Evaluation of index and compaction properties of lateritic soils treated with quarry dust based geopolymer cement for subgrade purpose

Kennedy Chibuzor ONYELOWE is a senior lecturer and researcher at the department of civil engineering, Michael Okpara University of Agriculture, Umudike, Nigeria. His research areas are geotechnical engineering, construction materials, soil mechanics, geotechnical engineering, and waste recycling.

Duc Bui Van is a lecturer at the Hanoi University of Mining and Geology, Hanoi, Vietnam. His research areas include soil stabilization, computational geotechnics, environmental geotechnics, structural construction materials, solid waste recycling wastes based geomaterials and geotechnical engineering.

Lam Dao-Phuc is a professor of Geotechnical engineering at the HUONG and another important member of the research group of Geotechnical engineering, Construction Materials and sustainability, HUONG, Vietnam. He is also a published researcher in this field.

Favour ONYELOWE is an undergraduate student of the department of biotechnology, Ebonyi state university, Abakaliki, Nigeria. She is also a contributing author in the area of biomass and greenhouse emission sequestration during the combustion stage of ash derivation.

Chidozie IKPA is currently a technologist in the department of civil engineering at the Alex Ekwueme Federal University, Ndufu Alike Ikwo, Nigeria. His research areas are construction materials, pavement materials, highway engineering and geotechnical engineering.

Charles N. EZUGWU is an Associate professor and the head of the department of civil engineering at the Alex Ekwueme Federal University Ndufu Alike Ikwo, Nigeria. His research areas are water and environmental engineering, materials engineering, waste recycling.

A. Bunyamin SALAHUDEEN is a senior lecturer and researcher at the University of Jos, Nigeria. His research areas are geotechnical engineering, construction materials, soil mechanics, computational geotechnics, etc. He is a member of many professional and learned societies.

1. Introduction

Index properties of soils are the consistency behavioral patterns soils exhibit within the liquid and plastic phases when they are mixed with moisture. The liquid and plastic behaviors of soft cohesive fine-grained soils determine the soils abilities to be molded, rolled or compacted under different molding moisture conditions [1]. Liquidity of soils is very important in soil mechanics and foundation engineering as it determines certain design factors more especially when the materials are under hydraulically bound conditions [2]. Similarly, the compactibility of soils depend also on the molding moisture conditions or the consistency under which the compaction is carried out [3]. Compaction is a mechanical process of soil stabilization but the state of the soil being compacted plays a
big role on the outcome of the compaction process [4]. For instance, highly plastic soils with plasticity index above 17%, are difficult to handle compared to medium, less or non-plastic soils [5]. It is important to note that both properties of consistency and compaction are the responses of soils when mixed with moisture [6]. They both are moisture limits within which soils characteristics are determined [7]. In compaction, the maximum density of soils is achieved at a moisture intake mark called the optimum moisture [8]. The whole aim is to achieve densification of soil mass in a pavement foundation procedure [8]. But in this case, an ecofriendly supplementary cementitious compound has been developed to enhance the index and compaction properties of soft soils utilized as pavement underlain in the laboratory [1-4]. Researchers are working hard in this line to develop composite geomaterials that replace the conventional methods or materials, which bring about greenhouse emissions [9]. And one of such materials is the quarry dust based geopolymer cement, which was utilized to treat soils in varying proportions [10]. This cementitious compound is a combination of quarry dust, metallurgical slag and alkali activators [11]. Both quarry dust and metallurgical slag are industrial waste materials from quarry and metal operations. Quarry dust and metallurgical slag have been in use as stabilization silicate-based agents in the improvement of the mechanical properties of soils especially problematic soils for use as pavement subgrade materials [11]. This has been successful because of the high content of aluminosilicates possessed by these waste materials from quarry and metal operations. Their pozzolanic properties as single independent admixtures have been incorporated into the composite silicate-based cement compound synthesized under the reactive influence of alkali activators [11-13]. This work studied the effect of quarry dust based geopolymer cement on the index and compaction characteristics of treated problematic soils to be utilized as pavement foundation materials.

2. Methodology

2.1 Materials preparation

Three different borrow pit locations, with coordinates 5°29’16” North and 7°28’58” East (Olokoro location), 5°27’0” North and 7°31’60” East (Amaba location), and 5°31’0” North and 7°28’58” East (Ohia location), were the source point of the test soils. Lumps were eliminated by tapping with rubber pestle, and open dried for four days to start of experiment procedure. Fundamental properties, particle size distribution and chemical compounds composition of the three studied soil specimens and test materials are presented in the Table 1, Fig. 1 and Table 2. The test soils have high free swell indexes and low shrinkage limits. This desiccation behavior makes the soils unsuitable as foundation materials. Exposure of these untreated test soils to moisture for a long time creates room for failures of infrastructures constructed on these soils because of the high potential to swell. It is also observed that the soils are highly plastic. This property also makes the untreated material unsuitable to be utilized as subgrade materials or as hydraulically bound materials. The A-2-7, A-2-6 and A-7 test soils are observed to be poorly graded soils [14]. Soils A and C contain high percentage of clay and are designated as highly clay (CH) content soils, which is a property responsible for the expansivity of clayey soils in contact with moisture. Table 2 presents that the test materials have high percentage of aluminosilicate compounds. Quarry dust (QD) also contains high pozzolanic property [11]. The quarry dust based Geopolymer cement was synthesized according to the procedures and findings of Davidovits [12-13]. The aluminosilicate materials required to materialize the Geopolymer cements consist of quarry dust. The geopolymer cements synthesis was activated by the reactive stimulus of Sodium Hydroxide (NaOH) and Sodium Silicate (Na2SiO3) [12-13]. According to previous research findings, a molarity concentration NaOH of 12 was used to achieve an environmentally friendly material handling and construction process and better strength properties of geopolymer cement might be attained. The synthesis of geopolymer matrixes was carried out by mixing these above materials in a proportion of 4.8% activator, plus 80% quarry dust by weight and 15% metallurgical slag by weight [12-13].
2.2 Experimental methods

Preliminary conventional tests; particle size distribution, Atterberg limits, compaction, free swell test and shrinkage limit tests, were conducted to determine the basic properties of the test soils in accordance with British standards [15-17]. Laboratory tests were conducted on the soils treated with varying proportions of quarry dust based geopolymer cement (QDbGPC) at the rate of 10%, 20%, 30% to 150% by weight of the dry soil to the determine the index properties of the treated soils in accordance with British Standards [16]. Similarly, the standard proctor compactive effort was used on test involving moisture/density relationship. Air dried soils samples passing through sieve number 4 (4.76 mm aperture BS sieve) mixed with 10%, 20%, 30% to 150% by weight of the dry soil of the ecofriendly binding admixture were used. The Standard Proctor procedure was conducted in the laboratory in accordance with British Standard [16].

3. Results and analysis

3.1 Consistency limits and compaction behavior

The consistency behavior of QDbGPC treated uncemented lateritic soils are presented in Fig. 2. The plasticity indexes (PI) of the natural untreated lateritic soils were recorded as 22, 25 and 28% respectively. These were considered highly plastic soils and undesirable as construction materials. Upon the treatment of these soils with QDbGPC, the PI was observed to reduce consistently at the rate of 18%, 8% and 4% respectively at 10% by weight utilization of the geopolymer cement. On further treatment with the geopolymer cement at 20% to 100% by weight utilization, the PI consistently reduced at the rate of 9% for treated soils A and B and 13% for treated soil C. At 130%, 140% and 150% utilization of the geopolymer cement, the consistency behavior of soil A showed a steady PI of 4%. This observed behavior of the treated soils has been contributed by increased calcium content from the geopolymer cement during the formation of transitional compounds. The hydration and calcination of the treated soils under high proportional aluminosilicate and pozzolanic geopolymer cement had caused this improvement. This however, produced stabilized treated soils of stiff consistency. Moreover, the cations release deposited at the adsorbed complex interface of the treated soils from the synthesized geopolymer cement constituents during the cation exchange reaction had also caused this reaction [18-19].

![Graph showing consistency limits of QDbGPC treated soils](Fig. 2)
4. Conclusions

The effect of solid waste based composite silicate based geopolymer cement, the quarry dust based geopolymer cement on the treated problematic soils has been observed under laboratory experiments. After the soils were treated through deep mixing with varying proportions of the composite ecofriendly cement, the index and compaction characteristics of the soils showed substantial and consistent improvement. The highly plastic soils improved to less plastic soils with plasticity indexes below 7% while the maximum dry densities obtainable at the optimum moisture condition also improved to good compactness. With the above observations, the quarry dust based composite geopolymer cement has proven to be a good supplementary cementing material for the stabilization of problematic soils and the improvement of the index and compaction properties when used as pavement subgrade materials exposed to moisture conditions.

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References


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