



Stiffness and Strength of an Artificially Cemented Waste-PET-Shred Reinforced Clay

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Abstract

This study explores whether the polyethylene terephthalate bottle shreds (PETBS), could be a viable alternative additive in order to reduce the usage of traditional cement in geotechnical and transportation projects. Through a comprehensive study, clayey soil was stabilized with varying quantities (0.1–1% of solid mass) of PETBS of two different size ranges. Optimal dosages were chosen, followed by additional tests incorporating small amounts of (5, 7 and 10% of solid mass) cement enhancement. After curing periods of 7 and 28 days, California bearing ratio (CBR) tests and ultrasonic pulse velocity (UPV) test results revealed that the addition of PETBS enhanced CBR values and initial shear modulus (G_0) in both plain and cement treated samples. Scanning electron microscope (SEM) images also affirmed the improvement of strength at the microstructural level. Notably, PETBS of size 2–4.75 mm exhibited superior performance compared to size 0.42–0.841 mm, with an optimal content range of 0.6–0.8%. It was observed that the addition of PETBS to artificially cemented soil improved CBR values by up to 35%, while also modifying stiffness and brittleness, rendering the soil more ductile. Ultimately, a regression model was proposed to facilitate estimates of CBR and G_0 in PETBS-reinforced cemented clay, to accommodate varying PETBS grading and content. The suggested approach promotes cost-effective and eco-friendly solutions by reducing pavement thickness and enhancing soil stability, demonstrating the potential of repurposing PET waste as a sustainable strategy in various engineering projects.

Keywords Polyethylene therephthalate (PET) · Clay stabilization · Stiffness · Cement · Waste management

1 Introduction

Managing weak subgrade soil is a critical challenge in construction, particularly for transportation infrastructure where the foundation relies on soil composition. The properties of the subgrade significantly influence the design and lifespan

of the entire highway system. In many regions, natural subgrade soil contains problematic clay minerals, posing risks to construction and structural stability. This issue is particularly notable in areas such as the middle east, including Iraq, where the abundance of problematic clay soils can complicate construction projects and impact the stability of structures. Expansive clayey subgrades lack essential mechanical and hydraulic properties, leading to issues like differential settlement and poor strength. Traditional solutions such as soil replacement, cement treatment, or increasing base layer thickness come with drawbacks like high costs and environmental impact. Soil stabilization, particularly through the incorporation of binding agents like cement, is a widely recognized technique to enhance soil properties and meet engineering criteria. However, the cement production process is a harmful practice to the environment, as it releases considerable amounts of carbon dioxide (CO_2) to the atmosphere (Andrew 2019). The production of cement contributes to nearly 5% of international CO_2 emissions (Ali et al. 2011). This process discharges about 900 kg of CO_2 for

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each 1000 kg of cement produced (Mahasenan et al. 2003). The European Cement Association states that every 1000 kg of cement produced needs 60–130 kg of fuel and about a 105 kWh of electricity (Oggioni et al. 2011). Due to these issues, many studies have been conducted to seek alternative approaches to the use of cement in the stabilization of soil; to reduce global CO₂ emissions (Iravanian and Ali 2020; Ekinci 2019; Frías et al. 2017).

Global waste disposal, particularly the exponential increase in Polyethylene Terephthalate (PET) waste, demands effective management approaches as well. PET, a major contributor to plastic waste, persists for over a century in the natural environment, emphasizing the need for alternative disposal methods (Islam et al. 2016; Zander et al. 2018; Zhang et al. 2020). With 390.7 million metric tons of plastic produced globally in 2021, the environmental impact is exacerbated by the annual production of 1500 thousand tons of plastic for water bottling (PlasticsEurope, PEMRG 2022). Unfortunately, a substantial portion of these bottles ends up in oceans or landfills (Kawecki et al. 2018; Iravanian and Ravari 2020). The disposal of PET waste, a major plastic fraction, poses critical environmental challenges. To address this, recent research explores repurposing PET bottles in construction, offering potential solutions to this problem (Ochi et al. 2007; Thomas and Moosvi 2020; Yin et al. 2015). This path seeks to provide sustainable alternative uses and mitigate the environmental impact of PET waste.

Reinforcing cemented soil with shredded waste plastic bottles offers an effective method for plastic waste disposal, simultaneously reducing cement usage in soil improvement and reducing CO₂ emissions. Soil samples containing strips of plastic waste bottles, specifically Polyethylene Terephthalate (PET), demonstrate enhanced shear strength properties, similar to the reinforcing effect of traditional soil fibers (Louzada et al. 2019; Singh and Mittal 2019; Iravanian and Haider 2020). Studies by Ilies et al. (2015) and Peddaiah et al. (2018) confirm the improvement in properties of stabilized clay soil through the addition of PET shreds, with a positive impact on the California Bearing Ratio (CBR) value.

Research on cement stabilization of clay, by Ekinci (2019), Hanafi et al. (2020), and Horpibulsuk (2012), consistently indicates an increase in soil strength with the inclusion of cement. Investigations into plastic fiber-cement-soil blends, as conducted by Alzaidy (2019), Consoli et al. (2009), and Khattak and Alrashidi (2006), underline the positive influence of fibers on cemented soil properties. Tang et al. (2007) report that combining fibers and cement significantly boosts strength in clay samples, aligning with findings from Estabragh et al. (2012), Kim et al. (2008), and Xiao et al. (2013).

Haider et al. (2023) employed ultrasonic pulse velocity (UPV) tests to assess the shear modulus of PET-reinforced

cemented clays during cyclic wetting–drying tests. The findings revealed that in 28-day cured samples, there was a consistent decrease in stiffness after each cycle. However, the decrease ratio was notably less in samples enhanced with PET shreds compared to those without.

The current article seeks to investigate the effect of polyethylene terephthalate bottle shreds (PETBS) addition on clayey soil samples, mainly to find the optimum percentages range of plastic bottle shreds needed for the soil to be used as an effective subgrade material. The strength and stiffness of cemented soil reinforced with PETBS was investigated through the California Bearing Ratio (CBR) and Ultrasonic Pulse Velocity (UPV) tests, respectively. The microstructure of the soil before and after the treatment was monitored through scanning electron microscope (SEM) analysis. Eventually, a regression model was proposed to estimate the CBR value and initial shear modulus of PETBS-reinforced artificially cemented clay to be used for varying percentage of PETBS content and grading size.

2 Materials and Methods

2.1 Materials

The soil sample used in this study was collected from a site located in Duhok governorate, situated in the northern region of Iraq (36°59'24.5"N and 42°39'20.7"E) about 500 km away from the Iraqi capital, Baghdad as shown in (Fig. 1). The physical characteristics tests, such as Atterberg limits, sieve analysis, specific gravity, and standard Proctor compaction test, were done according to ASTM standards (ASTM D4318-17e1; ASTM D422-63, 2007; ASTM D854-14; ASTM D698-12e2). Table 1 illustrates the results of the characterization tests of untreated soil. The soil sample used in this study is identified as low plasticity clay, CL, according to the unified soil classification system (USCS) (ASTM D2487-17e1). The gradation curve of the soil is presented in Fig. 2. Additionally, scanning electron microscopy (SEM) analysis was conducted on the soil sample to investigate the microstructure of the untreated clay, as shown in Fig. 3, which shows the hollow and flaky structure of clay with relatively substantial voids. Chemical characterization of the soil sample was performed using Energy-dispersive X-ray spectroscopy (EDX), as depicted in Fig. 4, indicating that the sample is rich in silica and calcium.

The cement used as binding agent in this study was ordinary Portland cement (OPC) Type I. The physical properties of cement such as fineness, specific gravity, and setting time, were tested according to ASTM standards: ASTM C150/C150M-18; ASTM C204-18e1; ASTM C188-17; ASTM C191-19 respectively. The basic properties of cement could be seen in Table 2.

Fig. 1 **a** A satellite map of location of the sample, **b** appearance of the soil at site



(a)



(b)

The fibers used in the tests were produced from waste plastic water bottles. The polyethylene terephthalate bottles were ground using a knife mill and sieved, in two size ranges of 2–4.75 mm and 0.42–0.841 mm, corresponding to material retaining on sieve sizes number 10 and 40, respectively. These size ranges will be termed as size no. 10 and size no. 40 throughout this paper. The sieve analysis of the milled polyethylene terephthalate bottle shreds, PETBS, is depicted in Fig. 5 showing the used range sizes

in full lines. Size no.10 shreds pass through sieve number 4 and remain on sieve number 10 while size no. 40 shreds pass through sieve number 20 and remain on sieve number 40. This grading represents coarse and medium sand sizes and could be easily obtained without the use of high-energy or heavy-duty mills. The characteristics of PETBS are detailed in Table 3. The SEM analysis of the PETBS images exhibit that the surface of the polyethylene shreds is not completely smooth (Fig. 6).

Table 1 Characterization tests results of soil

Properties	Value
Liquid limit (%)	37
Plastic limit (%)	24
Plasticity index (%)	13
Specific gravity	2.70
Classification	CL
Maximum dry density (kg/m ³)	1581
Optimum moisture content (%)	23.3
California bearing ratio, CBR (%)	3.15

2.2 Methods

The standard Proctor compaction test was used to detect the maximum dry density (MDD) and optimum moisture content (OMC) of the clay samples mixed with 0 to 1% of solid mass of PETBS, with increments of 0.1%. This range was selected based on literature review, as most of the research works suggest that the optimum effective content of PET shreds is less than 1% of the mixture's solid mass (Thomas and Moosvi 2020; Haider et al. 2023). The tests were carried out for PETBS additions of both size ranges of 2–4.75 mm and 0.42–0.841 mm. The CBR samples were later prepared on the obtained MDD and OMC results and were tested to find out the optimum percent of PETBS content.

The California Bearing Ratio (CBR) test was used as a strength indicator in this study. CBR specimens were tested according to ASTM standard D1883-16. The samples were prepared with quantities of 0, 0.6, 0.7 and 0.8% of solid dry mass of PETBS of both size ranges, and the effect of

cement enhancement of 5, 7 and 10% was investigated in each of the prepared samples. The cement-treated samples were cured for 7 and 28 days prior to CBR test. Previous studies on cement-stabilized soil generally recommend the addition of cement of less than 10% to fulfill the desired strength properties (Bahmani et al. 2016; Basha et al. 2005; Bozyigit et al. 2021). In this research, maximum of 10% cement addition was tested, and additional trial percentages of 5% and 7% were chosen to explore the minimum required cement content.

The Ultrasonic Pulse Velocity (UPV) test was conducted in accordance with ASTM D2845-08 and was used to

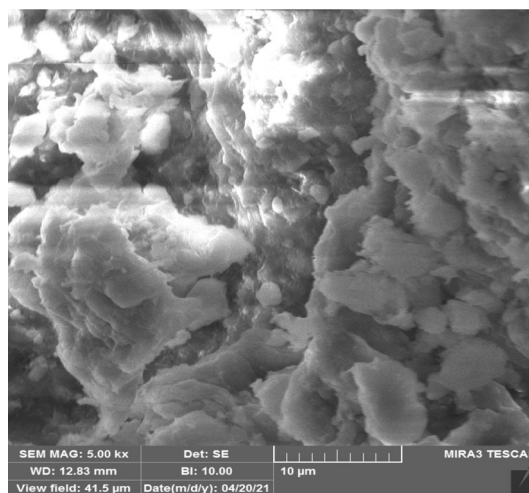
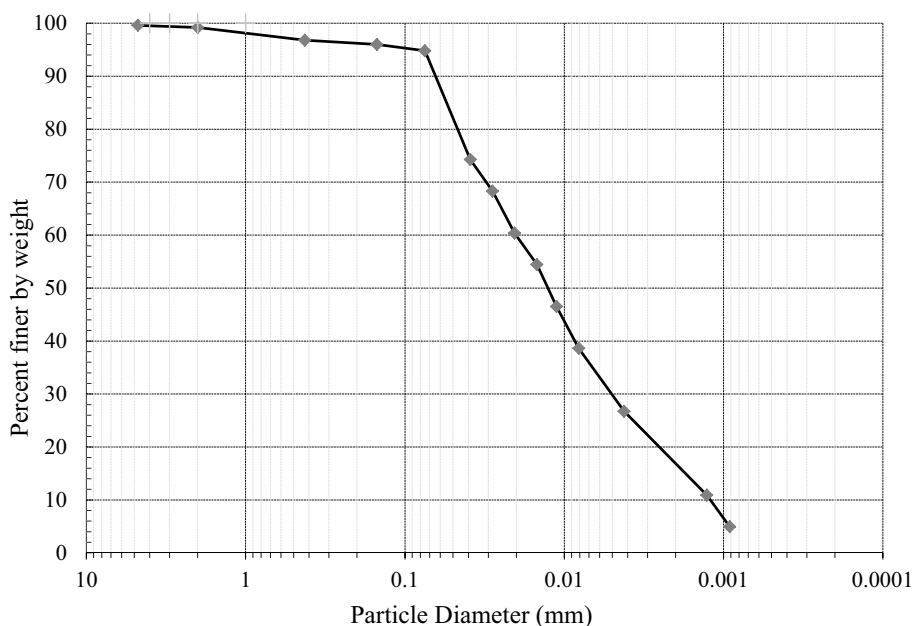
**Fig. 3** SEM of untreated clay sample magnified ×5000**Fig. 2** Grain size distribution of the soil

Fig. 4 EDX of untreated soil sample

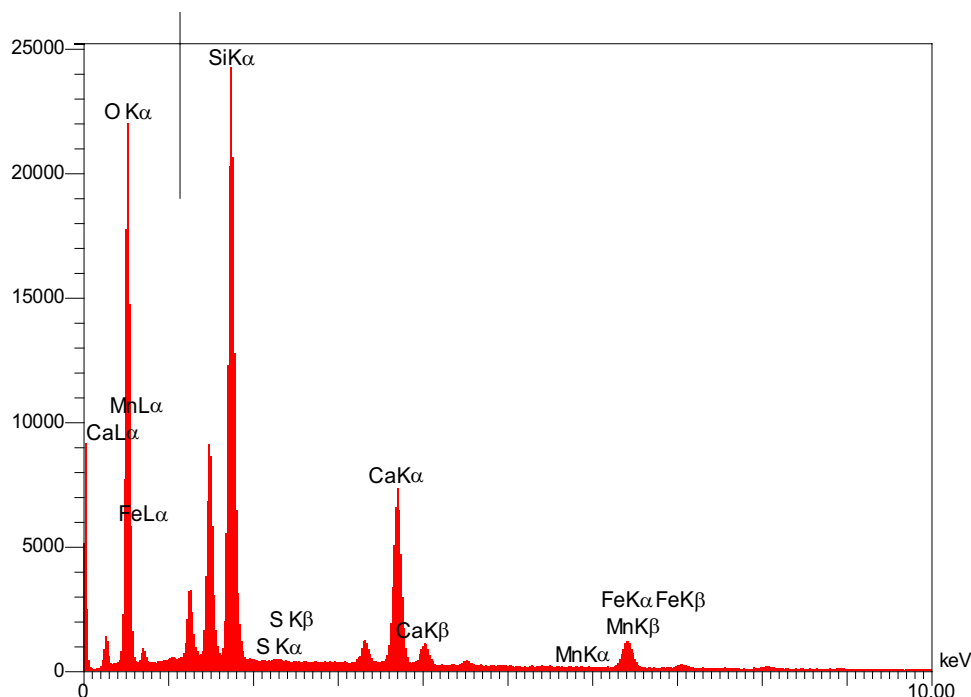


Table 2 Index test results of cement

Type	Value	Standard codes
Specific gravity	3.15	ASTM C188-17
Fineness (m ² /kg)	403	ASTM C204-18e1
Initial setting time (minute)	180	ASTM C191-19
Final setting time (minute)	230	ASTM C191-19

evaluate the maximum shear modulus (G_{max}) of the mixtures. For this evaluation, all samples were prepared at a dry density of 1400 kg/m³ based on the maximum dry densities acquired in standard Proctor compaction test $\pm 2.5\%$. The process of mixing and preparation of cement treated mixtures was completed prior to the initial setting time of the cement. The samples were sealed in plastic bags for curing and tested after 7 and 28 days following the ASTM C511-19 standard. Figure 7 summarizes the methods followed in this study.

Fig. 5 Grain size distribution of the PETBS

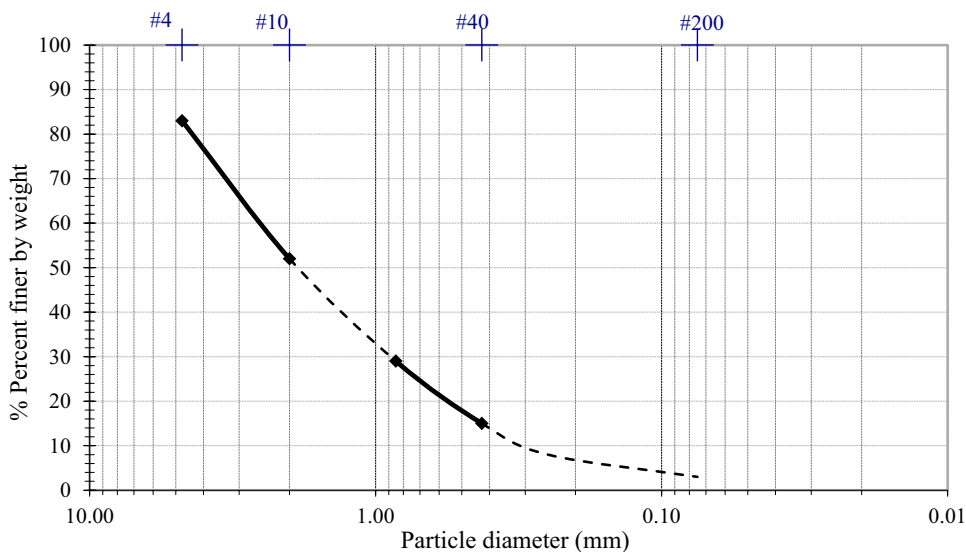
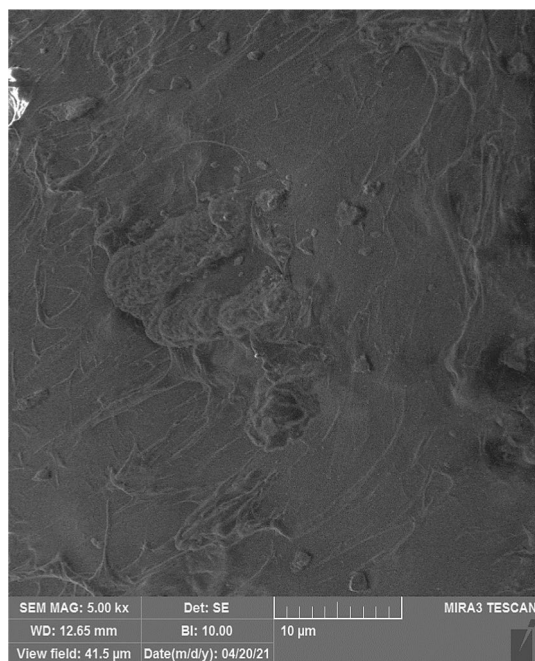


Table 3 Properties of polyethylene terephthalate bottle shreds

Type	Value
Water absorption (%)	0.16
Specific gravity	1.3–1.4
Melting point (°C)	260
Modulus of elasticity (GPa)	2.8–3.1
Tensile strength (GPa)	0.055–0.075

**Fig. 6** SEM analysis image of PETBS magnified $\times 5000$

3 Results and Discussion

3.1 Effect of PETBS on Compaction Characteristics and Strength (CBR)

The maximum dry density (MDD) and optimum moisture content (OMC) of samples mixed with 0 to 1% of PETBS (solid mass), with increments of 0.1% is shown in Fig. 8. It can be seen that, regardless of the grading, the addition of PETBS to clay reduced the MDD of samples in a linear manner. The decrease in density is attributed to the lower density of PETBS compared to soil grains. The replacement of a portion of soil grains with the lighter PETBS, has led to in a lower overall density. The OMC of the samples, however, were increased with the introduction of PETBS to the soil. This can be explained by the requirement for extra water to facilitate the contact between soil grains and PETBS, thereby requiring a slightly increased

water content for the proper integration of PETBS into the soil.

A series of California Bearing Ratio (CBR) tests were conducted to study the influence of PETBS on CBR value. The test samples were prepared at their MDD and OMC with differing contents of PETBS in both size ranges. Figure 9 shows the results of the CBR tests. The addition of PETBS in all content ratios improved the CBR values of soil samples. The improvement was however only observed up to 0.6% content, beyond which it declined for PETBS sieve size no. 40. Similarly, for PETBS of sieve size no. 10, improvement was recorded until 0.7%, followed by a decline. Additionally, PETBS of sieve size no. 10 appeared to be more effective in enhancing CBR values than size 40. The possible reason for that could be attributed to the larger size of PETBS in sieve size 10, which allows more soil grains to attach to its surface, and therefore the matrix integrity and mobility of the PETBS could be better and stronger. The addition of 0.7% PETBS of size no. 10 played the most significant role in improvement, showing a 90.79% enhancement in CBR, compared to untreated soil samples. Meanwhile, the addition of 0.6% had the most favorable impact on samples treated with PETBS size no. 40, resulting in a 63.49% improvement in CBR value.

A research work conducted by the Wisconsin department of transportation, WDT, has concluded that a minimum California Bearing Ratio (CBR) of 6 in the top 60 cm of soil would provide sufficient strength for the construction traffic (Crovetti and Schabelski 2002). On other hand, the local standard of Iraq, the country where this study is conducted, suggested the CBR to be at least 4% for the subgrade layer (Iraqi state corporation for roads and bridges, SCRB 2005). According to the CBR test results, the addition of PETBS, regardless of percentage and size, met the minimum requirements of the local standard, SCRB. However, only samples supplemented with PETBS of sieve size no. 10 at a content of 0.7% conformed to the standards set by the WDT. Contents of 0.6%, 0.7%, and 0.8% contribute significantly to the CBR values; nevertheless, the incorporation of an additional binder such as cement, would be essential.

3.2 Effect of Cement on Strength (CBR)

The effect of curing period on California Bearing Ratio (CBR) of artificially cemented clay samples can be seen in Fig. 10. The results show that cement stabilization increases the strength of the soil, regardless of the amount of cement added, and the increase in cement content results in an increase in CBR. The effect of cement addition may be explained by the instant influence of it on the internal structure of the soil. An increase in sample strength is noted due to flocculation and agglomeration mechanisms, leading to pozzolanic reactions among

Fig. 7 Schematic diagram of the research methodology

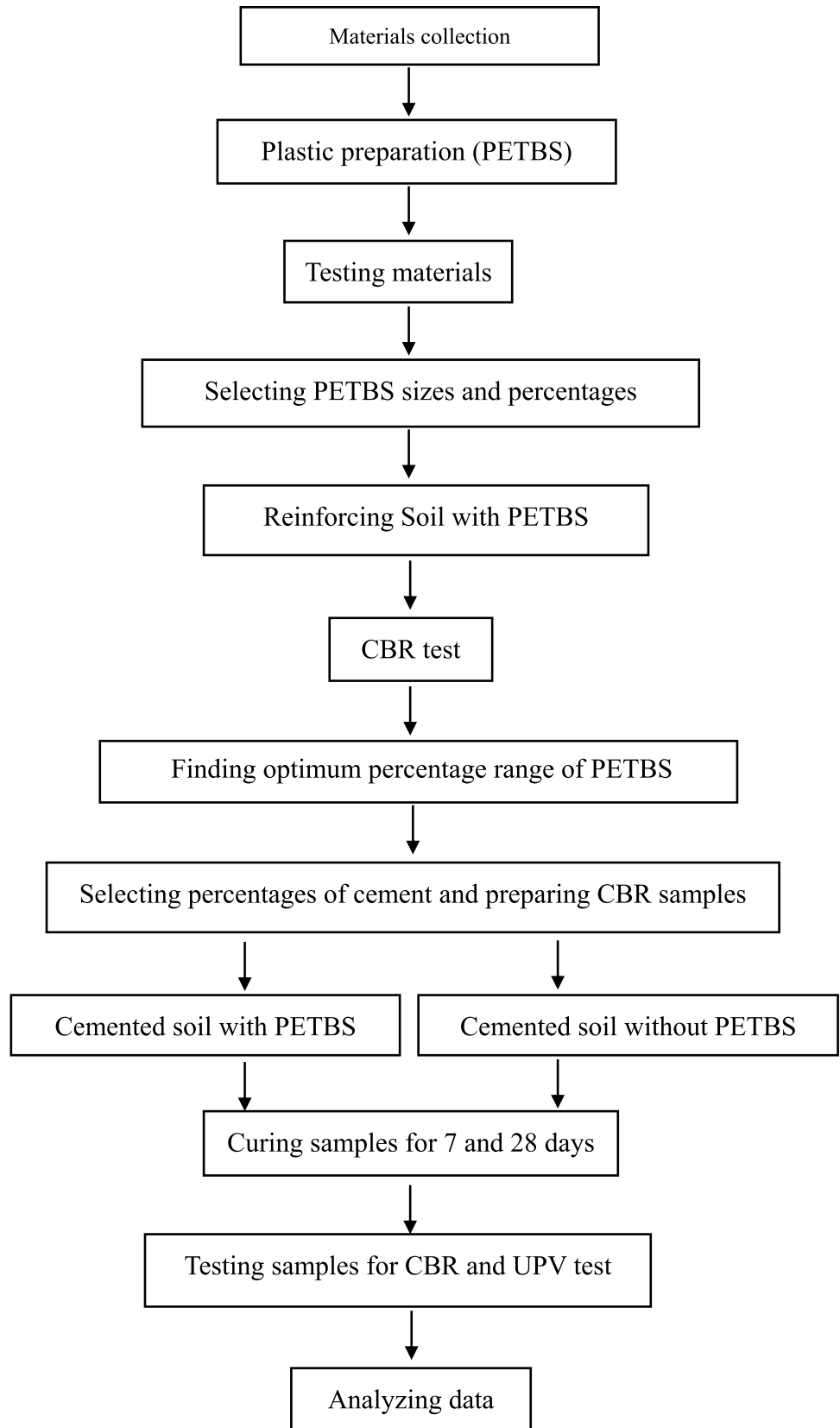


Fig. 8 Maximum dry density and optimum moisture content of PETBS added samples

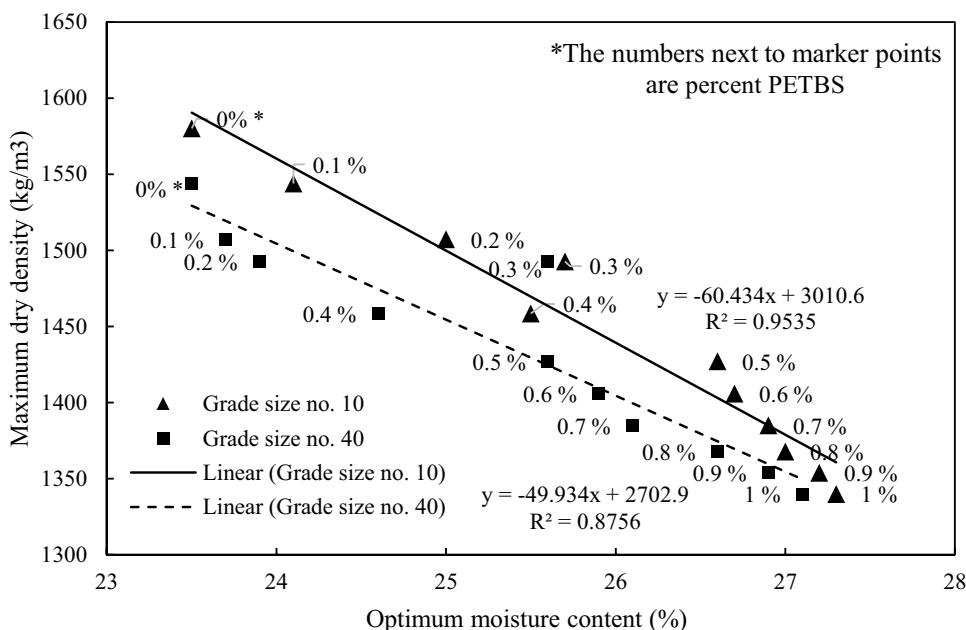
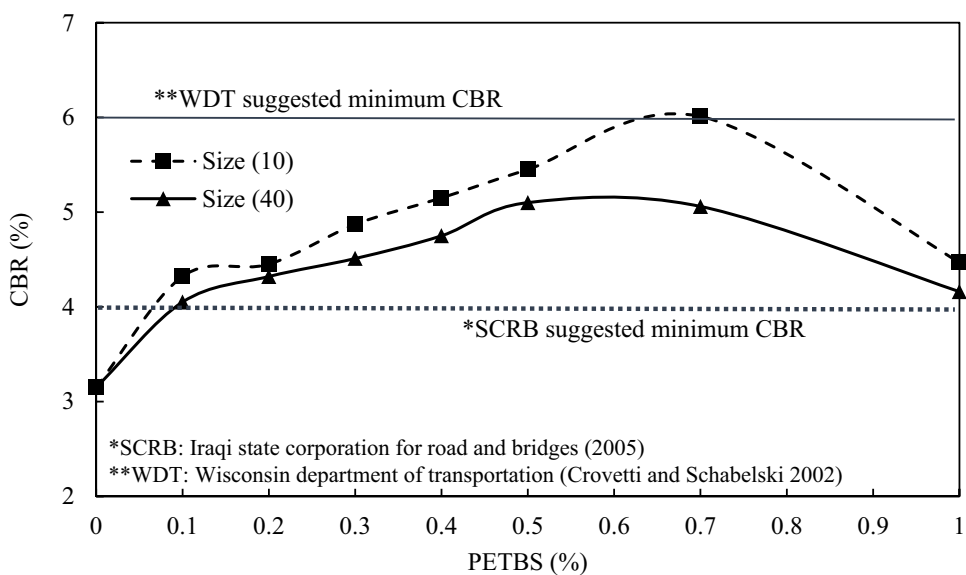


Fig. 9 CBR of soil reinforced with PETBS



clay minerals and free calcium hydroxide $\text{Ca}(\text{OH})_2$. These processes promote the deposition of hydrated cement compounds and consequently result in denser structure. The addition of cement to the soil decreases the elastic response of the soil and enhances the bond between soil particles. This characteristic elevates the resistance against failure and deformation in cement-stabilized soils. Soil stabilization with cement improves the CBR of soils, as cement establishes a robust bond between soil particles, resulting in a more rigid behavior. Therefore, a longer curing duration is appropriate for the generation of the mentioned reactions, as well as for the mechanisms of cement hydration.

3.3 Effect of PETBS Addition on Strength (CBR) and SEM Analysis

Figure 11 illustrates the influence of addition of PETBS on CBR values of artificially cemented clay samples after 7 and 28 days curing days. The variables considered in this assessment were cement content, PETBS content, PETBS size number, and the curing period. As it was expected, with cement content increase, higher strength was gained and CBR values were improved. It is also evident that the CBR values show the most significant enhancement when the PETBS content is at 0.7% in combination with varying amounts of cement. The comparison of samples enhanced

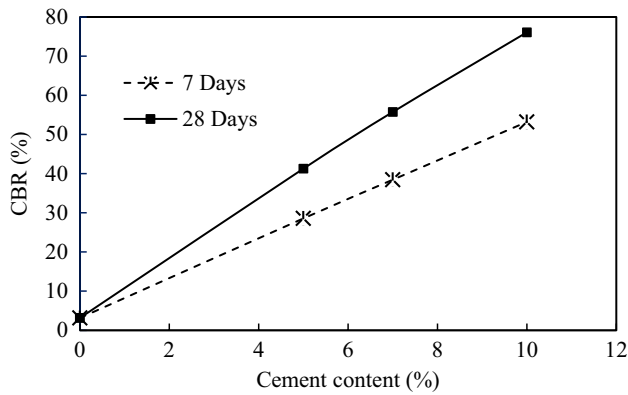


Fig. 10 CBR of cement treated soil samples in 7 and 28 days curing periods

with 0.7% PETBS of size no. 10 to non-PETBS treated cemented samples shows 35.5, 35 and 33% improvement at cement contents of 5, 7 and 10% respectively. Furthermore, the specimens reinforced with sieve no. 10 PETBS exhibit improved CBR values by performing an average of 11, 18 and 12% higher, compared to samples using PETBS size no. 40, for PETBS contents of 0.6, 0.7 and 0.8% respectively. This improvement holds true across all cement content ratios for both curing durations.

In Fig. 12a and b, scanning electron micrographs depict samples with 7% cement content and 0.7% PETBS of size no. 10 after a 28-day curing duration at magnification ratios of $\times 300$ and $\times 1000$, respectively. Circles annotated on the SEM images show the cement hydration products adhering to the PETBS surface and edges. It appears that when shredded, the blades of the shredder cut the PET unevenly

and scratch its surfaces, resulting in a rough surface that provides sufficient opportunities for particles and hydration products to adhere to. This, in turn, contributes to increased friction resistance in the sample. The hydration products, possessing greater strength than clay particles, enhance the interaction between the soil and PETBS. Consequently, the interface and bonding strength of cemented soil reinforced with PETBS exceeds the strength of the samples without PETBS (Fig. 11).

On the other hand, the longer curing time allows the hydration process to continue, effectively filling voids and cracks. As depicted in Fig. 13a and b, the cracks and voids in a sample with 0.7% PETBS no. 10 and 7% cement, cured for 28 days, are noticeably reduced compared to the same sample after 7 days of curing. Compounds of clay, alumina, and silica react with calcium, producing calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) in the pozzolanic reactions of the cement hydration process. These products continue to extend and strengthen (Hanafi et al. 2020), thereby enhancing the strength of cemented PETBS clay over the curing time.

3.4 Effect of PETBS and Cement Addition on Stiffness

Figure 14a and b illustrate the effect of PETBS on stiffness through ultrasonic pulse velocity (UPV). The results confirm that the addition of PETBS decreases the stiffness of the soil regardless of the amount and size. Therefore, it makes the soil less brittle and more ductile, which is due to the elastic character of PET that confirms the findings of Consoli et al. (2002). As the content of PETBS increases, the stiffness decreases,

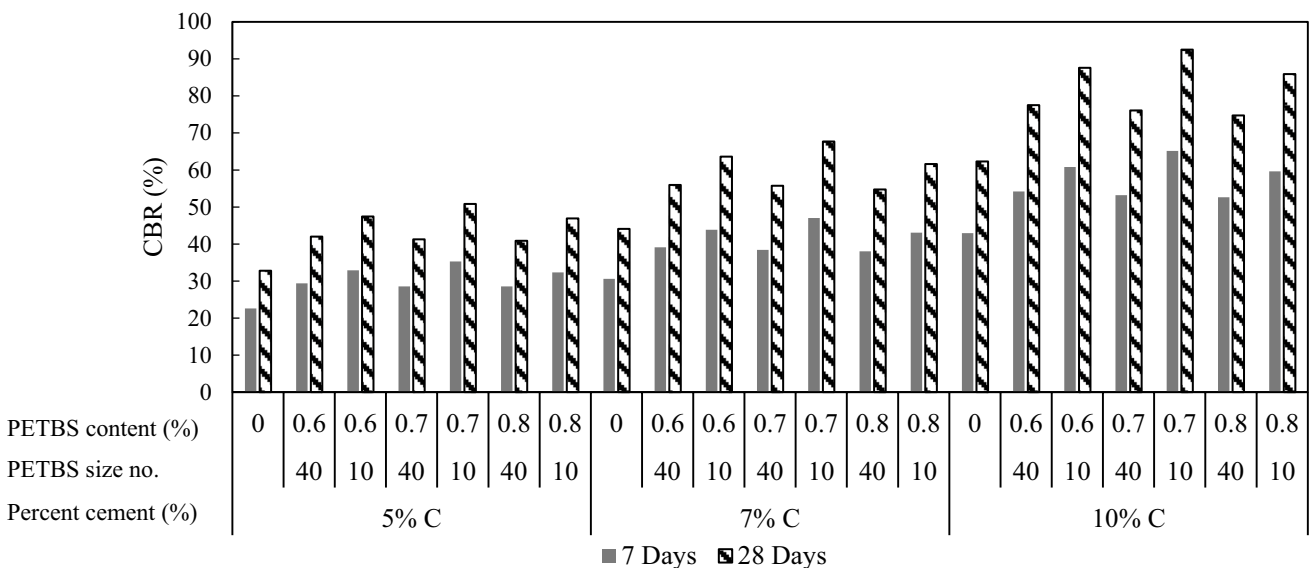


Fig. 11 CBR of cement and PETBS treated soil samples in 7 and 28 days curing periods

Fig. 12 SEM images of samples with 7% cement and 0.7% of PET shreds size 10 cured for 28 days **a** $\times 300$ and **b** $\times 1000$

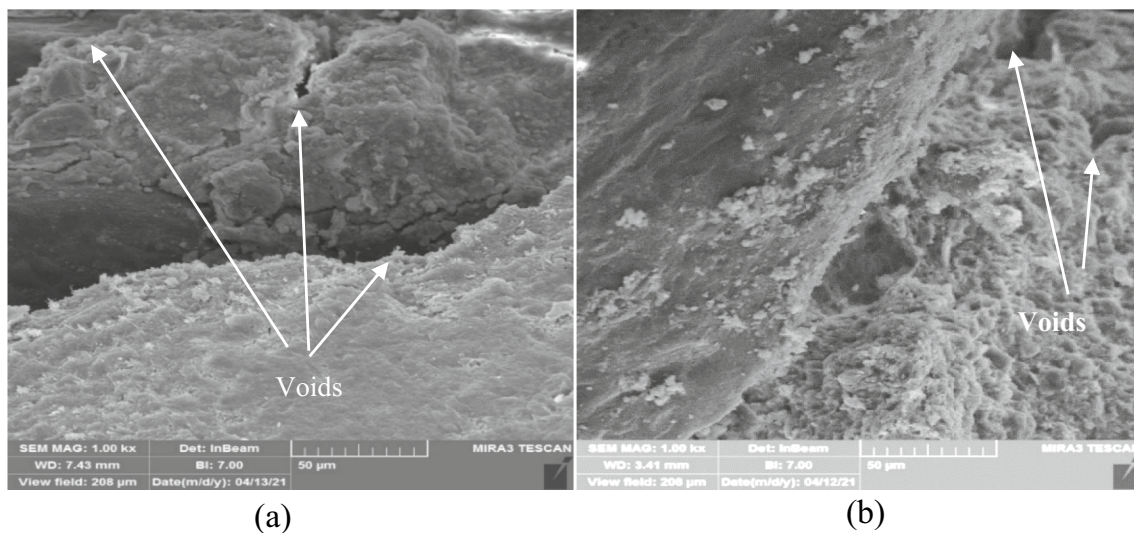
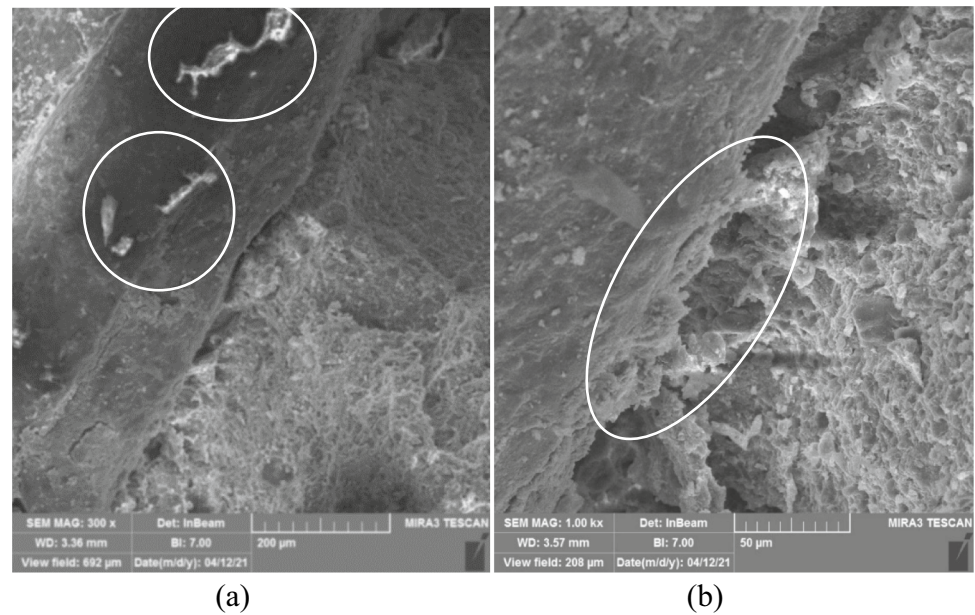


Fig. 13 SEM images of samples with 7% cement and 0.7% of PET shreds size 10 cured for **a** 7 days, $\times 1000$ and **b** 28 days $\times 1000$

which is an expected behavior, given that the amount of the elastic materials rises in the mixtures. As the cement content in the soil increases, the stiffness of the soil also increases, which is attributable to the brittle nature of the cement hydration products. These results are consistent with findings from other studies (Consoli et al. 2012; Jovičić et al. 2006; Puppala et al. 2006; Trhlíková et al. 2012).

3.5 Analysis of the Key Factors Influencing CBR and G_0

In this study, the analysis of variance (ANOVA) was used with a significance level (p -value) set at 5%. This was done so that any significant differences among variables affecting the CBR and G_0 of artificially cemented clay samples

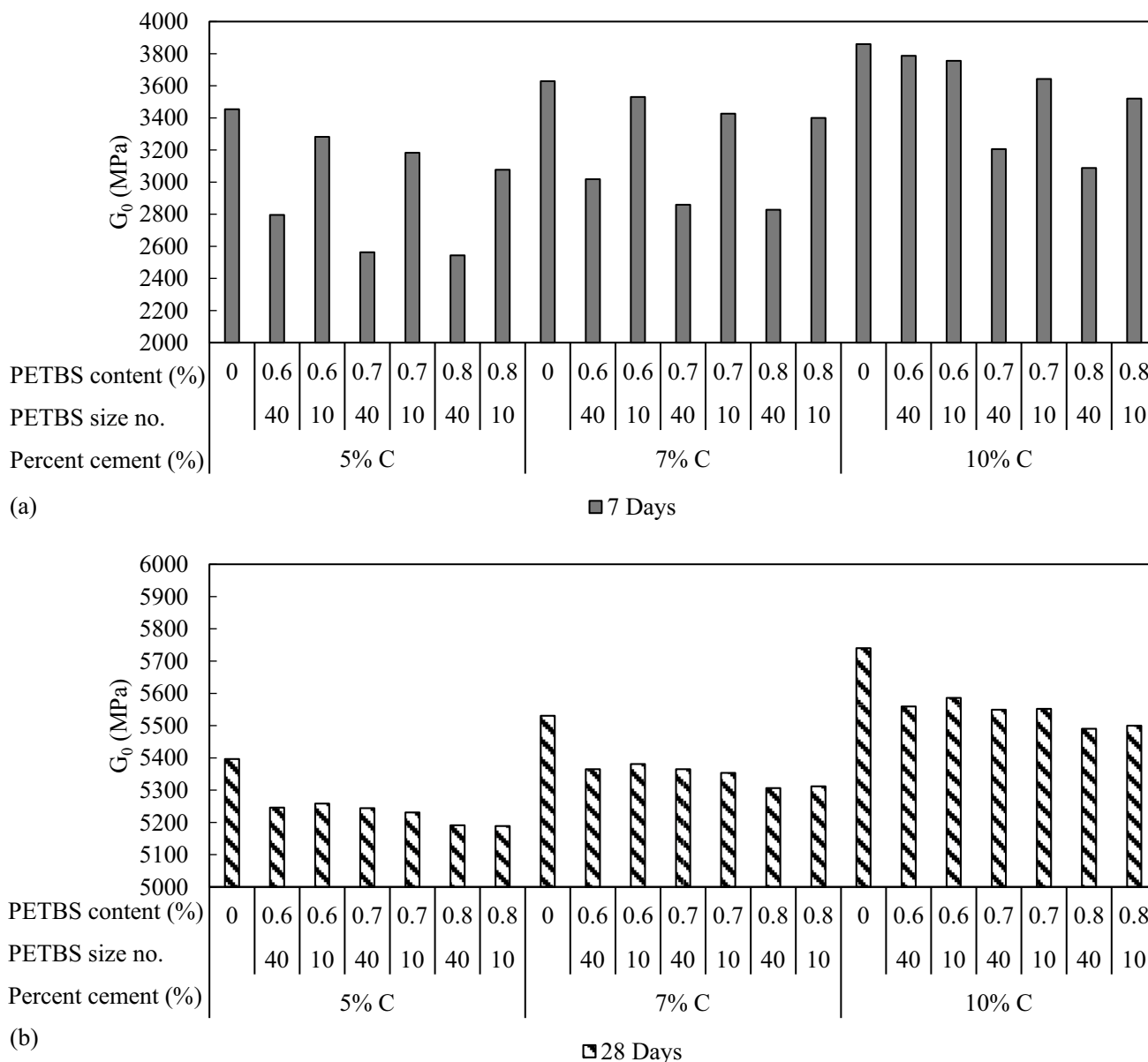


Fig. 14 Stiffness for all blends for curing of a 7 and b 28 days

reinforced with PETBS could be identified. The analysis was conducted using the Statgraphics v18 software package. Independent variables were cement content (5%, 7%, 10%), PETBS grading, PETBS content (0.6%, 0.7%, 0.8%) and curing period (7 and 28 days) while the dependent variables were California bearing ratio (CBR) and initial shear modulus (G_0).

Table 4 presents the ANOVA analysis parameters for up to two-order interactions. Statistical analysis of variances showed that all interactions of any single independent parameters and the combination of any two independent parameters are statistically significant correlated with the dependent parameters at a p -value less than 5%. A p -value

less than 5% is statistically significant which shows a probability of 5% that the null hypothesis (no relationship between dependent and independent parameters) may be correct. The relative importance of each variable that affects the coefficient of determination (R^2) of the obtained model was evaluated to determine the most relevant factor. Based on the statistical results shown in Table 4, the most important variables that affect the California bearing ratio (CBR) and initial shear modulus (G_0) of a PETBS reinforced clay were, in the order, cement content, curing period, PETBS grading and PETBS content.

Figure 15 shows the relationship between independent variables (cement content, PETBS grading, PETBS content

Table 4 Analysis of variance for CBR and G_0

Effecting variables	Sum of squares	Df	Mean square	F-ratio	<i>p</i> -value
A: Cement content (%)	6205.22	2	3102.61	12724.81	0.0000
B: PETBS content (%)	45.6863	2	22.8431	93.69	0.0000
C: PETBS grading	567.313	1	567.313	2326.74	0.0000
D: Curing (Days)	3216.21	1	3216.21	13190.74	0.0000
Interactions					
AB	2.68166	4	0.670415	2.75	0.0648
AC	34.8144	2	17.4072	71.39	0.0000
AD	187.261	2	93.6306	384.01	0.0000
BC	37.2676	2	18.6338	76.42	0.0000
BD	1.38309	2	0.691544	2.84	0.0882
CD	20.9001	1	20.9001	85.72	0.0000
Residual	3.90118	16	0.243824		
Total (Corrected)	10322.6	35			

Where: Df-degree of freedom, F-Ratio is the variance ratio, and *p*-value is probability value (significance level)

and curing period) and dependent parameters (CBR and G_0) for all samples studied. Figure 15a and b show that the increased cement content of the samples at both sizes of sieve no. 10 and no. 40 contributes well to the increase of the CBR and G_0 of the PETBS-reinforced clay. However, it is notable that shreds with the size no. 10 are contributing the most. It can also be seen in that an increase in PETBS content results in a reduction in G_0 where the effect of PETBS content is seen to be minimal from a CBR point of view. From these graphs it is evident that the increase in the curing period from 7 to 28 days results in substantial increase in both CBR and G_0 , moreover, this increase is almost linear for the shear modulus values. The highest rate of growth of G_0 with an increase in cement content was monitored in 7-day cured samples.

3.6 Predicting CBR Parameters Using Introduced Variables

Equation 1 was established to predict the CBR value from the different effecting variables namely: cement content, PETBS grading, PETBS content and curing period. The output in Fig. 16 illustrates the outcomes of applying a multiple linear regression model to show the association between CBR (%) and four independent variables, in comparison with the measured CBR (%). The model demonstrates a robust predictive capability, with a high coefficient of determination ($R^2=0.97$).

$$\begin{aligned} \text{CBR (\%)} = & 1.33862 + 6.39393 * \text{cement content (\%)} \\ & - 0.265204 * \text{PETBSGrading} - 6.35833 \\ & * \text{PETBSContent (\%)} + 0.900979 \\ & * \text{Cure (Days)} \quad R^2 = 0.97 \end{aligned} \quad (1)$$

where,

CBR: California bearing ratio.

PETBS: Polyethylene terephthalate bottle shreds.

R^2 : Coefficient of determination.

Cement content (%) ranges from 5 to 10%

PETBS grading ranges from 0.42 to 4.75 mm.

PETBS content ranges from 0.6 to 0.8%

Cure (Days) ranges from 7 to 28 days.

3.7 Acquiring CBR Parameters Using UPV Test

Fitting a linear model for all samples with 28 days curing duration, allows CBR to be determined as a function of G_0 , as seen in Fig. 17. Equation 2 calculates the CBR value of a specific artificially cemented clay reinforced with PETBS for any mixture using the G_0 of only one soil-PETBS mixture sample.

$$\text{CBR} = -1234.44 + 0.760417 * G_0 R^2 = 0.96 \quad (2)$$

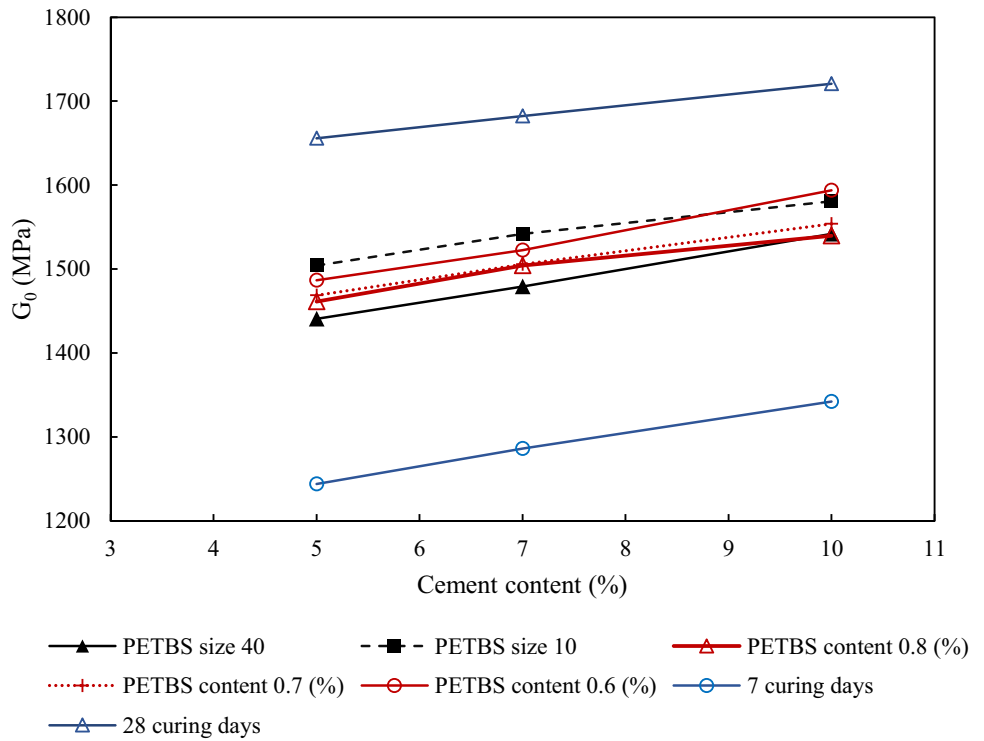
where,

CBR: California bearing ratio.

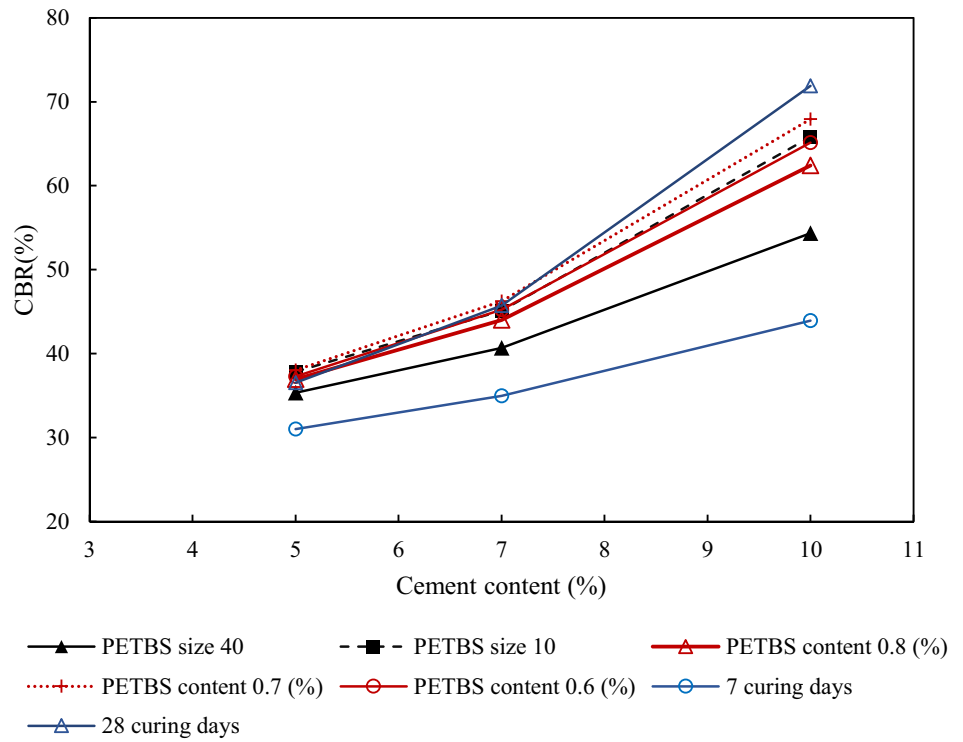
G_0 : Initial shear modulus (1680 to 1750 MPa).

R^2 : Coefficient of determination.

Fig. 15 The interaction between controllable factors cement content, PETBS Sizes, PETBS content and curing period for CBR and G_0 . **a** Effect of PETBS size, content and curing period on initial shear modulus, G_0 **b** effect of PETBS size, content and curing period on California bearing ratio (CBR)



(a)



(b)

Fig. 16 Comparison between predicted and tested CBR

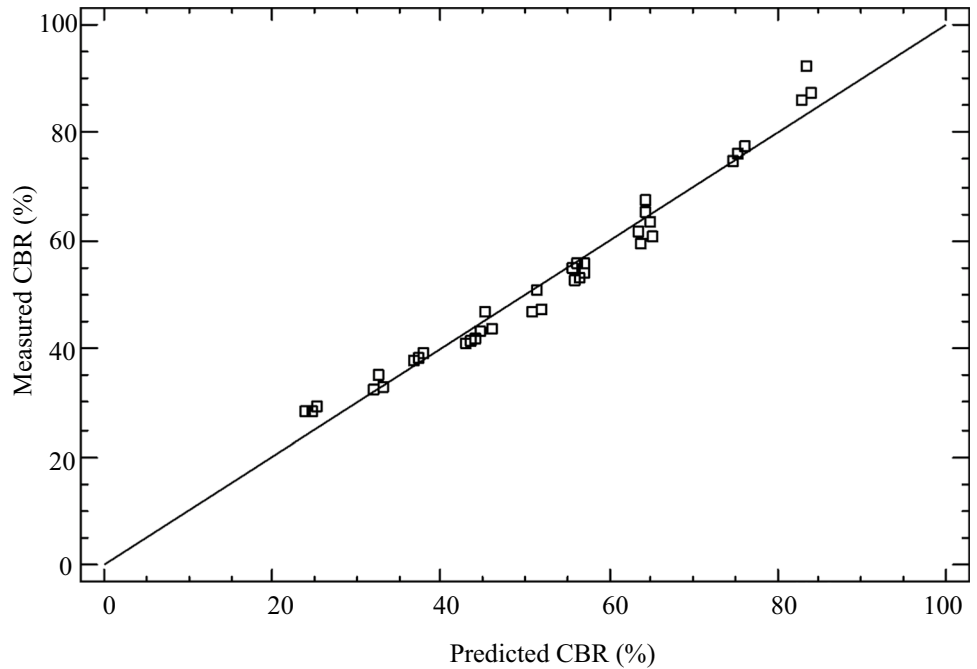
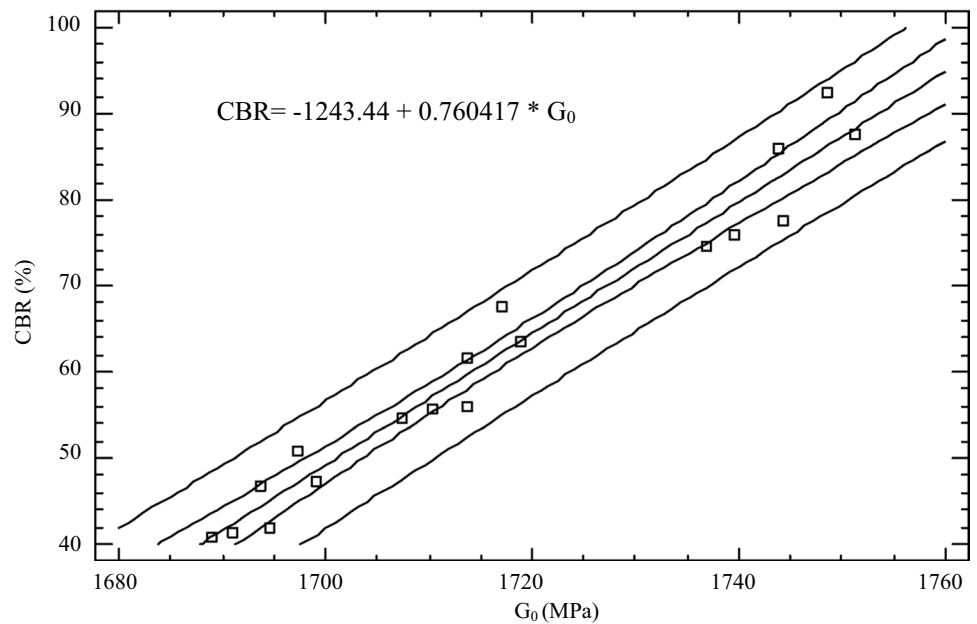


Fig. 17 Relationship between CBR and G_0 for 28 days cured specimens



4 Conclusions

Based on the experimental and the statistical analysis presented in this research the following conclusions can be drawn.

- The addition of polyethylene terephthalate bottle shreds, PETBS, improved the CBR of the soil compared to the untreated soil, with an improvement range

of 28.5 to 90.7%. It was observed that the coarser size range of PETBS, 2–4.75 mm, performs better than the finer size range, 0.42–0.841 mm, in terms of improving soil CBR values. The optimum percentage of PETBS was shown to be 0.6, 0.7 and 0.8%.

- The addition of cement improved the strength (CBR) of the soil. A higher percentage of cement resulted in a higher strength gain.
- The addition of PETBS to artificially cemented soil resulted in an improvement of up to 35% CBR val-

ues. Once again, the samples containing PETBS size 2–4.75 mm reached higher values in comparison to the samples containing PETBS size 0.42–0.841 mm. The highest strength contribution was found to be at 0.7% PETBS content.

- The addition of cement increased the stiffness and strength of the soil and it was evidenced by scanning electron micrographs representing a decrease in voids and cracks. However, the introduction of PETBS to the cemented soil mitigated the stiffness, thereby reducing the brittleness and transforming the cemented soil into a ductile material. This occurrence could be attributed to the elastic properties of PETBS.
- The regression model proposed in this study enables the estimation of the California Bearing Ratio and the initial shear modulus of a PETBS-reinforced artificially cemented clay with any PETBS grading, PETBS content or cement content through the outcome of a single test.
- The use of PETBS, either independently or in conjunction with cement, contributes to a reduction in pavement thickness, providing a cost-effective environmentally friendly solution. Furthermore, it showed to be effective in stabilizing weak soil, as it improved the mechanical properties of the natural untreated clay.
- Incorporating recycled PET into construction projects has the potential to decrease both costs and environmental impacts, as the local weak soil would be improved with less amount of cement through the addition of waste PETBS.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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