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Cement modification of tropical black clay using iron ore tailings as admixture

K.J. Osinubi *, P. Yohanna, A.O. Eberemu

Department of Civil Engineering, Ahmadu Bello University, Zaria 810001, Kaduna State, Nigeria

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ABSTRACT

The effect of iron ore tailings (IOT) on cement modified tropical black clay was studied. The natural soil was treated with up to 4% cement and 10% IOT by dry weight of soil. Specimens of treated soil compacted with British Standard light, BSL or standard Proctor (relative compaction = 100%) were subjected to index, sieve analysis, compaction, and shear strength parameters tests. The results of laboratory tests show that properties of the modified soil improved when treated with cement–IOT blends. Test results show a decrease of the fine fraction, decrease in liquid and plastic limits, and an increase in maximum dry density (MDD), with a decrease in optimum moisture content (OMC) as well as a decrease in shear strength value of the natural soil up to 6% IOT content. Microanalysis of the natural and optimally (4% cement/6% IOT) modified soil using scanning electron microscope (SEM) showed a change in the fabric orientation of the soil particles. Although the engineering properties of the soil was improved, the modified soil did not meet the requirements of the Nigerian General Specifications of not more than 35% passing sieve No. 200, maximum plasticity (PI) index of 30% and liquid limit (LL) of a maximum of 50% when used as a sub grade material in road construction. However, an optimal blend of 4% cement/6% IOT improved its workability with increase in curing period.

Introduction

Tropical black clay (also known as black cotton soil because cotton plant thrives well on it) is expansive in nature. It belongs to the smectite group, and includes montmorillonite, a highly expansive and the most troublesome clay mineral when encountered in construction (Osinubi et al., 2010). Expansive soils are normally found in semi-arid regions of tropical and temperate climate zones and are abundant where the annual evaporation exceeds the precipitation and can be found anywhere in the world. The first group comprises sedimentary rock of volcanic origin, which can be found in North America, South Africa and Israel, while the second group of parent materials is basic igneous rocks found in India, Nigeria and South Western U.S.A. (Plait, 1953).

The industrially manufactured additives for modifying soils are lime, cement and bitumen. However, research into new and innovative use of waste material is continually being advanced, particularly concerning the feasibility, environmental suitability and performance of the beneficial reuse of most waste materials. In order to make soil useful and meet foundation engineering design requirements, since the cost of procuring materials that meet specification requirement are increasingly becoming uneconomical, researches have been intensified with the aim of using admixtures to minimize the cost of procuring cement and other standard modifying agents.

Therefore, in view of increasing demand for safe and cost-effective engineering technology, construction mate-

* Corresponding author.
E-mail address: kosinubi@yahoo.com (K.J. Osinubi).

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rials in their natural forms may not satisfy all technology engineering requirements, hence the necessity for modification of construction materials to enhance their use. This explains why effort is being directed to material conversion of industrial wastes for engineering use (Collins and Ciesiellski, 1993). One of the ways of achieving such optimum engineering is to use lime, cement, bitumen, agricultural and industrial waste or agro-industrial waste to modify soils such as black cotton soils which otherwise will be unworkable and unstable for engineering purposes in their natural form.

Soil modification essentially involves the improvement of the soil strength characteristics and the reduction of its plasticity characteristics as well as its original properties to meet specific engineering requirements. The technique is aimed at the enhancement of the engineering properties of deficient soils to enable them perform and sustain their intended engineering use (Osinubi, 1995; Nicholas and Lester, 1999).

Iron ore tailings (IOT) are a mining and mineral waste obtained from the iron ore mining industry. In Nigeria, the Itakpe iron ore deposit is about 200 million tonnes with average ore content of 36% (Adedeji and Sale, 1984). The ores are dark grey in colour, fine-grained, non-plastic and rich in iron oxide. A study by Samadou (2015) on the soil improvement potential of IOT showed that although the grading of black cotton soil improved and plasticity characteristics reduced; the material cannot be used as a stand-alone additive for the stabilization of black cotton soil but, can only be used as an admixture in cement or lime improvement of the soil. Hence the need for this study that was focused on the evaluation of the likely effects of iron ore tailings when used as admixture on cement modified black cotton soil in road construction.

Materials and methods

Materials

Soil: Samples of black cotton soil was collected by disturbed sampling method from a borrow pit in Gombe state (Latitude 10°19′N and Longitude 11°30′E), Nigeria. The top soil was removed to a depth of 0.5 m before samples were collected and placed in bags for transportation to the laboratory. The soil sample was air-dried before lumps were broken to obtain particles passing BS No. 4 sieve (4.75 mm aperture) used for the tests.

Cement: The ordinary Portland cement (OPC) used in the study was sourced from the open market. Cement was added to black cotton soil in stepped increments of 1%, 2%, 3% and 4% by dry weight of soil.

Iron ore tailings: The iron ore tailings (IOT) used for the study was collected from Itakpe National Mining Ore Company in Kogi state, geographically located in north central Nigeria. The IOT used was passed through No. 200 sieve (75 μm aperture) before use. The sieved IOT was placed in air-tight containers to prevent pre-hydration during storage. The IOT was admixed with the black cotton soil–cement mixtures in stepped increments (i.e., 0%, 2%, 4%, 6%, 8% and 10%) by dry weight of the soil used. The oxide compositions of OPC and IOT determined by Energy Dispersive X-Ray Fluorescence are summarized in Table 1.

Iron ore tailings is classified as Class F pozzolana in accordance with the specifications in ASTM C618-12a (2013).

Methods

Index properties: Laboratory tests such as sieve analysis (wet sieving/hydrometer), Atterberg limits, specific gravity, etc) were performed on the natural black cotton soil and cement–iron ore tailings modified soil without curing in accordance with British Standards BS 1377 (1990) and BS 1924 (1990), respectively.

Compaction: Compaction tests were carried out in accordance with BS 1377 (1990) to determine the compaction characteristics of black cotton soil–cement–IOT mixtures. Specimens containing cement in stepped concentrations of 1%, 2%, 3% and 4% and admixed with 0%, 2%, 4%, 6%, 8% and 10% IOT by dry weight of dry soil were prepared and tested without curing. Compaction was performed using British Standard light energy that involved a 2.5 kg rammer falling from a height of 300 mm onto three layers in a 1000 cm^3 British Standard mould, each receiving twenty-seven (27) blows.

Shear strength parameters: The shear strength tests were performed using the quick undrained triaxial test procedure in accordance with BS 1377 (1990). The specimens were not saturated prior to the test. Black cotton soil–cement–IOT mixtures were compacted at their respective optimum moisture content (OMC) and extruded from the compaction mould without curing. Extruded specimens were trimmed into cylindrical undisturbed specimens of 38.1 mm diameter and 76.2 mm height and placed in the triaxial cell. Three specimens were used for each test at cell pressures of 103, 206, and 310 kN/m^2, respectively, and sheared at a controlled strain rate of 0.10%/min. Peak stresses were obtained from the stress–strain plots.

Cation exchange capacity: The test was carried out in accordance with the procedures given by ISRIC (1998). 10 g of 2 mm sieved soil was put into a 100 cm^3 plastic beaker, about 40 ml of Ammonium acetate (1 N pH7.0)

Table 1
Oxide compositions of ordinary Portland cement and iron ore tailing.

Oxide	Composition by weight (%)	
	*Ordinary Portland cement	Iron ore tailings
Lime (CaO)	63.0	0.607
Silica (SiO_2)	20.0	45.64
Alumina (Al_2O_3)	6.0	3.36
Alkali (Na_2O)	1.0	0.405
Alkali (K_2O)	–	0.607
Sulphur oxide (SO_3)	2.0	–
Tin oxide (TiO_2)	–	0.24
Manganese oxide (MnO)	–	0.067
Iron oxide (Fe_2O_3)	3.0	47.7
MgO	–	0.393
Loss on ignition	2.0	3.0

* Czernin (1962).