# INVESTIGATION OF CALCIUM CARBIDE RESIDUE AS A STABILIZER FOR TROPICAL SAND USED AS PAVEMENT MATERIAL

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ABSTRACT
Wastes that have cementitious properties can become a useful source of cheap materials for soil improvement, thereby reducing the cost of construction projects on sites that have unsuitable soils. This research work investigated the effects of the application of calcium carbide residue (CCR) to a tropical soil on its geotechnical properties in order to assess the suitability of the stabilized soil for use as a road pavement material. Tests to determine the grain size distribution, specific gravity, liquid and plastic limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) of the natural soil and its stabilization with varying percentages of CCR were carried out. The outcome showed that increasing application of CCR generally reduced the soil's specific gravity, plasticity index and maximum dry unit weight. A direct proportionality was also found between the CCR content and each of the liquid and plastic limits, optimum moisture content, CBR and UCS. Thus, the soil became more workable and its strength properties were improved by stabilization with CCR. Consequently, the subgrade characteristics of the soil for use as earthworks materials for road construction was improved. Based on strength properties of the stabilized soil, an optimal application of 4% CCR was found suitable for the stabilization of the sand with similar properties as those studied. The use of CCR for stabilizing sand for road construction is recommended as a cheap and sustainable approach for developing countries.
*Keywords: earthworks, foundation, geotechnical properties, lateritic soil, soil improvement, sustainability.*

## 1 INTRODUCTION

Transportation played an important role in the industrialized civilization of today and is vital to the organization, comfort, convenience, economic growth and well-being of the society [1]. In many countries of the world, roads or highways are the most utilized transportation infrastructure [2], [3]. Poor road infrastructure can lead to job loss, high vehicle operating costs, road traffic congestion, a general rise in the prices of goods and services, and consequently, impact negatively on the economy of a country [4].

Soils used as materials for earthworks foundation of road pavements play an important role in ensuring the stability and durability of roads. Suitable natural soils are, however, getting fast depleted; making some road pavement designers and constructors favour the stabilization of in situ soils with poor engineering properties [5], [6] over their replacement with suitable materials in order to reduce road construction costs. A soil can be said to be unsuitable for use as earthworks material if it: is difficult to work with (that is, it has a high plasticity), has low strength, has a tendency to retain moisture and a high natural moisture content [7].

This research work investigates the suitability of using calcium carbide residue (CCR) to stabilize a tropical sand in order to evaluate the use of the stabilized sand as road pavement


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layer material. The process of producing acetylene gas, which is of great commercial importance, based on the calcium carbide process leaves CCR as its by-product. Though acetylene is largely produced in some developed countries by the partial oxidation of natural gas [8], its production in many developing countries involves the use of calcium carbide. The process involves the reaction of calcium carbide ($CaC_2$) with water, as expressed in eqn (1), producing a slurry that is basically hydrated lime ($Ca(OH)^2$)

$$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2. \quad (1)$$

Eqn (1) shows that for every gram of acetylene gas ($C_2H_2$) produced, the weight of CCR generated in the process is more than twice the weight of the acetylene gas. This provides an idea of the enormous waste (CCR) generated by this process. CCR is usually disposed of, as it finds no or little use in the society, thereby constituting an environmental nuisance.

CCR, however, can become cementitious by pozzolanic action [9], [10]. Du et al. [11] recommended CCR as a binder to treat clays with high natural moisture content and reported that it performed better than lime treatment of the clay. Also, researchers have investigated the effects of mixtures of CCR and fly ash [9], [10], [12], CCR and rice husk ash [13], and CCR and bagasse ash [14] on the engineering properties of some clays. However, no literature was found on the CCR stabilization of tropical soil that predominantly contains sand with silt.

## 2 MATERIALS AND METHODS

The soil used was collected from a borrow pit at point latitude 06º 40' 52" North and longitude 03º 09' 11" East, Ota, Ogun state, Nigeria. Vegetative materials were removed from the samples before being placed in collection polythene bag and sacks. The natural moisture content of the soil was determined using samples collected in the polythene bag and using laboratory oven-drying method. Samples collected using sacks were air-dried in the laboratory prior to being used.

The CCR was obtained from an industrial gas company in Ogun state, Nigeria. It was air-dried, pulverized and sieved through a sieve with 425 μm opening. The fraction passing through the 425 μm sieve was used for stabilizing the soil [15]. Varying percentages of CCR (0, 4, 8, 12 and 16% by dried mass of soil) were used to stabilize the soil. The effects of the various CCR contents on the geotechnical properties of the soil were evaluated. The geotechnical properties tests carried out were specific gravity, Atterberg limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) tests. They were carried out in accordance with procedures described by British Standards Institution [16].

## 3 RESULTS AND DISCUSSION

The soil has a colour that can be described as 2.5YR 3/4 in accordance with the Munsell Soil Colour Chart. It is a well-graded sand with silt (SW-SM), according to the Unified Soil Classification System. The geotechnical properties of the soil are presented in Table 1. The in-situ moisture content of the soil is 8.6, while its specific gravity is 2.55. Its CBR and UCS is 54% and 212.2 $kN/m^2$, respectively. The distribution of the sizes of particles of the soil is presented in Fig. 1. The percentage of the particles of the soil passing the sieve with 75 μm openings is 7.86. The distribution curve shows that the sand is well-graded.

3.1 Specific gravity

The effect of the application of CCR on the specific gravity of the soil is graphically shown in Fig. 2. The progressive addition of CCR to the soil decreased the specific gravity of the stabilized soil.

Table 1: Geotechnical properties of the natural soil.

| Properties | Natural soil |
|---|---|
| Natural moisture content | 8.6 |
| Specific gravity | 2.55 |
| Liquid limit (%) | 43 |
| Plastic limit (%) | 28 |
| Plasticity index (%) | 15 |
| Maximum dry unit weight (kN/m$^3$) | 16.97 |
| Optimum moisture content (%) | 15.6 |
| California bearing ratio (%) | 54 |
| Unconfined compressive strength (kN/m$^2$) | 212.2 |

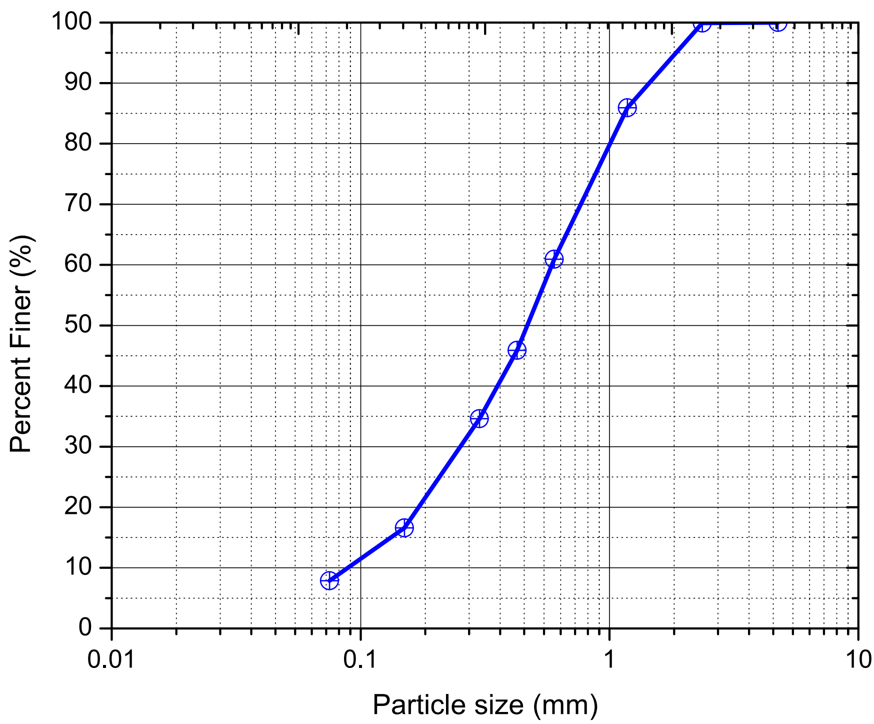


Figure 1: Particle size distribution for the natural soil.

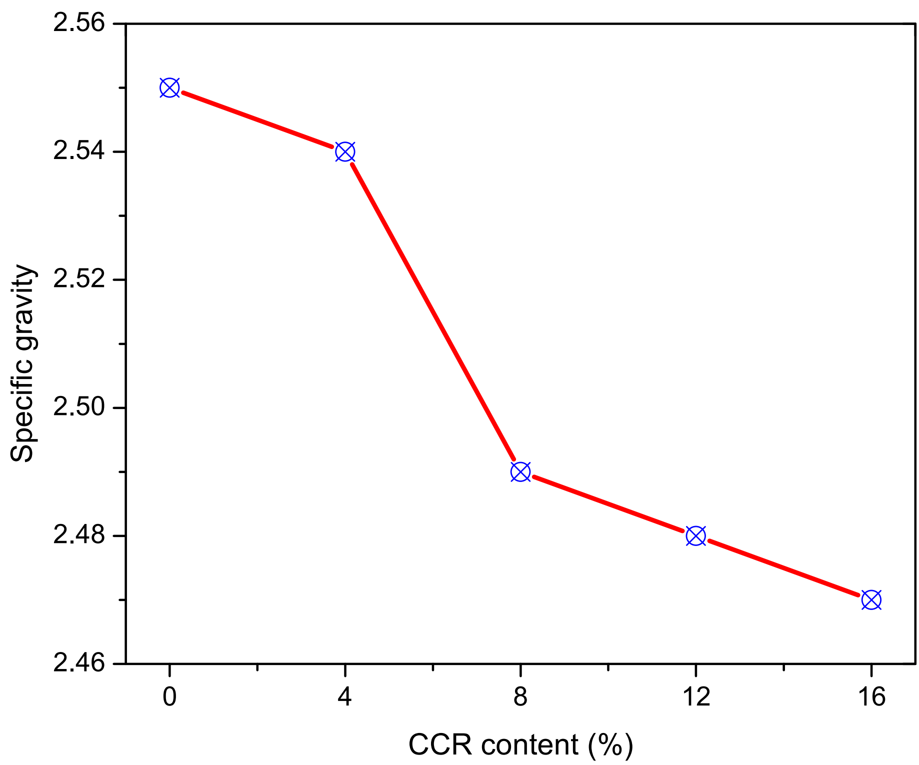


Figure 2: Variation of specific gravity of soil with CCR content.

A review of the literature [14], [17]–[22] shows that the specific gravity of CCR ranges from 2.04–2.92. The specific gravity of the CCR used was found to be 2.34 and this is responsible for the progressive decrease in the specific gravity of the soil-CCR mixture as its CCR increased.

### 3.2 Plasticity index

The plasticity index of the soil varied with its CCR as shown in Fig. 3. It decreased with increasing percentage of CCR in the stabilized soil.

The decrease in the plasticity index of the stabilized soil should normally indicate that the application of CCR to the soil made it more workable [23], [24]. However, a plot of the results of the Atterberg limits test, for the soil-CCR mixtures, on the plasticity chart shows otherwise (Fig. 4). Fig. 4 shows that the fines of the natural soil, which was classified as a silt of low plasticity became of high plasticity after the application of 8% CCR. Consequently, it can be said that the plasticity of the stabilized soil increased with an increase in its CCR content.

### 3.3 Compaction characteristics

The variation of the optimum moisture content (OMC) and maximum dry unit weight (MDUW) of the stabilized soil with its CCR content is presented in Fig. 5.

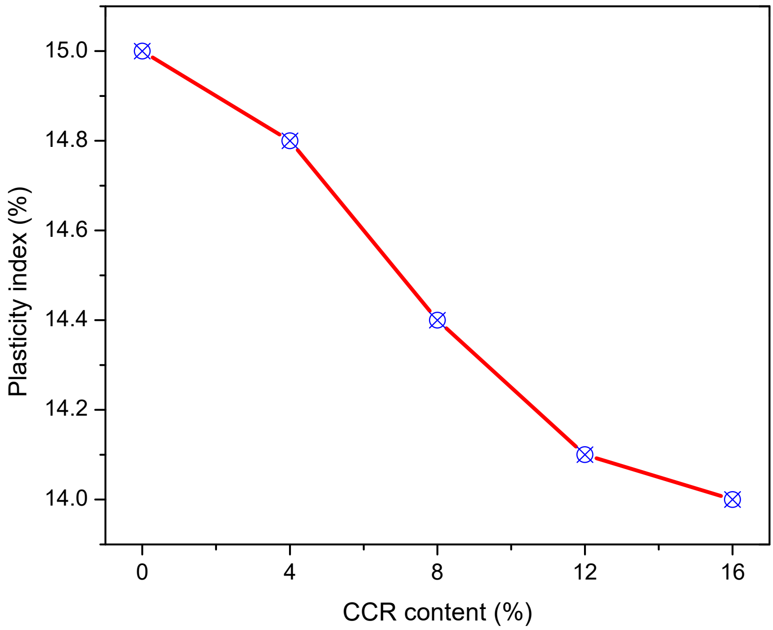


Figure 3: Variation of plasticity index of soil with CCR content.

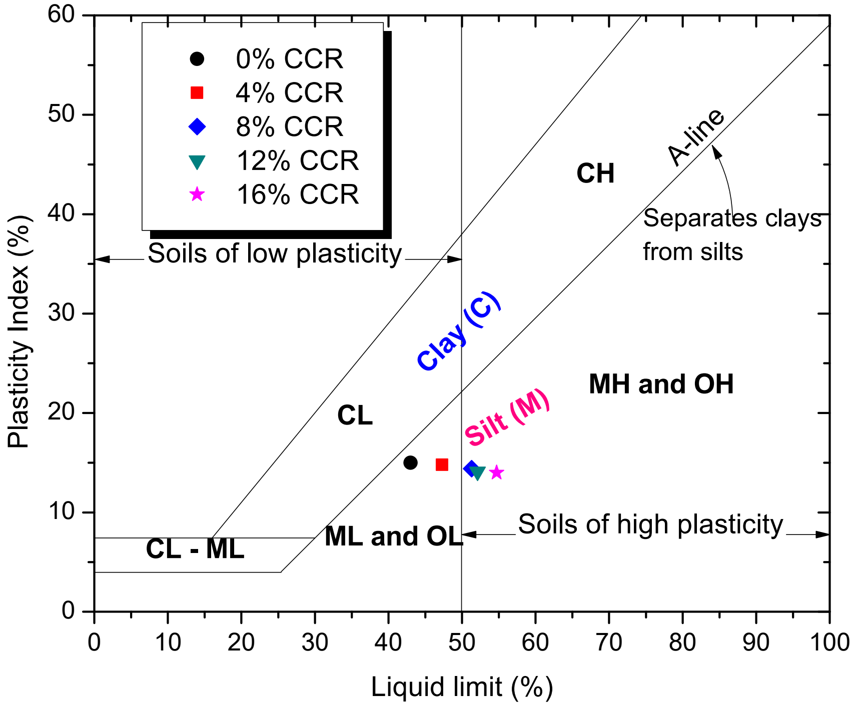


Figure 4: Change in plasticity as indicated on the plasticity chart.

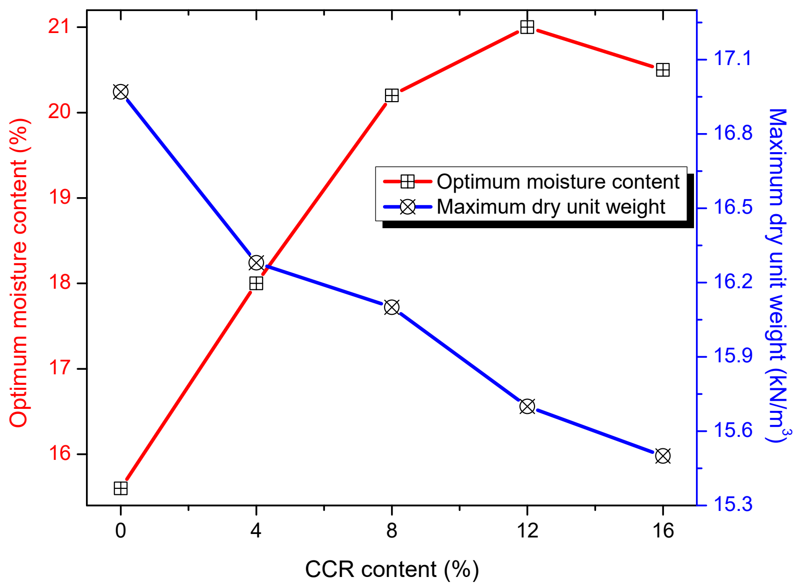


Figure 5: Variation of compaction characteristics of soil with its CCR content.

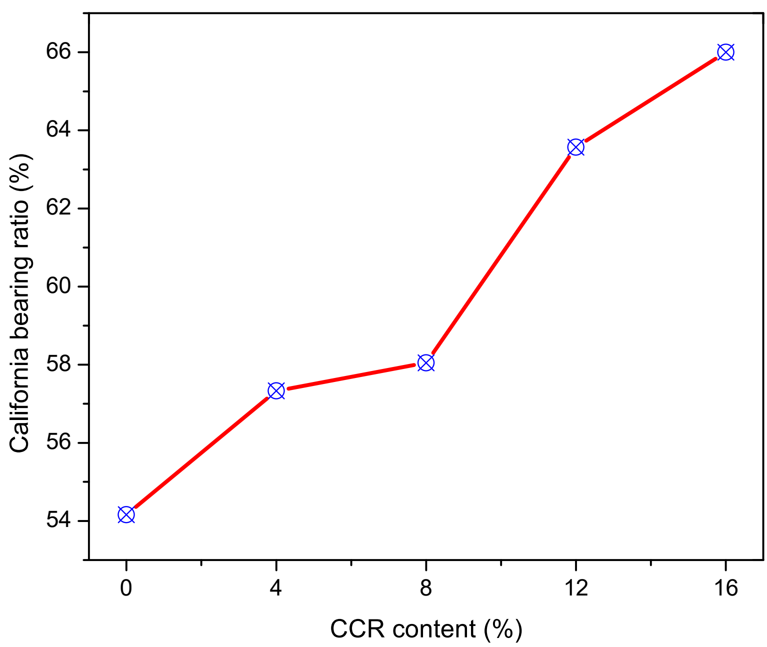


Figure 6: Variation of CBR of soil with its CCR content.

The OMC of the stabilized soil increased with increasing CCR content, while its MDUW decreased (Fig. 5). The water content in the stabilized soil required to attain MDUW increased with increasing CCR content because part of the water was required for the formation of cementitious materials, when the CCR reacts with pozzolanic materials [15].

### 3.4 California bearing ratio

The effect of the application of CCR on the CBR of the soil is graphically presented in Fig. 6. The addition of CCR to the soil increased its CBR, meaning that the capacity of the soil to bear load subjected to it increased.

### 3.5 Unconfined compressive strength

The variation of UCS of the stabilized soil with its CCR content is graphically presented in Fig. 7. The UCS of the soil is understandably low because the soil has a larger proportion of its particles to be cohesionless. In a similar manner as the CCR stabilization effect on the CBR, the UCS increased with increasing CCR content.

Fig. 7 shows that there is a sharp increase in UCS of the natural soil to the value corresponding to 4% CCR content, when compared with the progressive increment that followed after the application of 4% CCR. It can be seen that the slope of the initial part of the graphical plot is steeper than that of the later part. The increase in the UCS of the soil with increasing CCR content resulted from the cementation of the particles of soil brought about by the application of the CCR.

Comparing the results of particle size distribution, Atterberg limits and CBR of the soil with the Nigerian General Specification [25] indicate that the unstabilized and CCR-stabilized soil only satisfied the requirements for use as subgrade material. Though they satisfied the particle size and CBR requirements for use as subbase material, they did not meet the plasticity requirement of being ≤12%. Further research can be carried out to investigate the addition of low percentage of cement with the CCR-soil mixture in order to further strengthen the soil and also reduce the plasticity index.

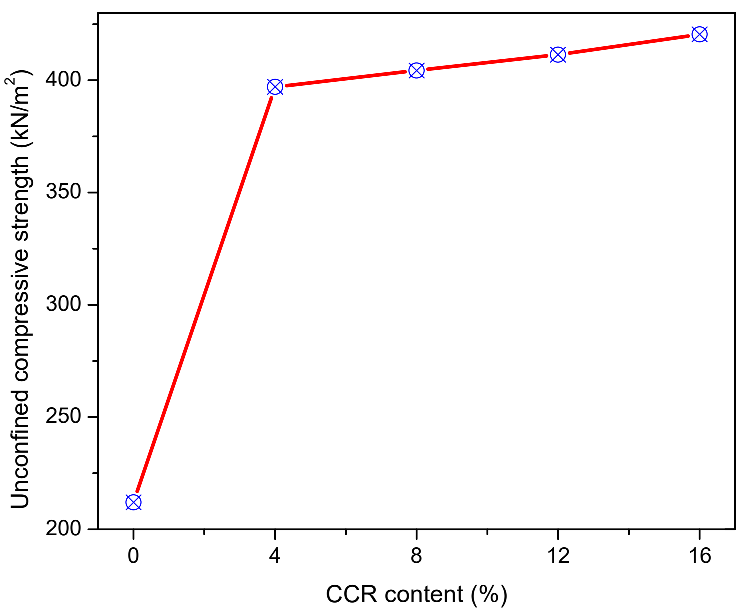


Figure 7: Variation of UCS of soil with its CCR content.

## 4 CONCLUSIONS

This study aimed at investigating the suitability of using CCR to stabilize a tropical soil in order to assess the use of the stabilized soil as road pavement layer material. The soil is classified as a well-graded sand with silt (SW-SM), according to the Unified Soil Classification System. The application of the CCR to the sand resulted in a reduction of the plasticity index, specific gravity and MDUW, while it increased the OMC, CBR and UCS of the stabilized sand.

The pozzolanic reaction of the CCR with some of the constituent of the soil may be responsible for the cementation of its particles that led to the improvement of its strength properties. Based on strength, an optimal CCR content recommended for the stabilization of soils of similar engineering properties as that studied is 4%.

Comparing the results of particle size distribution, Atterberg limits and CBR of the soil with the Nigerian General Specification [25] indicate that the unstabilized and CCR-stabilized soil only satisfied the requirements for use as subgrade material. Though they satisfied the particle size and CBR requirements for use as subbase material, they did not meet the plasticity requirement of being ≤12%. The subgrade characteristics of the stabilized soil became improved by the application of the CCR.

These findings are particularly important because of their potential to use CCR as a soil stabilizer, while consequently ridding the environment of the pollution that may arise from the indiscriminate disposal of the CCR. Further research work can be carried out to investigate the addition of low percentage of cement with the CCR-soil mixture in order to further strengthen the soil and also reduce the plasticity index.

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