International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444
International Journal of Engineering and Technology Volume 6 No.6, June, 2016

Effect of Calcium Carbide Residue and Crushed Granite Fine on Cement Stabilized Laterite

Manasseh Joel, Joseph Ejelikwu Edeh
Department of Civil Engineering, University of Agriculture P.M.B 2373, Makurdi Benue state, Nigeria.

ABSTRACT

The effect of calcium carbide residue (CCR) and Crushed granite fine (CGF) on the strength indices of Laterite obtained from Ikpayongo, Nigeria treated with cement was investigated. 20% to 60 % crushed granite fine (CGF) plus 6% and 8 % calcium carbide residue, (CCR) was mixed with laterite stabilized with 2 to 8 % cement content by dry weight of soil. Atterberg's limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) tests were conducted on the natural laterite and laterite mixed with the additives. Results of tests shows that addition of CGF and CCR to Ikpayongo laterite treated with cement greatly enhance its suitability for use as pavement material. 7 day UCS value of Ikpayongo laterite which increased from 500 N/mm^2 to 958 N/mm^2 when treated with 8 % cement increased to a maximum value of 4, 192 N/mm^2 when treated with 60 % CGF plus 8 % CCR and 8 % cement. CBR value of Ikpayongo laterite which increased from 26 % to 110 % when treated with 8 % cement increased to optimum value of 260 % when 60 % CGF and 8 % CCR, was combined with 8 % cement in the stabilization of laterite. The use of CCR and CGF in the stabilization of laterite will ensure economy in road construction, and provide an effective way of disposing both wastes.

Keywords: *Cement, Calcium Carbide Residue, Crushed Granite Fine, Laterite, Stabilization*

1. INTRODUCTION

The search for indigenous road building materials has been a major source of concern to materials and highway engineers. This problem is compounded, where locally available materials may not be suitable for use in road construction. To overcome such challenges, emphasis is normally placed on the importation of suitable materials from other locations, a factor responsible for the high cost of road construction. To reduce cost, one viable alternative is the stabilization of locally available material for use in the construction of roads. One of such materials that are readily available in Nigeria is laterite.

Laterite as defined by Ola (1983), is the products of tropical weathering with red, reddish brown, and dark brown colour, with or without nodules or concreting and generally (but not exclusively) found below hardened ferruginous crust or hard pan. Laterite according to Ford (1989) is found mainly, but not exclusively, as a residual weathering product on partially or wholly decomposed basalts and other basic to intermediate igneous rocks. Nigeria according to Umar and Elinwa (2005) is among the countries blessed with vast deposits of laterite, which is residual in nature, and one of the cheapest materials for road construction.

The behaviour of laterite soils in pavement structure has been found to depend mainly on their particle-size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted, as well as the traffic and environmental conditions. However, their tendency to be gap-graded with depleted sand-fraction, to contain a variable quantity of fines, and to have coarse particles of variable strength which may break down, limits their usefulness as pavement materials on roads with heavy traffic. Treatment with additives is normally required as a way of overcoming deficiencies associated with such lateritic materials.

Laterite obtained from Ikpayongo, in Makrudi, the capital of Benue State, Nigeria, West Africa, has been the main source of borrow material for road construction in Makurdi metropolis. Despite the abundant deposit of laterite at Ikpayongo, it is not suitable for use as sub-base and base material and cannot be treated economically for use as pavement material with only cement, based on findings by Joel and Agbede (2011) and Eze-Uzomaka and Agbo (2010).

Lime and cement have been meaningfully used for soil stabilization and modification (Reids and Brooks, 1999, Basha, et al., 2005; Eze-Uzomaka and Agbo, 2010; Joel and Agbede, 2010; Joel and Agbede, 2011). Improvement in soil properties associated with the use of cement has been attributed to the hydration reaction of cement, while changes in properties of soil treated with lime has been attributed to cation exchange, pozzolanic and carbonation reactions of lime. Findings by (Garber and Hoel, 2010; Yoder and Witczak, 1975) favour the use of cement for soil stabilization where plasticity index value is less than 10 %, and modification with lime when greater than 10 %. However, the high cost of lime seems not to favour its usage, as the cost of hydrated lime or quick lime in Makurdi is twice the equivalent cost of ordinary Portland cement.

A readily available alternative is Calcium carbide residue (CCR) a by-product recovered from the production of acetylene gas (C_2H_2) used in oxy-acetylene welding. It consists mainly of ($Ca(OH)_2$) lime, caustic solid substances, and white in appearance when pure. CCR can be obtained at little or no cost, from mechanic villages and industries where oxy-acetylene gas welding is carried out. At such sites it is normally disposed off via land fill or open dumping which has effect on surface and ground water, due to leaching of harmful compounds and alkali to ground and surface water. Utilization of the waste material to upgrade the engineering properties of laterite would serve as one of the best disposal outlets. The effective utilization of calcium carbide residue in soil stabilization was reported by (Somna, et al. 2011; Horpibulsuk, et al. 2012; and Du, et al. 2011). The reaction expected with the use of CCR in the treatment of soil is the same as the reaction associated with lime usage.

Crushed granite fine (CGF) referred to as quarry rock dust or quarry waste fines by some researchers, was used to improve the particle size distribution curve of Ikpayongo laterite in this stduy. According to Ilangovana, et al. (2008) quarry rock dust can be defined as residue obtained after the extraction and processing of rocks to form fine particles less than 4.75 mm. it is considered as waste material, as it causes environmental load due to disposal problem, and normally dumped at quarry sites. Since granite was the original parent rock from which the quarry rock dust used in the study was obtained from it was referred to as crushed granite fine (CGF).

The use of quarry dust as an admixture in the stabilization of laterite was reported by Eze-Uzomaka and Agbo (2010). The use of CCR and cement in the treatment of Ikpayongo laterite was also reported by Joel and Edeh (2014). Little or no work has been done on the combine use of different industrial waste material such as CCR and CGF to enhance the properties of laterite stabilized with cement. The aim of this study is to ascertain the effect of both CCR and CGF on the strength properties of Ikpayongo laterite treated with cement within the economic cement content of 8 % specified by the Nigerian General Specification (1997).

2. MATERIALS AND METHODS

Laterite samples were collected from Ikpayongo, located at a distance of 22 kilometres from Makurdi, the capital of Benue State, Nigeria, along Makurdi-Otukpo road. The borrow pit was located at a distance of 150 m, at an angle of 90° East from the centre line of the road. Disturbed samples were collected at a depth of 0.5 to 2.0 m after the removal of the top soil. CCR used was collected from a welder located at the North bank Automobile mechanic site in Makurdi. It was dried in the open air, and grinded into fine particles, using pestle and mortar (in the absence of a ball mill and made to pass through the 300 µm B.S sieve), before materials passing through the sieve was used while those retained on the sieve was discarded. Ordinary Portland cement as obtained from the open market in Makurdi was used for the work. CGF was obtained from the quarry site at Ahua, of Mkar, near Gboko, the headquarters of Gboko local Government area of Benue State. Analysis of chemical components of CCR and ordinary Portland cement was carried out using x-ray analyzer together with Atomic Absorption Spectrophotometer (AAS).

Specimens of soil samples used for different laboratory test were prepared by mixing laterite with CCR and CGF before the addition of cement in proportions of 0, 2, 4, 6, and 8 % by dry weight of laterite. Cement content used was restricted to the economic upper limit value of 8 % specified by the Nigerian General Specification (1997). Laterite was mixed with 20 %, 40 %, and 60 % CGF by dry weight of laterite, each combination of CGF mixed with laterite was treated with 6 % and 8 % CCR respectively, before the addition of cement. 2% to 4 % CCR was not used in test, since Joel and Edeh (2014) reported that the use of 2 % to 4 % CCR combined with cement did not yield satisfactory result in the stabilization of Ikpayongo laterite.

Laboratory tests were performed on the samples obtained from Ikpayongo in accordance with the provision of BS1377 (1990) for the natural laterite and BS1924 (1990) for laterite mixed with cement CCR and CGF. California Bearing Ratio (CBR) tests were conducted in accordance with the Nigerian General Specification (1997), which stipulated that specimens be cured in the dry for six days then soaked for 24 hours before testing. Samples of Ikpayongo laterite mixed with different percentages of cement, CCR and CGF were subjected to Atterberg’s limits tests, compaction tests, Unconfined Compressive strength (UCS) tests and California bearing ratio tests. While their specific gravity values were also determined using pyknometer. Liquid limit values were determined using the casagrande method.

Compaction was carried out using the West African standard compactive effort, because it was the conventional energy level commonly used in the region and recommended by the Nigerian General Specification (1997) for road work. The compactive effort was achieved using energy derived from a rammer of 4.5 kg mass falling through a height of 0.45m in a 1.0×10^{-3} m^3 mould. The soil was compacted in five layers, each layer receiving 10 blows. The resistance to loss in strength was determined as a ratio of the unconfined compressive strength (UCS) of specimens cured for 7 days under controlled conditions, which were subsequently immersed in water for another 7 days to the UCS of specimens cured for 14 days. The particle size distribution of the laterite and CGF was determined using the wet sieving method.

3. RESULTS AND DISCUSSION

The grain size distribution curves of Ikpayongo laterite and CGF is presented in Figure 1, the chemical analysis of ordinary Portland cement and calcium carbide residue is summarized in Table 1. Summary of the result of test on the natural laterite is presented in Table 2.

Table 1: Chemical Composition of CCR and Cement.

Elemental Oxide	Percentage Composition (%)	
	CCR	Cement
CaO	61.41	64.0
MgO	0.80	1.94
Al_2O_3	1.78	5.75
Fe_2O_3	0.17	2.50
SiO_2	2.69	20.40
SO_3	0.36	2.75
LOI	32.51	1.20

LOI: Loss on Ignition.

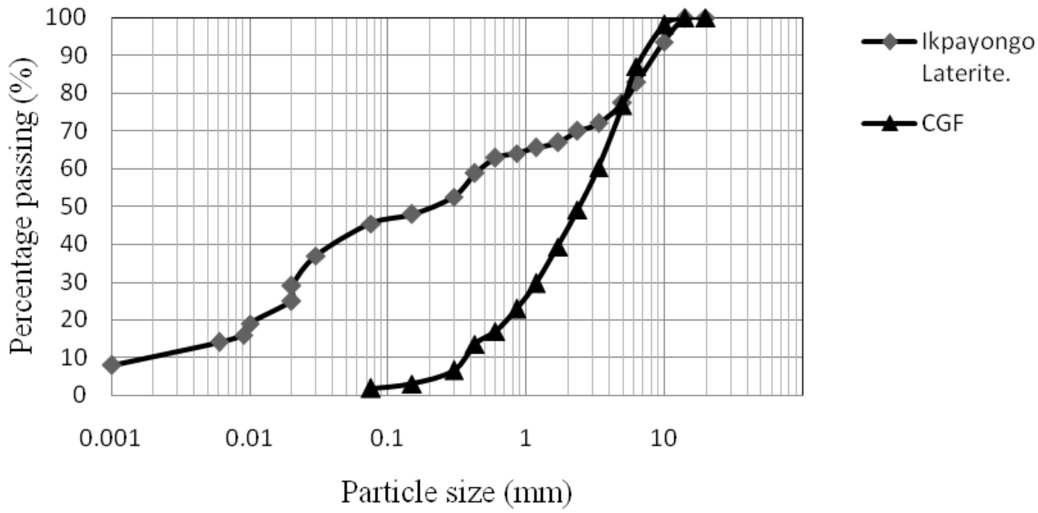

Figure 1: Particle size distribution of Ikpayongo laterite, and CGF.

Table 2: Some Geotechnical Properties of Ikpayongo Laterite

Property	Quantity
Percentage Passing BS Sieve No 200 (%)	45.5
Liquid Limit, (%)	49.0
Plastic Limit (%)	27.0
Plasticity Index (%)	22.0
AASHTO Classification	A-2-6
USCS Classification	GC
Maximum Dry Density (Mg/m^3)	1.81
Optimum Moisture Content (%)	12.0
Unconfined Compressive Strength (KN/m^2)	500
California Bearing Ratio,% (after 24hrs soaking)	26
Specific Gravity	2.69
Colour	Reddish brown
Natural Moisture Content (%)	6.24

Ikpayongo laterite was found to be an A-2-6 and GC soil by the AASHTO and Unified Soil Classification systems (USCS) respectively. The specific gravities of Ikpayongo laterite, CCR, cement and CGF were determined as 2.69, 2.20, 3.15 and 2.60 respectively. The liquid limit, plastic limit and plasticity index values of Ikpayongo laterite in Table 2 are below the requirement specify by the Nigerian General Specification (1997) for materials intended for use in the base or sub base course of flexible pavement. This clearly shows that Ikpayongo laterite will require stabilization to make it fit for use in flexible pavement work.

4. EFFECT OF CGF, CCR AND CEMENT ON ATTERBERG'S LIMITS OF LATERITE

The effect of CGF and CCR on the liquid limit, plastic limit and plasticity index of Ikpayongo laterite treated with cement, is presented in Table 3. Addition of CGF and CCR to Ikpayongo laterite treated with cement improves its consistency indices, as the plasticity index which reduced from 22 % to 14 % when treated with 8 % cement reduced further to a minimum value of 3 % when treated with a combination of 60 % CGF, 8 % CCR, plus 8 % cement. Reduction in plasticity index can be attributed to the cation exchange and pozzolanic reaction of CCW and the hydration reaction of cement. The use of a combination of CGF and CCR greatly enhanced the suitability of Ikpayongo laterite stabilized with cement for road work, and the satisfaction of the Nigerian general specification (1997) for road building materials. such requirement include the liquid limit values of less than 45 % and 30 % for sub-base and base material respectively, and plasticity index value of less than or equal to 15 % and 9 % for sub-base and base material respectively.

Table 3: Atterberg's Limits values (%) of Ikpayongo Laterite Treated with CCR, CGF and Cement

Cement Content (%)		0	2	4	6	8
0% CGF Plus 0% CCR	LL	49	47	44	41	38
	PL	27	26	25	24	23
	PI	22	21	19	17	15
20% CGF Plus 6% CCR	LL	46	43	40	37	35
	PL	26	25	24	23	23
	PI	20	18	16	14	12
20% CGF Plus 8% CCR	LL	43	41	38	34	31
	PL	25	24	24	22	21
	PI	18	17	14	12	10
40% CGF Plus 6% CCR	LL	38	36	35	30	29
	PL	23	23	23	20	20
	PI	15	13	12	10	9
40% CGF Plus 8% CCR	LL	36	34	31	28	26
	PL	23	22	22	21	18
	PI	13	12	9	9	8
60% CGF Plus 6% CCR	LL	30	28	27	23	22
	PL	20	19	19	18	18
	PI	10	9	8	5	4
60% CGF Plus 8% CCR	LL	29	26	24	21	19
	PL	20	18	18	17	16
	PI	9	8	6	4	3

LL= Liquid Limit (%), PL = Plastic Limit, (%), PI = Plasticity Index, (%).

CCR= Calcium Carbide Residue. CGF= Crushed Granite Fine.

5. COMPACTION CHARACTERISTICS OF LATERITE TREATED WITH CGF, CCR AND CEMENT

The effect of CGF and CCR on the maximum dry density and optimum moisture content of Ikpayongo laterite treated with cement content is presented in Figures 2 and 3 respectively. Treatment of Ikpayongo laterite with a combination of CGF, CCR and cement resulted in increased maximum dry density, due to a decrease in the surface area of the clay fraction of Ikpayongo laterite arising from cation exchange and aggregation reaction of CCR and the hydration reaction of cement. The maximum dry density of the untreated laterite increased from 1.81 Mg/m^3 to 1.87 Mg/m^3 when treated with 8 % cement and increased further to 2.23 Mg/m^3 when Ikpayongo laterite was treated with a mixture of 60 % CGF, 8

% CCR plus 8 % cement. Increase in maximum dry density of soil with additive content according to Amu, et al. (2011) is indicative of improvements in the soil properties. While the optimum moisture content of Ikpayongo laterite which increased from 12 % to 16 %, when treated with 8 % cement increased further to 23 % when a combination of 60 % CGF, 8 % CCR plus 8 % cement was used to treat the laterite. Increase in optimum moisture content can be attributed to more moisture required for effective hydration of cement and the pozzolanic reaction of CCR.

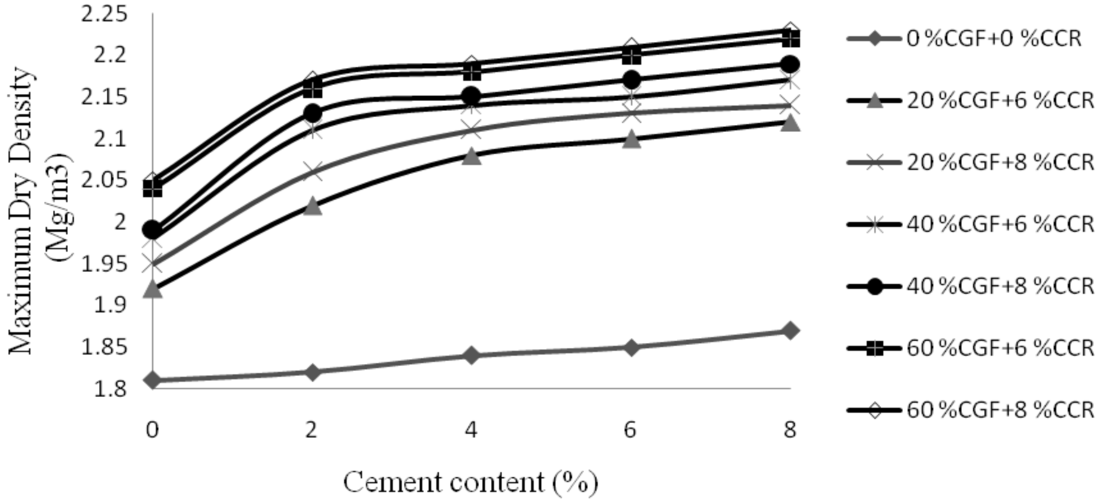

Figure 2: Variation of Maximum Dry Density with cement, CGF and CCR content.

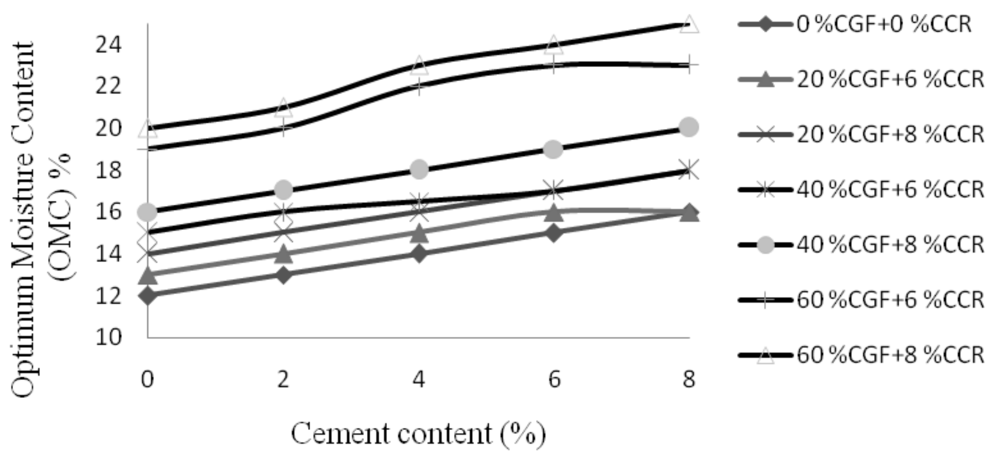

Figure 3: Variation of Optimum Moisture Content (OMC) of Ikpayongo Laterite with Cement, CGF, and CCR content.

6. EFFECT OF CGF, CCR AND CEMENTON STRENGTH INDICES OF LATERITE

The strength criterion used in assessing the effects of CGF and CCR on laterite treated with cement are California bearing ratio and unconfined compression strength tests result values. UCS values and resistance to loss in strength values of laterite treated with cement, CGF and CCR is presented in Table 4.

Table 4: 7, 14 and 28 day UCS and Resistance to loss in strength values of Ikpayongo Laterite Stabilized with Cement CGF, and CCR

Cement Content (%)		0	2	4	6	8
0% CGF Plus 0% CCR	7dUCS	500	590	680	750	958
	14dUCS	500	740	800	910	1,044
	28dUCS	500	860	1,059	1,268	1,392
	R (%)	0	40	46	60	70
20% CGF Plus 6% CCR	7dUCS	1136	1280	1763	2019	2306
	14dUCS	1475	1502	1820	2138	2525
	28dUCS	2294	2393	3017	3870	4763
	R (%)	50	60	70	75	80
20% CGF Plus 8% CCR	7dUCS	1471	1674	1954	2115	2502
	14dUCS	1451	1712	2252	2513	2800
	28dUCS	2118	2284	2408	2967	3060
	R (%)	60	66	75	80	82
40 % CGF Plus 6% CCR	7dUCS	1606	1624	2337	2789	3586
	14dUCS	1799	1843	2556	3008	3805
	28dUCS	2458	2576	3508	4290	5127
	R (%)	65	70	82	86	88
40 % CGF Plus 8% CCR	7dUCS	1694	1820	2533	2985	3786
	14dUCS	1842	1918	2631	3083	3880
	28dUCS	2566	2673	3600	4188	5224
	R (%)	68	72	85	87	91
60% CGF Plus 6% CCR	7dUCS	1856	1978	2732	3355	3996
	14dUCS	2117	2197	2951	3574	4215
	28dUCS	2872	3036	4016	4826	5660
	R (%)	74	77	87	89	93
60% CGF Plus 8% CCR	7dUCS	1931	1993	2928	3551	4192
	14dUCS	2154	2300	3026	3649	4290
	28dUCS	2921	3390	4114	4924	5757
	R (%)	76	78	87	89	93

R = Resistance to loss in Strength, (%). CCR = Calcium Carbide Residue,
CGF= Crushed Granite fine, 7 dUCS= Seven day Unconfined Compressive Strength, kN/m^2
14 dUCS= Fourteen day Unconfined Compressive strength, kN/m^2
28 dUCS = Twenty eight day Unconfined Compressive strength, kN/m^2

7 day UCS value of Ikpayongo laterite which increased from 500 kN/m^2 to 958 kN/m^2 when treated with 8 % cement increased further to a maximum value of 4,192 kN/m^2 when treated with 60 % CGF, 8 % CCR plus 8 % cement. Similar trend was observed with 14 and 28 day UCS values. Increase in

UCS values with days and CCR, cement, and CGF content can be attributed to the pozzolanic reaction of CCR, hydration reaction of cement, and the presence of more sand size particles from the addition of CGF. Increase in UCS value of Ikpayongo laterite with cement and CGF content observed was consistent with the observation of Eze-Uzomaka and Agbo (2010), while increase in UCS value with CCR observed is in agreement with findings of Joel and Edeh (2014).

The addition of CGF and CCR to Ikpayongo laterite treated with cement greatly enhanced the laterite resistance to loss in strength, as the minimum resistance to loss in strength value of 80 %, specified by Ola (1974), for effective stabilization was easily attained. The resistance to loss in strength value of Ikpayongo laterite increased from 67 % when treated with 8 % cement to a maximum value of 93 % when 60 % CGF and 8 %

CCR was added to the mixture of laterite and 8 % cement. The effect of CGF and CCR on the California bearing ratio (CBR) of laterite treated with cement, is presented in Figure 4.

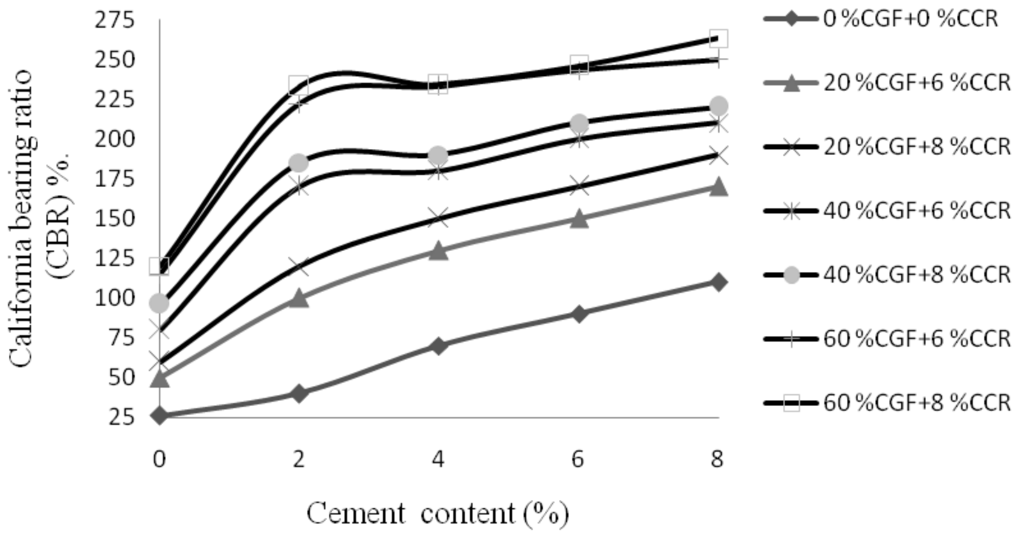

Figure 4: Variation of California bearing ratio (CBR) of Ikpayongo Laterite with Cement ,CGF and CCR content.

The California bearing ratio of untreated Ikpayongo laterite which increased from 26 % to 110 % when treated with 8 % cement, increased further to a maximum value of 263 % when 60 % CGF, 8 % CCR was added to the mixture of laterite and 8 % cement. Increase in CBR value with the addition of CGF, CCR and cement can bt attributed to the contribution of more sand size particles from CGF, hydration reaction of cement and pozzolanic reaction of CCR. Findings observed are consistent with result obtained by Eze-Uzomaka and Agbo (2010).

Using the combined criteria of minimum 7day UCS value of 1720 kN/m,^{2} specified by Millard (1993), attainment of CBR value of 180 % or 160 % using the mix in place method or plant mix method, specified by the Nigerian General Specification (1997), minimum resistance to loss in strength value of 80 % specified by Ola (1974). Ikpayongo laterite treated with a combination of 40 % CGF, 8 % CCR plus 4 % cement, 60 % CGF, 6 % CCR plus 4 % cement, and 60 % CGF, 8 % CCR plus 4 % cement are recommended for use as base material, using either the plant mix or mix in place method. The use of Ikpayongo laterite treated with 40 % CGF, 6 % CCR plus 4 % cement is recommended for use as sub-base material.

7. CONCLUSIONS

I. The addition of CGF and CCR to Ikpayongo laterite treated with cement improved the properties of the laterite and contributed greatly to the attainment of minimum standard specified for material designed for use as sub-base and base material in flexible pavement.

II. The addition of a combination of CGF and CCR to Ikpayongo laterite treated with cement have effect on the plasticity of the laterite, as the plasticity index value of the natural laterite decrease from 14 % when treated with 8 % cement to a minimum value of 3 % when a combination of 60 % CGF and 8 % CCR was added to the mixture.

III. The use of CGF and CCR increase the UCS values of Ikpayongo laterite stabilized with cement, this was reflected in the 7 day UCS value which increased from 958 kN/mm^2 when treated with 8 % cement to a maximum value of 4,192kN/mm^2 when 60 % CGF plus 8 % CCR and 8 % cement was used in the treatment of the same latertie, similar trend was observed with 14 and 28 day UCS results.

IV. The CBR value of Ikpayongo laterite increased from 100% when treated with 8 % cement to a value of 263 % when 60 % CGF, 8 % CCR and 8 % cement was used in the stabilization of the laterite.Based on the results of test and the positive impact the addition of CGF and CCR have on Ikpayongo laterite stabilized with cement the use of laterite treated with 40 % CGF, 8 % CCR plus 4 % cement, 60 % CGF, 6 % CCR plus 4 % cement, and 60 % CGF, 8 % CCR plus 4 % cement are recommended for use as base material in the construction of flexible pavement.

REFERENCES

Amu, O. O, Bamisaye, F. O and Komolafe, A. I. (2011). The suitability and lime stabilization requirement of some lateritic soil samples as pavement. Int. J. Prue Appl. Sci. Technol., Vol.2, No.1 pp. 29-46.

Basha, E . A., Hashim, R., Mahmud, H. B. and Muntohar, A. S. (2005). Stabilization of residual soil with rice husk ash and cement. Construction and Building Materials, Vol 19, pp. 448-453.

British Standards (BS) 1377. (1990). Methods of Testing Soils for Civil Engineering Purposes. British Standards Institution: London, UK.

British standards (BS) 1924. (1990). Methods of Test for Stabilized Soils. British Standards Institution: London, UK.

Du, Y., Zhang, Y. and Liu, S. (2011). Investigation of strength and California bearing ratio properties of natural soils treated by calcium carbide residue. Geo-Frontiers, pp.1237-1244.

Eze-Uzomaka, O. J. and Agbo, D. (2010). Suitability of quarry dust as improvement to cement Stabilized-laterite for road bases. Electronic Journal of Geotechnical Engineering Vol.15 (k), pp. 1053-1066.

Ford, O. S. (1989). The economic mineral resources of the Benue trough, In: C.A. Kogbe, (ed.), *Geology of Nigeria,* (pp. 473-484). Jos, Nigeria: Rock View.

Garber, J. N. and Hoel, L. A. (2010). Traffic and highway engineering. Philadelphia, PA: Cengage Learning., pp.1027-1031.

Horpibulsuk, S., Phetchuay, C., and Chinkulkijniwat, A. (2012). Soil stabilization by calcium carbide residue and fly ash . *J.Mater. Civ. Eng.*, Vol.24, No. 2, pp. 184-193.

Ilangovana, R., Mahendrana, N and Nagamanib, K. (2008). Strength and durability properties of concrete containing quarry dust as fine aggregate. Asian Research Publishing Network. (ARPN). Vol. *3No.*5, pp. 20-26.

Joel, M and Edeh, J. E (2014). Stabilization of Ikpayongo laterite with cement and calcium carbide waste. Global Journal of Pure and Applied Sciences. Vol 20. Pp. 49-55.

Joel, M. and Agbede, I. O. (2011). Mechanical-cement stabilization of laterite for use a flexible pavement material. J.Mater. Civ. Eng., Vol.23, No.2, pp.146-152.

Joel, M. and Agbede, I. O. (2010). Cement stabilization of Igumale shale lime admixtures for use as flexible pavement construction material".*Electronic Journal of Geotechnical Engineering*, Issue 15, pp.1661-1673.

Millard, R.S. (1993). Road buildings in the tropics. state-of-the –Art Review 9. HMSO Publication. 312.

Nigerian General Specification. (1997). Roads and Bridges Works. Lagos, Nigeria: Federal_Ministry of Works and Housing.

Ola, S. A. (1983). Geotechnical properties and behaviour of some Nigerian lateritic soils: In, S. A. Ola, (ed.), Tropical Soils of Nigeria in Engineering practice, (pp. 61-84)__A.A. Balkema/Rotter dam: Netherlands.

Ola, S. A. (1974). Need for estimated cement requirements for stabilization of Laterite Soils. Journal of Transportation Engineering, Division , ASCE, Vol.100, No.2, pp.379-388.

Reids, J. M. and Brooks, H. A. (1999). Investigation of Lime stabilized contaminated soils. Engineering Geology, Vol. 53, pp. 217-231.

Somna, K., Jaturapitakkul, C. and Kajitvichyanukul, P. (2011). Microstructure of calcium carbide residue-ground fly ash paste. J. Mater. Civ. Eng., Vol.23, No.3, pp.298-304.

Umar, S.Y. and Elinwa, A.U. (2005). Effects of iron ore tallings (IOT) and lime on engineering properties of problem laterite. Journal of Raw Materials Research. Vol.2 No.1 pp.56-66.

Yoder, E. J and Witczak, M.W. (1975). Principles of pavement Design. New York: Wiley.PP.302-303.

