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Effect of Curing Age on the Prospect of Used Plastics to Enhance Engineering Properties of Road Pavements within a Development and Property Agency Estate in Benin City, Edo State, Nigeria

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ABSTRACT: This study investigated the effect of curing age on the possibility of using plastic powder to enhance the engineering properties of subgrade for road pavements. The soil samples utilized for the study were collected from four distinct locations within the Edo Development and Property Agency estate in Benin City, Edo State, Nigeria using appropriate standard methods. They were stored in airtight polythene bags and taken to the University of Benin Geotechnical Laboratory for testing. Polyethylene terephthalate (PET) plastics sourced from recycled soft drink and bottled water containers were pulverized and added to the soil in various proportions of 2%, 4%, 6%, 8% and 10% by weight of the soil. The resulting mix was subjected to various tests such as Atterberg limits, compaction and California Bearing Ratio (CBR). The results showed that the addition of the PET plastic powder led to substantial transformation in the soil's properties. There was a reduction in the liquid limit, plastic limit and plasticity index, as the proportion of the plastic powder increased. The maximum dry density (MDD) and the optimum moisture content (OMC) was also seen to increase and decrease correspondingly as the proportion of the plastic powder was increased in the soil. The results also showed that as proportion of the plastic powder in the soil was increased, the CBR of the soil also increased. This increase in the soil strength was also observed as the curing age of the CBR samples increased from 0 to 14 days. This shows that a combination of extended curing periods and a larger proportion of plastic powder can significantly improve the load-bearing capacity and saturation resistance of the soil. This study underscores the considerable potential of plastic powder stabilization in elevating the engineering properties of subgrade materials, thereby conferring notable benefits to the domain of road pavement construction.

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Since highway pavements ultimately rest on native soil, the subgrade serves as the foundation material for the pavement structure. Therefore, the properties of the subgrade have an impact on the pavement's performance (Nikolaides, 2015). Extensive research efforts have been devoted to the exploration of various additives, encompassing both natural and chemical agents, to augment the engineering properties of subgrade soils. A study by Ogundare *et al.* (2018) focused on using geotextile for soil stabilization. They conducted CBR tests with non-woven geotextiles placed at specific depths in the soil, and results showed an increase in the CBR value, suggesting that geotextiles can be an effective modern method for road construction improvement. Plastic waste, which has devastating impacts on the environment (Kehinde, 2020), has also emerged as a promising ground improvement material. In a study by Carvalho *et al.*

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(2019), polyethylene terephthalate (PET) flakes to stabilize the base of a pavement. They conducted physical tests, compaction, and cyclic triaxial tests on natural soils mixed with PET flakes in varying percentages. The results showed that PET had a significant impact on the mechanical characteristics of the soil, increasing the resilient modulus at lower percentages but reducing it at higher percentages. This indicated that clayey soils with low PET content can be effectively used for base soil stabilization. Kumar *et al*. (2018) investigated soil mixed with plastic strips of different lengths and percentages. As the plastic content increased, the maximum dry density (MDD) decreased while the optimum moisture content (OMC) increased. Additionally, the CBR values increased with higher plastic strip percentages, reaching a maximum value with 2cm strip length and 0.8% plastic content by weight. Kassa *et al*. (2020) attempted to reinforce and stabilize expansive clay soil using plastic bottle strips. They mixed plastic strips at various ratios and aspect ratios with the soil and observed substantial improvements in the shear strength parameters, indicating the effectiveness of plastic strips for soil improvement in geotechnical engineering. Das *et al*. (2017) used plastic strips from polythene bags to stabilize soil and found a significant increase in soil strength after reinforcement with plastic strips. Gowtham *et al*. (2018) and Javed; Chakraborty (2020) employed glass and plastic waste powder, respectively, for clay soil stabilization. They conducted tests at different percentages and found that 4% to 6% of the plastic and glass powder by mass of the soil yielded the best results in terms of soil properties. Khan and Mateeullah (2018) used glass powder as a stabilizer for foundation soils with different proportions, identifying 8% as the ideal percentage for maximum improvement in soil properties. Olufowobi *et al*. (2014) assessed clay soil stabilization using powdered glass, finding significant improvements in maximum dry density and CBR values at 5% glass powder content. Subash *et al*. (2016) used glass and plastic granules to stabilize black cotton soils, achieving better results and reducing construction costs. Babatunde *et al*. (2019) also used glass powder for the stabilization of black cotton soil, and 4% glass powder replacement resulted in the highest unconfined compressive strength. Gorad *et al*. (2022) explored the effect of PET bottles (powder) on black cotton soil and concluded that plastic-soil combination is a cost-effective and environmentally friendly waste disposal method.

Although some studies have been conducted on subgrade stabilization using plastic powder, limited research has focused on the impact of curing when plastic powder is used as an additive. Hence, the objective of this paper as to investigate the effect of curing age on the prospect of used plastics to enhance engineering properties of road pavements within a development and property agency estate in Benin City, Edo State, Nigeria

MATERIALS AND METHODS

Description of the study Area: The study area is located within the Edo Development and Property Agency (EDPA) estate in Ugbowo, Ovia North-East Local Government Area, Benin City (see Figure 1).

Fig 1: Map of sampling locations

The geology of the soil is marked by top reddish soil consisting of ironized or literalized clayey sand. The region belongs to the coastal plains, with steep hills leading to the Ikpoba River in the western part. The Benin formation, a secondary and tertiary sedimentary rock formation, underlies much of the region, and the Upper Senonian group of Cretaceous sedimentary strata is prevalent in Benin City (Emeribe *et al.* 2017).

Soil Sampling and Collection and Preparation of Plastic Powder: Disturbed soil samples were obtained from four existing road segments within the location (as shown in Figure 1). The samples were extracted by means of a hand auger at a depth of 0.5m below the natural ground level. After extraction, the soil samples were placed in airtight polythene bags to prevent moisture loss, and thereafter, taken to the University of Benin Geotechnical Engineering Laboratory for testing.

Preparation of plastic powder: The plastics used in this study were polyethylene terephthalate (PET) plastics. They were obtained in the form of recycled soft drinks and bottled water containers. After collection, they were washed and dried under air for three days to remove any form of moisture. The dried plastic bottles were cut into smaller pieces and thereafter ground to fine particles. The grinding was done using a milling machine. The ground plastic obtained was sieved through a 212 microns sieve to obtain the pulverized plastic that was used for the test (Figure 2).

Fig 2: Processing of plastic powder (a) Ground plastic powder before sieving (b) Ground plastic powder after sieving

Soil stabilization procedure: The sieved plastic powder was mixed with the soil samples in various proportions of 2%, 4%, 6% and 10% by weight of the soil sample, as shown in Table 1. Mixing was done manually until a homogenous mix was obtained. The resulting mix was then compacted and placed in cylindrical or prismatic moulds to form the specimens that were used for the tests.

Table 1: Mix programme for the soil stabilization

Mix ID	Plastic powder (%)
PP0% (Control)	0
PP2%	2
PP4%	4
PP6%	6
PP10%	10

Determination Specific gravity: The specific gravity of a soil is the ratio of the weight or mass of a volume of the material to the weight or mass of an equal volume of water. The test was performed on the natural soil and it was done in accordance with procedures laid out in BS EN 1997-2:2007. About 200 g of oven-dried sample was placed into the pycnometer and weighed. Thereafter, water is added to the soil sample in the pycnometer until the jar is full, and the weight recorded. The entire contents of the glass jar is then emptied and replaced with water, and the weight also recorded. The specific gravity of the soil can then be calculated using Eq. (1):

$$G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (1)$$

Where; G_s Specific gravity; M_1 Weight of empty glass jar; M_2 Weight of glass jar and dry soil sample; M_3 Weight of glass jar, dry soil sample and water; M_4 Weight of glass jar and water

Determination of Natural moisture: This test was carried out using the oven-drying method as specified in BS EN 1997-2:2007. The procedure included the use of an oven of 105 °C temperature and a 0.01 g sensitive weighing scale. The amount of moisture in the soil was calculated as a percentage of the dry soil through the equation 2:

$$w = \left[\frac{m_2 - m_3}{m_3 - m_1}\right] \times 100\% \quad (2)$$

Determination of Particle size distribution test: Sieve analysis was performed on the natural soil samples to determine the particle size distribution of the soil. The test was carried out in accordance with BS EN 1997-

2:2007. Representative sample of approximately 100g was used for the test. The sample was washed using the BS 200 sieve (0.075 mm aperture) and the fraction retained on the sieve was oven dried and used for the sieve analysis. The sieving was done by mechanical method using an automatic shaker and a set of sieves. The fractions retained on each sieve were then weighed and their percentage weights calculated. The percentage passing per sieve size was calculated using Eq. (3):

$$\% \text{ passing} = \frac{\text{Wt. of soil passing}}{\text{Wt. of soil retained}} \times 100 \quad (3)$$

Evaluation of Consistency/Atterberg limit: Consistency/Atterberg limits were determined on the natural and stabilized soil specimens. The test was done in accordance with the procedures outlined in BS EN 1997-2:2007. The Atterberg limits are boundaries between the liquid and plastic states (Liquid Limit, LL), and between the plastic and brittle states (Plastic Limit, PL). For the determination of liquid limit, the soil sample passing through 425 µm sieve, weighing 200 g was mixed with water to form a thick homogeneous paste.

The paste was placed inside the Casagrande's apparatus cup, and a grove was created in the center of the sample. The number of blows needed to close the grove was recorded. For plastic limit determination, the soil sample weighing 200 g was taken from the material passing the 425 µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3mm diameter. The 3mm diameter sample was placed in the oven at 105 °C to determine the plastic limit. The range of water contents over which a soil behaves plastically is the Plasticity Index, PI. This is the difference between the liquid limit and the plasticity limit (LL – PP).

Determination of Compaction: This test involves the densification of soils with mechanical equipment thereby rearranging the soil particles, which makes them more closely packed resulting in an increase of the ratio of the horizontal effective size to the vertical effective stress. The tests was carried out in accordance with BS EN 1997-2:2007, using the standard proctor method. The soil samples were first broken up in such a way that the soil particles were reduced to their natural individual sizes. The moisture-density relationships were then determined. Two parameters were obtained from this test – optimum moisture content (OMC) and maximum dry density (MDD).

Determination of California Bearing Ratio (CBR): The California Bearing Ratio (CBR) test is a widely recognized method used to assess the mechanical strength and load-bearing capacity of subgrade soils. The test was performed in accordance with the guidelines specified in BS EN 1997-2:2007. In this test, the soil samples were prepared at specific moisture contents and then compacted into a CBR mould to achieve a defined density. The compacted samples were then left to cure for 7 and 14 days before testing. This enabled not only the immediate impacts of plastic powder inclusion on soil properties to be determined, but also the time-dependent changes in the mechanical properties of the soil.

A standard piston is then uniformly inserted into the compacted soil. The test measures the force required for the piston to penetrate the soil, recording this force at various depths. The CBR is calculated as the ratio of the force needed to penetrate the soil sample to a specific depth compared to the force required to penetrate a standard crushed stone material to the same depth, expressed as a percentage (see Eq. 4).

$$CBR = 100\left(\frac{MLR\ at\ either\ 2.5mm\ or\ 5.00mm}{SP\ for\ the\ well\ graded\ crushed\ stone}\right) \quad (4)$$

Where MLR = material load resistance SP = standard pressure

RESULTS AND DISCUSSION

Characteristics of the natural soil: Table 2 shows the results obtained from the laboratory tests conducted on the natural soil from the various test points. From Table 2, it can be seen that the natural moisture content values across the various test samples ranged from 12.81% to 18.29%, while the specific gravity values indicated a range of 2.57 to 2.63. Notably, these ranges indicates the existence of an inorganic clayey soil type (Bowles, 2012). The percentage of fines as obtained from sieve analysis ranged from 28 to 36%, indicating that the natural soil samples contains significant proportion of fines, which may be in the form of silt or clay. For the Atterberg limits, the liquid limit of the four soil samples ranged from 29.13% to 32.49%, while the plastic limit ranged from 14.27% to 16.26%. The plasticity index, which was taken as the difference between the liquid limit and the plastic limit, was seen to range from 12.87% to 16.86%. Based on AASHTO classification, it can be seen that the natural soil samples fall clearly within the A-2-6 class. The principal constituent materials in this classification are often clayey sand, a classification with a fair subgrade rating in the context of pavement design. The optimum moisture content (OMC) and the maximum dry density (MDD), both of which are characteristics of the compaction properties of the soil, was seen to fall within the range prescribed for inorganic clayey soil (BS EN 1997-2:2007). The CBR values obtained for the natural soil in the soaked condition is also shown in Table 2. According to the Federal Ministry of Works and Housing (FMWH) highway design manual (FMWH, 2013), a minimum California Bearing Ratio (CBR) value of 5% is necessary to classify a subgrade material as adequate. Comparing the CBR values obtained for the natural soil with this requirement, it can be seen that the soil samples from Points 1 and 3 are not adequate as subgrade materials, while those from Points 2 and 4 will make excellent choices as subgrade materials.

Table 2: Properties of the natural soil as obtained from laboratory tests

Property	Point 1	Point 2	Point 3	Point 4
Moisture content, %	18.29	15.69	16.67	12.81
Specific Gravity	2.63	2.62	2.57	2.61
Percentage fines, %	32	36	34	28
Liquid limit (LL), %	29.50	32.49	29.13	30.75
Plastic limit (PL), %	15.21	15.63	16.26	14.27
Plasticity index (PI), %	14.29	16.86	12.87	16.48
Optimum moisture content (OMC), %	12.40	13.20	12.40	11.60
Maximum dry density (MDD), g/cm^3	1.72	1.68	1.72	1.73
California Bearing Ratio (CBR), %	4.58	12.22	4.90	13.71

Effect of addition of plastic powder on the properties of the natural soil: Effect of addition of plastic powder on the index properties of the natural soil Table 3 shows the liquid limit, plastic limit, and plasticity index of the plastic powder stabilized soil. From the table, it can be seen that the addition of the plastic powder resulted in a significant decrease in the liquid limit of the soil samples. For example, the liquid limit of the soil samples obtained from Point 1 fell from 29.50% to 27.22%, when the soil samples were stabilized with 2% plastic powder. Similar drops were also observed in the plastic limit and plasticity index of the soil samples, with increase in the addition of the plastic powder. This decreasing trend in the consistency limits implies a drop in the moisture content at which the soil changes from a plastic to a liquid condition, and this is caused by the presence of the plastic powder in the soil matrix. Gowtham et al. (2018) also reported similar findings, and this highlights the persistent trend of reducing consistency limits in clayey soil with the addition of plastic powder. Understanding these changes in soil behavior is critical in geotechnical engineering and soil modification because they have an impact on construction techniques and material development.

Table 3: Atterberg limits of natural and stabilized soil

Sampling Points	Atterberg Limits	0%	2%	4%	6%	10%
Point 1	Liquid limit (%)	29.50	27.22	26.37	25.04	24.77
	Plastic limit (%)	15.21	14.03	13.22	12.98	12.73
	Plasticity index (%)	14.29	13.19	13.16	12.06	12.04
Point 2	Liquid limit (%)	32.49	32.23	29.94	29.00	25.57
	Plastic limit (%)	15.63	15.54	13.47	13.21	13.16
	Plasticity index (%)	16.86	16.69	16.47	15.79	12.41
Point 3	Liquid limit (%)	29.13	28.32	27.57	24.55	23.82
	Plastic limit (%)	16.26	15.82	15.50	14.07	14.02
	Plasticity index (%)	12.87	12.50	12.07	10.48	9.81
Point 4	Liquid limit (%)	30.75	27.99	25.62	23.83	22.10
	Plastic limit (%)	14.27	13.91	12.65	11.80	10.56
	Plasticity index (%)	16.48	14.08	12.97	12.03	11.54

Table 4 shows the maximum dry density (MDD) and optimum moisture content (OMC) of the plastic powder stabilized soil. From the table, it can be seen that the addition of the plastic powder to the soil resulted in considerable changes in maximum dry density (MDD) and optimum moisture content (OMC) of the natural soil. When a 10% plastic powder content was added, the MDD values rose from 1.72 g/cm^3, 1.68 g/cm^3, 1.72 g/cm^3, and 1.73 g/cm^3 to 1.90 g/cm^3, 1.86 g/cm^3, 1.80 g/cm^3, and 1.79 g/cm^3, for Points 1, 2, 3 and 4 respectively. This rise in MDD shows that the soil's compactability and density have improved, which can be useful in building and civil engineering applications. In contrast, the addition of the plastic powder to the natural soil resulted in a decrease in the OMC of the natural soil. The OMC values for soil at Points 1, 2, 3, and 4 reduced from 12.40%, 13.20%, 12.40%, and 11.60% to 8.90%, 7.80%, 7.70%, and 10.01%, respectively. The drop in OMC means that less moisture is required to produce maximum compaction, which is beneficial for building operations since it decreases the amount of water required to reach the appropriate soil density. This pattern of rising MDD and decreasing OMC following the addition of plastic powder to laterite soil corresponds with the findings of Thasleema et al. (2020), offering further support of these tendencies. These findings are significant for engineers and researchers because they can influence soil stabilizing techniques and material development.

Table 4: Compaction results of natural and stabilized soil

Sampling Points	Compaction Results	0%	2%	4%	6%	10%
Point 1	MDD (g/cm^3)	1.72	1.76	1.80	1.88	1.90
	OMC (%)	12.40	11.40	10.70	10.40	8.90
Point 2	MDD (g/cm^3)	1.68	1.77	1.79	1.84	1.86
	OMC (%)	13.20	12.50	10.20	9.40	7.80
Point 3	MDD (g/cm^3)	1.72	1.73	1.74	1.75	1.80
	OMC (%)	12.40	11.40	9.80	9.30	7.70
Point 4	MDD (g/cm^3)	1.73	1.75	1.77	1.78	1.79
	OMC (%)	11.60	10.40	10.20	10.10	10.01

Effect of addition of plastic powder on the strength properties of the natural soil: Table 5 shows the average unsoaked and soaked California bearing ratio (CBR) of the plastic powder stabilized soil in 2%, 4%, 6% and 10% by weight.

Table 5: CBR results of the plastic stabilized soil after 0-days curing

Sampling Points	CBR Results	2%	4%	6%	10%
Point 1	Unsoaked	12.63	12.92	15.69	18.50
	Soaked	7.01	8.13	9.53	10.77
Point 2	Unsoaked	22.71	23.82	24.90	29.93
	Soaked	12.76	13.83	14.20	14.49
Point 3	Unsoaked	15.89	17.67	20.11	22.30
	Soaked	9.04	10.12	11.68	11.93
Point 4	Unsoaked	28.55	32.77	33.24	34.02
	Soaked	14.30	15.12	16.43	17.18

The addition of plastic powder to soil samples in amounts up to 10% had a clear effect on California Bearing Ratio (CBR) readings in both unsoaked and soaked states across all measurement locations. As shown in Table 4.6, the CBR values increased consistently with the addition of plastic powder, indicating an improvement in the soil's load-bearing ability. The compatibility of subgrade materials is an important factor, and this suitability is frequently assessed using CBR values. Soils with CBR soaked values greater than 5% are regarded appropriate subgrade materials for road pavement, according to the general standards set by the Federal Ministry of Works (FMWH) in 2013. Based on this criterion, soil from all of the tested regions with CBR values greater than this threshold may be classed as viable subgrade materials for road pavement construction. Table 6 presents the average unsoaked and soaked California bearing ratio (CBR) of the plastic powder stabilized soil in 2%, 4%, 6% and 10% by weight after 7- days of curing. This rise in CBR values under saturated conditions indicates that the plastic powder not only stabilizes the soil but also enhances its resistance to saturation, which is important in road construction because moisture penetration might impair the subgrade's performance.

Table 6: CBR Results of the Plastic Stabilized Soil After 7-days curing

Sampling Points	CBR Results	2%	4%	6%	10%
Point 1	Unsoaked	14.13	15.20	16.29	19.11
	Soaked	9.01	10.43	12.43	13.17
Point 2	Unsoaked	24.01	26.28	27.99	30.13
	Soaked	13.16	14.53	14.79	15.88
Point 3	Unsoaked	16.90	17.81	21.61	23.10
	Soaked	9.66	10.79	11.99	12.47
Point 4	Unsoaked	29.44	34.17	34.60	34.83
	Soaked	14.67	15.71	17.03	17.49

A comparison of the CBR values in Table 6 with the findings obtained before to the 7-day curing period, as shown in Table 5, shows a consistent rise in CBR values across all sample locations. This discovery shows that the soil's load-bearing ability improved more after curing. With the addition of 10% plastic powder, the CBR values increased from 10.77%, 14.49%, 11.93%, and 17.18% in the wet condition to 13.17%, 15.88%, 12.47%, and 17.49% at points 1, 2, 3, and 4, respectively.

Table 7: CBR Results of the Plastic Stabilized Soil After 14-days Curing

Sampling Points	CBR Results	2%	4%	6%	10%
Point 1	Unsoaked	14.67	15.60	16.41	19.82
	Soaked	9.68	10.99	13.30	13.84
Point 2	Unsoaked	24.77	26.80	28.76	32.76
	Soaked	13.74	14.69	15.41	16.08
Point 3	Unsoaked	17.20	18.46	21.87	23.75
	Soaked	10.69	11.89	12.99	13.70
Point 4	Unsoaked	30.17	34.97	35.30	35.83
	Soaked	15.66	16.72	17.54	17.91

When these higher CBR values are compared to the Federal Ministry of Works (FMWH) regulations for sub-grade materials for roads, it is clear that the soil in the tested locations continues to satisfy the criteria for excellent subgrade material. Table 7 shows the average unsoaked and soaked California bearing ratio (CBR) of the plastic powder stabilized soil in 2%, 4%, 6% and 10% by weight after 14-days of curing.

The comparison of CBR values obtained after 7 and 14 days of curing gives useful insights into the evolution of the soil's engineering qualities over time. After the longer curing period, there was a significant rise in soaking CBR readings at all sample places. With the addition of 10% plastic powder, the soaking CBR values increased by 13.84%, 16.08%, 13.70%, and 17.91% at points 1, 2, 3, and 4, respectively. This large improvement in wet CBR values implies that the soil's load-bearing ability is continuing to improve with continued curing. The observed trend in the influence of plastic powder stabilization on soil strength is highly noteworthy, particularly as represented in the soaking CBR values.

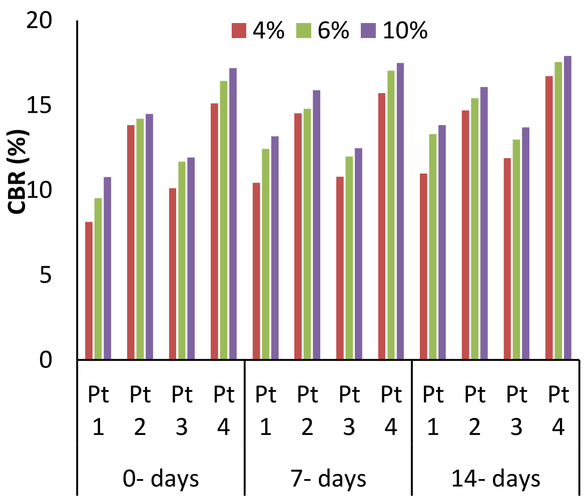

Fig 3: Effect of the Plastic Powder Stabilization on the Soil soaked CBR Values

The results, as shown in Figure 3, clearly shows that as the number of curing days and the percentage of plastic powder rise, so does soil strength. This shows that a combination of extended curing periods and a larger proportion of plastic powder can significantly improve the load-bearing capacity and saturation resistance of the soil. Such advancements are very desirable, particularly in subgrade materials used in road building, where durability and stability are crucial. It is vital to understand the link between curing time, plastic powder content, and soil strength in order to optimize soil stabilizing procedures and material development. It has the potential to lead to more efficient and cost-effective building processes, as well as to secure the long-term functioning of infrastructure projects. The results shown in Figure 3 give useful insights into the possibilities for improving soil qualities by strategically using plastic powder and suitable curing durations. The optimum soaked CBR value of 17.91% was observed at 10% plastic powder stabilization after 14-days of curing.

Conclusions: This study demonstrates that incorporating recycled PET plastic powder significantly enhances soil characteristics, as evidenced by reductions in plasticity and increases in compaction and California Bearing Ratio (CBR). These findings suggest a more stable soil matrix suitable for road construction. Furthermore, the sustained improvement in CBR over curing periods indicates long-term effectiveness. Overall, this research highlights the potential of plastic powder stabilization as a viable and sustainable approach for soil improvement.

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