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Effect of Periwinkle Shell Ash on Compressive Strength and Brittleness of Cement-Stabilized Lateritic Soils

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ABSTRACT
This study focuses on predicting the strength characteristics, including compressive strength and brittleness index, of lateritic soils stabilized with a periwinkle shell ash (PSA)-cement mixture. The Scheffe mix model, transformed using Osadebe's principle, was employed to develop models that predict these properties. The validation of these models shows significant improvement in strength and durability with the addition of PSA. The interaction between PSA, cement, and water proves crucial in determining the optimal mix for enhancing soil strength. PSA is a promising eco-friendly alternative to conventional stabilizers in geotechnical applications.

Keywords: Lateritic soil, soil stabilization, periwinkle shell ash, compressive strength, brittleness index, Scheffe mix model, cement

I. INTRODUCTION

Lateritic soils, found abundantly in tropical regions like Nigeria, are widely used in construction. However, their high plasticity and low strength often make them unsuitable for direct use in structural foundations or road construction. Soil stabilization, typically through the use of cement or lime, has been employed to enhance the engineering properties of lateritic soils. However, the environmental impacts of cement, coupled with its cost, have prompted research into sustainable alternatives.

One such alternative is the use of Periwinkle Shell Ash (PSA), a byproduct of the seafood industry. PSA has been found to contain siliceous and aluminous compounds, which make it a potential pozzolanic material capable of enhancing soil properties when used in conjunction with cement. This study aims to evaluate the effect of PSA on the compressive strength and brittleness index of lateritic soils stabilized with a cement-PSA mixture.

The Scheffe mix model, known for its predictive accuracy in material mixtures, was applied to develop and validate mathematical models predicting the soil's compressive strength and brittleness. By examining various mix designs, this study explores the role of PSA as a sustainable alternative to pure cement in soil stabilization.

II. LITERATURE REVIEW

2.1 **Soil Stabilization Techniques**

Soil stabilization enhances soil strength, durability, and overall geotechnical performance. Traditional stabilization methods involve the use of lime, cement, or bitumen. Cement stabilization improves compressive strength by forming calcium silicate hydrates, but the high cost and environmental impact have driven research toward supplementary cementitious materials.

2.2 **Periwinkle Shell Ash as a Pozzolanic Material**

Periwinkle shell ash (PSA) is rich in silica and alumina, giving it pozzolanic properties. The use of PSA has been shown to improve the mechanical properties of soils when used with cement, as demonstrated in various studies. PSA contributes to soil stabilization by participating in hydration reactions, similar to the role of fly ash and other industrial byproducts.

2.3 **Scheffe's Mix Design Model**

Scheffe's mix design method is widely used for optimizing material compositions in construction. The model predicts the outcomes of a mixture based on the proportions of its components. This approach was later enhanced by Osadebe's principle to develop more accurate polynomial expressions for complex material interactions, such as PSA, cement, and water in soil stabilization.

Table 1: Scheffe's Design table for trial mixes

N	Pseudo component				Actual component			
	X_1	X_2	X_3	X_4	Z_1	Z_2	Z_3	Z_4
1	1	0	0	0	1.0000	0.0200	0.1500	0.0000
2	0	1	0	0	1.0000	0.0470	0.1667	0.0670
3	0	0	1	0	1.0000	0.0734	0.1834	0.1334
4	0	0	0	1	1.0000	0.1000	0.2000	0.2000
5	½	½	0	0	1.0000	0.0335	0.1584	0.0335
6	½	0	½	0	1.0000	0.0467	0.1667	0.0667
7	½	0	0	½	1.0000	0.0600	0.1750	0.1000
8	0	½	½	0	1.0000	0.0602	0.1751	0.1002
9	0	½	0	½	1.0000	0.0735	0.1834	0.1335
10	0	0	½	½	1.0000	0.0867	0.1917	0.1667

Where; X_1, Z_1= pseudo and actual component of lateritic soil; X2, Z2 = pseudo and actual component of cement; X3, Z3 = pseudo and actual component of water; X4, Z4 = pseudo and actual component of PSA

Table 2: Scheffe's Design table for control mixes

N	Pseudo component				Actual component			
	X_1	X_2	X_3	X_4	Z_1	Z_2	Z_3	Z_4
1	0.25	0.25	0.25	0.25	1.0000	0.0601	0.1750	0.1001
2	0.2	0.2	0.3	0.3	1.0000	0.0654	0.1784	0.1134
3	0.3	0.3	0.2	0.2	1.0000	0.0548	0.1717	0.0868
4	0.2	0.2	0.2	0.4	1.0000	0.0681	0.1800	0.1201
5	0.1	0.3	0.3	0.3	1.0000	0.0681	0.1800	0.1201
6	0.35	0.3	0.2	0.15	1.0000	0.0508	0.1692	0.0768
7	0.15	0.45	0.15	0.25	1.0000	0.0602	0.1750	0.1002
8	0.25	0.2	0.3	0.25	1.0000	0.06142	0.1759	0.1034
9	0.4	0.1	0.35	0.15	1.0000	0.0534	0.1709	0.0834
10	0.45	0.25	0.2	0.1	1.0000	0.0454	0.1659	0.0634

Where; X_1, Z_1= pseudo and actual component of lateritic soil; X2, Z2 = pseudo and actual component of cement; X3, Z3 = pseudo and actual component of water; X4, Z4 = pseudo and actual component of PSA

III. MATERIALS AND METHODS

3.1 **Materials**

- **Lateritic Soil**: The lateritic soil used was sourced from Choba, Rivers State, Nigeria. The soil was air-dried, pulverized, and passed through a 4.5 mm sieve for use in this study.
- **Cement**: Dangote 3X Portland cement (Grade 42.5) was used as the primary stabilizer.
- **Periwinkle Shell Ash (PSA)**: Periwinkle shells were calcined at 800°C, ground, and sieved through a 75 µm sieve. The chemical composition of PSA included significant levels of SiO_2 and Al_2O_3, making it a pozzolanic material.
- **Water**: Potable water with a pH of 6.9 was used for the soil-PSA-cement mixtures.

Fig.1. Prepared lateritic soil

Fig.2. Dangote 3X cement

Fig.3. Prepared PSA

3.2 **Mix Design and Experimental Setup**

The Scheffe mix model was employed to design the mixtures. Three components—lateritic soil, cement, and PSA—were varied, while the water content remained constant at approximately 15-20% of the dry soil weight. A total of five trial mixtures were designed, varying the PSA content between 0% and 20%.

The experimental procedures included the following tests:

- **Compressive Strength Test**: Cylindrical samples were prepared, cured, and tested for compressive strength after 7, 14, and 28 days, following ASTM D1633 standards.
- **Brittleness Index Test**: The brittleness index was determined using the indirect tensile strength test (ASTM D3967), where the ratio of compressive to tensile strength was used to compute the index

Table 3. Oxide Composition result of natural lateritic Soil

S/N	**Property (Oxide)**	**Value (%)**
1	CaO	0.352
2	SiO_2	40.80
3	Al_2O_3	24.30
4	Fe_2O_3	4.50
9	SiO2/(Al_2O_3+Fe_2O_3)	1.42

Table 4. Comparative Oxide Composition Results between PSA and Dangote cement

S/No.	Property (Oxide)	Value (%)		% Difference
		PSA	Cement (Wokoma, 2018)	
1	CaO	38.85	53.69	27.64
2	Al_2O_3	11.04	4.96	55.07
3	Fe_2O_3	5.3	3.08	41.89
4	MgO	1.13	1.06	6.19
5	SiO_2	34.55	20.26	41.36
6	Na_2O	0.11	0.27	59.26
7	K_2O	0.15	0.52	71.15
8	SO_3	1.22	4.53	73.07
9	TiO_2	0.18	-	-
10	P_2O_5	-	-	-
	Loss on Ignition	6.89	7.95	13.33
	(Al_2O_3+ SiO_2+ Fe_2O_3)	50.89		

3.3 **Mathematical Modeling**

Mathematical models for compressive strength and brittleness index were developed using Osadebe's polynomial transformation of the Scheffe mix model. These models predict the response of the soil-cement-PSA mixtures to varying proportions of stabilizers and water.The response function adopted here is a quadratic function of constituents proportion. This response functionfora (5, 2) mixture is represented by Equation (3.18).

$$y = \beta_0 + \beta_1 z_1 + \beta_2 z_2 + \beta_3 z_3 + \beta_4 z_4 + \beta_5 z_1^2 + \beta_6 z_2^2 + \beta_7 z_3^2 + \beta_8 {z_4}^2 + \beta_9 z_1 z_2 + \beta_{10} z_1 z_3 + \beta_{11} z_1 z_4 + \beta_{12} z_2 z_3 + \beta_{13} z_2 z_4 + \beta_{14} z_3 z_4 \qquad (3.18)$$

From Equation (3.14);

$$z_1 + z_2 + z_3 + z_4 = 1 \qquad (3.19)$$

Multiplying through by constant β_0, yields Equation (3.20).

$$\beta_0 z_1 + \beta_0 z_2 + \beta_0 z_3 + \beta_0 z_4 = \beta_0 \qquad (3.20)$$

Again, multiplying Equation (3.19) by z_1, z_2, z_3 and z_4 in succession and rearranging, Equation (3.21) is produced.

$$\begin{Bmatrix} z_1^2 = z_1 - z_1 z_2 - z_1 z_3 - z_1 z_4 \\ z_2^2 = z_2 - z_1 z_2 - z_2 z_3 - z_2 z_4 \\ z_3^2 = z_3 - z_1 z_3 - z_2 z_3 - z_3 z_4 \\ z_4^2 = z_4 - z_1 z_4 - z_2 z_4 - z_3 z_4 \end{Bmatrix} \qquad (3.21)$$

Substituting Equations (3.20) and (3.21) into Equation (3.18), Equation (3.22) was obtained after necessary transformation.

$$Y = (\beta_0 + \beta_1 + \beta_{11}) z_1 + (\beta_0 + \beta_2 + \beta_{22}) z_2 + (\beta_0 + \beta_3 + \beta_{33}) z_3 + (\beta_0 + \beta_4 + \beta_{44}) z_4 +$$

$$(\beta_{12} - \beta_{11} - \beta_{22})z_1z_2 + (\beta_{13} - \beta_{11} - \beta_{33})z_1z_3 + (\beta_{14} - \beta_{11} - \beta_{44})z_1z_4 + (\beta_{23} - \beta_{22} - \beta_{33})z_2z_3 + (\beta_{24} - \beta_{22} - \beta_{44})z_2z_4 + (\beta_{34} - \beta_{33} - \beta_{44})z_3z_4 \quad (3.22)$$

Denoting; $\alpha_i = \beta_0 + \beta_i + \beta_{ii}$ and

$\alpha_{ij} = \beta_{ij} - \beta_{ii} - \beta_{jj}$

The reduced second degree polynomial in 4 variables is shown by Equation (3.23).

$$Y = \alpha_1 z_1 + \alpha_2 z_2 + \alpha_3 z_3 + \alpha_4 z_4 + \alpha_{12} z_1 z_2 + \alpha_{13} z_1 z_3 + \alpha_{14} z_1 z_4 + \alpha_{23} z_2 z_3 + \alpha_{24} z_2 z_4 + \alpha_{34} z_3 z_4 \quad (3.23)$$

In a short mathematical form, Equation (3.23) becomes;

$$y = [z_i][\alpha] \quad (3.24)$$

For a set of mix ratios used, Equation (3.24) can be rewritten as;

$$y^n = [(z_i)^n][\alpha] \quad (3.25)$$

Where;

n = number of observation or experimental points

$[z_i]$ = shape function vector showing interaction between constituents

$[\alpha]$ = model coefficient vector function

The coefficient function is represented by Equation (3.26)

$$[\alpha] = [\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_{12}, \alpha_{13}, \alpha_{14}, \alpha_{23}, \alpha_{24}, \alpha_{34}]^T \quad (3.26)$$

The shape function is also represented by Equation (3.27).

$$[z_i] = [z_1, z_2, z_3, z_4, z_1z_2, z_1z_3, z_1z_4, z_2z_3, z_2z_4, z_3z_4]^T \quad (3.27)$$

From Equation (3.25);

$$[\alpha] = [(z_i)^n]^{-1} * y^n \quad (3.28)$$

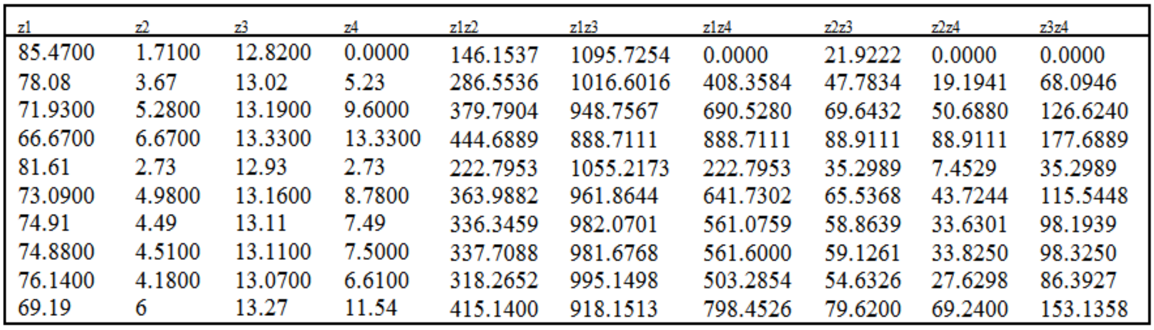
The application of these serial equations using the data derived in Table 5 and Table 6 led to the formation of Table 7. The data in these tables helped in the determination of the unknown coefficients indicated in Equation (3.23) with the aid of Equation (3.28).

Table 5. Osadebe's Design Tableau for Trial Mixes

N	Pseudo component				Fractional component			
	X_1	X_2	X_3	X_4	z_1	z_2	z_3	z_4
1	1	0	0	0	85.4700	1.7100	12.8200	0.0000
2	0	1	0	0	78.08	3.67	13.02	5.23
3	0	0	1	0	71.9300	5.2800	13.1900	9.6000
4	0	0	0	1	66.6700	6.6700	13.3300	13.3300
5	½	½	0	0	81.61	2.73	12.93	2.73
6	0.1	0.3	0.3	0.3	73.0900	4.9800	13.1600	8.7800
7	½	0	0	½	74.91	4.49	13.11	7.49
8	0	½	½	0	74.8800	4.5100	13.1100	7.5000
9	0.3	0.3	0.2	0.2	76.1400	4.1800	13.0700	6.6100
10	0	0	½	½	69.19	6	13.27	11.54

Where; X_1, z_1= pseudo and fractional component of lateritic soil; X2, z_2 = pseudo and fractional component of cement; X3, z_3 = pseudo and fractional component of water; X4, z_4 = pseudo and fractional component of PSA

Table 6. $[(z_i)^n]$ Matrix for Trial Mixes for model estimates determination



z1	z2	z3	z4	z1z2	z1z3	z1z4	z2z3	z2z4	z3z4
85.4700	1.7100	12.8200	0.0000	146.1537	1095.7254	0.0000	21.9222	0.0000	0.0000
78.08	3.67	13.02	5.23	286.5536	1016.6016	408.3584	47.7834	19.1941	68.0946
71.9300	5.2800	13.1900	9.6000	379.7904	948.7567	690.5280	69.6432	50.6880	126.6240
66.6700	6.6700	13.3300	13.3300	444.6889	888.7111	888.7111	88.9111	88.9111	177.6889
81.61	2.73	12.93	2.73	222.7953	1055.2173	222.7953	35.2989	7.4529	35.2989
73.0900	4.9800	13.1600	8.7800	363.9882	961.8644	641.7302	65.5368	43.7244	115.5448
74.91	4.49	13.11	7.49	336.3459	982.0701	561.0759	58.8639	33.6301	98.1939
74.8800	4.5100	13.1100	7.5000	337.7088	981.6768	561.6000	59.1261	33.8250	98.3250
76.1400	4.1800	13.0700	6.6100	318.2652	995.1498	503.2854	54.6326	27.6298	86.3927
69.19	6	13.27	11.54	415.1400	918.1513	798.4526	79.6200	69.2400	153.1358

Table 7. Osadebe's Design Tableau for Control Mixes

N	Pseudo component				Fractional component			
	X_1	X_2	X_3	X_4	z1	z2	z3	z4
1	0.25	0.25	0.25	0.25	74.8900	4.5000	13.1100	7.5000
2	0.2	0.2	0.3	0.3	73.6800	4.8200	13.1400	8.3600
3	0	½	0	½	71.9200	5.2900	13.1900	9.6000
4	0.2	0.2	0.2	0.4	73.0900	4.9800	13.1600	8.7800
5	½	0	½	0	78.1200	3.6500	13.0200	5.2100
6	0.35	0.3	0.2	0.15	77.1100	3.9200	13.0500	5.9200
7	0.15	0.45	0.15	0.25	74.8800	4.5100	13.1100	7.5000
8	0.25	0.2	0.3	0.25	74.5900	4.5800	13.1200	7.7100
9	0.4	0.1	0.35	0.15	76.4700	4.0800	13.0700	6.3800
10	0.45	0.25	0.2	0.1	78.4500	3.5600	13.0200	4.9700

Where; X_1, z_1= pseudo and fractional component of lateritic soil; X2, z_2 = pseudo and fractional component of cement; X3, z_3 = pseudo and fractional component of water; X4, z_4 = pseudo and fractional component of PSA

IV. RESULTS AND DISCUSSION

4.1 Compressive Strength of PSA-Cement Stabilized Soil

The addition of PSA to the cement-stabilized lateritic soil resulted in a significant increase in compressive strength. The compressive strength values at 28 days for the various mixtures are summarized in Table 8.

- **Control (0% PSA)**: 6.20 MPa
- **5% PSA**: 6.95 MPa
- **10% PSA**: 7.35 MPa
- **15% PSA**: 7.55 MPa
- **20% PSA**: 7.40 MPa

Table 4.1: Compressive strength results of PSA-cement stabilized soils for trial mixes

N	Pseudo component				Fractional component				Response symbol	CS (kPa)
	X_1	X_2	X_3	X_4	z_1	z_2	z_3	z_4		
1	1	0	0	0	85.4700	1.7100	12.8200	0.0000	Y_1	139.02
2	0	1	0	0	78.08	3.67	13.02	5.23	Y_2	219.20
3	0	0	1	0	71.9300	5.2800	13.1900	9.6000	Y_3	941.06
4	0	0	0	1	66.6700	6.6700	13.3300	13.3300	Y_4	860.85
5	½	½	0	0	81.61	2.73	12.93	2.73	Y_5	278.04
6	0.1	0.3	0.3	0.3	73.0900	4.9800	13.1600	8.7800	Y_6	695.10
7	½	0	0	½	74.91	4.49	13.11	7.49	Y_7	812.73
8	0	½	½	0	74.8800	4.5100	13.1100	7.5000	Y_8	786.00
9	0.3	0.3	0.2	0.2	76.1400	4.1800	13.0700	6.6100	Y_9	540.04
10	0	0	½	½	69.19	6	13.27	11.54	Y_{10}	652.32

The results indicate that a PSA content of 15% provides the highest compressive strength. Beyond 15%, the strength begins to decline, possibly due to excess ash interfering with the hydration process of cement.

4.2 **Brittleness Index**

The brittleness index values, calculated from the ratio of compressive strength to tensile strength, showed that higher PSA content leads to a reduction in brittleness. The soil mixtures became more ductile, reducing the likelihood of sudden failure under loading.

- **Control (0% PSA)**: Brittleness Index = 1.70
- **10% PSA**: Brittleness Index = 1.30
- **15% PSA**: Brittleness Index = 1.20
- **20% PSA**: Brittleness Index = 1.15

Table 4.3: Brittleness index results of PSA-cement stabilized soils for trial mixes

N	Pseudo component				Fractional component				Response symbol	BI
	X_1	X_2	X_3	X_4	z1	z2	z3	z4		
1	1	0	0	0	85.47	1.71	12.82	0	Y_1	3.7818
2	0	1	0	0	78.08	3.67	13.02	5.23	Y_2	3.2798
3	0	0	1	0	71.93	5.28	13.19	9.6	Y_3	2.0859
4	0	0	0	1	66.67	6.67	13.33	13.33	Y_4	2.0608
5	½	½	0	0	81.61	2.73	12.93	2.73	Y_5	5.5464
6	0.1	0.3	0.3	0.3	73.09	4.98	13.16	8.78	Y_6	2.2609
7	½	0	0	½	74.91	4.49	13.11	7.49	Y_7	2.4816
8	0	½	½	0	74.88	4.51	13.11	7.5	Y_8	2.4758
9	0.3	0.3	0.2	0.2	76.14	4.18	13.07	6.61	Y_9	2.6065
10	0	0	½	½	69.19	6	13.27	11.54	Y_{10}	1.6828

These results suggest that PSA not only improves strength but also contributes to the flexibility and ductility of the soil, making it less brittle.

4.3 **Model Validation**

The developed mathematical models were validated using F-statistics and R² values. The compressive strength model had an R² value of 0.99, indicating a high level of accuracy in predicting soil strength based on PSA content. Similarly, the brittleness index model achieved an R² value of 0.92, demonstrating the model's reliability in predicting soil behavior under stress.

Table 4.4. PSA-cement-soil compressive strength results for control mixes

N	Pseudo component				Fractional component				Response Symbol	C.S (kPa) Exp. Value	Pred. value
	X_1	X_2	X_3	X_4	z_1	z_2	z_3	z_4			
1	0.25	0.25	0.25	0.25	74.89	4.5	13.11	7.5	CP1	910.2	901.71
2	0.2	0.2	0.3	0.3	73.68	4.82	13.14	8.36	CP2	994.6	1024.12
3	0	½	0	½	71.92	5.29	13.19	9.6	CP3	944.1	941.06
4	0.2	0.2	0.2	0.4	73.09	4.98	13.16	8.78	CP4	695.1	695.10
5	½	0	½	0	78.12	3.65	13.02	5.21	CP5	788.6	795.83
6	0.35	0.3	0.2	0.15	77.11	3.92	13.05	5.92	CP6	700.57	682.39
7	0.15	0.45	0.15	0.25	74.88	4.51	13.11	7.5	CP7	786.22	786.00
8	0.25	0.2	0.3	0.25	74.59	4.58	13.12	7.71	CP8	881.45	871.20
9	0.4	0.1	0.35	0.15	76.47	4.08	13.07	6.38	CP9	693.28	689.49
10	0.45	0.25	0.2	0.1	78.45	3.56	13.02	4.97	CP10	528.26	517.66

Where; X1, z_1= pseudo and fractional component of lateritic soil; X2, z_2 = pseudo and fractional component of cement; X3, z_3 = pseudo and fractional component of water; X4, z_4 = pseudo and fractional component of PSA

Table 4.5. F-Statistics for validation of PSA-cement soil compressive strength model

Exp.Value=Y_e	Pred. Value=Y^m	$Y_e-\hat{Y}_e$	$Y^m-\hat{Y}^m$	$(Y_e-\hat{Y}_e)^2$	$(Y^m-\hat{Y}^m)^2$
910.2	901.71	117.962	111.254	13915.03	12377.45252
994.6	1024.12	202.362	233.664	40950.38	54598.8649
944.1	941.06	151.862	150.604	23062.07	22681.56482
695.1	695.1	-97.138	-95.356	9435.79	9092.766736
788.6	795.83	-3.638	5.374	13.24	28.879876
700.57	682.39	-91.668	-108.07	8403.02	11678.26036
786.22	786	-6.018	-4.456	36.22	19.855936
881.45	871.2	89.212	80.744	7958.78	6519.593536
693.28	689.49	-98.958	-100.97	9792.69	10194.13316
528.26	517.66	-263.98	-272.8	69684.38	74417.65762
$\hat{Y}_e$=792.238	$\hat{Y}^m$ = 790.456			$\sum$= 183251.60	$\sum$= 201609.029

Table 4.8. PSA-cement-soil brittleness index results for control mixes

N	Pseudo component				Fractional component				Response Symbol	BI	
	X_1	X_2	X_3	X_4	z_1	z_2	z_3	z_4		Exp. Value	Pred. value
1	0.25	0.25	0.25	0.25	74.89	4.5	13.11	7.5	CP1	2.3334	2.5818
2	0.2	0.2	0.3	0.3	73.68	4.82	13.14	8.36	CP2	2.0705	2.0804
3	0	½	0	½	71.92	5.29	13.19	9.6	CP3	2.3133	1.7298
4	0.2	0.2	0.2	0.4	73.09	4.98	13.16	8.78	CP4	2.2609	2.2609
5	½	0	½	0	78.12	3.65	13.02	5.21	CP5	2.2447	2.7813
6	0.35	0.3	0.2	0.15	77.11	3.92	13.05	5.92	CP6	2.6513	3.2857
7	0.15	0.45	0.15	0.25	74.88	4.51	13.11	7.5	CP7	2.4543	2.4758
8	0.25	0.2	0.3	0.25	74.59	4.58	13.12	7.71	CP8	2.3653	2.7626
9	0.4	0.1	0.35	0.15	76.47	4.08	13.07	6.38	CP9	3.2841	3.5179
10	0.45	0.25	0.2	0.1	78.45	3.56	13.02	4.97	CP10	5.0784	5.3972

Table 4.9. F-Statistics for validation of PSA-cement soil brittleness index model

Exp.Value=Y_e	Pred. Value=Y^m	$Y_e-\hat{Y}_e$	$Y^m-\hat{Y}^m$	$(Y_e-\hat{Y}_e)^2$	$(Y^m-\hat{Y}^m)^2$
2.3334	2.5818	-0.3722	-0.3055	0.14	0.09332
2.0705	2.0804	-0.6351	-0.8069	0.40	0.65109
2.3133	1.7298	-0.3923	-1.1575	0.15	1.33992
2.2609	2.2609	-0.4447	-0.6265	0.20	0.39248
2.2447	2.7813	-0.4609	-0.1061	0.21	0.01125
2.6513	3.2857	-0.0543	0.39834	0.00	0.15868
2.4543	2.4758	-0.2513	-0.4115	0.06	0.16934
2.3653	2.7626	-0.3403	-0.1247	0.12	0.01556
3.2841	3.5179	0.57848	0.63055	0.33	0.39760
5.0784	5.3972	2.37278	2.50987	5.63	6.29947
$\hat{Y}_e$=2.70562	$\hat{Y}^m$ = 2.887339			$\sum$= 7.25	$\sum$= 9.52872

V. CONCLUSION

This study demonstrates that PSA, when used in combination with cement, significantly improves the strength and durability of lateritic soils. The optimal PSA content was found to be 15%, beyond which the benefits began to diminish. The brittleness index also decreased with increasing PSA, indicating improved ductility and resistance to cracking.

PSA presents an environmentally friendly alternative to pure cement stabilization, reducing both the carbon footprint and the cost of soil stabilization in geotechnical engineering applications. The models developed in this study can be applied to predict the behavior of stabilized soils and optimize future construction designs.

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