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Modification of the Engineering Properties of Road Base Course Soil Materials with Cement and Polyethylene Terephthalate (PET)

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Abstract

Highways have high capital costs, which include the cement or lime used in soil hardening. However, alternative construction materials such as recycled plastic can be used to reduce the cost and mitigate the effect of environmental pollution by plastic disposal. This study aimed at improving the engineering properties of road base course soil materials with Cement of 2% and Polyethylene terephthalate (PET) of size 10mm x 5mm with (0.2-0.5) % inclusion. The soil was obtained from Dungulbi borrow pit at latitude 10.2748599^{0}N, longitude 9.9506166^{0}E, and Altitude 550m in Bauchi L.G.A of Bauchi State. The design expert software used for the experiment gave rise to 13 mix proportions. The chemical analysis of the soil revealed that, the soil is laterite due the silica sesquioxide (S-S) ratio of 1.25. The soil is classified as A-7-6 group in accordance with the American Association of State Highways and Transportation Officials (AASHTO). Soil classification system classified it as CL with group index (GI) of 17. The unconfined compressive strength (UCS) value of 673kN/m^2 for stabilized soil with cement and PET indicated an improvement compared with natural soil value of 394kN/m^2 the California bearing ratio (CBR) for unsoaked and soaked with the value of 79% and 29% respectively, compared to the natural soil of 25% and 13% respectively, which indicates an adequate improvement in the bearing capacity of stabilized soil. Optimization value of factors responses and desirability are PET, 10.5%, Cement 2%, CBR unsoaked 74%, and soaked 26%. The UCS, at 28days is 671kN/m^2 with desirability value of 0.8. The analysis of variance (ANOVA) revealed that F-value was 147.88 with P-value less than 0.0001 which indicated that the un soaked CBR quadratic model of stabilized soil is significant. The same applicable to soaked and UCS of 28 days. This research work can aid in solving two current problems of the modern world: pollution reduction of PETS and using them to improve the engineering properties of weak soils.

Keywords: *Stabilization, polyethylene terephthalate (PET), cement, soil.*

1.0 Introduction

Highways are high-cost structures which are considered as one of the country's development factors. The soil underneath the highway contributes significantly to the structure to serve as required. However, sometimes the available soil is weak, and it needs hardening and stabilization. One of the popular stabilization methods is adding cement or lime to soil but it has several undesirable side effects. Plastic waste can be recycled and today they are being brought for making materials such as buckets, cups, kettles, etc. On the other hand, the disposal of plastic waste causes harmful effects on the environment. A known waste component is waste plastic bottles, which the use and disposal of them are increasing annually worldwide. As is known Civil engineers always try to use economic materials and eco-friendly materials [1].

Waste management worldwide is still a challenge brought about by urbanization, population increase and industrial growth [2]. Conventional methods of disposing of solid waste are landfilling incineration, and recycling. However, landfill spaces are reducing, the incineration process emits hazardous gases and recycling plastic to meet the same performance as virgin materials is expensive [3]. Also, cleaning and sorting plastics during recycling process is expensive [4].

Plastics have become a widespread commodity that has infiltrated every aspect of human life. [5] The production of plastics increased from 2 million metric tons in 1950 to 322 million metric tons in 2015 [6]. The cumulative amount of plastic production reached 8.3 billion metric tons in 2017. Lacking awareness of being recycled or reused, plastics have rapidly become a major concern of municipal solid waste MSW [7].

In a study by Urian et. al, Polyethylene Terephthalate (PET) Waste was used to improve the mechanical characteristics of clay. PET was added to clay at multiple percentages in an experimental study, there was improvement in mechanical properties at low PET addition of 2% and 4% [8]. Also, soil-filled bottles were used to horizontally place at different depths width and height in a study. The results showed that there was an improvement in the bearing capacity ratio by up to a factor of 3 with up to 80% reduction in soil settlement [9].

2.0 Materials and Methods

Materials used for the research work are soil, cement, polyethylene terephthalate (PET) and water. The soil material used in this practical work was obtained from the Dungulbi borrow pit in Bauchi L.G.A of Bauchi State with Latitude 10°2748599 North, Longitude 9° 9506166 East and Altitude 550meters. The cement material used was ordinary Portland cement (OPC). Plastic waste flakes, a type of polyethylene terephthalate (PET) were used as reinforced material and were obtained from waste empty bottles of assorted beverages and water. Cut to size 10 mm by 5mm, and pipe-borne water was used. Experimental tests conducted on the soil were in accordance with BS 1377 (2022) and that of the soil stabilization in accordance with BS 1924 (1990). The tests include moisture content, particle size distribution, Atterberg limit, compaction tests (BSL), linear shrinkage (LS) Unconfined Compressive Strength.

3.0 Results and Discussions

3.1 Characterization of Natural Soil

The preliminary test result conducted on the soil revealed that the soil possesses liquid limit 42.4%, plastic limit of 13.1%, plasticity index of 29.3%, and linear shrinkage was 14%. Hence the soil classified A-7-6 in accordance with the American association of state highways and transportation officials (AASHTO M 145-2012) soil classification system and CL in accordance with the unified soil classification system. The soil contains the following main oxide composition; $A1_2O_3$ – 23.07% SiO_2 52-816% Fe_2O_3 – 18.997 % and CaO-0.390%. The soil was classified as laterite due to the S-S ratio of 1.25.

Table 1: Preliminary results of the natural soil

S/N	Properties	Value
1	Natural moisture content %	3.86
2	Liquid limit %	42.4
3	Plastic limit %	13.1
4	Plasticity index %	29.3
5	Linear shrinkage %	14
6	Activity	1.4
7	Specific gravity	2.59
8	% Passing No. 200 sieve	57.3
9	% (Fines) < 0.075 - 4.76mm %	57.3
10	% Sand (0.075 - 4.76) %	38
11	% Gravel (< 4.76mm) %	0
12	Maximum dry density (MDD) Kg/m³	1.66
13	Optimum moisture content (OMC) %	10.2
14	7 days UCS kN/m²	332
15	7 + 7 days UCS kn/m²	363
16	14 days UCS kN/m²	386
17	28 days UCS kN/m²	394
18	Unsoaked CBR %	25
19	Soaked CBR %	13
20	Colour	Reddish Brown
21	Aashto classification	A - 7 - 6
22	UCSC classification	CL

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Table 2: Oxide Compositions of soil from the XRF Analysis

Oxide	Concentration (%)
Silicon oxide (SiO_2)	52.816
Aluminum oxide (AI_2O_3)	23.017
Iron oxide (Fe_2O_3)	18.997
Calcium oxide (CaO)	0.390
Magnesium oxide (MgO)	0.000
Potassium oxide (K_2O)	1.402
Manganese oxide (MnO)	0.155
Barium oxide (BaO)	0.109
Zinc oxide (ZnO)	0.014
Vanadium (V) oxide (V_2O_5)	0.118
Niobium Pentoxide (Nb_2O_5)	0.016
Copper (II) oxide (CuO)	0.042
Chlorine (Cl)	0.480
Titanium oxide (TiO_2)	1.789
Zirconium dioxide (ZrO_2)	0.269
Tin Oxide (SnO_2)	0.000

3.2 Soil Treated with PET and Cement (Unsoaked CBR)

Soil with 0% Cement and varying PET. At 0.2% PET, the CBR (California Bearing Ratio) is 65.1%. At 0.35% PET, the CBR drops to 64%, and at 0.5% PET, it further decreases to 63.3%. When cement is not added, an increase in PET content results in a slight decline in CBR values; however, all values remain significantly higher than those of the control sample. Soil with 1% cement and varying PET, with 0.2% PET, the California bearing ratio (CBR) is 68.6%. With 0.35% PET, the CBR increases to 71.2%. At 0.5% PET, the CBR reaches 74.6%. Adding 1% cement significantly increases the CBR values compared to using 0% cement, however, an increase in PET content results in only a slight increase in the CBR. Soil with 2% cement and varying PET. With 0.2% PET, the California Bearing Ratio (CBR) is 73.7%. At 0.35% PET, the CBR increases to 76.4%, and with 0.5% PET, the CBR reaches 78.5%. Notably, with 2% cement, the CBR values are the highest among all samples, indicating a significant improvement in soil strength. Similarly, with 1% cement, an increase in PET content resulted in a slight rise in CBR values.

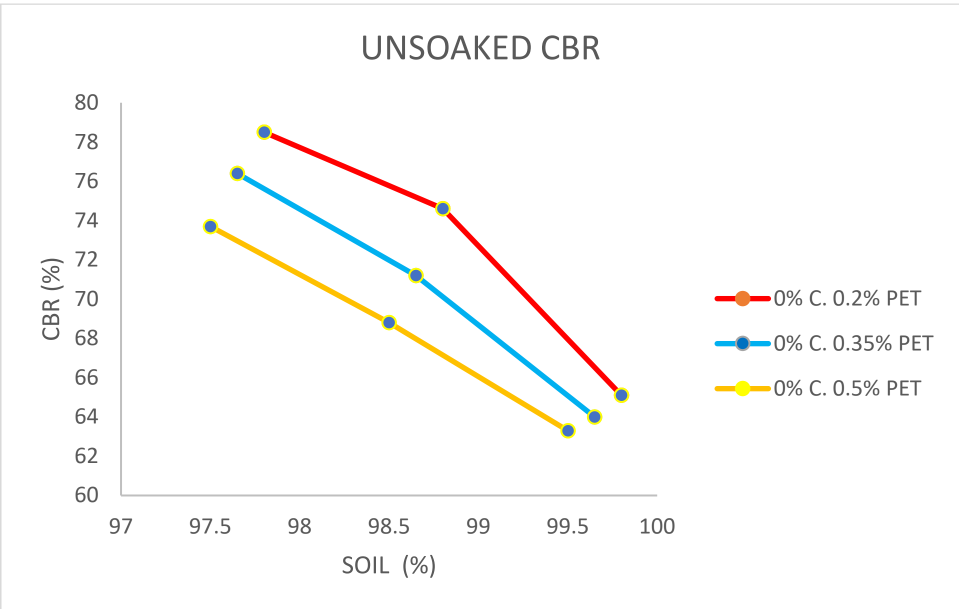

Figure1: Soil/cemented/PET (unsoaked CBR) plotting

3.3 Soil Treated with PET and Cement (Soaked CBR)

California bearing ratio (CBR) data under soaked conditions. Soil with 0% cement and varying PET: When using 0.2% PET, the California bearing ratio (CBR) is 23.0%. Increasing the PET content to 0.35% results in a CBR of 24.5%, and at 0.5% PET, the CBR further rises to 25.1%. Overall, adding PET without cement significantly improves the CBR compared to the control sample; however, higher PET content leads to a gradual increase in CBR. Soil with 1% cement and varying PET: When the PET content is 0.2%, the CBR (California

Bearing Ratio) is 24.5%. With an increase to 0.35% PET, the CBR improves to 25.1%, and at 0.5% PET, the CBR reaches 26.0%. Additionally, adding 1% cement enhances the CBR compared to a mixture with 0% cement. Overall, increasing the PET content leads to gradual improvement in the CBR. Soil with 2% cement and varying PET: The CBR (California Bearing Ratio) values vary with different percentages of PET (polyethylene terephthalate) and cement. Specifically, at 0.2% PET, the CBR is 25.7%. At 0.35% PET, the CBR increases to 26.6%. With 0.5% PET, the CBR further rises to 28.8%. Notably, when 2% cement is added, the CBR values are the highest among all samples, indicating a significant improvement in soil strength. Overall, a slight increase in PET content correlates with an increase in CBR values.

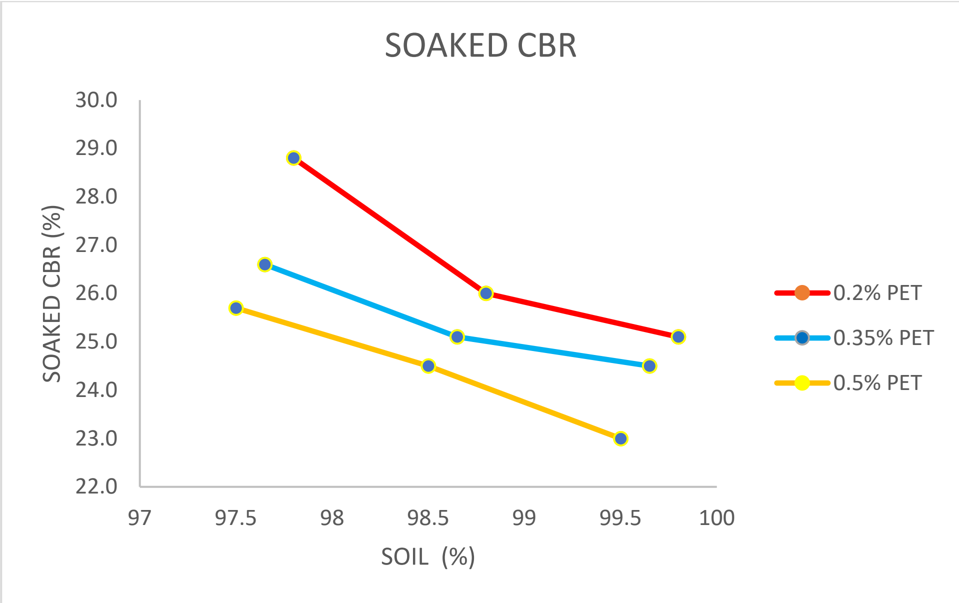

Figure 2: Soil/cemented/PET (soaked CBR) plotting

3.4 UCS 7 Days for Soil/Cement/PET

This analysis focuses on the Unconfined Compressive Strength (UCS) values for various mixtures of soil, cement, and PET that were cured for 7 days. 0.2% PET, with 99.8% soil and 0% cement, the UCS is 368 kN/m², adding 1% cement increases UCS to 438 kN/m², and adding 2% cement further increases UCS to 457 kN/m². 0.35% PET, with 99.65% soil and 0% cement, the UCS is 434 kN/m², adding 1% cement increases UCS to 460 kN/m², and adding 2% cement further increases UCS to 568 kN/m². 0.5% PET, with 99.5% soil and 0% cement, the UCS is 479 kN/m², adding 1% cement increases UCS to 573 kN/m², and adding 2% cement further increases UCS to 600 kN/m².

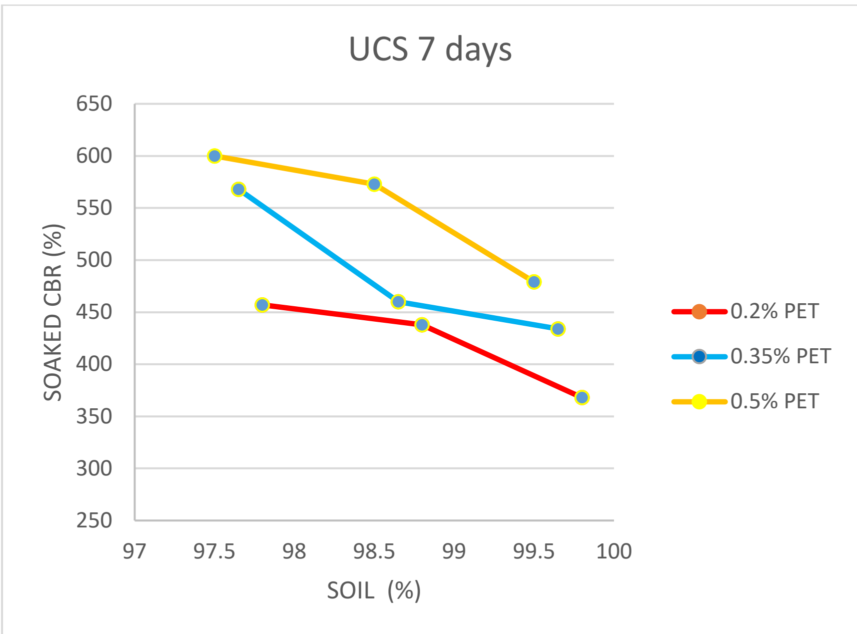

Figure 3: Soil/cement/PET UCS 7 days plotting

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3.5 7 +7 Days for Soil/Cement/PET

In a mixture consisting of 0.2% PET, 99.8% soil, and 0% cement, the unconfined compressive strength (UCS) is measured at 304 kN/m². When 1% cement is added, the UCS increases to 326 kN/m². With an additional 2% cement, the UCS further rises to 346 kN/m². In a mixture of 0.35% PET, 99.65% soil, and 0% cement, the UCS starts at 327 kN/m². Adding 1% cement enhances the UCS to 377 kN/m², and increasing the cement content to 2% raises the UCS to 389 kN/m². 0.5% PET, with 99.5% soil and 0% cement, the UCS is 382 kN/m², adding 1% cement increases the UCS to 398 kN/m², and adding 2% cement slightly decreases the UCS to 397 kN/m².

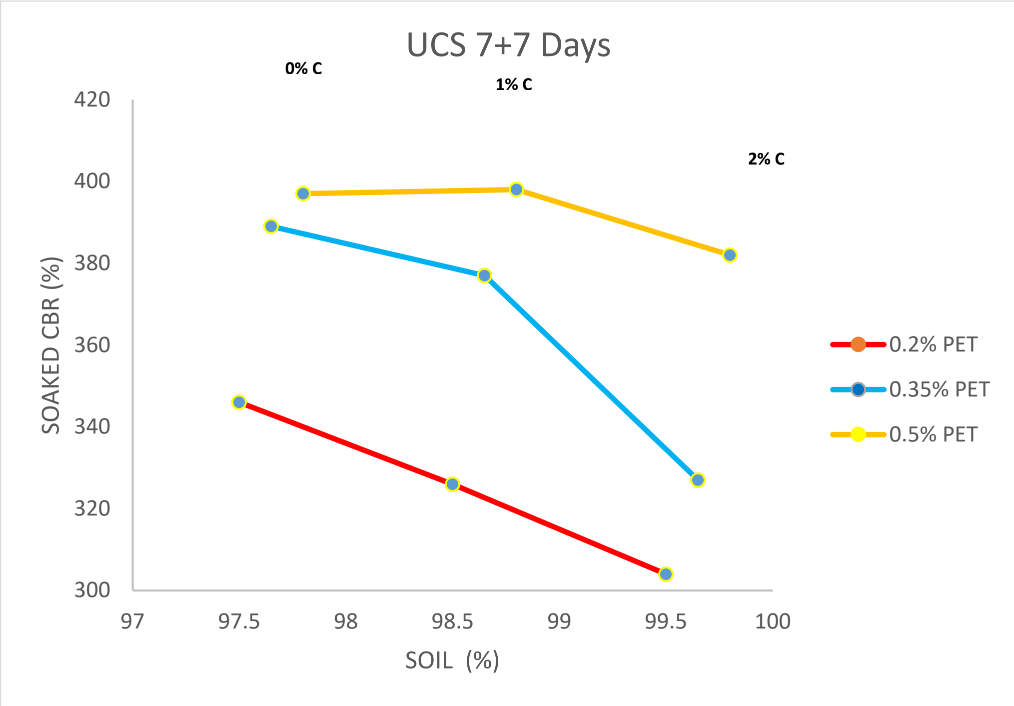

Figure 4: Soil/cement/PET UCS 7 + 7 days plotting

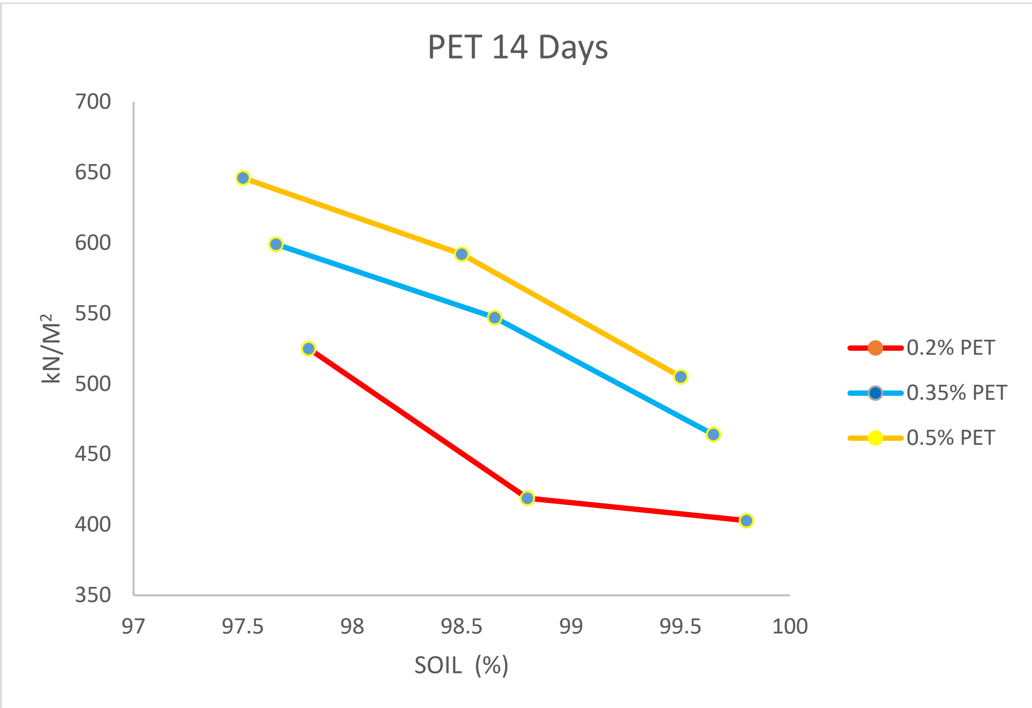

Figure 5: Soil/cement/PET UCS 14 days plotting

3.6 14 Days for Soil/Cement/PET UCS

Soil with 0% Cement and varying PET, with 0.2% PET, the UCS is 403 kN/m²; with 0.35% PET, the UCS is 464 kN/m²; with 0.5% PET, the UCS is 505 kN/m². Adding PET without cement significantly increases the

UCS, with the highest increase observed at 0.5% PET. Soil with 1% Cement and varying PET, the unconfined compressive strength (UCS) values for different percentages of PET are as follows: with 0.2% PET, the UCS is 419 kN/m²; with 0.35% PET, it increases to 547 kN/m²; and with 0.5% PET, the UCS reaches 592 kN/m². Introducing 1% cement significantly enhances the UCS. Additionally, incorporating PET further increases the UCS, with the most substantial improvement observed at 0.5% PET. This suggests a synergistic effect between cement and PET. Soil with 2% cement and varying PET, with 0.2% PET: UCS is 525 kN/m², with 0.35% PET: UCS is 599 kN/m² and with 0.5% PET: UCS is 646 kN/m².

3.7 28 Days for Soil/Cement/PET (UCS)

Soil with 0% cement and varying percentages of PET shows the following unconfined compressive strength (UCS) results: at 0.2% PET, the UCS is 485 kN/m²; at 0.35% PET, it increases to 521 kN/m²; and at 0.5% PET, the UCS reaches 534 kN/m². The addition of PET without cement significantly enhances the UCS, with the most substantial increase observed at 0.2% PET. Although the increase continues at higher PET concentrations, the rate of improvement slows down. For soil with 1% cement and varying PET, the UCS values are as follows: with 0.2% PET, the UCS is 507 kN/m²; with 0.35% PET, it rises to 562 kN/m²; and at 0.5% PET, the UCS reaches 584 kN/m². Introducing 1% cement significantly increases the Unconfined Compressive Strength (UCS) of the soil. Additionally, adding PET further enhances the UCS, with the greatest improvement seen at 0.5% PET, suggesting a synergistic effect between cement and PET. For soil with 2% cement and varying amounts of PET, the UCS values are as follows: at 0.2% PET, the UCS is 588 kN/m²; at 0.35% PET, it rises to 637 kN/m²; and at 0.5% PET, the UCS reaches 673 kN/m².

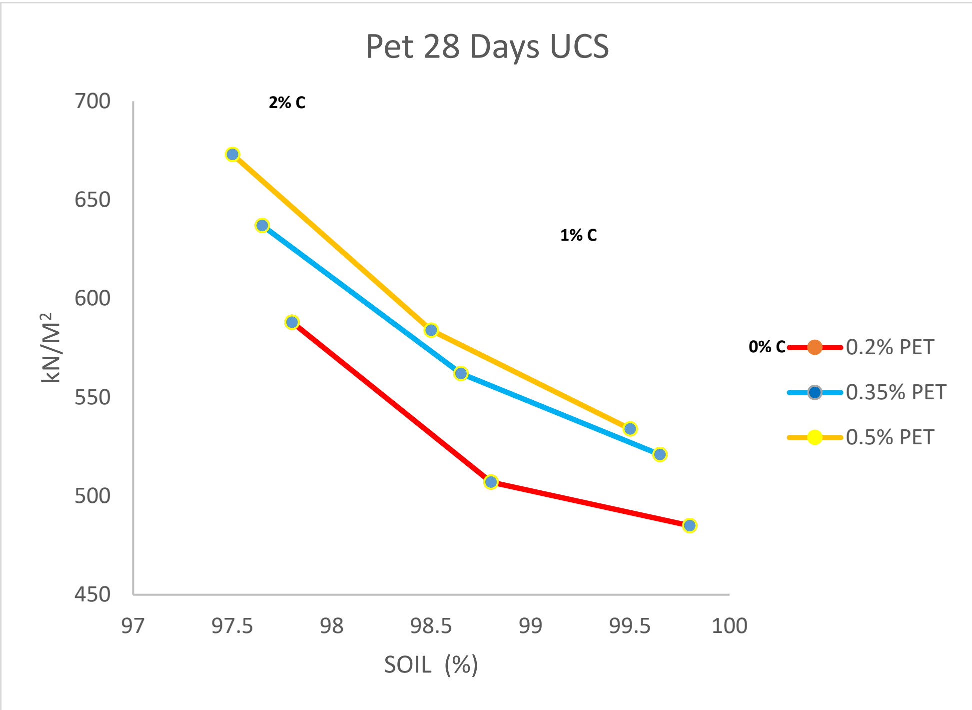

Figure 6: Soil/cement/PET UCS 28 days plotting

3.8 Comparison to Previous Work

In this study, when cement and PET are mixed with the soil, the CBR for unsoaked ranges from 63.3 to 78.5. While the soaked mixture has a CBR ranging from 23 to 28.8. The natural soil has an unsoaked and soaked CBR of 25 and 13 respectively. A study in Indonesia used oil palm bunch ash mixture at different percentages, and 10% cement to increase the value of the CBR of clay soil. The mixture of 15% oil palm and 10% cement resulted in a maximum CBR of 70.5% [10]. Another study used plastic bottle strips to reinforce silty sand, which had a natural soil CBR of 3.3. The reinforced soil achieved a CBR of 115.2 to 278.8 [11].

4.0 Conclusion

The characterization of the natural soil revealed that the soil investigated is classified as A-7-6 group in accordance with the American Association of State Highways and Transportation Officials (AASHTO). The chemical analysis of the soil revealed that, the soil is laterite due the silica sesquioxide (S-S) ratio of 1.25. The unconfined compressive strength (UCS) value of 673kN/m² for stabilized soil with cement and PET indicated an improvement compared with natural soil value of 394kN/m². The California bearing ratio (CBR) for unsoaked and soaked with the value

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of 79% and 29% respectively, compared to the natural soil of 25% and 13% respectively. Which indicates an adequate improvement in the bearing capacity of stabilized soil.

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