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Effect of Waste PET Bottle Strips (WPBS) on the CBR of Cement-Modified Lateritic Soil

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Abstract: ***Modified Proctor compaction and CBR tests were performed to evaluate the effect of randomly distributed Waste PET Bottle Strips (WPBS) and cement on a lateritic soil sample. The parameters that were varied are the cement content (0%, 1%, 3%, 5% and 7%) and the WPBS content (0%, 5%, 10%, 15% and 20%). Results obtained showed a general decrease in Optimum Moisture Content (OMC) from 16.00% of the natural soil to 13.2% at optimum value of 10%WPBS while Maximum Dry Density (MDD), increased from 1.67g/cm^3 to 2.2g/cm^3 at optimum value of 10%WPBS. At specific cement contents and addition of WPBS, CBR increased significantly at optimum value of 10% WPBS. Regression analysis was conducted to establish a relationship between CBR, cement and WPBS. Cost-Benefit analysis was also conducted to show the economic and environmental advantage of using WPBS in road construction.***

Keywords: California Bearing Ratio (CBR), Compaction, Soil Reinforcement, Waste PET Bottles

1. Introduction

Lateritic soils are in high abundance in Nigeria and are mostly used as sub-base materials in road construction due to their various physical and engineering properties which makes them suitable for the purpose. However, there are instances where lateritic soil may contain substantial amount of clay minerals such that its strength and stability cannot be guaranteed under load, especially in the presence of moisture. In most cases, sourcing for alternative soil may prove economically unwise, rather, improving the available soil to meet the desired objective can be a more economical approach [1].

The over-dependency on the utilization of industrially manufactured soil-improving additives (cement, lime, etc.) which have rapidly increased in price due to the sharp increase in the cost of energy since 1970s [2], have kept the cost of construction of roads with stabilized soils, financially high. This hitherto, has continued to hinder the developing and poor nations of the world from providing accessible (all-weather) roads to their rural dwellers that constitute the higher percentage of their population. Thus the use of unconventional stabilizing agents or additives (such as waste PET bottle strips) will considerably reduce the cost of construction and as well reduce the environmental hazards they cause. It has also been reported that Portland cement, by the nature of its chemistry, produces large quantities of CO_2 for every ton of its final product [3]. Therefore, using small proportions of Portland cement in soil stabilization and mixing with waste PET bottle strips (WPBS) will reduce the overall environmental impact of the stabilization process.

Polyethylene Terephthalate Ethylene (PET) bottles are thermoplastic materials/industrial wastes obtained from plastic processing industries. The following are properties of plastic bottle:

1) Wax-like in appearance, translucent, odourless and one of the lightest plastics.
2) Flexible over a wide temperature.
3) Chemically stable.
4) Non-biodegradable
5) Do not absorb moisture.

Plastic bottles make up approximately 11% of the content landfills and because they are non-biodegradable, they cause serious environmental consequences [4]. Due to the consequences, some of the plastic facts are as follows:

1) More than 20,000 plastic bottles are needed to obtain one ton of plastic.
2) It is estimated that 100 million tons of plastic are produced each year.
3) Plastics packaging totals 42% of total consumption and every year, little of this is recycled [5].
4) The five largest plastics types (polyolefins, PVC, PS, EPS and PET) account for about 70% of the total global demand i.e. 200 million tons [6].
5) In Nigeria, about 30% of the 3.2million tons of waste generated annually are plastic wastes [7].

Plastics, if used for reinforcing or stabilizing soil can improve strength, stiffness, ductility and toughness of soil, it can also maintain strength isotropy which resists shear band formation, improve the piping resistance of soil, increase resistance against liquefaction under dynamic loading conditions and reduce compressibility of soil [8]. This will go a long way in actualizing the dreams of the Federal Ministry of Works in Nigeria of scouting for readily cheap construction materials. The World Bank too has been spending substantial amount of money on research aimed at harnessing industrial waste products for further usage.

2. Materials and Methodology

The materials used in this research work are: Lateritic soil, Ordinary Portland Cement, and Waste PET bottle strips.

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2.1 Lateritic Soil

The lateritic soil sample was collected from a suitable borrow pit at Atan community, (along Agbara, Ogun state, Coordinates: 6^0 46' 00" N, 2^0 48' 00" E) and had the following properties, as presented in Table 1. The particle size distribution is also shown in Fig 1.

Table 1: Properties of laterite soil sample

S/N	*Properties*	*Characteristic Value*
1.	Natural Moisture Content (%)	10.17
2.	Specific Gravity	2.5
3.	Liquid Limit (%)	35.2
4.	Plastic Limit (%)	22.2
5.	Plasticity Index (%)	13.0
6.	AASHTO Classification	A-6
7.	Unified Classification. System	CL
8.	Soil Type	Silty Sand
9.	Colour	Reddish Brown
10.	OMC (%)	16.0
11.	MDD (g/cm^3)	1.67
12.	CBR (Un-soaked; %)	70.08
13.	CBR (Soaked; %)	18.05

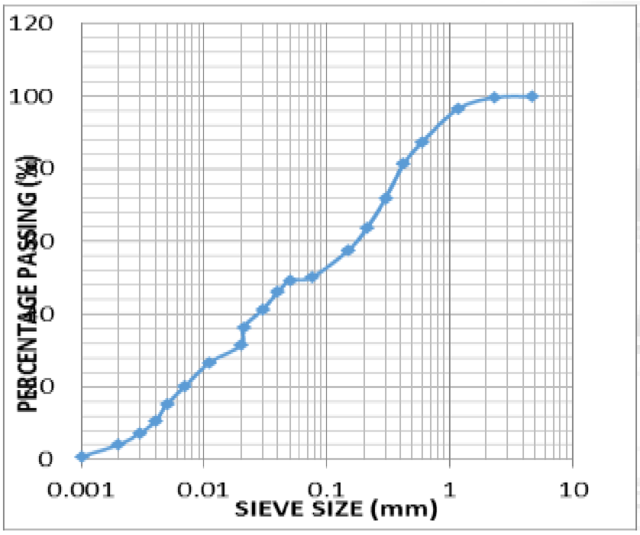

Figure 1: Particle size distribution curve

2.2 Ordinary Portland Cement (OPC)

Dangote 3X 42.5R Portland cement was used for this research.

2.3 Waste PET Bottle Strips (WPBS)

The waste PET bottle strips used had an average width and length of 5mm and 10mm respectively. The experimental methodology is presented in Table 2.

Table 2: Laboratory tests conducted

Mixture	*Tests Conducted*
A. First Set of Tests	
Soil sample only	Atterberg Limits
	Sieve Analysis
	Specific Gravity
	Compaction
	CBR (Un-soaked and 4days Soaked)
B. Second Set of Tests	
Soil Sample + Portland Cement (1 – 7%)	Compaction
	CBR (Un-soaked and 4days Soaked)
C. Third Set of Tests	
Soil Sample + WPBS (5% - 20%)	Compaction
	CBR (Un-soaked and 4days Soaked)
D. Fourth Set of Tests	
Soil Sample + Portland Cement (1 – 7%) + WPBS (5 - 20%).	Compaction
	CBR (Un-soaked and 4days Soaked)

The laboratory tests were conducted according to ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM D422 - Standard Test Method for Particle-Size Analysis of Soils, ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer. Compaction and CBR tests were carried out as specified by BS Codes of Practice Procedures 1377: 1990 (Methods of Tests for Soils for Civil Engineering Purposes).

Figure 2: Waste PET bottles

Figure 3: Waste PET bottle strips

3. Results, Analysis and Discussions

3.1 Effect of Cement-WPBS on Compaction Characteristics

The variations of OMC and MDD with the stabilizers' contents are shown in Figures 4 and 5 respectively. At specific cement contents, the results indicate a decrease in OMC and increase in MDD with increase in WPBS contents up to an optimum value of 10%. It was also noticed that beyond 10% of WPBS, OMC increases and MDD decreases. OMC decreases because WPBS fibers have no water absorption capacity which in turn increases the MDD. The increase in MDD, below optimum 10% WPBS, can also be attributed to the interfacial mechanical interaction between the WPBS fiber and the soil-cement matrix. Beyond the

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optimum value of 10% WPBS, there is increase of void ratio due to separation of soil grains caused by the WPBS fibers and as a result, MDD decreases and OMC increases.

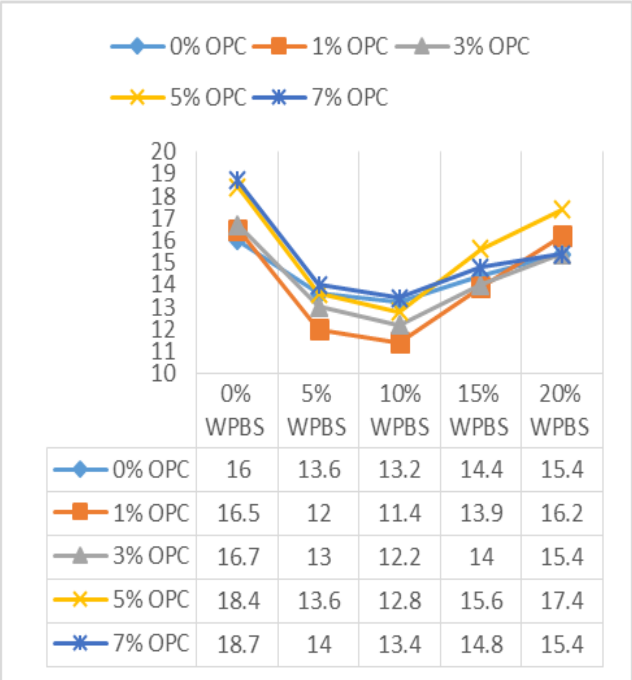

Figure 4: Variation of OMC with WPBS and OPC content

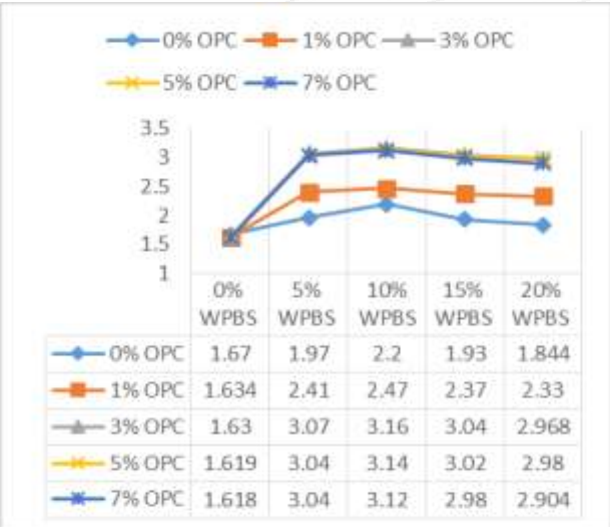

Figure 5: Variation of MDD with WPBS and OPC content

3.2 Effect of Cement-WPBS on California Bearing Ratio (CBR)

The CBR value of a compacted soil is an indicator of soil strength and bearing capacity and this is widely used in the design of base and sub-base material for road pavement. It is also one of the common tests used to evaluate the strength of stabilized soils. The variations of 4-days soaked CBR with increase in WPBS from 0 to 20% with specific percentages of cement are shown in Figure 6.

Addition of cement and WPBS to the soil, showed marked improvement in the CBR compared to the low CBR value of 18.05% recorded for the natural soil. CBR values increased with increase in WPBS contents for specific cement contents up to an optimum WPBS content of 10%. CBR increased significantly from 62.65% at 1% OPC only to 131.43% at optimum value of 10% WPBS, from 82.95% at 3% OPC only to 185.93% at 10% WPBS, from 106.35% at 5% OPC only to 243.55% at 10% WPBS, and from 145.35% at 7% OPC only to 326.83% at 10% WPBS.

These improvements resulted from the tensile support offered by the WPBS. The presence of WPBS in the soil matrix, up to 10%, held the particles together which increased its resistance to load pressure. Beyond the optimum 10% WPBS content, the excess WPBS created weak bonds within the soil matrix which resultantly reduced the soil's resistance to pressure, hence, reduction in CBR value.

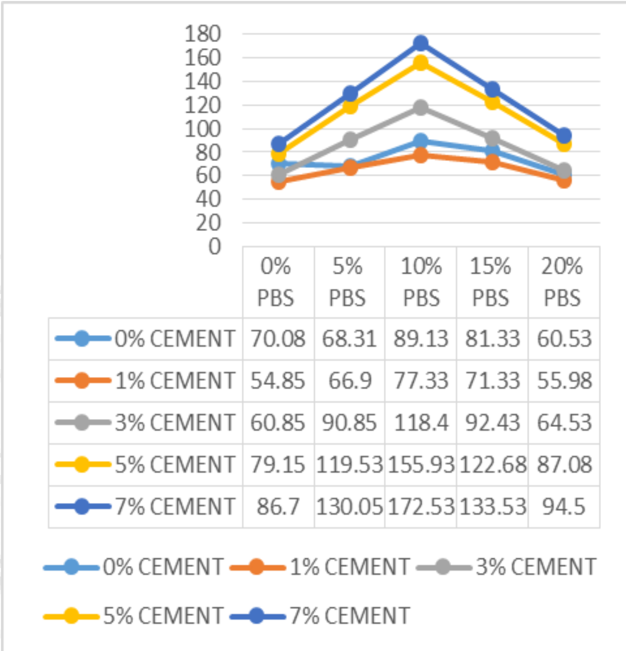

Figure 6: Variation of soaked CBR with WPBS and OPC content

3.3 Regression Analysis

Regression analysis was conducted using Microsoft Excel software package to establish a relationship between the CBR value, OPC and WPBS contents. The data analysed and results obtained are presented in Tables 3 and 4.

TABLE 3: CBR Values of soil with WPBS and OPC contents

Soaked CBR Value (Y)	% OPC Content (X_1)	% WPBS Content (X_2)
18.05	0	0
48.80	0	5
63.88	0	10
40.88	0	15
26.53	0	20
62.65	1	0
75.20	1	5
131.43	1	10
76.43	1	15
64.53	1	20
82.95	3	0
118.13	3	5
185.93	3	10
121.13	3	15

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85.88	3	20
106.35	5	0
153.15	5	5
243.55	5	10
159.53	5	15
115.93	5	20
143.35	7	0
207.85	7	5
326.83	7	10
217.90	7	15
160.55	7	20

The regression equation obtained is:

$$Y = 44.40358049 + 22.9302561X_1 + 0.37152X \qquad (1)$$

This suggests that for a unit increase in OPC content, CBR increases with 22.93 units. Also, for a unit increase in WPBS, CBR increases by 0.37 units.

ANOVA was used to verify that the above estimated regression equation fits the data.

Table 4: Analysis of variance

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	220594.6	2	110297.3	59.86421	4.87E-16	3.123907
Within Groups	132657	72	1842.459			
Total	353251.7	74				

The ANOVA result shows that F > F critical (59.86421 > 3.123907), which therefore means we can safely state that the estimated regression fits the data and thus, there is a reliable relationship between CBR value, OPC and WPBS contents.

3.4 Cost Analysis and Comparison

Primary and secondary sources of data were employed. This was achieved through informal interviews with contractors and project managers in Nigeria. To determine the cost of base course material needed for construction, a road of length one kilometre (1km) and standard width 7.3 meters was used as basis for the analysis. Thickness of Base Course is taken as 150mm and moneytary unit is the Nigerian Naira (N). The computation of the cost analysis is shown in table 5 and the summary of the cost analysis for the construction of the base material is shown in table 6. The parameters used for cost computation are:

1) Length of Road = 1Km = 1,000m
2) Width of road = 7.3m
3) Cost of Cement/bag (50kg) = N3,000
4) Cost of base material (Laterite)/ tonne = N4,000
5) Cost of processing WPBS = N20,000/tonne of PET bottles

The costs of transportation, labour, equipment and other pavement layers are not included in this analysis.

Table 5: Computation of cost analysis

Description	Unit Cost (N)	Total Cost (N)
Soil + 5% Cement (Soaked CBR of 106.35%)		
Cement: Total Volume of Base = 1000 X 7.3 X 0.15 m^3 = 1095m^3 Quantity of Cement required = 5% of 1095 m^3 = 54.75m^3 (Taking 1 tonne = 0.66m^3 in Portland cement unit scale and 1tonne = 1000Kg) Therefore, 54.75m^3 of cement = (54.75 X 1000)/0.66= 82,954.5Kg (1,660 bags of cement)	3000	4,980,000
Base Material (Laterite): Quantity of laterite required = 1,095 – 54.75 m^3 = 1040.25m^3 (Taking 1 tonne = 0.40m^3 in Lateritic soil unit scale). Therefore 1040.25m^3 = 2,600.6 tonnes	4000	10,402,400
TOTAL		**15,382,400**
Soil + 1% Cement + 10% WPBS (Soaked CBR of 131.43%)		
Cement: Total Volume of Base = 1,000 X 7.3 X 0.15 m^3 = 1,095 m^3 Quantity of Cement required = 1% of 1,095 m^3 = 10.95m^3 (Taking 1 tonne = 0.66m^3 in Portland cement unit scale and 1tonne = 1000Kg) Therefore, 10.95m^3 of cement = (10.95 X 1000)/0.66 = 16,590.9Kg (332 bags of cement)	3000	996,000
WPBS: Quantity of WPBS required = 10% of 1,095 m^3 = 109.5m^3 (Taking 1 tonne = 0.72m^3 in PET bottle unit scale and 20,000PET Bottles = 1tonne) Therefore 109.5m^3 of WPBS= (109.5 X 1000)/0.72= 152.1 tonnes of WPBS (1 PET Bottle (50cl) produced 0.55Kg of WPBS). Therefore 152.1 tonnes of WPBS will be obtained from 152.1 X 1000 X (1/0.55) = 276,546 PET bottles (13.83 tonnes of PET bottles).	20,000	276,600
Base Material (Laterite): Quantity of Base material required = 1095 – 10.95 – 109.5 = 974.55m^3 (Taking 1 tonne = 0.40m^3 in Lateritic soil unit scale). Therefore, 974.55m^3 of laterite= (974.55 X 1000)/0.4= 2,436.4 tonnes	4000	9,745,600
TOTAL		**11,018,200**

Table 6: Cost analysis

Materials	CBR (%)	Cost of Base Material (N)
Soil + 5% Cement	106.35	15,382,400
Soil + 1% Cement + 10% WPBS	131.43	11,018,200
Difference		4,364,200
% Difference		28.4%

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4. Conclusions

From the results of the investigation carried out within the scope of the study, the following conclusions can be drawn:

- At specified cement contents, treatment with WPBS showed a general increase in MDD with increase in the WPBS content up to optimum values at 10% WPBS, after which reduction in MDD was observed. The OMC generally decreased with increase in the WPBS content at specified OPC contents up to optimum values at 10% WPBS.
- There was a tremendous improvement in the CBR of modified soil compared with that of the natural soil. There was increase in CBR with increase in WPBS at specified OPC contents with optimum values at 10% WPBS contents.
- From the regression analysis conducted, there is a reliable relationship between CBR, OPC and WPBS contents.
- The cost-benefit analysis proved WPBS as an economic alternative to OPC stabilized soil with a percentage difference in construction cost of base course to be about 28.4%. It also proved to be environmentally beneficial with over 275,000 waste PET bottles per kilometer of road being recycled.

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