engineering proceedings

Proceeding Paper

Agro–Industrial Waste Blends on the Mechanical Response of Selected Soils †

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† Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: https://asec2023.sciforum.net/.

Abstract: Due to urbanization, it is nearly impossible to construct civil infrastructure without encountering soil materials with poor geotechnical response. In soil re-engineering, the trending practice is the use of supplementary cementitious material with the aim of reducing carbon footprints and construction costs. This has necessitated the usability of integrating the blends of palm oil fuel residue (POFR) and calcium carbide powder (CCP) in the amelioration protocols of two soil materials. The amelioration protocols were implemented by the inclusion of 0, 2, 4, 6, 8, and 10% dosages of POFR and 0, 2, 4, 6, and 8% dosages of CCP at the requisite weight of soil materials. The experimental work was performed in three phases, namely material characterization, mechanical performance, and microstructural testing. Judging from the index performance, black clayey soil (BCS) and reddish lateritic soil (RLS) are clayey materials with a plasticity index of 28.70 and 28.80%, respectively. Concerning the mechanical performance (compaction, California bearing ratio, and durability), the inclusion of the blends of POFR-CCP into the soils (BCS and RLS) activated a positive response and was later validated via means of microstructural tests. This research has shown the potential of blended waste residues in soil re-engineering studies. The study was vividly achieved through a qualitative approach known as scanning electron microscopy and Fourier transform infrared.

Keywords: California bearing ratio; durability; micro-fabric arrangement; sustainable materials

Citation: Attah, I.C.; Alaneme, G.U.; Etim, R.K.; Jagaba, A.H.; Giri, N.C. Agro–Industrial Waste Blends on the Mechanical Response of Selected Soils. *Eng. Proc.* **2023**, *56*, 23. https://doi.org/10.3390/ASEC2023-15292

Academic Editor: Simeone Chianese

Published: 26 October 2023

1. Introduction

Rapid population growth in rural and urban areas has resulted in a shortage of stable road construction materials, thereby instigating civil engineers to build road infrastructure on soft and unstable soil materials. Soil materials form an integral part of any road pavement, and as such, they should be of good strength. In tropical areas such as Nigeria, the predominant soil materials are black cotton soil and reddish lateritic soil materials [1]. In their natural form, they contain a considerable volume of clay minerals, which renders the material unfavorable for civil engineering applications. Materials with such behavior beneath road pavements are mostly linked to undesirable foundation difficulties such as loading movements, bearing capacity issues, and differential settlement problems [2]. Thus, the technique of substituting the unfavorable soil with borrowed material of good geotechnical performance or enhancing the mechanical performance of the soil is a trending practice among construction experts. The most common amelioration agents known to soil scientists are lime and cement. Howbeit, environmental concerns such as the high rate of carbon footprint, global warming, and sustainability issues attached to cement production have made soil scientists question its continuous usage in soil amelioration studies. Thus, there is a need for the utilization of eco-friendly materials, such as by-products from industrial and agricultural processes, to achieve economically viable and sustainable options. Based on a literature search, some by-products of industrial and agricultural processes have displayed a good pozzolanic tendency, and a good number of scientists have used them as cement replacement materials (CRMs) in civil engineering infrastructures [3–7].

Howbeit, an enormous amount of experimental work has been performed on the usage of waste residue in civil infrastructure, such as improvements in soil materials. CCP, which is a calcium-based industrial waste residue, has been proven to be practicable in soft soil amelioration processes with documented positive responses [8]. Chindaprasirt et al. [9] studied the engineering response and evaluation of marginal soil treated with CCP for civil engineering applications. The experimental work shows that the incorporation of CCP instigated the studied soil properties to display positive performance when compared to the unmodified soil. A step further, Akinwumi et al. [10] explored the usability of CCP as an amelioration agent and reported that incorporating CCP diminished the soil's plasticity index, specific gravity, and maximum dry density and resulted in an enhancement of the soil's strength behavior. An investigation by Behnood [11] affirmed that utilizing CCP in combination with other pozzolanic materials ensures better cementing performance. In the same vein, POFR is a derivative of the burning processes of palm waste, and its utilization is gaining momentum in highway applications. It has been explored experimentally as a standalone cement replacement material (CRM) in concrete studies [12]. Furthermore, POFR has magnificently been admixed in conjunction with cement, lime, and high-calcium fly ashes for the enhancement of marginal soil's geotechnical performance [13–15]. The use of CCP-POFR mixtures in soil re-engineering is due to their inherent cementitious materials. It may interest one to know that multiple investigations have been performed using CCP and POFR either as standalone stabilizers or combined with other surrogate materials to investigate the strength behavior of soil materials. It is worth noting that the expectation of this current manuscript is to unravel the mechanical performance (such as California bearing ratio and durability) and microstructural arrangement of two soil materials treated with CCP-POFR. It is believed that this investigation will provide innovative insight into the utilization of CCR-POFR-stabilized BCS and RLS soil materials for civil infrastructural construction, and it may also offer solutions to minimize the impact of waste in society, which will in turn promote a sustainable environment.

2. Materials and Methods

In this study, locally sourced BCS together with RLS, POFR, and CCP were utilized as constituent materials. Using a disturbed sampling strategy, BCS was acquired from its deposit in Deba LGA, Gombe State, whereas RLS was collected from its deposit in Mkpat Enin LGA, Akwa Ibom State.

Methods

Basic geotechnical investigations were performed on the unaltered soil (BCS and RLS). In the course of achieving the compaction response of the studied marginal soil materials, a 2.5 kg rammer and a standard proctor mold were utilized with reference to British standard light principles. For CBR testing, the guiding principles of British standard light compacting effort were utilized, and the test was conducted on unaltered and typically additive-altered soil samples according to the steps as specified by BS 1377 [16] and BS 1924 [17]. Both the virgin and additive-altered soil samples were subjected to durability testing, which is also known as resistance to loss in strength based on the guiding principles of BS 1924 [17] and Ola [18].

3. Results

Soil materials BCS and RLS are clayey materials that have percentages passing a BS no. 200 of approximately 72 and 42.50%, a plasticity index of 28.70 and 28.80%, and a specific gravity of 2.40 and 2.58, respectively. In the course of this study, it was obvious that CCP and POFR had a specific gravity of 2.26 and 2.43, respectively. Their specific gravity is parallel with the upshots of [19]. However, the lower specific gravity recorded for CCP might not be far from its powdered form. The CBR values indicate that both soils are unsuitable materials and far from the minimum benchmark for usage as a road construction material (NGS) [20]; therefore, there is a need for soil amelioration. In summary, the AASHTO [21] classification rates BCS and RLS as A-7–6 (14) and A-7–6 (20), respectively. The elemental oxides of the constituent materials are shown in Table 1.

Table 1. Elemental compositions of constituent materials used in this manuscript.

Elemental Compositions	Al_2O_3	CaO	FeO_3	SiO_2	SO_3	TiO_2	MgO	Na_2O	K_2O	LOI
BCS *	18.60	0.90	2.20	48.50	-	-	2.22	1.55	0.70	10.10
RLS **	22.60	0.45	6	56.70	-	0.75	0.20	-	-	8.50
CCP	1.80	62.10	1.90	2.95	0.76	0.12	-	-	0.96	29.20
POFR	24.10	9.09	5.10	40.15	1.11	0.60	1.22	1.50	7.10	8.80

* [22]; ** [1].

3.1. Maximum Dry Density (MDD) of BCS-CCP-POFR and RLS-CCP-POFR

The MDD of the soil materials (RLS and BCS) was studied by blending the proportions of CCP-POFR, as shown in Figure 1. The MDD behavior of both soil materials dropped with the inclusion of varying CCP-POFR contents compared to the virgin soil materials. The MDD of BCS and RLS dropped from their natural values of 1.615 and 1.825 Mg/m^3 to 1.528 and 1.695 Mg/m^3 at 8% POFR–8% CCP. The documented decrease in MDD might be attributable to POFR and CCP having a low specific gravity of 2.43 and 2.28 compared to BCS and RLS having a higher specific gravity of 2.40 and 2.58, respectively [23].

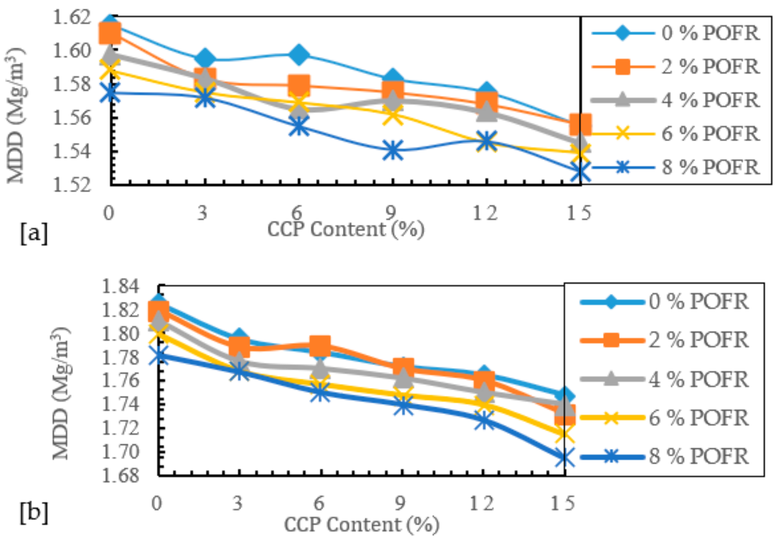

Figure 1. MDD of (**a**) BCS-CCP-POFR and (**b**) RLS-CCP-POFR.

3.2. Optimum Moisture Content (OMC) of BCS-CCP-POFR and RLS-CCP-POFR

Figure 2 displays the consequences of POFR and CCP on the OMC of BCS and RLS, respectively. The OMC values for mixtures of BCS ranged from 18 to 20.15%, whereas those of RLS mixtures varied from 13.10 to 15%. These values depict an incremental trend in the course of blending the studied soil materials with POFR and CCP. Probably, the cause of this trend of outcome might not be far from the accumulation of fines as well as the pozzolanic interplay instigated by the additive materials. The response of the studied soil materials aligns with the trend reported by [24].

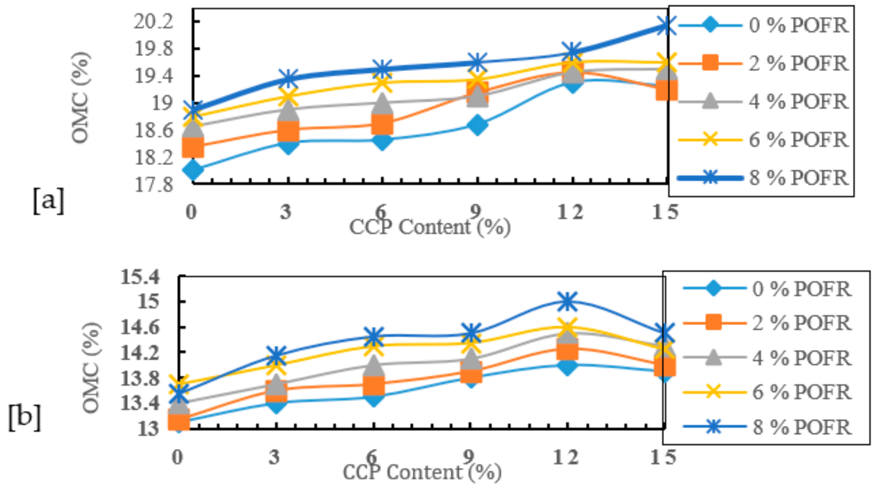

Figure 2. OMC of (**a**) BCS-CCP-POFR and (**b**) RLS-CCP-POFR.

3.3. Strength Performance of BCS-CCP-POFR and RLS-CCP-POFR

The upshots of the California bearing ratio (CBR) testing of soil BCS and RLS performed under soaked conditions exhibited a substantial percentage increase as the mixtures of POFR-CCP became incorporated (see Figure 3). The soil material understudy had CBR values of 3 and 6% in their unmodified form, and the incorporation of 8% POFR–15% CCP instigated an upsurge of approximately 10 and 6 times their initial values. Remarkably, the CBR values for both additive blended soil materials revealed an inclination pattern, and this could be ascribed to the fact that the finer fractions of POFR and CCP filled up the pores within the soil matrix, which thereby engendered a reduction in plasticity and altered the soil structure as well. This phenomenon is similar to the reports of other investigators who utilized other additives in soil re-engineering [25].

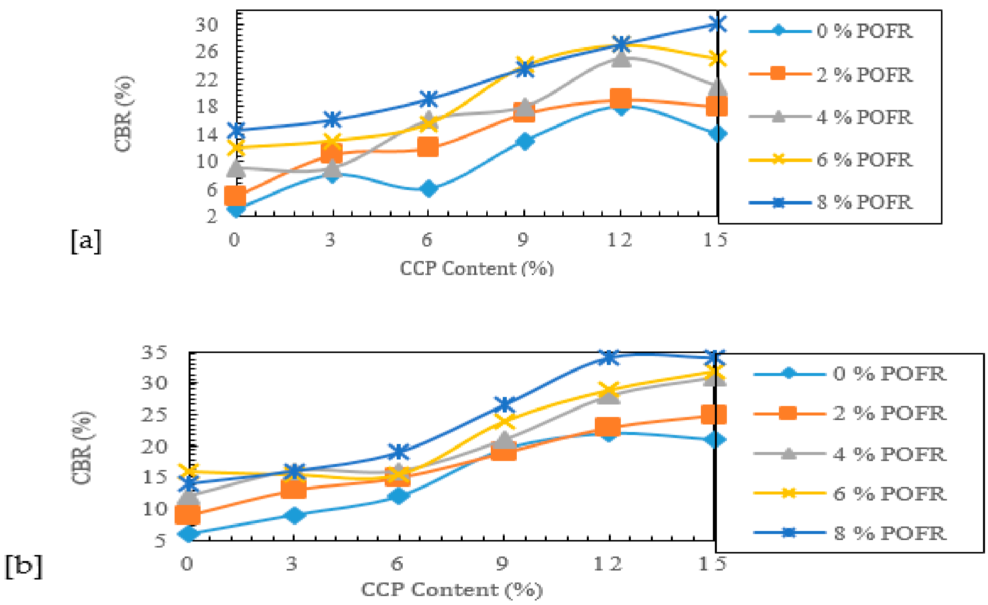

Figure 3. CBR of (**a**) BCS-CCP-POFR and (**b**) RLS-CCP-POFR.

3.4. Durability Performance of BCS-CCP-POFR and RLS-CCP-POFR

Figure 4 reveals the durability outcomes of BCS-POFR-CCP and RLS-POFR-CCP, respectively. Generally, the durability response varied between 9 and 39% and 11.5 and

41% for BCS-POFR-CCP and RLS-PPOFR-CCP mixtures. Looking at these values, the incorporation of additive materials instigated some level of alteration in terms of the durability response. This alteration might be indorsed by the inter-additives reaction building up bonds and tightening the soil matrix due to pozzolanic interplay. Howbeit, the durability values for RLS-POFR-CCP mixtures were high compared to those documented for the BCS-POFR-CCP mixtures. Judging from the recommendation made by [20], the peak values looked promising. Interestingly, this was not expected due to the exposure of soil mixtures for 7 days versus the 4-day soaking duration.

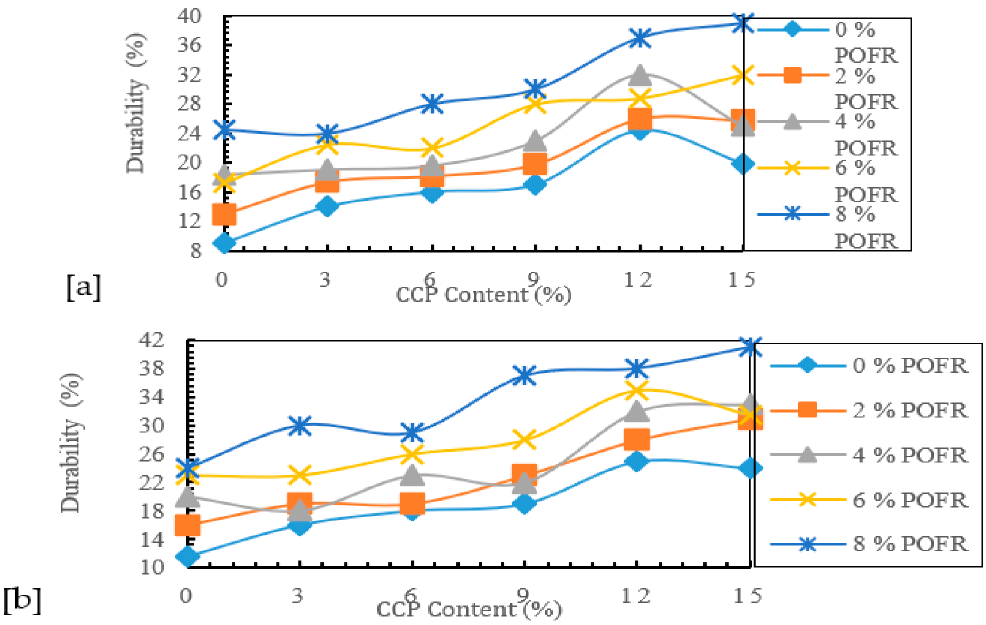

Figure 4. Durability of (**a**) BCS-CCP-POFR and (**b**) RLS-CCP-POFR.

3.5. Morphological Performance of BCS-CCP-POFR and RLS-CCP-POFR

The micrographs of the unmodified soil materials were compared with those of the soil materials modified at 8% POFR–15% CCP to unravel the possible alteration within the microstructural fabric of the soil (see Figures 5 and 6). The unmodified BES displayed a good number of dark-colored cavities, whereas the unmodified RLS was made up of a few broken grain particles, which may possibly be a result of poor linkage performance manifesting in the soil. In the course of incorporating the mixtures of POFR-CCP into the soil materials (BCS and RLS), the morphology was altered (Figures 5b and 6b). The micrograph of both treated soils appears to show the presence of whitish fissures and dense grain structures. The whitish background might be a result of the presence of additive materials, which might as well translate to strength development in the modified samples. In addition, the dense matrix might be linked to the microfilling of the soil matrix by the additive materials. This report is not at variance with other authors who used other solid wastes [1].

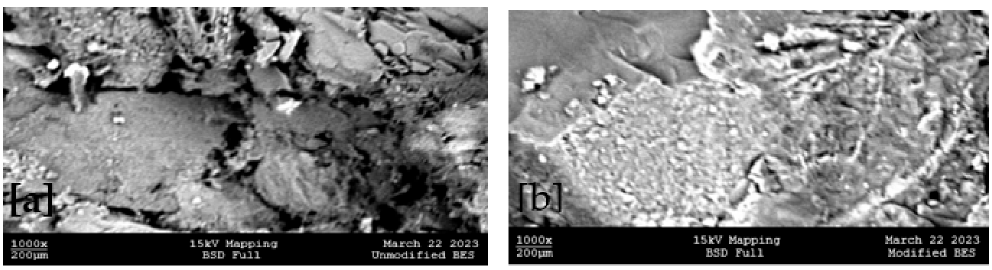

Figure 5. SEM morphology of (**a**) unmodified BES and (**b**) CCP-POFR-modified BES.

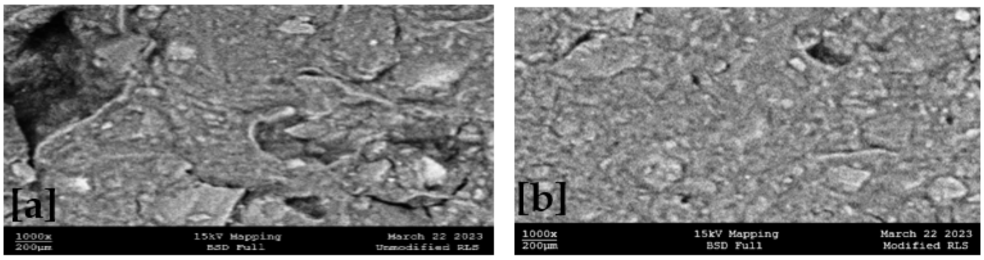

Figure 6. SEM morphology of (**a**) unmodified RLS and (**b**) CCP-POFR-modified RLS.

4. Conclusions

In the course of completing this study on the impact of blending POFR-CCP on the mechanical response of two marginal soils, the following conclusions could be made: Judging from AASHTO, the marginal soil materials (BCS and RLS) in their unmodified form were categorized as A-7-6 (14) and A-7-6 (20), or CH and SC in USCS. For both soil materials, the MDD displayed a downward trend with a corresponding increasing OMC with the incorporation of POFR-CCP blends. Further, the highest CBR values of 30 and 34% for BCS and RLS were within the safe limit of 20–30%, as stated for sub-base materials by the NGS. Additionally, the highest durability performance of the optimally modified soil materials was found to be 39 and 41%, respectively. The microfabric assessment confirmed that the modified soils had morphological alterations. Finally, it is believed that the additives instigated the presence of new phases such as calcium silicate hydrate and calcium aluminate hydrate in the soil and were alleged to be the major factor causing an increase in strength.

Author Contributions: Conceptualization, I.C.A. and G.U.A.; methodology, I.C.A.; software, G.U.A.; validation, I.C.A., G.U.A. and R.K.E.; formal analysis, A.H.J.; investigation, N.C.G.; resources, I.C.A.; data curation, G.U.A.; writing—original draft preparation, I.C.A.; writing—review and editing, G.U.A.; visualization, R.K.E.; supervision, A.H.J.; project administration, N.C.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data generated in this study are included in this article.

Conflicts of Interest: The authors declare no conflict of interest.

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