tend to undergo significant volume changes with moisture variation, posing challenges in subgrade applications.

Table 1. The physical properties of the soil used in the study

Soil Properties	Composition
Original moisture content (w)	31.07%
Wet bulk density of the soil (γ_b)	1.84 gr/cm^3
Specific gravity (Gs)	2.70
Liquid limit (LL)	52.44%
Plastic limit (PL)	32.61%
Plasticity index (PI)	15.77%
Soil classification	AASHTO A-7-5 (12)
Optimum moisture content (w_{opt})	24%
Maximum dry density (γd)	1.54 gr/cm^3

The results of the unsoaked CBR test showed a moderate improvement in soil strength upon the addition of plastic waste. The original, untreated soil recorded a CBR value of 6.8%. When 1% PET plastic chips of 0.5 × 0.5 cm were added, there was change in the CBR value—it became 7.1%. However, increasing the plastic content to 2% and using larger chip sizes yielded improved outcomes. The soil mixed with 0.75 × 0.75 cm plastic chips showed a CBR value of 7.7%, while the mix with 1 × 1 cm chips achieved a slightly higher value of 8.1%. These results suggest that larger plastic particles and higher content levels contribute to better interlocking with soil particles, thereby enhancing load-bearing capacity under unsoaked conditions.

In the soaked CBR test, where soil samples were subjected to moisture saturation to simulate field conditions, the original soil exhibited a lower strength with a CBR value of 3.8%. This drop in performance is expected due to the loss of cohesion and internal friction in wet conditions. The addition of 2% plastic chips improved the performance, though to a lesser extent compared to the unsoaked test. The soil treated with 0.5 × 0.5 cm plastic chips reached a CBR of 4.5%, while the use of 1 × 1 cm chips resulted in a CBR value of 5.1%. These results indicate that PET plastic chips can moderately enhance soil strength even under saturated conditions, with larger chip sizes yielding better outcomes.

Visual comparisons of the results are presented in Figure 2 and Figure 3, which illustrate the relationship between plastic content and CBR values under unsoaked and soaked conditions, respectively, while PWC is Plastic Waste Chips. The graphs highlight a trend of improved performance with increasing chip size and plastic dosage, supporting the hypothesis that plastic waste can be effectively utilized as a stabilizing agent for clay soils.

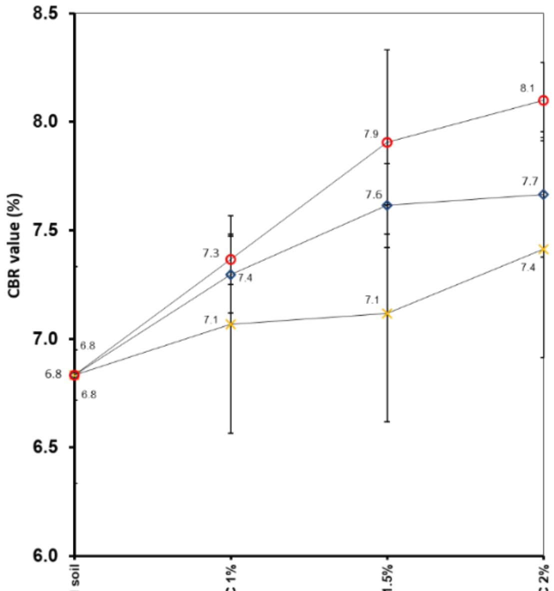

Figure 2. Relationship between plastic content and CBR values under unsoaked conditions (error bars represent standard deviation of mean, n = 30)

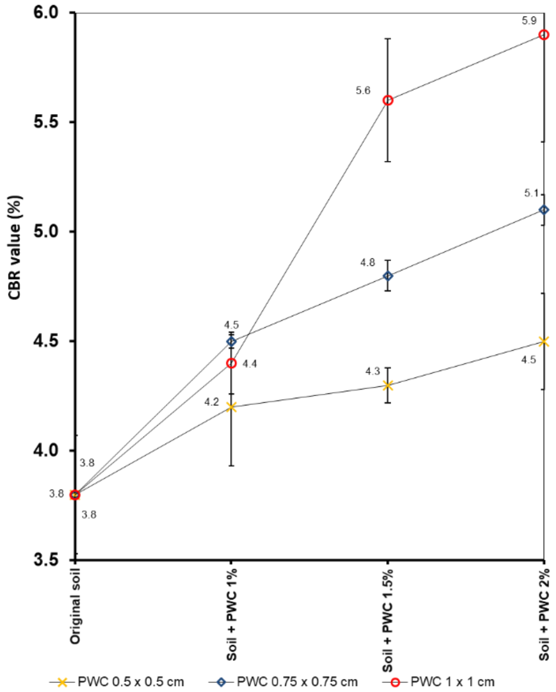

Figure 3. Relationship between plastic content and CBR values under soaked conditions (error bars represent standard deviation of mean, n = 30)

The increase in CBR values observed in this study supports the prevailing theory that plastic chips enhance the internal resistance and ductility of clay soils. Specifically, the sample treated with 2% PET chips of 1×1 cm size exhibited the highest CBR value under both soaked and unsoaked conditions. This improvement can be attributed to more effective interlocking between the larger plastic particles and soil aggregates, which likely contributes to increased frictional resistance and a reduction in pore pressure under loading. This finding is consistent with the mechanism outlined by (Subha Pradha & Saranya, 2023), who noted that larger plastic inclusions create bridging effects that distribute stress more evenly within the soil matrix. The improved load distribution helps minimize localized deformation, thus enhancing the bearing capacity of clayey subgrades.

Statistical analysis further confirmed that the differences in CBR values between control and treated samples were significant, with p-values less than 0.05 in all comparisons (Table 2 and 3). This statistical significance affirms the effectiveness of PET plastic waste as a stabilizing agent. These findings reinforce prior studies conducted by Pujiastuti and Ngudiyono (2013), who demonstrated the reinforcing potential of plastic chips in soft soils, as well as Renaningsih et al. (2022), whose work advocated the use of recycled plastic in sustainable construction.

Table 2. Independent sample t-test between control and treated samples under unsoaked condition

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Soil_treatment	Equal variances assumed	3.040	.092	-2.879	28	.008	-.67407	.23416	-1.15373	-.19442
	Equal variances not assumed			-6.638	9.493	.000	-.67407	.10154	-.90198	-.44617

Table 3. Independent sample t-test between control and treated samples under soaked condition

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Soil_treatment	Equal variances assumed	1.739	.204	-2.398	18	.028	-1.03889	.43329	-1.94920	-.12858
	Equal variances not assumed			-5.055	3.370	.011	-1.03889	.20550	-1.65405	-.42373

5. CONCLUSION

The incorporation of polyethylene terephthalate (PET) plastic waste chips into clay soil has demonstrated the potential to improve engineering performance, particularly in terms of CBR values. This enhancement directly translates into improved load-bearing capacity, making the treated soil more suitable for use as subgrade material in flexible pavement systems. The most notable improvement was observed at an optimum combination of 2% plastic content by weight and chip size of 1 × 1 cm. This configuration likely maximized the interlocking between plastic particles and soil grains, contributing to increased shear resistance and reduced deformation under applied loads. The results confirm that not only does plastic reinforcement increase strength, but it also enhances the soil's ductility and stability under both dry and saturated conditions. The practical implications of these findings are twofold. First, the treatment addresses a fundamental geotechnical challenge—the inherently low strength and high compressibility of clayey soils. Second, and perhaps more significantly from an environmental perspective, the reuse of PET plastic waste presents a sustainable engineering solution aligned with global waste reduction initiatives. While the laboratory results are promising, further research is necessary to validate the long-term durability and performance of PET-stabilized soils under real-world conditions. Field-scale implementation, cyclic loading, freeze-thaw durability, and leaching behavior are among the parameters that should be assessed in future studies.

REFERENCES

AASHTO. (2020). *Standard specifications for transportation materials and methods of sampling and testing*. American Association of State Highway and Transportation Officials.

Alqaisi, R., Le, T., & Khabbaz, H. (2020). *Applications of recycled sustainable materials and by-products in soil stabilization* (pp. 91–117). https://doi.org/10.1007/978-3-030-34199-2_7

Basha, E. A., Hashim, R., Mahmud, H. B., & Muntohar, A. S. (2005). Stabilization of residual soil with rice husk ash and cement. *Construction and Building Materials*, *19*(6), 448–453. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2004.08.001

Bowles, J. E. (1992). *Engineering properties of soils and their measurement* (4th ed.). McGraw-Hill.

Endaryanta, R., & Wibowo, A. (2016). Pengaruh ukuran dan bentuk partikel plastik terhadap daya dukung tanah dasar jalan. *Jurnal Teknik Sipil Dan Perencanaan*, *18*(2), 101–108.

Hardiyatmo, H. C. (2002). *Stabilisasi tanah di bidang teknik sipil*. Gadjah Mada University Press.

Herman, Widya S. R., & Andrea, F. Y. (2021). Kajian pengaruh limbah plastik terhadap prilaku tanah bermasalah di lapangan. *Ensiklopedia of Journal*, *3*(4), 75–84. https://doi.org/10.33559/eoj.v3i4.805

Hoque, M. I., Hasan, M., & Datta, S. D. (2023). Effect of waste plastic strip on the shear strength and permeability characteristics of black cotton soil. *Journal of Applied Science and Engineering*, *27*(2), 2019–2028. https://doi.org/10.6180/jase.202402_27(2).0003

Kaifan, A., Munardy, Irham, Miswar, K., & Gani, F. A. (2025). Pemanfaatan limbah konstruksi untuk memperbaiki gradasi tanah pada produksi Bata Compressed Stabilized Earth Block (CSEB). *Teras Jurnal*, *15*(01), 114–123. https://doi.org/https://doi.org/10.29103/tj.v15i1.1208

Khalid, B., & Alshawmar, F. (2024). Comprehensive review of geotechnical engineering properties of recycled polyethylene terephthalate fibers and strips for soil stabilization. *Polymers*, *16*(13). https://doi.org/10.3390/polym16131764

Kumar, M., Pratap, B., Mondal, S., Singh, R., & Azhar, M. (2024). The utilization of plastic waste for stabilizing expansive soil subgrade: A critical review. *Civil Engineering Infrastructures Journal*. https://doi.org/10.22059/CEIJ.2024.369358.1991

Malkanthi, S. N., Wickramasinghe, W. G. S., & Perera, A. A. D. A. J. (2021). Use of construction waste to modify soil grading for compressed stabilized earth blocks (CSEB) production. *Case Studies in Construction Materials*, *15*(July), e00717. https://doi.org/10.1016/j.cscm.2021.e00717

Pujiastuti, R., & Ngudiyono, D. (2013). Pemanfaatan limbah plastik sebagai bahan stabilisasi tanah lempung. *Jurnal Rekayasa Sipil*, *7*(1), 45–52.

Radhi, M. S. (2021). Utilization of waste plastic in geotechnical engineering applications in Iraq: A review. *Journal of Techniques*, *3*(4), 9–14. https://doi.org/10.51173/jt.v3i4.351

Raza, M. A., Khan, M. I., & Ahmed, W. (2021). Soil stabilization using plastic waste for subgrade enhancement. *Materials Today: Proceedings*, 2797–2804.

Renaningsih, S., Sari, M. D., & Dewi, I. A. (2022). Evaluasi penggunaan limbah plastik sebagai bahan stabilisasi tanah untuk konstruksi jalan. *Jurnal Teknik Sipil Indonesia*, *29*(1), 40–51.

Subha Pradha, S., & Saranya, K. (2023). Recycling plastic waste into construction materials for sustainability. *IOP Conference Series: Earth and Environmental Science*, *1210*(1). https://doi.org/10.1088/1755-1315/1210/1/012016

Wesley. (1977). *Basic geotechnical engineering*. Wiley.