Effect of Zeolite on Unconfined Compressive Strength of Cement Stabilized Clay soil as a Construction Material

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ABSTRACT
Effect of zeolite on Unconfined Compressive Strength (UCS) of cement stabilized clay soil as a construction material is presented. Clay collected from Giri Village, Gwagwalada area of Federal Capital Territory (FCT), Nigeria, and classified as A-7-6 and CH based on American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) methods of soil classification respectively, was used for the study. The soil was treated with up to 6% cement, at 2% variations and admixed up to 15% zeolite, at 3% variations, by dry weight of the soil. Performance of the additives (cement and zeolite) was investigated with respect to unconfined compressive strength. The results showed UCS of the treated soil increasing with increase in cement content. Addition of zeolite to the soil-cement mixtures increased UCS to their maximum values at 6% zeolite content, after which the values decreased. The study therefore established that clay of high plasticity can be treated with 6% zeolite (and less cement content), to achieve the 1710 or 1750 kN/m^2 reported in the literature, as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements with light to medium traffic.

Keywords: *Cement, Clay soil, Stabilization, Unconfirmed Compressive Strength, Zeolite.*

1.0 INTRODUCTION

In construction of civil engineering structures, different types of soils are used. Some of these soils, in their natural state possess suitable engineering properties for construction purposes, while others are unsuitable. In the latter case, the soils need to be excavated and replaced, or their properties modified before they can sustain the applied loads by the structures. Typical of these unsuitable soils is clay, some of which are regarded as problematic, and others as expansive. These types of soils are frequently observed due to their existence worldwide, except at the arctic regions (Steinberg, 2000). Due to cost implication of total excavation (removal) of these unsuitable soils, when they are encountered during construction, geotechnical engineers often prefer modifying their properties in-situ, using different stabilization techniques.

Stabilization has been widely employed to enhance deficient soils engineering properties such as consistency, density, strength, compressibility and hydraulic conductivity. Additives have been used to modify these properties through waterproofing, bonding or a combination of both (Chittoori, 2008). Puppala and Chittoori (2013) classify these additives into three main categories: traditional, non-traditional and by-product stabilizers. The traditional stabilizers include cement, lime bituminous materials and fly ash; non-traditional stabilizers include polymers, enzymes, ammonium chloride, while the by-product stabilizers comprise of cement kiln dust, iron ore tailings, bagasse ash etc. Amongst these three categories, the traditional stabilizers still remain the most widely used for stabilization (NCHRP 11, 2009). For most highway construction, there is the need to treat the base, subbase and sometimes, subgrade materials to improve workability during compaction, to increase strength and stiffness of the foundation layers and reduce shrink-swell characteristic due to moisture changes (Rauch *et al.* 2002). How stabilization (using different additives) effects strength, compressibility, hydraulic conductivity and other engineering properties of soils have been extensively researched (Clough *et al.*, 1981; Kamon and Bergado, 1992; Yin and Lai, 1998;

Miura *et al*., 2001; Horpibulsuk and Miura, 2001; Horpibulsuk *et al.*, 2004; Horpibulsuk *et al* 2005; Horpibulsuk *et al* 2006; Horpibulsuk *et al* 2011). Based on available compression and shear test results, many constitutive models were developed to describe the engineering behavior of stabilized clay (Gens and Nova, 1993; Kasama *et al*., 2000; Horpibulsuk *et al*., 2010; Suebsuk *et al*., 2010 and 2011).

Soil stabilization has proven to be economical as it provides affordable construction materials for geotechnical structures, especially subgrades, sub-base and base courses for road construction. Deficient soils improvement using Portland cement is one of such methods, which has proven to be effective especially in the case of sandy soil due to the ease of pulverization. The primary reaction of cement is with the water in the soil, which leads to formation of cementitious material. Cement stabilized road bases, provide substantial support to the overlaying pavement layer, thereby reducing stresses on subgrade soil. However, the cost of using cement for improvement of deficient soils, and the enormous carbon emission during its production, has led to seeking for alternative low-cost, naturally available, sustainable and low-carbon additives (techniques), that can lead to reduction in the quantity of cement (or lime) used in the process of stabilization. These alternatives ranges from naturally occurring, industrially produced, industrial and agricultural waste products. One of these additives that is being recently studied is zeolite.

Natural zeolite contains large quantities of reactive SiO_2 and Al_2O_3 (Poon *et al*., 1999). Similar to other pozzolanic materials, zeolite substitution can improve the strength of cement stabilized clay by pozzolanic reaction with $Ca(OH)_2$, prevent undesirable expansion due to alkali-aggregate reaction, reduce porosity of the blended cement paste, and improve the interfacial microstructure properties between the blended cement paste (Feng *et al*., 1990; Poon *et al*., 1999; Canpolat *et al*., 2004). Poon *et al*. (1999) observed that the pozzolanic activity of natural zeolite is higher than that of fly ash but lower than that of silica fume. Yılmaz *et al*. (2007) observed that clinoptilolite blend decreases the specific weight of cements.

Zeolite has unique characteristics such as high specific surface area and cation exchange capacity as well as ability to store heat between hydration and dehydration cycles (Colella *et al*., 2001). Kaolin clay, which is considered as a sources of zeolites, is a naturally occurring mineral, and has been found in commercial deposits in many places in Nigeria, including Ahoko, Kogi state (Tatabu, 2015), which is considered as the most promising local sources of zeolites in Nigeria (Okoro, 2015). The total reserve of kaolin in Nigeria is estimated at about three billion metric tons in at least 45 known deposits, distributed in some state of the country (Alabi and Omojala, 2013).

Natural zeolites have been used for industrial applications in different ways because of its distinctive and attractive characteristics that includes high cation exchange capacity and specific surface area, and their ability to store heat during hydration and dehydration cycles (Sahmaran, 2008). Zeolite contains reactive silica (SiO_2) and alumina (Al_2O_3) in high proportion (Afshin *et al.*, 2019) (Table 1) which chemically react with the excess calcium hydroxide ($Ca(OH)_2$), produce during cement hydration, to form additional calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H) gels, thus improving the microstructure of the hardened cement (Ortega *et al*., 2000; Perraki *et al*., 2003; Caputo *et al*., 2008). Mola-Abasi *et al*. (2016) carried out a study on effect of natural zeolite on the Unconfined Compressive Strength (UCS) of cement-sand mixtures, and revealed that the UCS of the cement-soil mixtures increased with increase in zeolite, and then decreased after attaining an optimal level.

Table 1: Chemical Composition of Zeolite

Oxide	(%)
Calcium oxide (CaO)	4.2
Silicon dioxide (SiO2)	69.12
Magnesium oxide (MgO)	0.65
Potassium oxide (K2O)	1.09
Sodium oxide (Na2O)	0.84
Aluminum oxide (Al2O3)	10.79
Ferric oxide (Fe2O3)	0.73
Sulfur trioxide (SO3)	0.04

Source: *Afshin K. et al.* (2019)

Moreover, zeolite, which is a softer material than cement, increases fineness of the ground material and reduces the grinding time (Canpolat *et al*., 2004). Replacement of Portland clinker by zeolitic tuff reduces workability (Sersale, 1995) and increases water demand. This because, as the cement–water mixture comes in contact with zeolite minerals, the alumina-silicate framework of the zeolite starts decomposing, under the attack of OH^- in a high pH solution. Depolymerized species, such as $[SiO(OH)_3]^-$ and $[Al(OH)_4]$, enter the solution and react with Ca^2, forming hydrated calcium silicate and calcium aluminate compounds, very similar to those formed during hydration of cement**.** Therefore, there is need to minimized or replace the use of cement with abundant natural resources like zeolite, which is sustainable and encourage greenhouse technology. This will go a long way to reducing the over dependence on cement and reduce the environmental pollution caused by CO_2 emitted during its production, and in a way, harnessing the natural resources deposits in Nigeria. This study is aimed at evaluating the strength characteristic of a clay soil stabilized with different percentages of cement and zeolite.

According to (Singh and Singh 1991), the most suitable and adaptable method of evaluating the strength of stabilized soil is the unconfined compressive strength which is regarded as the basic test recommended for determination of the required amount and proportion of additives to be used in stabilization of soil. Therefore, this approach was adopted in the study.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used in this study were Tropical Black Clay (TBC), cement, zeolite and distilled water.

2.1.1 Tropical black clay

The Tropical Black Clay (TBC) used in the study was collected from Gwagwalada area of FCT, Abuja, North Central, Nigeria. Gwagwalada is located at an elevation of 210m above sea level and on a latitude of 8º56'29" N, longitude of 7º 5'31" E on the Nigerian geographic map (FCDA, 2015) as shown in the google Earth map (Figure1). The soil sample was collected at depth of between 1.0 to 1.5m below the ground surface to avoid organic matter. Disturbed sampling method was used in collection of the sample. The collected soil sample was wrapped in polythene bags to avoid loss of moisture and transported to Civil Engineering Laboratory, Federal University of Technology, Minna. In the laboratory, the natural soil sample was air dried and pulverized before further tests were conducted.

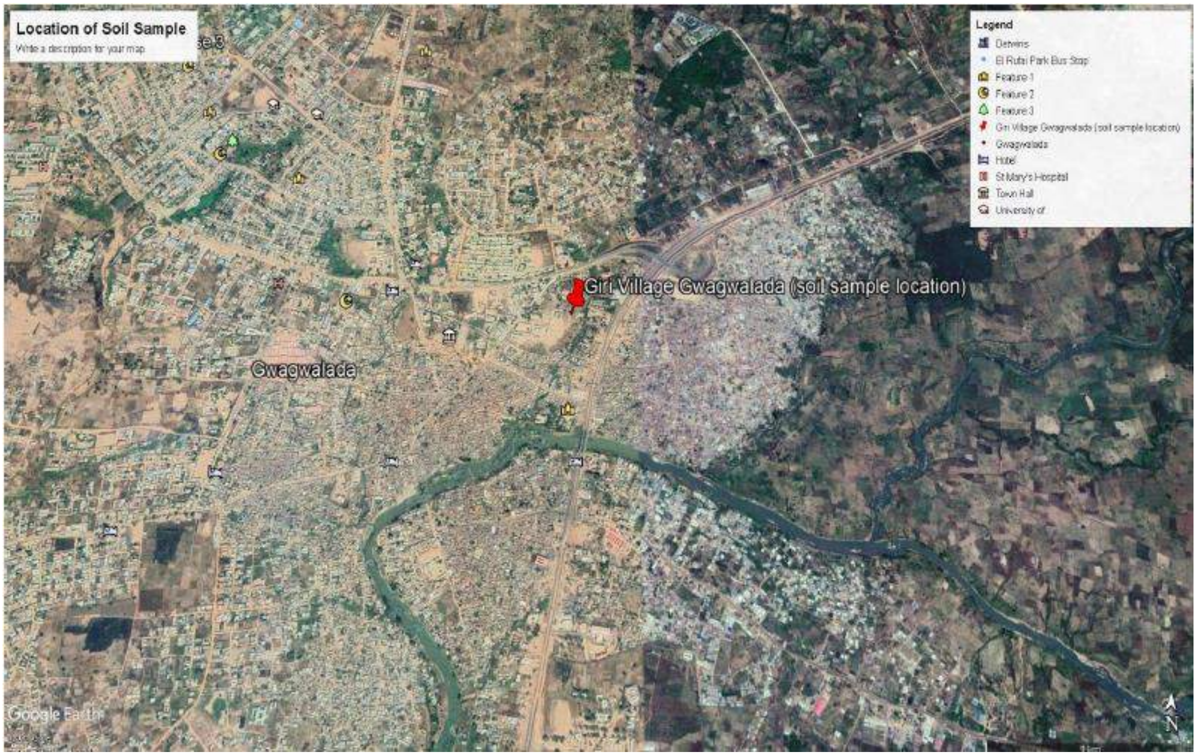

Figure 1: Location of sampling point (Source: Google Earth Maps)

2.1.2 Cement

The Portland cement used for the study was procured from a cement vendor at Minna building materials market. Dangote cement brand of grade 42.5R was used. The cement was properly stored under dry condition.

2.1.3 Zeolite

The zeolite used for the study was purchased from a vendor in Kaduna State. It was produce by TM Media.

2.1.4 Water

Distilled water, used in the study was purchased from a laboratory equipment/chemicals store, along hospital road, Minna, Niger state.

2.2 Methodology

The laboratory test performed on the natural soil in order to determine its engineering properties were in accordance with BS 1377 (1990) parts 2, 4 and 7, while on the stabilized soil, the tests were conducted in accordance with BS 1924 (1990). In accordance with the literature, the soil was mixed with 0, 2, 4 and 6% cement, and each was then admixed with 0, 3, 6, 9, 12 and 15% zeolite. Natural moisture content, specific gravity, particle size distribution, Atterberg limits (liquid limit, plastic limit and plasticity index), compaction at Standard Proctor energy level, Unconfined Compressive Strength (UCS) tests were performed on the natural soil, while on the stabilized soil, compaction and UCS tests were performed. Samples for UCS test (Figure 2) were prepared at Maximum Dry Densities (MDD) and Optimum Moisture Contents (OMC), obtained from compaction test at respective mixtures of the soil and the additives (cement and zeolite).

Figure 2: UCS Test

3.0 RESULTS AND DISCUSIONS

3.1 Properties of Natural Soil

The results of preliminary tests conducted on the natural soil, for identification and classification purposes, is presented on Table I. From the results, the soil is classified as CH and A-7-6 according to Unified Soil Classification System (USCS) and American Association for State Highway and Transportation Officials (AASHTO) respectively. The result indicates that the geotechnical properties of the soil fall below the standards, recommended for most civil engineering construction works, especially pavement structures (Osinubi and Medubi, 1997) and therefore needs stabilization.

Table 1: Geotechnical Properties of Natural Soil

Property	Quantity
Percentage passing BS No 200 sieve (%)	79.03
Moisture Content (%)	35.06
Liquid limit (%)	58
Plastic limit (%)	26.6
Plasticity Index (%)	31.4
Specific Gravity	2.43
AASHTO	A-7-6
USCS	CH
Maximum Dry Density (Mg/cm³)	1.692
Optimum Moisture Content (%)	18.0
Colour	Greyish black
Dominant clay mineral	Montmorillonite

3.2 Unconfined Compressive Strength

Unconfined Compressive Strength (UCS) is regarded as the most common and adaptable method of evaluating the strength of stabilized soils (Alhassan and Alhaji, 2007). According to Singh and Singh (1991), it is the main test recommended for determination of the required amount of additive to be used in stabilization of soil.

Variation of UCS with increase in zeolite from 0 to 15% (at 3% variations) with specific cement contents at British Standard Light energy level and for 1, 7, 14, 28 and 60 days curing periods were studied and the results for the five curing periods are presented in Figures 3, 4, 5, 6 and 7 respectively. There was a tremendous improvement in the UCS with addition of cement and zeolite, when compared with the relatively low UCS value of 71kN/m^2 for the natural soil.

Apart from the increase in UCS recorded with increase in cement content, there was also increase in UCS with increase in zeolite content at specific cement contents, up to the peak UCS values at 6% zeolite, after which the values dropped. This trend was observed at all the curing periods considered. Also, observation and comparison of the figures revealed that as the curing period increases, UCS of the treated soil increased. At 1 day curing period, UCS of the soil increased from 71kN/m^2 for the natural soil to a maximum value of 929 kN/m^2 at 6 and 4% cement and zeolite respectively. At 7 days curing period, UCS of the soil rose to a maximum value of 1291kN/m^2 at 6 and 4% cement and zeolite respectively, while at 14 days curing period, UCS of the soil increased to a maximum value of 1574kN/m^2 at 6 and 4% cement and zeolite respectively. At 28 days curing period, UCS of the soil increased to a maximum value of 1634kN/m^2 at 6 and 4% cement and zeolite respectively, while at 60 days curing period, UCS of the soil increased to a maximum value of 1746kN/m^2

at 6 and 4% cement and zeolite respectively. This noticeable increase in UCS of the treated soil, with increase in curing period is attributed to the progress of hydration reaction of cement and the pozzolanic reaction of the zeolite.

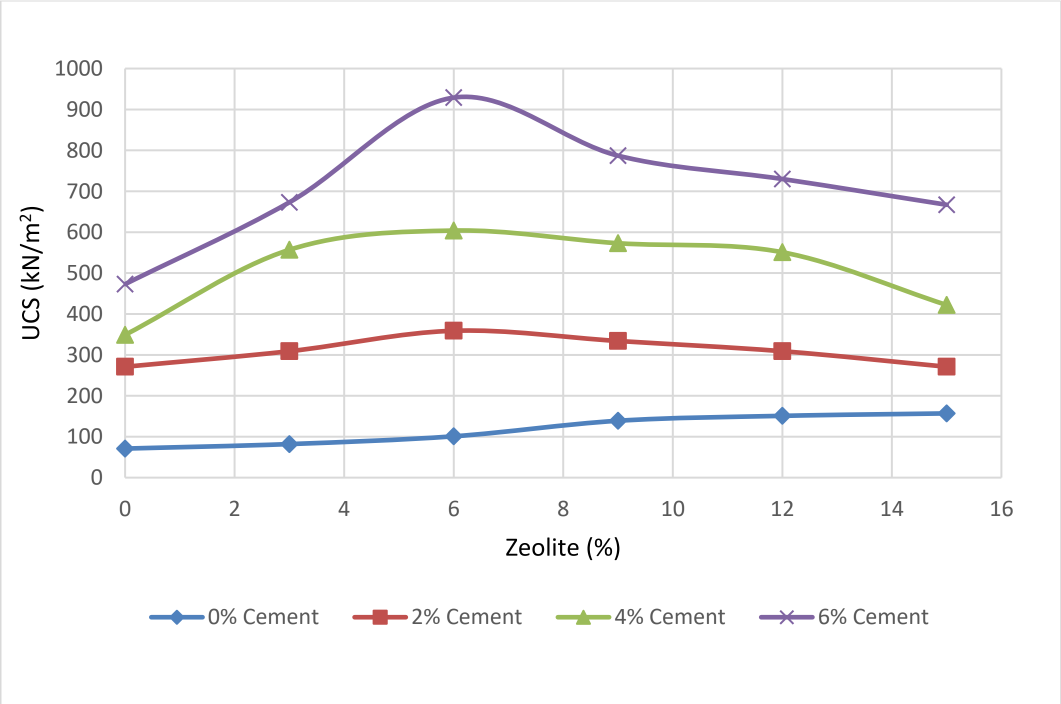

Figure 3: Variation of unconfined compressive strength with various dosages of both cement and zeolite after 1 day curing period

Addition of zeolite resulted in additional increase in the UCS. The UCS improvement due to increase in zeolite resulted from the pozollanic reaction between the lime (CaOH) librated from the hydration reaction of the cement and the pozollanic zeolite to form secondary cementitious materials in the soil matrix (Osinubi and Medubi, 1997). This is primarily due to the formation of various compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes, which are responsible for strength development (Negi *et al.*, 2013), which peaks at 6% zeolite. Since cement hydration with subsequent liberation of Ca(OH) is time dependent, effect of pozzolanic reaction of the zeolite will also be time dependent. The drop in strength after 6% zeolite content can be attributed to excessiveness in mixtures, of Fe_2O_3 and Al_2O_3, from zeolite in the presence of less liberated byproduct of cement hydration reaction (lime). This excessive SiO_2, Fe_2O_3 and Al_2O_3 (from zeolite), with less available Ca(OH) within the mass of the mixtures, created barrier that hinders bonding of the soil particles by the formed cementitious materials, resulting to decrease in strength.

From the results, it can be observed that at 6% zeolite content, it is possible to achieve UCS values above the 1710 kN/m^2 recommended by TRRL (1977) and 1750 kN/m^2 reported by Khanna and Justo (2011), which is regarded as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements with light to medium traffic.

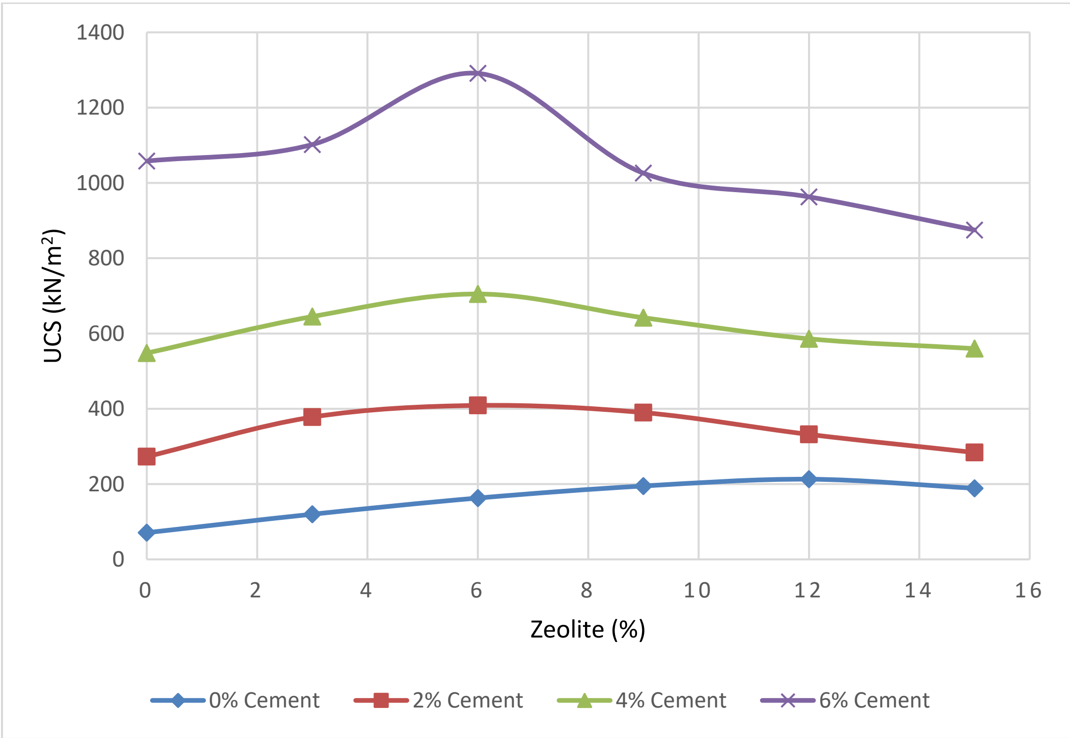

Figure 4: Variation of unconfined compressive strength with various dosages of both cement and zeolite after 7 days curing period

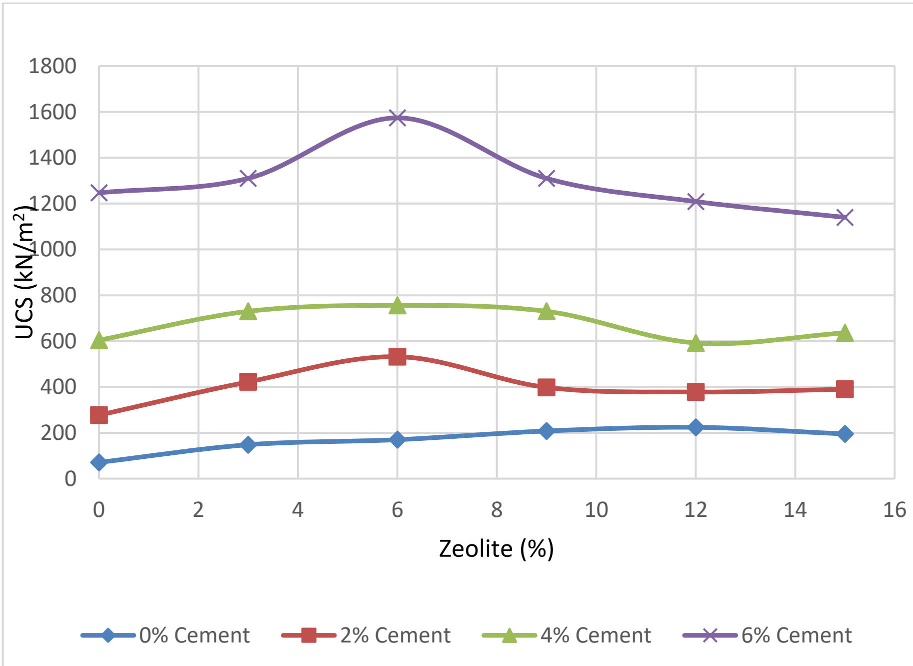

Figure 5: Variation of unconfined compressive strength with various dosages of both cement and zeolite after 14 days curing period

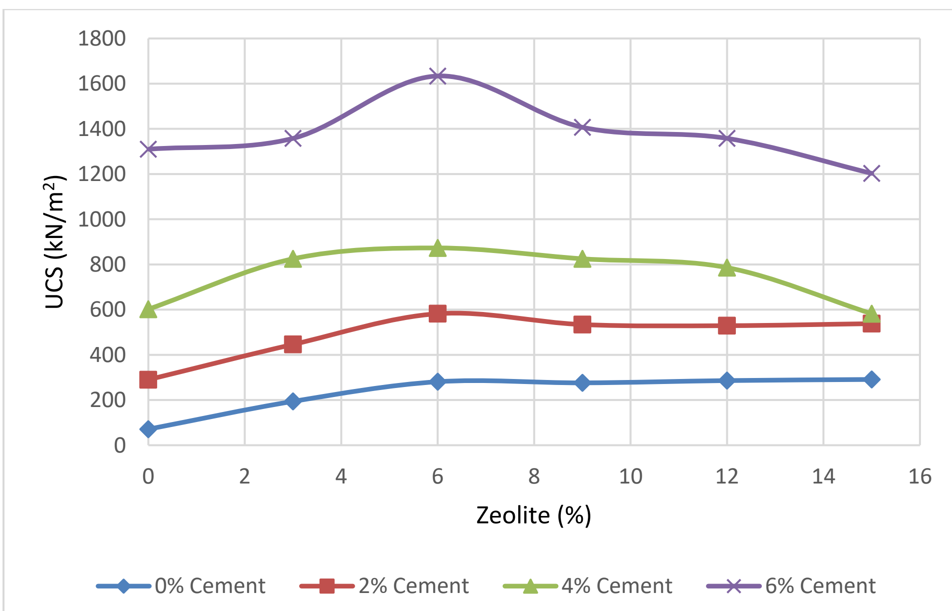

Figure 6: Variation of unconfined compressive strength with various dosages of both cement and zeolite after 28 days curing period

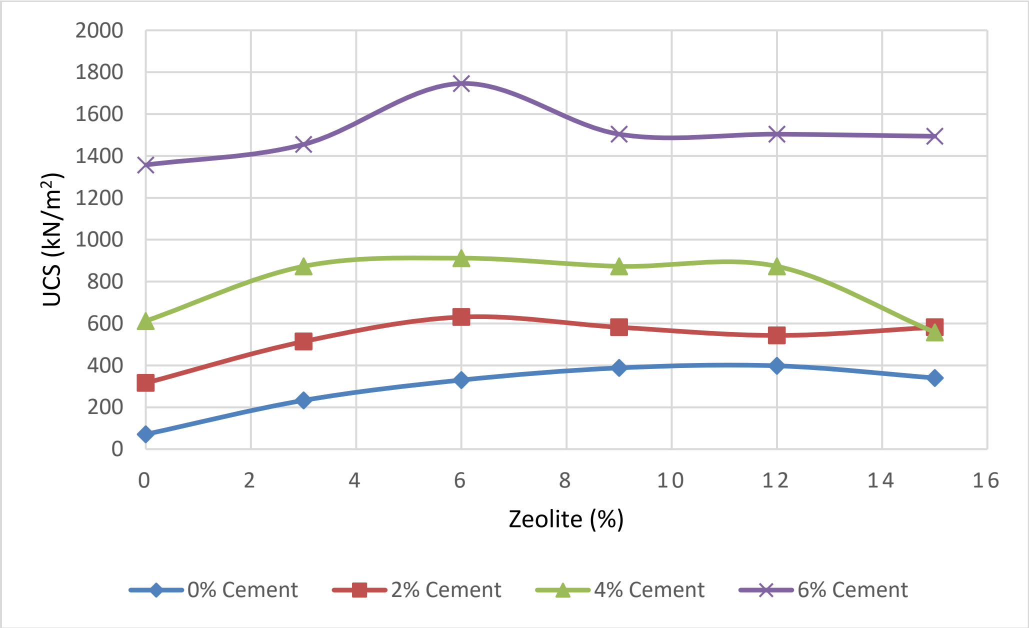

Figure 7: Variation of unconfined compressive strength with various dosages of both cement and zeolite after 60 days curing period

4.0 CONCLUSION

From the study, the following conclusion is drawn:

The soil was classified under CH and A-7-6, according to Unified Soil Classification System (USCS) and American Association for Highway and Transportation Officials (AASHTO) respectively.

Unconfined compressive strength was observed to increase as cement content increase, while at constant cement content, UCS increased to their maximum values at 6% zeolite content, after which the strength decreased. This indicates that 6% zeolite content is the optimal.

Clay of high plasticity can be treated with 6% zeolite and less cement content, to satisfy the 1710 kN/m^2 recommended by TRRL (1977) and 1750 kN/m^2 reported by Khanna and Justo (2011), as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements with light to medium traffic.

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