Impact of Palm Fruit Bunch Ash on Unconfined Compressive Strength of Cement-Stabilized Soils for Road Construction

*Omoloye E. Abe and Olugbenga O. Amu
Department of Civil Engineering, Federal University Oye-Ekiti
abeomoloye@yahoo.com | olugbenga.amu@fuoye.edu.ng

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Abstract- This study assesses the impact of Palm Fruit Bunch Ash (PFBA) on unconfined compressive strength (UCS) of cement-stabilized soils for road construction in south-western Nigeria. Three soil samples were collected from a federal road in each of the eighteen senatorial districts making a total of fifty-four samples. Classification tests were conducted on the soil samples. Thereafter, cement stabilization was carried out on the selected soil samples to determine the optimum cement content. This was followed by adding Palm Fruit Bunch Ash (PFBA) at varying percentages of 2, 4, 6, 8 and 10% to the optimum cement content. Results of classification tests showed that the soil samples fell within the range A-3 to A-7, that is excellent to good and fair to poor soils according to AASHTO classification system. Values of plasticity indices varied from 7.60% to 35.10%. Results of UCS of cement stabilization showed that optimum cement content was obtained at 6%. The results also revealed that addition of ashes of PFBA to 6% optimum cement content increased the values of UCS to an optimum content of 4% PFBA. and decreased thereafter. Range of values of UCS at 4% optimum content of PFBA ranged from 1621.22 kN/m2 to 2017.09 kN/m2 which met the requirement for sub-base and base materials. Summary of optimum UCS test results by statistical analysis showed that PFBA significantly contributed to the increase in UCS values of the soils. Therefore, optimum content of 4% PFBA further increased the UCS of cement-stabilized soils for road construction in southwestern Nigeria.

Keywords- Palm fruit bunch ash, unconfined compressive strength, cement-stabilized soil, road construction.

1 INTRODUCTION

In the tropical part of the world, lateritic soils are used as a road building material in the subgrade of some roads in Nigeria. For low-cost roads with low to medium traffic, the lateritic soils are used in the construction of base and subbase courses in the road surface. According to Habeeb *et al.*, (2012) they are used for building materials in moulding blocks and for plastering. Olugbenga *et al.*, (2007) reported that laterite is an inexpensive, environmentally friendly material that is abundant in tropical regions of the world. However, there are cases where a laterite can contain a significant amount of clay minerals to the extent that its strength and stability under load, especially in the presence of moisture, cannot be guaranteed. These types of laterites are also common in many tropical regions of the world; where in most cases the procurement of alternative soils may prove to be economically unwise, but rather to improve the available soil in order to achieve the desired goal (Mustapha, 2006).

Roadways for unpaved roads are built from local soils, which have high proportion of fines and high plasticity index. The soils may not possess the required engineering properties for road construction, but can be improved upon by soil modification or stabilization methods in order to make the materials suitable for use as a foundation material (Siswosoebrotho *et al.*, 2005).

*Corresponding Author

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Improving the strength and stability of lateritic soils has recently become imperative, which has led researchers to use stabilizing materials that are locally available at very low cost (Amu and Adetuberu, 2010; Amu, *et al.*, 2011). The capability to mix the naturally occurring lateritic soil with some chemical additives to give it better engineering properties in terms of strength and water proofing is very essential (Amu, *et al.* 2011; Bello, *et al.*, 2014). Tesfaye (2001) and Nebro (2002) stated that the three most utilized conventional stabilizers for lateritic soils are lime, bitumen and cement. Argu (2008) reported that stabilizing lateritic soils with cement or lime is very effective, but the exorbitant cost of the materials makes their use as stabilizers economically unreasonable.

Recent studies focus on the utilization of agricultural and industrial wastes that are locally available and has disposal problems. Due to its high content of aluminosilicates, these wastes can be utilized as the sole stabilizer or as supplements to conventional stabilizers. Utilization of palm fruit bunch as a supplement to cement is the focus of this research. Palm fruit bunch is one of the main waste products that arise from the processing of fresh fruit bunch in oil palm mills (Lim and Zaharah, 2000). According to Tanaka *et al.* (2004), when 88 tonnes of fresh fruit bunches are stripped, approximately 22 tonnes will be produced as empty fruit bunches by-product, which are either partially dehydrated and used as fuel in the boilers or recycled back to the field as mulch for oil palm trees.

Reports on the utilization of palm fruit bunch ash as a soil improving additive are sparse, but few researchers have conducted few studies on laterite soils containing this waste material. Oyelowe and Ubachukwu (2015) conducted a study to examine the influence of palm fruit bunch ash on the geotechnical properties of lateritic soil used for construction, and concluded that significant improvements in the mechanical and geotechnical properties of the soil was observed when mixed with different proportions of palm fruit bunch ash. Gaidajis, *et al.* (2010) conducted extended research on the influence of nanosized palm fruit bunch ash on the geotechnical properties of lateritic soils used for the same purpose. The results also showed great improvements in the properties of the soil, in line with engineering standards for use as an additive for soil stabilization.

Fapohunda and Shittu (2017) examined the properties of concrete containing empty palm fruit bunch ash as a partial replacement for ordinary Portland cement. The result showed that the compressive strength of the concrete samples at 5% cement substitute with empty palm fruit bunch ash was better than that of the control samples without empty palm fruit bunch ash. The aim of this study was therefore to determine the influence of palm fruit bunch ash on the unconfined compressive strength of cement-stabilized soils for highway construction.

2 METHODOLOGY

Materials used for this research were soil samples, cement, palm fruit bunch, and water. Three soil samples were taken from borrowed pit material at depths between 1.5 m and 2.0 m used on a federal road in each senatorial district in each of the six states of southwestern Nigeria, making a total of 54 samples. Fig. 1 shows the map of southwestern Nigeria where the soil samples were taken. These samples were collected in large bags while substantial quantities were stored and sealed in polythene bags for moisture content determination. The soil samples were labelled to denote the locations where they were taken as follows: Ekiti (A), Ondo (B), Osun (C), Oyo (D), Ogun (E) and Lagos (F), while 1, 2, 3 are the soil samples in each of the senatorial districts. Palm fruit bunches were obtained from a palm oil mill in Ijan-Ekiti, a village near Ado-Ekiti. The bunches of the palms were sun-dried for about five weeks and then burned to ashes at between 850-950^{0}C and sieved with the 0.075mm sieve.

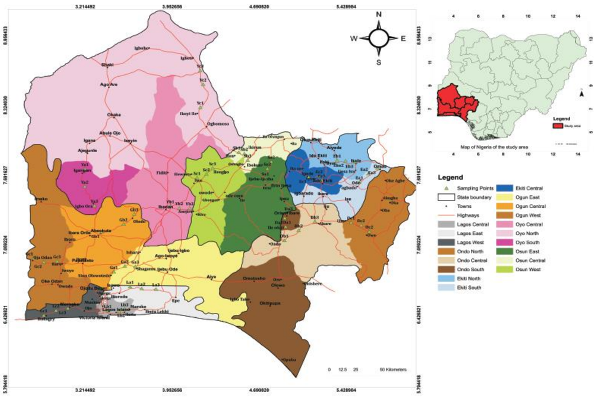

Fig. 1: Map of Southwestern Nigeria showing the sampling points

Classification tests such as moisture content, specific gravity and Atterberg limit values were carried out on the soil samples according to BS 1377 (1990) in order to determine the soil samples with the lowest plasticity index for stabilization. On this basis, eighteen soil samples, three from each state, were selected for stabilization with cement in proportions of 2,4,6,8 and 10% in order to determine the optimum cement content.

A test on the unconfined compressive strength (UCS) was then carried out on the optimum cement-stabilized soil samples with different PFBA percentages of 2,4,6,8 and 10% according to BS 1924 (1990). Proctor mould specimens were used as unconfined compressive specimens and a correction factor of 1.04 was used to make the results correspond to cylindrical specimens with a height to diameter ratio of 2:1 or cube specimens of 150 mm. The specimens were tested by crushing after 7 days of curing according to Road Note 39 and the load that caused the specimen to fail divided by the cross-sectional area of the specimen gave the strength of the soil. The optimum of the test results was summarized by statistical analysis.

3 RESULTS AND DISCUSSIONS

3.1 RESULTS OF CLASSIFICATION TESTS

Table 1 shows the results of classification tests for all the fifty-four soil samples with the results of the eighteen selected soil samples in bold.

3.1.1 Natural Moisture Content

Results of the natural moisture content indicated that the values ranged between 1.20 and 29.80. Most values correspond to the average range (5-15%) as recommended by (FMWH, 2000) for road construction, while only a few from Ondo State (B), Lagos State (F) are above the recommended range, which may be as a result of high-water absorption capacity of the soil samples.

3.1.2 Specific Gravity

The specific gravities ranged as follows: Ekiti A (2.30 - 2.60), Ondo B (2.23 - 2.69), Osun C (2.40 - 2.76), Oyo D (2.26 - 2.80), Ogun E (2.25 - 2.65) and Lagos F (2.30 - 2.52). All the soil samples, with the exception of one of the soil samples from Ondo State, in which it fell, agree with the range of values for the specific gravities (2.25-2.90) and (2.6-2.7) as reported by Crowder *et al.*, (2000) and Brooks (2009) respectively. As a result, the soils would stabilize more strongly at these moderately high specific gravities, as stated by Adeyemi and Oyeyemi (2000).

3.1.3 Atterberg Limits

Results of Atterberg limits showed that liquid limits ranged as follows: A (37.00 - 60.00), B (38.00 -54.00), C (31.00 - 60.00), D (27.00 - 50.00), E (23.40 - 44.00) and F (22.50 - 48.80). Range of values of plasticity index in percentages are: A (12.50-35.10), B (14.10-26.0), C (9.69-22.3), D (15.0-28.3), E (7.6-21.2) and F (NP-19.1). Most of these soil samples did not meet the requirement that the PI should not be more than 12% (NGS, 1997).

3.1.4 AASHTO Classification

Table 1 shows that most of the soils fell within A-1 to A-3 (excellent to good) and A-4 to A-7 (fair to poor), according to AASHTO classification system for use as subgrade materials. Only four samples met the requirements of specification BS 1377 (1990) as base and subbase materials on the basis of percentage that passed a 200 mm sieve and the plasticity index (PI)%.

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Table 1. Results of classification tests for natural soils samples

State	Senatorial District	Road	Sample	Natural moisture content %	Specific Gravity	Particle Size Analysis			Atterberg Limits				AASHTO Classification
						% fines (<0.075mm)	% sand (0.075-4.75mm)	% gravel (>4.75mm)	LL (%)	PL (%)	PI (%)	SL (%)	
A	South	Ode- Omuo	**Aa1**	**3.68**	**2.30**	**26.96**	**9.04**	**64.0**	**37.00**	**24.5**	**12.50**	**11.4**	**A-2-6**
			Aa2	2.56	2.40	42.26	11.74	46.0	41.00	22.2	18.80	13.5	A-7-6
			Aa3	4.51	2.45	48.14	27.86	24.0	52.00	34.3	17.70	14.2	A-7-5
	Central	Ado-Iyin – Igede	Ab1	11.05	2.34	39.66	48.34	12.0	56.00	20.90	35.10	12.1	A-7-6
			Ab2	10.01	2.45	36.4	52.64	10.96	56.00	21.70	34.30	13.5	A-7-6
			Ab3	**10.55**	**2.50**	**24.58**	**57.38**	**18.04**	**43.5**	**24.10**	**19.4**	**10.8**	**A-2-7**
	North	Oye-Ikole	Ac1	14.09	2.40	37.86	59.14	3.0	56.00	32.60	23.40	6.4	A-7-5
			Ac2	11.88	2.60	33.22	28.78	38.0	60.00	43.3	16.70	6.4	A-2-7
			Ac3	**14.15**	**2.40**	**49.98**	**20.02**	**30.0**	**44.00**	**30.6**	**13.40**	**8.02**	**A-7-5**
B	South	Ileoluji - Ologundudu	Ba1	20.60	2.29	43.26	52.6	51.48	48.00	30.00	18.00	6.4	A-7-6
			Ba2	**22.60**	**2.23**	**40.84**	**20.16**	**39.0**	**52.00**	**35.20**	**16.80**	**9.58**	**A-7-5**
			Ba3	25.10	2.69	32.36	45.74	21.9	42.90	22.60	20.30	8.6	A-2-7
	Central	Akure-Ondo	Bb1	22.60	2.36	52.64	40.36	7.0	44.00	19.80	24.20	13.6	A-7-6
			Bb2	**23.80**	**2.32**	**24.26**	**39.74**	**36.0**	**38.00**	**18.00**	**20.00**	**7.0**	**A-2-6**
			Bb3	29.80	2.44	51.36	38.64	10.0	54.00	28.00	26.00	15.7	A-7-6
	North	Uso – Owo	**Bc1**	**2.60**	**2.31**	**31.8**	**57.2**	**11.0**	**52.60**	**38.50**	**14.1**	**10.25**	**A-2-7**
			Bc2	3.40	2.31	11.96	80.04	8.0	40.00	38.00	17.00	13.6	A-2-6
			Bc3	3.40	2.52	29.7	59.3	11.0	46.00	30.60	15.40	12.9	A-2-7
C	East	Ilesa - Ibokun	**Ca1**	**6.23**	**2.60**	**56.28**	**39.72**	**4.0**	**34.50**	**24.81**	**9.69**	**8.12**	**A-4**
			Ca2	3.34	2.65	54.95	39.05	6.0	38.90	22.70	16.20	9.21	A-6
			Ca3	4.09	2.40	43.66	49.34	7.0	31.00	18.09	12.91	7.55	A-6
	Central	Ifon – Osogbo	Cb1	6.40	2.76	65.54	19.06	15.4	47.20	24.90	22.30	6.4	A-7-6
			Cb2	**5.00**	**2.76**	**66.97**	**31.03**	**2.0**	**60.00**	**47.16**	**12.84**	**9.21**	**A-7-5**
			Cb3	3.93	2.50	66.31	19.79	13.9	38.00	19.85	18.15	6.93	A-6
	West	Ileogbo-Iwo	**Cc1**	**5.00**	**2.45**	**24.1**	**31.9**	**44.0**	**39.50**	**24.50**	**15.00**	**7.56**	**A-2-6**
			Cc2	5.00	2.65	29.16	38.84	32.0	38.00	18.43	19.57	5.0	A-2-6
			Cc3	4.20	2.61	17.12	28.88	54.0	43.50	22.17	21.33	4.2	A-2-7
D	South	Igangan - Igbo Ora	Da1	5.20	2.26	21.1	76.9	2.0	32.00	11.90	20.10	15.0	A-2-6
			Da2	1.20	2.54	26.7	70.3	3.0	27.00	10.20	16.8	10.2	A-2-6
			Da3	**3.80**	**2.60**	**57.1**	**32.9**	**10.0**	**30.8**	**15.80**	**15.00**	**9.9**	**A-6**
	Central	Asejire – Ibadan	**Db1**	**11.90**	**2.72**	**38.5**	**48.5**	**20.0**	**30.40**	**11.80**	**18.60**	**6.62**	**A-6**
			Db2	6.20	2.53	33	47	13.0	35.00	13.00	22.00	3.57	A-2-6
			Db3	13.40	2.62	54.6	33.4	12.0	34.20	8.00	26.20	6.4	A-6
	North	Ikoyi ile –Igbeti	Dc1	7.50	2.80	30.6	45.4	24.0	34.50	8.60	25.90	4.29	A-2-6
			Dc2	7.10	2.50	53.2	42.8	4.0	50.00	21.70	28.30	6.43	A-7-6
			Dc3	**5.20**	**2.60**	**26.42**	**45.58**	**28.0**	**33.00**	**11.90**	**21.10**	**6.15**	**A-2-6**
E	East	Siun – Olowotedo – Shagamu	Ea1	4.70	2.40	45.62	49.38	5.0	33.0	15.6	17.4	8.00	A-6
			Ea2	**7.90**	**2.62**	**44.88**	**45.12**	**10.0**	**31.6**	**16.0**	**15.6**	**10.7**	**A-6**
			Ea3	10.30	2.30	42.12	46.88	11.0	38.0	19.7	18.3	9.2	A-6
	Central	Olodo – Abeokuta	Eb1	8.50	2.25	50.42	40.58	09.0	44.0	29.2	14.8	8.12	A-7-6
			Eb2	12.20	2.56	55.08	26.92	18.0	32.0	11.3	20.7	12.8	A-6
			Eb3	**5.50**	**2.65**	**52.09**	**33.91**	**14.0**	**37.9**	**24.10**	**13.8**	**10.7**	**A-6**
	West	Ilaro – Oja Odan	Ec1	9.95	2.43	36.41	42.79	20.8	27.40	11.3	16.1	14.2	A-6
			Ec2	7.50	2.28	46.10	38.10	15.8	29.5	8.3	21.2	12.8	A-6
			Ec3	**10.30**	**2.50**	**21.38**	**46.62**	**32.0**	**23.40**	**15.80**	**7.6**	**7.83**	**A-2-4**
F	East	Ikorodu – Agbawo	Fa1	17.10	2.52	8.1	89.1	2.8	28.90	NP	NP	5.3	A-3
			Fa2	**14.40**	**2.36**	**6.50**	**92.26**	**1.24**	**22.50**	**NP**	**NP**	**6.28**	**A-3**
			Fa3	12.10	2.40	7.05	90.80	2.15	24.10	NP	NP	8.00	A-3
	Central	Lagos Island-Maroko	**Fb1**	**19.70**	**2.30**	**44.78**	**43.72**	**11.5**	**48.8**	**38.20**	**10.60**	**9.21**	**A-7-5**
			Fb2	14.60	2.50	44.0	48.0	8.0	34.40	15.30	19.10	8.4	A-6
			Fb3	15.00	2.40	50.52	42.18	7.3	36.10	20.40	15.70	8.10	A-6
	West	Badagry – Marogbo	**Fc1**	**13.60**	**2.30**	**27.18**	**72.6**	**0.22**	**46.70**	**38.20**	**8.50**	**7.51**	**A-2-5**
			Fc2	12.20	2.52	33.78	64.4	1.82	38.00	19.70	18.30	4.3	A-2-6
			Fc3	12.00	2.41	26.56	70.3	3.14	40.10	24.50	15.60	6.0	A-2-6

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3.2 Results of Unconfined Compressive Strength (UCS) of Cement-stabilization

Table 2 shows the results of UCS tests that were conducted on cement stabilization. The results showed that the addition of cement to the selected soil samples resulted in a significant increase in UCS values up to 6% of the optimum cement content, beyond which the UCS values showed no remarkable increases. The UCS values at 0% cement content varied as follows: A (322.0 - 430.3), B (233.2 - 321.15), C (258.11 - 352.81), D (280.1 - 420.8), E (380.68 - 411.61) and F (396.42 - 492.12). The results at 6% cement also varied as follows: A (1551.28 - 1769.3), B (1617.16 - 1886.2), C (1582.12 - 1920.29), D (1671.4 - 1822.5), E (1584.21 - 1902.66) and F (1734.7 - 1873.04). From the results, it was observed that the optimum cement content was obtained at 6%. It was also observed that some of the soil samples did not meet the requirement of the minimum specification of 1729 kN/m² (Nigerian General Specification, 1997; Kadiyali and Lal, 2008) for light traffic and therefore further improvements were required.

3.3 Results of Unconfined Compressive Strength (UCS) of Palm Fruit Bunch Ash (FPBA) on Cement-Stabilized Soil Samples

3.3.1 Oxide Composition of Palm Fruit Bunch Ash

Table 3 shows the results of oxide composition of palm fruit bunch ash. This shows that the percentage sum of SiO_2, Al_2O_3 and Fe_2O_3 is 73.22% which is greater than 70% as specified by ASTM C618 (2003) for pozzolanic material.

3.3.2 Results of Unconfined Compressive Strength

Table 4 & Fig. 1 show the results of UCS tests that were conducted on the optimum cement content of 6% with different percentages of PFBA. It was observed that the UCS values increased with an increase in PFBA content to an optimum of 4% PFBA and then decreased. The initial increase, according to Sadeeq *et al.,* (2015) and Amu *et al.,* (2011), can be as a result of the formation of calcium silicate hydrates, which are responsible for the gain in strength. Further decreases in UCS when the optimum content was reached can be caused by the termination of the pozzolanic phase when the cation exchange capacity of the soils was reached (Ako and Yusuf, 2016).

The values of UCS at 6% cement content + 0% PFBA content varied as follows: A (1551.28 - 1769.30), B (1617.16 - 1886.20), C (1582.12 - 1920.29), D (1671.4 -1822.5), E (1584.21 - 1902, 66), F (1734.7 - 1873.04). The UCS values at 6% cement content + 4% PFBA content are as follows: A (1621.22 - 1886.51), B (1700.98 - 2017.09), C (1622.74 - 1947.20, D (1901.6 - 1970.73), E (1670.5 - 1991.59), F (1788.78 - 1912.38). It was observed that the UCS values obtained at this optimum content met the requirement of Road Note 39 (2008) which stipulated 750 kN/m² to 1500 kN/m² for sub-base materials and 1500 kN/m² to 3000 kN/m² for road base with light traffic. Summary of the optimum of test results by statistical analysis showed that PFBA at optimum content of 4% contributed significantly to the increase in the unconfined compressive strength, since their p-values are less than 5% level of significance.

Table 2. Results of Unconfined compressive strength (UCS) tests for cement-stabilized soil samples

Property	Cement content %	STATES								
		A			B			C		
		1	2	3	1	2	3	1	2	3
UCS	0	430.3	322.0	365.1	321.15	233.2	295.2	300.23	352.81	258.11
	2	702.5	673.04	604.36	529.55	504.6	625.81	509.78	512.23	445.02
	4	1007.8	1125.53	987.11	1221.17	1106.91	1101.23	1250.90	1324.93	1048.62
	6	**1769.3**	**1644.4**	**1551.28**	**1731.6**	**1886.2**	**1617.16**	**1920.29**	**1762.40**	**1582.12**
	8	1801.23	1700.1	1580.5	1793.43	1919.15	1690.72	2005.1	1812.32	1611.47
	10	1890.5	1740.23	1622.3	1803.20	2022.0	1702.66	2120.72	1870.12	1628.86

Property	Cement content %	STATES								
		D			E			F		
		1	2	3	1	2	3	1	2	3
UCS	0	401.4	280.1	420.8	380.68	392.04	411.61	396.42	492.12	434.01
	2	628.5	648.28	802.35	591.62	651.42	773.79	639.81	683.41	723.14
	4	1412.3	1380.68	989.20	902.84	1360.14	1660.56	1602.98	1602.65	1295.15
	6	**1822.5**	**1792.8**	**1671.4**	**1584.21**	**1744.3**	**1902.66**	**1744.3**	**1873.04**	**1734.7**
	8	2001.2	1868.3	1722.0	1587.8	1790.59	2104.69	1790.32	1882.6	1800.15
	10	2015.31	1890.68	1769.3	1612.72	1802.46	2174.34	1800.85	1911.94	1865.7

Table 3. Results of Oxide Composition of Palm Fruit Bunch Ash

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	P_2O_5	K_2O	MgO	Na_2O	M_nO	C_uO	LOI
Concentration value (%)	49.80	13.22	10.20	9.12	2.00	7.50	4.10	0.28	0.60	0.18	3.80

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Table 4. Results of Unconfined compressive strength of palm fruit bunch ash (PFBA) on cement-stabilized soil samples

PROPERTY	OPTIMUM CEMENT +PFBA (%)	A 1	A 2	A 3	B 1	B 2	B 3	C 1	C 2	C 3
UCS (kN/m^2)	6%+0%	1769.30	1644.40	1551.28	1731.60	1886.20	1617.16	1920.29	1762.40	1582.12
	6%+2%	1827.55	1675.96	1610.85	1761.96	1989.42	1671.95	1935.90	1784.30	1589.14
	6%+**4%**	**1886.51**	**1739.12**	**1621.22**	**1802.67**	**2017.09**	**1700.98**	**1947.20**	**1821.60**	**1622.74**
	6%+6%	1852.82	1713.86	1612.79	1772.64	1963.60	1674.66	1942.20	1790.10	1614.58
	6%+8%	1802.29	1684.38	1579.11	1766.28	1934.95	1668.36	1928.50	1792.70	1618.90
	6%+10%	1772.81	1658.27	1562.26	1745.53	1927.27	1623.51	1921.70	1771.20	1598.01

PROPERTY	OPTIMUM CEMENT +PFBA (%)	D 1	D 2	D 3	E 1	E 2	E 3	F 1	F 2	F 3
UCS (kN/m^2)	6%+0%	1822.50	1792.80	1671.40	1584.21	1744.30	1902.66	1744.30	1873.04	1734.70
	6%+2%	1874.72	1949.67	1835.76	1645.60	1760.05	1935.89	1803.32	1880.17	1760.53
	6%+**4%**	**1962.30**	**1970.73**	**1901.60**	**1670.50**	**1791.39**	**1991.59**	**1867.12**	**1912.38**	**1788.78**
	6%+6%	1886.65	1949.67	1882.30	1648.64	1782.84	1974.18	1813.65	1901.07	1771.37
	6%+8%	1879.40	1915.98	1848.61	1594.67	1787.91	1932.40	1814.01	1892.30	1767.63
	6%+10%	1861.24	1882.30	1798.08	1586.22	1758.31	1922.79	1795.70	1882.79	1751.79

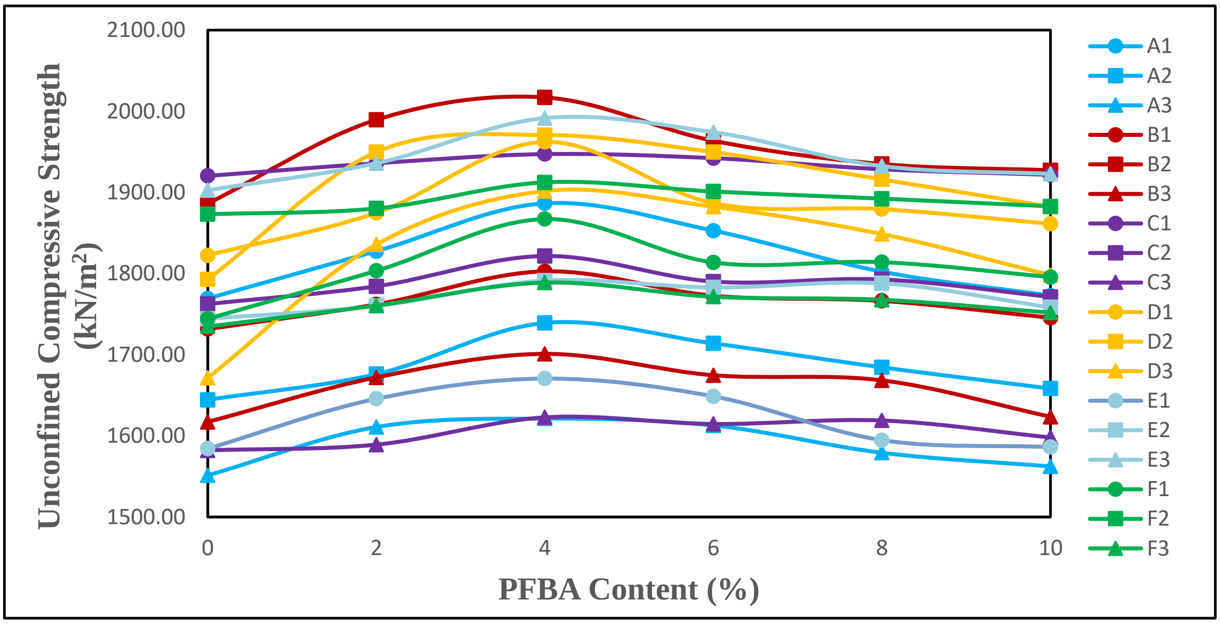

Fig. 1: Variation of the compressive strength of cement-stabilized soil samples with different proportions of palm fruit bunch ash (PFBA)

Table 5. Two-way analysis of variance for UCS of PFBA on cement-stabilized soil samples.

Source	Type III Sum of Squares	df	Mean Square	F	P-value
Corrected Model	1529976.302	22	69544.377	130.985	.000
Intercept	345440405.192	1	345440405.192	650628.540	.000
PFBA	92774.736	5	18554.947	34.948	.000
District	1437201.565	17	84541.269	159.231	.000
Error	45129.337	85	530.933		
Total	347015510.831	108			
Corrected Total	1575105.639	107			

3.4 Summary of Optimum of Test Results by Statistical Analysis

Table 5 summarizes the optimum of test results by statistical analysis using a two-way analysis of variance. It shows that p-value of the optimum PFBA content is 0.000, which is less than 0.05 significant level. Therefore, PFBA together with the senatorial districts contributed significantly to the output values of UCS.

4 Conclusion

From the results of this research, the following conclusions were drawn: Soil samples in the study states (A, B, C, D, E and F) fell in the silty or clayey gravel sand, silty soils and clayey soils, i.e. A-3 to A-7. The optimum cement stabilization for all soil samples in the study states (A, B, C, D, E and F) was achieved at 6% cement stabilization. The optimum content of PFBA on the cement-stabilized soils in the study states (A, B, C, D, E and F) was achieved at 4%. Lastly, statistical analysis of the optimum of test results showed that PFBA contributed significantly to the increase in strength properties of the cement-stabilized soils, as the p-value is less than 5% level of significance.

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