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Contents

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OPTIMAL USE OF BAGASSE ASH ON CEMENT STABILIZED LATERITE

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ABSTRACT

Bagasse ash (a residue obtained after the incineration of the fibrous by-product of the extraction of juice from sugarcane) was used as an admixture in the cement stabilization of a laterite classified as A-7-6 (12) and CL according to AASHTO and Unified Soil Classification System, respectively. California bearing ratio (CBR) and unconfined compressive strength (UCS) were used as evaluation criteria for specimens compacted at the energy of the British Standard Light (BSL). The durability of the soil-cement-bagasse ash specimens was assessed by immersion in water to determine resistance to loss in strength. Generally, substantial improvements in the strength and durability values of the treated lateritic soil were recorded with up to 6% bagasse ash content for specific cement contents. Based on durability assessment of soil-cement-bagasse ash mixtures tested, 6% cement/6% bagasse ash and 2% cement/6% bagasse ash are recommended as optimal additives for the stabilization of CB1 (heavily trafficked) and CB2 (lightly trafficked) roads, respectively.

INTRODUCTION

To an engineer, soil is any uncemented or weakly cemented accumulation of mineral particles formed by the weathering of rocks and contains void spaces between particles, which are filled by water and or air (Craig, 1998). Laterite is a soil group, which is commonly found in the leached soil of the humid tropics and is formed under weathering systems that cause the process of laterization (Gidigasu, 1976).

Laterite is a common construction material endowed in almost all the countries of the humid tropics of the world. Its formation is favored by the factors encouraging laterization processes such as high intensity rainfall, high vegetation cover, permeable soil profile, alternating ground water movement, e.t.c. The soil in some cases can on its own serve as base course for road structures. But there are instances where the laterization process is not complete and soil groups such as laterites, lateritic, and laterized soils are formed. These soils may contain substantial amounts of silica in the form of clay silicate minerals and could affect the strength and stability of the laterite. In areas where deposits of these types of laterite exist, sourcing for alternative suitable soil may be too expensive. Therefore stabilizing the available laterite to meet the desired strength and stability is inevitable.

Cement and lime are the two main materials used for the stabilization of soils. Cement has rapidly increased in price due to the sharp increase in the cost of energy since 1970s (Neville, 2000). Bagasse ash is obtained from the burning of the fibrous residue of sugarcane and it is a byproduct from sugar companies. It has been reported by Misari et al. (1998) that Nigeria has a potential of producing about 270.000 tonnes of bagasse ash per annum. Ogbonyomi (1998) reported that bagasse ash can be categorized under pozzolanas with about 60-70% silica, 9% alumina and 3% iron oxides. The need for readily available cheap construction materials, and the recycling of industrial waste products prompted this study to determine the optimum bagasse ash required as admixture with cement in proportion to stabilize deficient laterite.

LOCATION OF STUDY AREA

The soil sample used in this study was taken from a borrow pit at Shika along Zaria-Sokoto road (Longitude 7°36'E Latitude 11° 4'N) using the method of disturbed sampling. The soil from this pit classified as A-7-6 according to AASHTO soil classification system (AASHTO, 1986) and CL according to the Unified Soil Classification System (ASTM, 1992). It belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks (Osinubi, 1998; Osinubi and Nwaiwu, 2006)

ADMIXTURE STABILIZATION

Various researchers (Gillott, 1968; Gidigasu, 1976; Singh, 1991; Toro, 1997; Adeyemi and Abolurin, 1999) defined stabilization in their own words but with the same meaning. The more involving is that given by Singh (1991) who defined stabilization as the combination of soils and or other additives in such a way that, when it is compacted under specified conditions and to specified extent, would undergo material change in its properties and would remain in its stabie compacted state without undergoing any change under the effect of exposure to weather and traffic.

Stabilization could be mechanical or chemical or both. Cement or limes are common additives used for chemical stabilization. However, there are instances where the lacking properties of a particular soil cannot be restored by a single chemical additive like cement, lime, bitumen e.t.c, or a required strength cannot be gained by an economic amount of a single additive. In these circumstances, two or more chemical additives could be required to restore the lacking properties or required strength with an economic amount of an additive. For instance, cement, which is the most readily available soil stabilization additive in Nigeria, cannot be used economically on very soft clays like the black cotton clays. But addition of lime to this type of clay can help to increase its workability and hence high reduction in the amount of cement that would have been required for efficient stabilization of that clay.

Long term increase in strength with economic amount of cement can also be achieved with addition of any pozzolanic material along with cement. This increase in strength is due to the reaction between the pozzolana and the lime librated during the hydration reaction of cement. This long term reaction has prompted some researchers to employ new evaluation criteria for soil stabilization using combinations of additives and pozzolanas since the only criterion available have been those based on the use of cement and lime. One of the recent laboratory trials to achieve this objective is that of Osinubi (1999) who evolved an evaluation criterion for a cement stabilized residual black cotton soil when lime is used as an admixture. It was concluded that, due to time dependant increase in strength and attendant high durability due to enhanced pozzolanic reaction of the soil-lime-cement mixture, an unconfined compressive strength (UCS) of 1235 kN/m^2 and a California bearing ratio of 55% are recommended as evaluation criteria as against the UCS of 1720 kN/m^2 and CBR of 80% recommended by BS 1924 (1990) and Nigerian General Specification (1997).

Toro (1997), Osinubi (1999; 2006), Osinubi and Medubi (1997), Osinubi and Ijimdiya (2008), Osinubi and Eberemu (2009) as well as Osinubi et al. (2006; 2009a,b) conducted laboratory studies on admixture stabilization of various chemical additives and reported substantial increases in strength (i.e., CBR and UCS) for up to 28 days curing period. However, the variations of maximum dry density (MDD) and optimum moisture content (OMC) of the mixtures with increase in admixture contents are not consistent with those of single additives. Strength increased and decreased at no constant additive contents due to complex reactions between the additives and the soil being treated

METHODS OF TESTING

The laboratory tests carried out on the natural soil include particle size distribution, Atterberg limits and compaction. The geotechnical properties of the natural and treated soils were determined in accordance with BS 1377 (1990) and BS 1924 (1990), respectively. Specimens for UCS and CBR tests were prepared at their respective OMC and MDD at BSL compactive effort that is easily achieved under field condition. The CBR tests were conducted at a constant loading rate of 1.3 mm/min in accordance with Nigerian General Specifications (1997).

The sugarcane bagasse ash (SCBA) was obtained from the open burning of sugarcane bagasse (a fibrous residue obtained after the extraction of juice from sugarcane). The oxide composition of the SCBA was determined by using X-ray fluorescence analysis.

RESULTS AND DISCUSSIONS

Index Properties of Soil

The index properties of the natural soil are summarized in Table 1, while the particle size distribution of the natural soil is shown in Fig. 1

Oxide Composition of Sugarcane Bagasse Ash

The oxide composition of the sugarcane bagasse ash (SCBA) used in this study is summarized in Table 2. The total percentage composition of iron oxide (Fe_2O_3 = 3.96%), silicon dioxide (SiO_2 = 57.95%) and aluminium oxide (Al_2O_3 = 8.23%) is 70.14%. This value is within the required minimum value of 70% specified for pozzolanas (ASTM C618 – 78). However, the value is lower than that obtained by Ogbonyomi (1998). The difference might be due to the method of preparation of the ash and the species of the sugarcane.

Compaction Characteristics

The variations of MDD and OMC with SCBA admixed with specific percentages of cement are presented in Figures 2 and 3, respectively. The MDD for soil treated with varying SCBA admixed with 4% and 8% cement contents generally decreased with higher SCBA as shown in Fig. 2. This trend is in agreement with Gidigasu (1976), Ola (1983) and Obeahon (1993). This decrease could be due to the immediate reaction whereby combined cement and SCBA coated the fine-grained particles to form larger aggregates, which consequently occupied larger spaces with the tendency to decrease in dry density. The trends for varying SCBA admixed with 2 and 6% cement contents show initial reductions in MDD to minimum values in the range of 4 - 6% SCBA content after which the MDD increased. The initial decrease was probably due to the immediate reaction between cement admixed with SCBA and the fines fraction of the soil during which coarse aggregates were formed (Osinubi, 1998). The aggregates occupied larger spaces thus increasing their volume and consequently decreasing their dry densities. Above the range of 4 - 6% SCBA content, the MDD increased because the coarse aggregates formed were firmly bonded as a result of the excess cement and SCBA present in the mixture that plugged the voids to produce denser mixes.

There was a general trend of increase in OMC with higher SCBA content for the various cement contents considered as shown in Fig. 3. This trend is in agreement with Ola (1975), Gidigasu (1976) and Osinubi (1999). The increase in OMC was due to the addition of cement admixed with SCBA, which reduced the quantity of free silt and clay fraction and aided the formation of coarser materials with larger surface areas. This implies, that apart from the water needed for the hydration of cement to take place, more water was needed in order to compact the soil-cement-SCBA mixtures (Osinubi 1999). With increase in SCBA content beyond 4 - 6% range, there was an enhanced cation exchange reaction due to a combination of free lime product of hydration of cement and the SCBA admixture. This reaction resulted in the decrease in the thickness of the double layer thereby causing flocculation. As the clay flocculated under this action, water, which had become separated from the particles concentrated in the voids between the bonded particles thus reducing the OMC as was observed for soil-2% cement-SCBA mixture.

Strength Characteristics

California bearing ratio

The variation of CBR with SCBA content for specific percentages of cement is shown in Figure 4. Addition of cement and SCBA admixture to the natural soil generally resulted in marked improvements in CBR values with higher cement content between 4 and 6% SCBA treatment. Peak CBR values of 70% at 4% SCBA and 170% at 6% SCBA were recorded for the treated soils containing 2 and 8% cement, respectively (see Fig. 4). The CBR value of 180% recommended by the Nigerian General Specifications (1997) to be attained in the laboratory for cement stabilized materials to be constructed by mix-in-place method was not satisfied. However, this condition is expected to be attained at a later stage due to the time-dependent pozzolanic reaction between the calcium hydroxide released from the hydration reaction of cement and SCBA.

Ola (1974) suggested that CBR values of 60 – 80% for bases and 20 – 30% for sub bases of lightly trafficked roads with superior residual soil when compacted at 95% of British Standard Heavy compaction. Therefore, if 80% is adopted as criterion for adequate stabilization, then the peak CBR values of soil treated with specific cement contents and SCBA admixture satisfy the requirement for base course of lightly trafficked roads. This includes the soil treated with 2% cement that is expected to increase in strength with time.

Unconfined compressive strength

The variations of UCS with SCBA content for specific cement treatments for 7, 14 and 28 days curing periods are shown in Figures 5 - 7. There was substantial improvement in the UCS with higher cement content between 4 and 6% SCBA treatment. Peak UCS values recorded for 7, 14 and 28 days curing periods are 4800, 5510 and 5590 kN/m^2.

The improvement in UCS was due to two reactions: first, the initial hydration of cement that resulted in the formation of cementitious compounds responsible for the initial high strength development'; secondly, the secondary pozzolanic reaction between the lime liberated from the hydration reaction of cement and SCBA that was responsible for the time-dependent strength gain. This is in agreement with Osinubi and Medubi (1997).

TRL (1993) recommends UCS values in the range of 3000 – 6000 kN/m^2 to be attained by specimen cured for 7 days in order to b used as a road base for heavily trafficked roads (CB1) and 1500 – 3000 kN/m^2 as a road base for lightly trafficked roads (CB2). Singh (1991) recommends UCS value of 1720 kN/m^2 for specimen cured for 7 days to be used for lightly trafficked road bases (CB2) and 2750 – 3450 kN/m^2 for heavily trafficked road bases (CBI). If a UCS value of 3450 kN/m^2 is considered adequate for heavily trafficked road bases, which is within an agreeable range of values recommended by TRL (1993) and Singh (1991), only the peak UCS values of 4380 kN/m^2 obtained at 6% cement and 4% SCBA admixture and 4800 kN/m^2 at 8% cement and 4% SCBA admixture are adequate for (CBI) road base. The 7 day UCS value of 1720 kN/m^2 recommended for lightly trafficked (CB2) road bases is satisfied by all the soil-cement-bagasse ash mixtures considered.

Durability characteristics

There are different methods for evaluating the durability of stabilized soils but, the method used in this study and which is more acceptable for tropical regions like Nigeria, is the determination of resistance to loss in strength by immersion of specimens in water (Ola 1974). Resistance to loss in strength is the ratio of the UCS of specimen wax-cured for 7 days, de-waxed top and bottom and immersed in water for 7 days to the UCS of specimen wax-cured for 14 days.

Variation of UCS for specimens cured for 7 days and soaked for another 7 days with varied SCBA and specific cement contents is shown in Figure 8. The highest resistance to loss in strength of 90% (i.e., 10% loss in strength) was recorded for soil- 6% cement - 6% SCBA mixture, while the lowest resistance to loss in strength of 76% (i.e., 24% loss in strength) was recorded for soil- 4% cement - 6% SCBA mixture. These durability values are adequate going by the 80% resistance to loss in strength suggested by Ola (1974) for superior residual soil specimens immersed in water for only 4 days after the first 7 days curing period. In view of the harsher immersion condition the lowest resistance to loss in strength can be accepted as being adequate.

CONCLUSIONS AND RECOMMENDATION

The study considered the effect of sugarcane bagasse ash on cement – stabilized laterite. Tests conducted on samples of laterite collected from Shika along Zaria-Sokoto road classified as A-7-6 (12) according to AASHTO soil classification and clay of low plasticity, CL according to USCS.

Soil treated with cement and SCBA admixture generally showed a reduction in MDD with higher SCBA. However, for specimens containing 2 and 4% cement the MDD increased within the range of 4-6% SCBA. The corresponding OMC values showed initial increase with higher SCBA content and peak values recorded in the 4 – 6% SCBA range but thereafter decreased.

The CBR values substantially improved above that obtained for the natural soil. CBR values increased with higher SCBA content for specific cement treatments and peak values obtained within the 4 - 6% SCBA content range. A similar trend was observed for UCS values that also increased with curing periods.

The durability of the soil-cement-bagasse ash mixtures are higher than the conventional 80% recommended for a 4-day immersion in water period.

Based on durability test results 6% cement/6% SCBA and 2% cement/6% SCBA are recommended as optimal additives to deficient laterite in order to construct CB1 (heavily trafficked) and CB2 (lightly trafficked) roads, respectively.

Table 1: Index properties of the natural soil

Property	Quantity
Natural moisture content (%)	6.55
Percent passing BS No. 200 sieve	62.5
Liquid limit (%)	41.0
Plastic limit (%)	18.0
Plasticity index (%)	23.0
Linear shrinkage (%)	8.93
Group index	12
AASHTO classification	A-7-6
USCS classification	CL
Specific gravity	2.69
Maximum dry density (Mg/m^3)	1.84
Optimum moisture content (%)	15.2
California Bearing Ratio (%)	5
Unconfined Compressive Strength (kN/m^2)	610
Organic matter content (%)	6.75
Colour	Reddish Brown

Table 2: Oxide composition of sugarcane bagasse ash (SCBA)

Oxide	Concentration (% by weight)
SiO_2	57.95
Al_2O_3	8.23
Fe_2O_3	3.96
CaO	4.52
MgO	1.17
K_2O	2.41
LOI	5

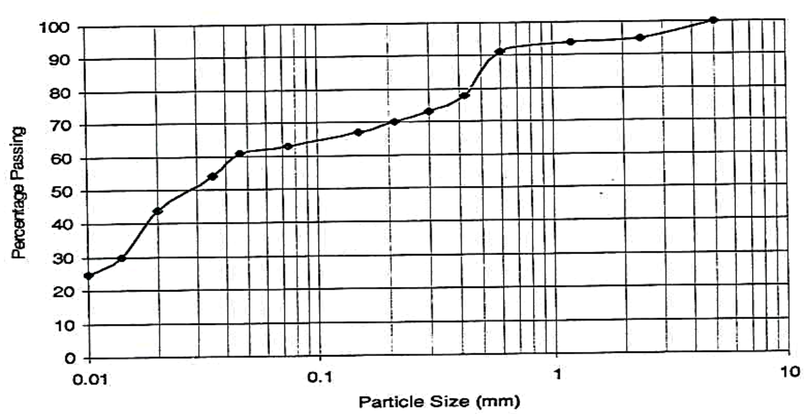

Fig. 1: Particle size distribution curve for the natural soil

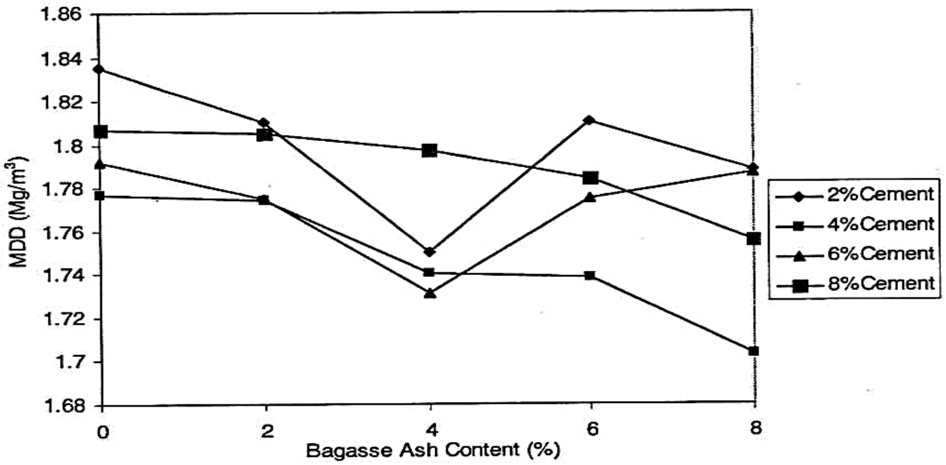

Fig. 2: Variation of MDD with Bagasse Ash Content

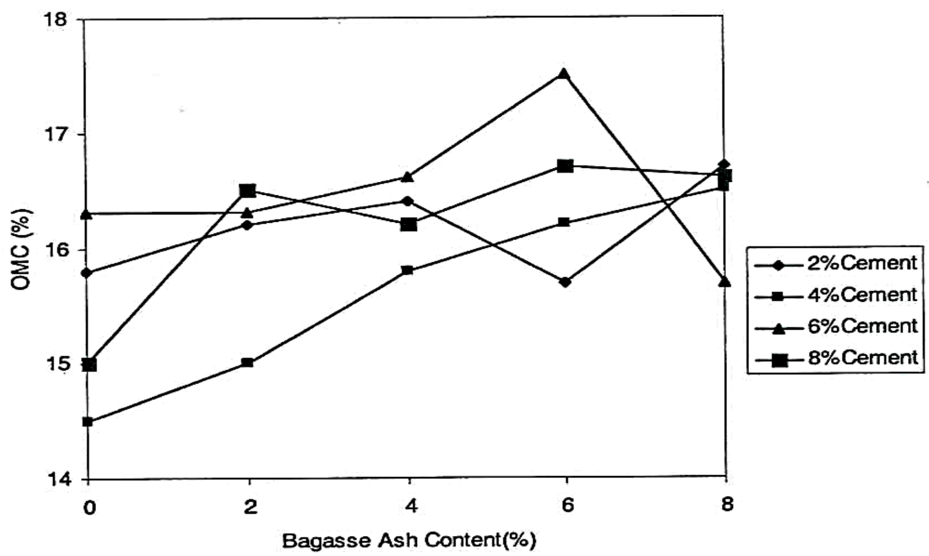

Fig. 3: Variation of OMC with Bagasse Ash Content

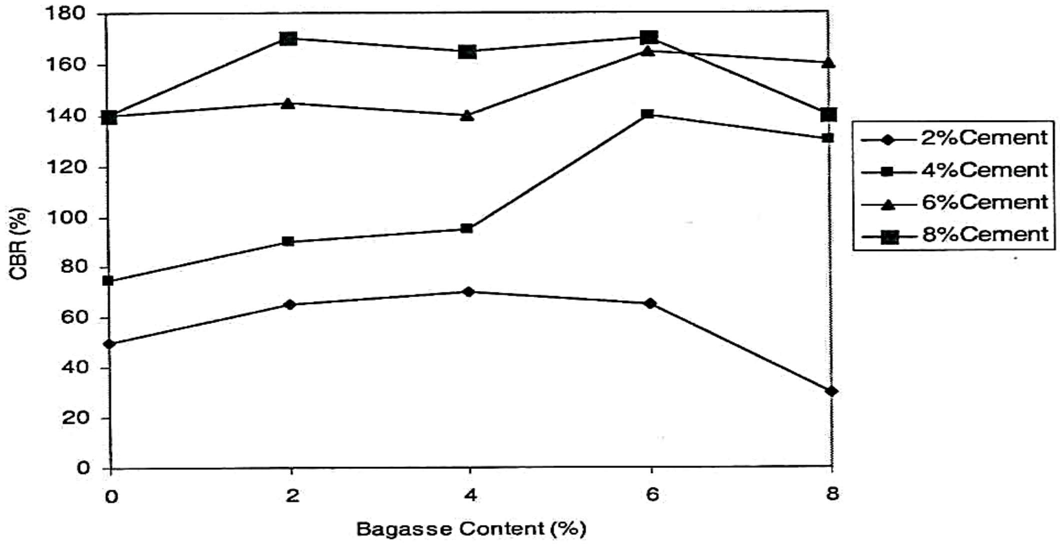

Fig. 4: Variation of CBR with Bagasse Ash Content

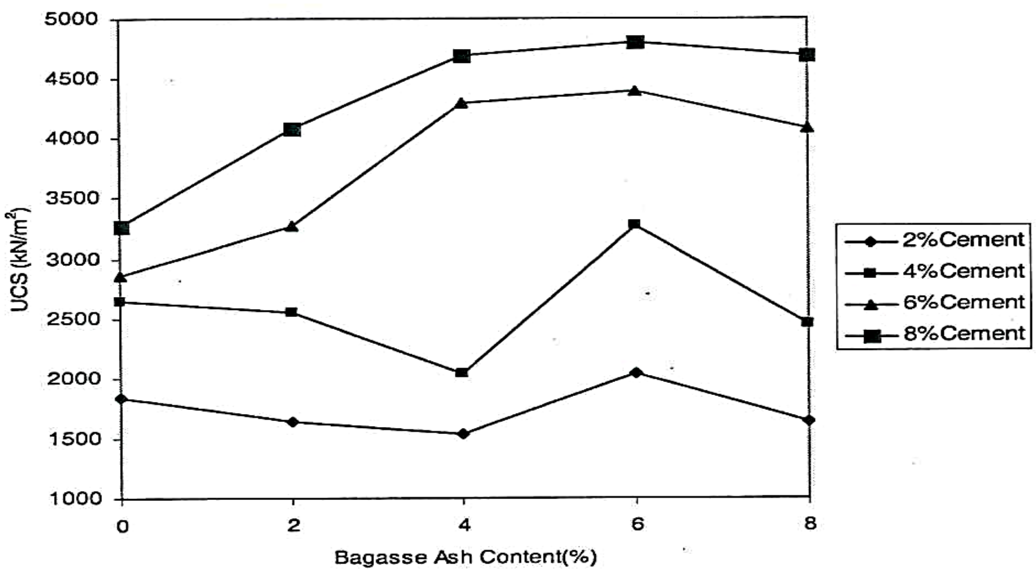

Fig. 5: Variation of UCS with Bagasse Ash Content for 7 days Curing Period

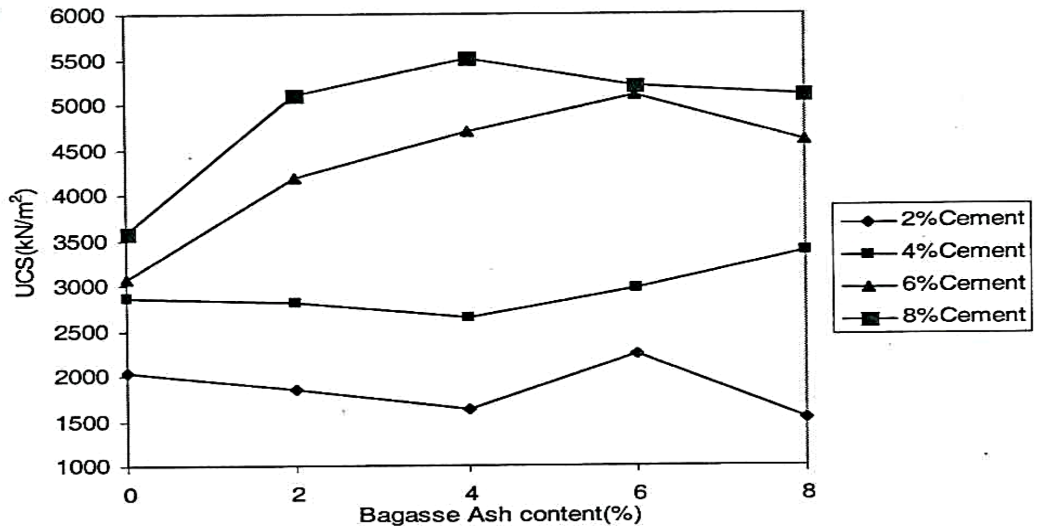

Fig. 6: Variation of UCS with Bagasse Ash Content for 14 days Curing Period

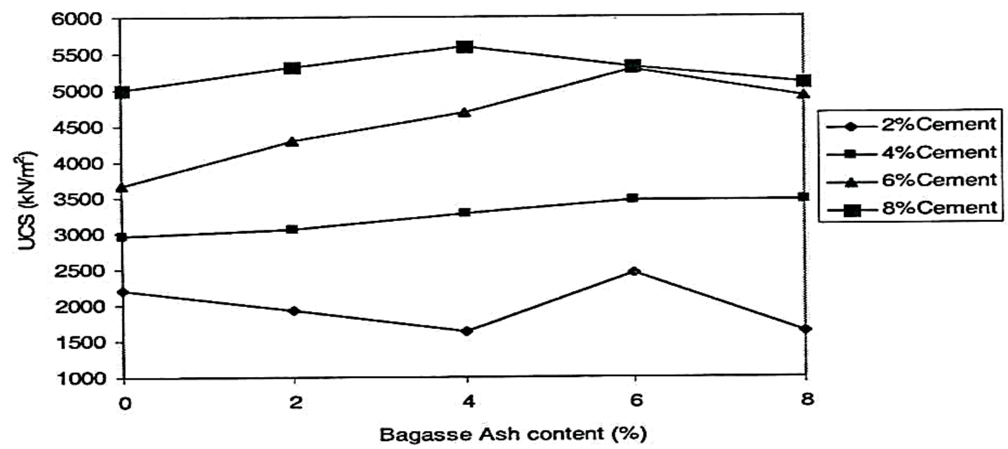

Fig. 7: Variation of UCS with Bagasse Ash Content for 28 days Curing Period

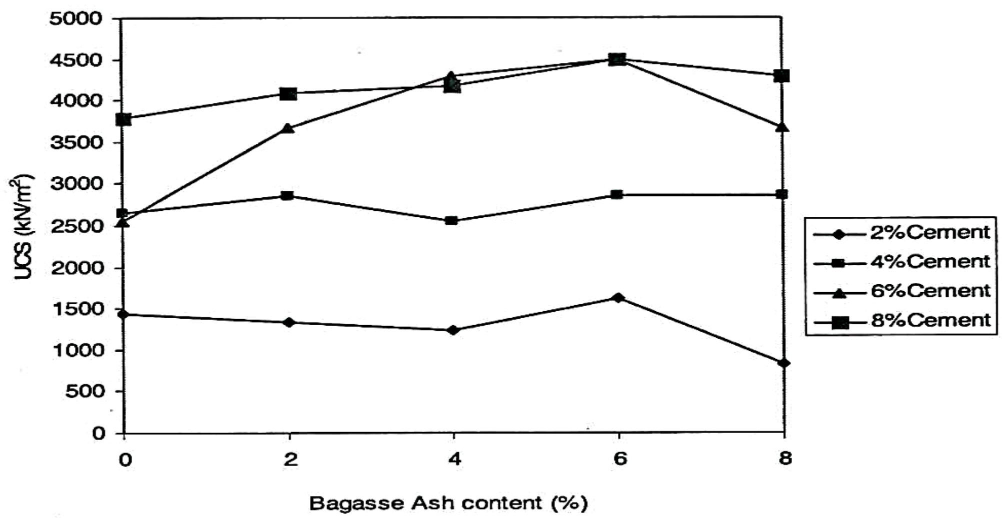

Fig. 8: Variation of UCS for 7 days cured and 7 days soaked with Bagasse Ash Content.

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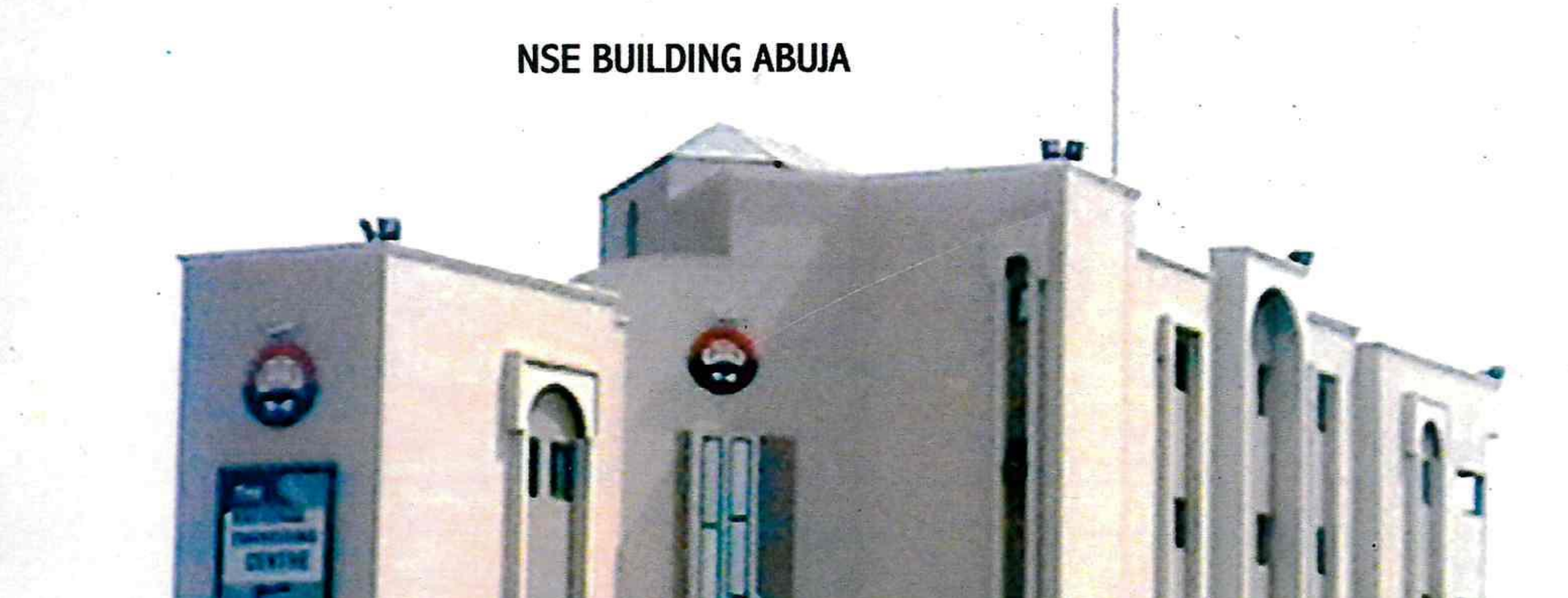

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