THE EFFECT OF ELAPSE TIME ON THE GEOTECHNICAL PROPERTIES OF LIME-BAGASSE ASH STABILIZED BLACK COTTON SOIL

BY

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M.Sc./ENG/40900/04-05

B.Eng (CIVIL) A.B.U.

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,

AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

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SEPTEMBER, 2008

DECLARATION

I hereby declare that this thesis is a product of my effort under the supervision of Professor K. J. Osinubi. All quotations and their sources are specifically acknowledged by means of references.

OCHEPO, Joshua
9th September, 2008

CERTIFICATION

The thesis titled "**THE EFFECT OF ELAPSE TIME ON THE GEOTECHNICAL PROPERTIES OF LIME-BAGASSE ASH STABILIZED BLACK COTTON SOIL",** by Ochepo Joshua meets the regulations governing the award of the degree of Master of Science in Civil Engineering of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

Prof. K. J. Osinubi Date

CHAIRMAN, SUPERVISORY COMMITTEE

Dr. S. P. Ejeh Date

MEMBER, SUPERVISORY COMMITTEE

Dr. S. P. Ejeh Date

HEAD OF DEPARTMENT

Prof. A. S. Nkom Date

DEAN, PG SCHOOL

DEDICATION

To GOD of the heaven and the earth, through whom I am yet alive and come thus far.

ACKNOWLEDGMENTS

I thank God, my creator, source and help in whom I have my being for all the privileges He has given me.

I am indeed grateful to my supervisor, Prof. K. J. Osinubi, for all his support and guidance throughout the period of this research. May God of heaven reward your kindness to me. To Dr. S. P. Ejeh, may God reward you. To my lecturers and colleague in the department of Civil Engineering, the Good God bless all of you. Mrs. Obi, (Secretary Civil Engineering), your children will not lack help in their lives.

My friends, you have been very supportive, The Lord grant you success in all your endeavors.

I am most grateful to God for my parents, Chief and Mrs. G. O. Ogbole, my brothers and sisters, cousins, uncles, for all your prayers and support. I am indebted to you all. To my fiancée, Meg, God bless you.

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ABSTRACT

This research was carried out to investigate the effect of elapse time after mixing on the geotechnical properties of soil-lime-bagasse ash mixture. Preliminary investigation on the black cotton soil used showed that the soil belongs to A-7-6 and CH in the AASHTO and Unified Soil Classification System (USCS), respectively.

Soils in these groups are unsuitable for engineering purposes. Evaluation of the effect of elapse time on the Atterberg limit, moisture – density relationship, unconfined compressive strength, durability and California bearing ratio (CBR) of the soil-lime-bagasse ash mixes showed that the consistency, compaction and strength properties of the soil decreased with increase in elapse time. The liquid limit, plastic limit and plasticity index of the soil reduced from 60 to 37 %, 22 to 11 % and 38 to 23 % at 8 % lime/6 %,

8 %lime/6 % bagasse ash and 8 % lime/4 % bagasse ash treatment respectively after 3 hours elapse time.

The maximum dry density (MDD) of soil treated with 6 % lime/8 % bagasse ash reduced from 1.42 to 1.31 Mg/m^3, 1.55 to 1.29 Mg/m^3 and from 1.83 to 1.42 Mg/m^3 after 3 hours delays for British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH) compactive efforts, respectively.

The unconfined compressive strength (UCS) values decreased for all compactive efforts and curing periods with elapse time. At the peak curing period of 28 days considered in this study, the UCS decreased from 540 to 380 kN/m^2, 850 to 620 kN/m^2, and 1330 kN/m^2 reduced to 1020 kN/m^2 for soil treated with 6% lime/ 8% bagasse ash at BSL, WAS and BSH energy levels.

Durability assessment of the soil-lime-bagasse ash mix showed a decrease in the resistance to loss in strength of the mixes with elapse time for all compactive efforts. A peak value of 50 kN/m^2 was attained at 6 % lime/8 % bagasse ash for BSL, 120 kN/m^2 for WAS and 200 kN/m^2 for BSH compactive efforts. This decrease to 20, 58 and 60 kN/m^2 after three hours respectivly.

The CBR values also showed a decrease in value with elapse time. A decrease from 14 % to 5 %, 24 to 11 % and 34 to 20 % after three hours elapse time was observed at 6 % lime/8 % bagasse ash treatment for BSL, WAS and BSH energy level.

The strength properties of the soil-lime-bagasse ash obtained in this work at no compaction delay and at compaction delay of three hours established the maximum and minimum that can be achieved. An optimal mix of 6 %lime/8 % bagasse ash is recommended at the BSH compactive effort and elapse time not exceeding one hour.

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CHAPTER ONE

INTRODUCTION

1.1 Preamble

Soil as a foundation or construction material is affected by environmental conditions. One of such conditions is the availability or otherwise of moisture. Soils can undergo detrimental volumetric and hydraulic conductivity changes because of variations in moisture content (Bishop, 1959; Fredlund and Rahardjo, 1993). These undesirable volumetric changes caused by fluctuations in moisture content are particularly severe in expansive soils, one of which is the black cotton soil (BCS).

Black cotton soil swells when it absorbs water during the wet season and shrinks because of evaporation of water during the dry season. During these wetting-drying cycles, an expansive soil can undergo a net increase in volume or exhibit volume reduction depending on the stress and suction history of the soil (Sharma, 1998, 2003; Alonso et al., 1987; Gens and Alonso, 1992). This dual characteristic of expansive soil causes distress in the structure founded on them. An estimate of the damages caused by expansive soils on civil engineering structures such as highway embankment and building in the United States is about one billion dollars annually. Worldwide, the cost is many billion of dollars (Gourley et al., 1993).

The black cotton soil is known to swell excessively exerting many kilo Newton per square area of swelling pressure when wet and shrinks extremely, developing cracks, often measuring 70 mm wide and 1.0 m deep (Adeniji,1991) and may extend up to 3.0 m in case of deep deposit. When wet, its index properties are high, its bearing value and strength are low.

To control the severity of distress caused on structures founded on expansive soils, many different foundation techniques have been tried which include stabilization with additives such as lime, cement and fly ash (Ingles and Metcalf, 1972; Sherwood, 1995; Osinubi, 1995; 1998a, b); cohesive non-swelling layer technique (Katti, 1978); reinforcement of soils with geosynthetics (Jewell, 1991; Koener and Soong, 1995); and other ground improvement techniques (Mitchell and Hooper, 1961).

Modification of black cotton soils by chemical admixtures is a common method for stabilizing the swell-shrink tendency of expansive soils. Advantages of chemical stabilization are that they reduce the swell-shrink tendency of the expansive soils and also render the soils less plastic. Among the chemical stabilization methods for expansive soils, lime stabilization is the most widely adopted method for improving the swell-shrink characteristics.

In recent times however, researches into new and innovative uses of materials with pozzolanic properties are on the increase. Most of these materials are agricultural and industrial wastes. Many highway agencies, private organization and individuals have completed or are in the process of completing a wide variety of studies and research projects with respect to the feasibility, environmental suitability and performance of beneficial reuse of most waste materials (Collins and Ciesiellski, 1993). These studies try to match the need of society for safe and economic disposal of waste materials with the geotechnical engineer’s need for better and more cost effective construction materials.

Some of these waste materials are coal combustion by-products (fly ash and bottom ash), blast furnace slag and steel slag, bagasse ash (by product from the combustion of sugar cane residue), ash obtained from the burning of rice husk, etc.

A large quantity of bagasse ash is generated annually by the various local sugar mills located in the northern part of the country without any beneficial use. This ash contains a substantial amount of amorphous silica which can react with lime. Mohammedbhai and Baguant

(1985) reported that bagasse ash contains a large amount of silica and other relevant oxides which enhance good pozzolanic activity.

There is an extensive deposit of black cotton soil in the north eastern part of Nigeria which has constituted a great problem for highway construction. There is thus a growing interest for the use of bagasse ash as a suitable stabilizer for the soil.

1.2 Statement of the Problem

In Nigeria, black cotton soil deposit is extensive in the north eastern part of the country. Some major roads linking the country with neighboring countries such as the republics of Chad and Cameroon pass through these problematic soil. In 1973 these roads carried Nigeria's export of fuel and other produce totaling about 250,000 tonnes. The problem is even more compounded now with increased population and trade necessitating development of expanded roads, housing and other infrastructure. This soil therefore poses a great challenge to engineers because of its undesirable engineering characteristics.

In their effort to take care of the problem, geotechnical engineers are working hard to provide the most appropriate shallow and deep ground improvement techniques so as to meet the engineering requirement necessary for the design and construction of associate infrastructure facilities. One of the ground improvement schemes adopted by researchers is chemical stabilization, using for example, calcium–based stabilizers such as lime and cement (Ola, 1983; Osinubi, 1995). However, these main stabilizers are expensive. Although lime is relatively cheaper but the price of the stabilizer is daily on the increase; consequently research of recent has focused on the use of other locally available materials with pozzolanic properties as possible substitute or as admixtures to main stabilizers. A large percentage of these materials are agricultural wastes.

Recent research in the Department of Civil Engineering, Ahmadu Bello University, Zaria, have focused on the use of bagasse ash as possible stabilizer/admixture (Osinubi and Stephen, 2005; 2006a,b, 2007: Osinubi and Alhaji, 2005; Osinubi and Mustapha, 2008; Osinubi and Eberemu, 2006; Osinubi et al., 2007a,b,c; 2008a,b). Stephen (2005) studied the potential of bagasse ash as stabilizer on black cotton soil. A general improvement on the properties of the soil using bagasse ash as additive was reported. The ash has also been used as admixture along with lime and cement in stabilizing black cotton soil (George, 2006; Osinubi et al., 2008a,b). This application will go a long way in reducing the total cost of stabilization and the potentials to use some quantities of the waste ash that have constituted an environmental problem.

1.3 Definition of Problem

The strength of soil-lime mixture depends among other things on the type of soil, time and temperature of curing. Only cohesive soils will react with lime to produce pozzolanic reactions. The reduction in plasticity is time dependent and has the effect of increasing the optimum moisture content (OMC) and decrease the maximum dry density (MDD) in compaction. The compaction characteristics are therefore constantly changing with time and delays in compaction can cause reduction in density and consequent reduction in strength and durability. This can be explained in the light of the fact that delays after soil-lime mix has been exposed to air leads to carbonation of the lime with consequent reduction in its effectiveness. It is thus desirable that mixing be done as soon as possible and certainly within 24 hours of exposure to air (Bell, 1989)

The effect of delay on the compaction and strength properties of soil-lime mix was investigated by Osinubi (1998; 1999). A decrease in compaction and strength properties of the lime treated soil was reported especially at higher lime content. Osula (1996) reported that modification of soils continued with time both for lime and cement modified laterite studied. Mitchell and Hooper (1961) reported that soil-lime samples compacted within 1 hour after mixing had higher strength than those compacted after 24 hours.

From these reports, it can be inferred that there is a decrease in the effectiveness of stabilization for soil-lime mixture for such parameter such as the MDD and the unconfined compressive strength (UCS) when there is a delay between mixing and compaction. The effect of delay before compaction on black cotton soil-lime-bagasse ash mix has however not yet been established. This research is thus intended to investigate the effect of time delay between mixing and compaction on the properties of black cotton soil-lime-bagasse ash cotton soil mix.

1.4 Justification for the Study

For cement stabilization, it is established that once the soil and cement are mixed the mixture should be placed immediately and compacted as delay will lead to decrease in the strength of the mix when eventually it is placed and compacted. Similarly, there are indications that delay before compaction affects the strength development of soil-lime mix.

In soil stabilization, usually the soil and additives are mixed in a plant (stationary plant construction) and the mix is transported to the site for subsequent placing spreading and compacting or the mixing is done in-situ (mix-in-place construction) in which the soil is prepared, pulverizes, admixing with the soil stabilizing agent and water, compaction, finishing and curing. From the view point of practice, there can be a breakdown of plant during construction; there can also be a delay in transporting an already prepared material to the site due to vehicular breakdown or traffic hold up especially in township construction operations. This is very important especially in the developing world where machine and human efficiency is still very low. There is therefore an urgent need to establish the effect of delay after mixing on the properties of black cotton soil-lime-bagasse ash mixture for proper understanding and efficient use of the material during construction.

1.5 Research Aim and Objectives

The aim of this research was to establish the effect of delay between mixing and compaction on the properties of black cotton soil stabilized with lime admixed with bagasse ash. The research aim was achieved through the following objectives:

(i) Evaluation of the natural properties of the black cotton soil.

(ii) Evaluation of the engineering properties of the soil mixed with 0, 2, 4, 6 and 8 % lime admixed with 0, 2, 4, 6 and 8 % bagasse ash in turn.

(iii) Establishment of the engineering properties of the soil-lime-bagasse ash mixed after 0, 1, 2 and 3 hours delay.

The parameters investigated were:

Compaction characteristics (i.e., dry density and moisture content), Atteberg limits, unconfined compressive strength (UCS), durability, and California bearing ratio (CBR).

CHAPTER TWO

LITERATURE REVIEW

2.1 Preamble

Expansive soil refers to soil material that has the potential for swelling and shrinking due to changing moisture conditions. The major problem arising with regard to expansive soils is that the deformations are significantly greater than elastic deformations and they can not be predicted by classical elastic or plastic theory. The movement is usually in an uneven pattern and of such magnitude as to cause extensive damage to the structures and pavements resting on them (Nelson and Miller, 1992). Expansive soils caused more damage to structures, particularly light buildings and pavements than any other natural hazard, including earthquakes and floods. The annual cost of damages to civil engineering structures is estimated at one billion dollars in the United State and many more billions of dollars worldwide (Gourley et al. 1993).

The black cotton soil so named on account of its black colour and great suitability for growing cotton is one example of an expansive soil. It is generally found on sedimentary plains as a result of thousands of years erosion of the clay content out of the surrounding hills. The soil can also be found on level locations and in depressions. The soils are confined to the semi arid regions of the tropical and temperate climate with marked alternating wet and dry seasons and where the annual evaporation exceeds precipitation. Globally, the soil occupies about 3 % of the world land area (i.e., about 340 million hectares).

In Nigeria, this soil occupies an area of some 10.4 x 10 km^2 (i.e., 400000 sq miles) in the North Eastern fringe of the country (Klinkenberg and Higgins, 1972). Near Maiduguri the Chad formation is known to be about 550 m (1800 ft) thick.

2.2 Geology of Black Cotton Soils

Generally, black cotton soils are formed in areas where the parent material is basic igneous rocks such as basalt that are made up of calcium rich feldspars and dark minerals which are high in the weathering order (i.e., unstable). All the constituents weather to form amorphous hydrous oxide and under suitable conditions clay minerals develop. The absence of quartz leads to the formation of fine-grained, mostly clay-size, plastic soil which is highly impermeable and easily becomes waterlogged. In addition, abundant magnesium and calcium present in the rock add to the possibility of forming of black cotton soils with their attendant swelling problems.

The parent materials from which these soils are generally formed are sedimentary rocks also of volcanic origin. The tuffs and ashes are made up of volcanic dust which is essentially a collection of minute particles of volcanic glass. These materials readily weather to form montmorillonite clays, the major clay mineral of the black cotton soils (Ola, 1983).

Other conditions favouring the formation of black cotton soils are evaporation exceeding precipitation, poor leaching, alkaline conditions and retention of magnesium and calcium in the soils. All these conditions prevail in the area of occurrence of the Nigerian black cotton soils (Ola, 1983).

2.3 General Characteristics of Black Cotton Soil

Black cotton soil (BCS) being an expansive soil swells excessively exerting many kilo Newton per square area of swelling pressure when wet and shrinks extremely, developing cracks, often measuring 70 mm wide and 1.0 m deep (Adeniji,1991) and may extend up to 3.0 m in case of deep deposit. When wet, the soil has high index properties, its bearing value and strength are low. These undesirable properties of BCS are consequent of the presence of the expansive clay mineral, montmorillonite, which is abundant in the soil. Ola (1983) reported 70 % montmorillonite in the Nigerian black cotton soils.

Generally, black cotton soils have comparatively high percentage of clay, more than 90 % with substantial proportions of silt and sand. Their organic content is low and they are alkaline in composition with a pH greater than 7.0. The soil is black to grey in colour and it contains a very high percentage of humus (i.e., 3 to 15 %).

2.4 Mineralogical and Chemical Composition of Black Cotton Soil

The expansive characteristics of soils are dictated by the types of clay minerals, specific surface areas of the clay particles and the chemistry of the soil water surrounding these particles. Although there are different types of clay minerals, those that are composed of montmorillonite and bentonite are the most expansive. Ola (1983) showed that the Nigeria black cotton soil contains about 70 % montmorillonite and 30 % kaolinite. The high percentage of montmorillonite in the black cotton soil imparts the swell capacity characteristics of the black cotton soil.

The montmorillonite clay structure consists of layer sheet formed and stacked one above the other. Bonding between successive layers is by van de Waals force and by cation that may be present to balance charge deficiencies in the structure. These bonds are weak and easily separate by cleavage or adsorption of water and other liquid.

There is an extensive isomorphous substitution for aluminium and silicon with the lattice of the montmorillonite crystal. Aluminium in the octahedral sheet may be replaced by Magnesium, Zinc, Iron, Nickel, Lithium or other cations. Aluminium may replace up to 15% of the silicon ions in the tetrahedral sheet. Possibly, some of the silicon positions can be occupied by phosphorous (Grim, 1968). Isomophous substitution in the clay mineral gives the clay a net negative charge resulting in the water absorbing tendencies as there is an attraction for hydroxyl ions and water molecule to the clay surface.

2.5 Mechanism of Soil Volume Change

Most clay minerals have orderly arrangement of atoms that form characteristic crystal lattice and most of these crystals are small in size. A typical thickness can be as small as 15Å and lateral dimensions are on the order of microns. All of the clay minerals groups have a layered crystal structure. The mineral groups are:

Kaolinite group - generally non-expansive.

Mica-like group - includes illites and vermiculites, which can be expansive but generally do not pose significant problems.

Smectite group - includes montmorillonite, which are highly expansive and are most troublesome clay minerals. The clay minerals have large specific surface. For example, the smectite group has its primary surface (i.e., surface due to particle surface exclusive of interlayer zones) generally in the range of 50 to 120 m^2/g. The secondary specific surface that may be exposed by expanding the lattice so that polar fluids can penetrate between layers may range from 700 to 840 m^2/g.

The isomophous substitution in clay minerals gives the clay particles a net negative charge. These net negative charges on the surface of the clay particle attract hydroxyl ions and water molecules to the clay crystal. Also, as salt cation held close to the crystal surface by strong hydrostatic force become hydrated in the presence of water, the cation hydration energy becomes sufficiently large to overcome inter-particle attraction force resulting in separation of crystal layer and expansion. This force is even more enhanced by the small size, platy shape and subsequent large surface area of the clay mineral (Mitchell, 1976).

Clay mineralogists have reported that a single pound (about 0.5 kg) of montmorillonite particles has an incredible total surface area of approximately 800 acres (324 hectare) with which to attract water. This, coupled with the moderate surface charge density; the silicate layer readily takes up polar molecules resulting in excessive volume change or expansion of the clay particles. In smectite and vermiculites, the strength of interlayer bond is low and a sensitive function of charge distribution, hydration energy of the cation, geometry of cation in relation to the silicate surface, surface ion configuration and structure of the polar molecule. (Mitchell, 1976)

2.6 Soil Stabilization

Soil stabilization is the improvement of soils to enhance original soil properties (especially in term of strength), to meet specific engineering requirements. Winterkorn (1955) defined *soil stabilization* as a term which applies to any process which improves the properties of soil and enables it to perform and sustain its intended engineering use. The main objectives of stabilization are to improve soil strength, to decrease permeability and water absorption, and to improve bearing capacity and durability under cyclical conditions such as varying moisture content or repeated applications of stress at amplitudes less than the soils ultimate strength-fatigue life.

Progress in soil stabilization has an economic base. Its economic importance arises from the possibility of improving soils at the site of construction for use as foundations or materials of construction. This is a better alternative to the removal of an unstable soil and replacement with other more suitable foundation material such as gravel or crushed rock. The costs of these materials are usually very high and the cost of transporting to the site especially when these materials are located at a distance from the site can also be exorbitant.

Soil stabilization has been used in the building of roads, aircraft runways, earth dams and embankment in erosion control (Diamond, 1975; Kawamura and Diamond, 1975) and in reduction of frost heaving. There are several methods of soil stabilization. These include mechanical stabilization, chemical stabilization, electro-kinetic stabilization, stabilization with bituminous and resinous materials as well as stabilization with additives such cement, lime and fly ash. The most appropriate method used for any situation depends upon economics, engineering requirements and the soil characteristics which have to be determined.

2.6.1 Chemical additives

The addition of inorganic and organic chemical compounds can increase the strength, bearing capacity and durability of soils. These chemical compounds perform mainly as cementitious and binding agents or as water proofers or as water repellant. The changes in consistency of clay soils induced by many of these compounds are also important.

Organic compounds including resinous and bituminous materials act as water proofers and sometimes behave similarly to glue and add to cohesive strength. Water proofing agents reduce the capacity for water uptake and help the soil to retain its dry strength even under wet conditions. Bonding agents enhance soil strength by cementing together the soil particles. Other chemicals known as surface active agents sometimes impart water repellant properties to soils.

Inorganic agents employed for soil stabilizations include Portland cement, lime, slag, sodium silicate, phosphorous compound and sometimes a combination of these various inorganic salts such as sodium chloride and calcium chloride that have long been used in stabilization, their

.main function being to reduce plasticity and facilitate densification (Slate and Johnson 1958; Bowles, 1979; Balogun, 1991).

The strength development and stabilization characteristics of soils are influenced by their petrography. Particle size distribution, mineralogy, grain shape and distribution of clay minerals with respect to the silt and sand sized particles are all important. Particle size distribution of the soil affects bulk density, packing and porosity. Air void content and void-size distribution influence durability factors such as freeze-thaw resistance (Powers, 1949; Klieger, 1952). Fine-grained cohesive soils are effectively stabilized by the use of chemical additives especially the calcium-based stabilizer such as lime and cement.

2.6.2 Lime stabilization

Lime and cement are widely used for treatment of cohesive soils with expansive properties due to their effectiveness in improving expansive properties and controlling volume change. (Chen, 1988; Hausmann, 1990; Osinubi, 1995). Lime and cement have also been used to increase strength and to decrease plasticity index and swell and shrinkage strain potential of expansive soils and fine-grained cohesive soils. (Hausmann, 1990; Osinubi, 1998a,b; 1999a,b Osinubi and Katte, 1997; 1999).

It has been shown, that when the clay-grade minerals contents are present in excess of about 30 % it is more difficult to achieve economic stabilization by the use of cement due to greater difficulties in pulverizing and mixing (Nelson and Miller, 1992). In general, the quantity of cement required increases with the proportion of clay-grade material. Also, using Atterberg limit as a guide, cement stabilization is said to be uneconomical for soils with plastic limits greater than 20 % or liquid limit in excess of 45 to 50 % (Croft, 1968). However, heavy clays can be cement stabilized by previously adding a small amount of lime which reduces the plasticity and makes the soil more workable.

The use of lime on the other hand for construction dates back from early times. Its principal use is in highway construction and maintenance, airfields construction, building foundation, railway beds and even under hydraulic conditions where the soils is partly or wholly submerged as in irrigation canals, reservoirs, levees and dams . Lime is used as a soil treatment for several reasons which include to expedite construction work on weak clay subgrade or to improve the engineering properties of plastic sands, plastic gravels and reactive clays.

For soil-lime mixture, improvement in the soil properties is attributed to the soil-lime reactions (Clare and Cruchley, 1957; Locat *et al*., 1990). The established mechanism used to explain the chemical change occurring in the soil according to O'Flaherty (2002) are: (1) cation exchange, in which if the exchange sites on the clay minerals are occupied by ions other than calcium, a rapid exchange reactions occurs in which many of the exchange sites become occupied by calcium ions. This takes place immediately and causes the clay particles to change from a state of mutual repulsion to one of mutual attraction, typically due to excess Ca^{2+} replacing dissimilar cations from the exchange complex of the soil. (As a general rule the order of replaceability of the common cations associated with soils follows the lyotropic series $Na^+ < K^+ < Ca^{2+} < Mg^{2+}$, with cations on the right tending to replace cations on the left in the series and monovalent cations being usually replaceable by multivalent cations). This has the immediate effect of promoting flocculation of the soil particles and a change in soil texture i.e. with the clay particles 'clumping' together into larger-size aggregates or lumps, the soil becomes more open texture with an improved gradation and at constant moisture content, the soil appears drier and more friable and is more easily worked. (2) Pozzolanic reactions (Ingles, 1964; Yoder and

Witczak, 1975) and results in the formation of cementitious products that have long term effects on the strength, volume stability, and in (colder environment), resistant to frost actions of the stabilized soil. (3) Carbonation, whereby carbon dioxide from the air and rain water convert free calcium and magnesium oxides and hydroxides into their respective carbonates. The consequence of this is that some lime which would have normally taken part in the pozzolanic reaction becomes unavailable for this purpose. This leads to the development of lower strength than might have been otherwise expected (O'Flaherty, 2002).

The first reaction is immediate which usually leads to improvement in workability, increase in stability, reduction of plasticity and creation of a more water and swell resistant material. The last two reactions are time-dependent (days to years) and affect strength development.

Cation exchange is believed to be mainly responsible for the change in the plasticity of the soil. The magnitude of the change in plasticity is affected by the soil clay mineralogy. Montmorillonite soils show the greatest change, the effect in illite-chlorite soil is intermediate and the effect in kaolinite soil is less (Hitt and Davidson, 1960). This order follows that of a decrease in cation exchange capacity (Grim, 1953).

Researchers (Nagaraji, 1964; Ingles, 1964; Ingles and Metcalf, 1972; Ola, 1983) have reported a flocculation type of fabric on addition of lime to soils.. The improvement in strength cannot however be attributed to this change alone, but to the formation of cementitious compounds. Ingles and Metcalf (1972) suggested that lime reacted with the clay minerals of the soil to form a tough water insoluble gel of calcium silicate, which cemented the soil particles. Ingles (1964) showed that there was a good improvement in the strength of lime treated soil with time due to the formation of cementatious compound. The strength of the soil-lime mixture according to Mitchell and Hooper (1961) is dependent on many variables such as soil type, lime content, type of lime, curing time and method (temperature and water availability) water content, unit weight and time between mixing and compaction. The interaction among the above variables were said to exert a major influence on the soil strength.

Lime treatment causes the soil to become more alkaline (i.e., pH rises) (Clare and Cruchley, 1957). The pH of the pore solutions has a significant bearing on reaction including those influencing strength-gain since it affects the solubility of both alumina and silica. The solubility of alumina is high at low pH, decreases rapidly above about pH 3 to 4, continues to decrease slowly to about pH 8 and increases rapidly again at higher values pH. The presence of significant amounts of amorphous, reactive, alumina in a soil may not be beneficial. Reactions with the aluminates may use up significant amounts of the added lime forming calcium aluminates hydrates not all of which have good cementitious properties. In the case of silica the solubility increases steadily with higher pH value up to 9 and thereafter increases rapidly. Hence, as is to be expected, formation of new cementitious minerals such as calcium silicate hydrates is favored by the alkaline condition which results from addition of lime (Eades and Grim., 1960).

The foregoing review shows that the addition of lime to soil alters its properties and this is mainly due to the formation of various compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes. Eades and Grim (1960) showed reactions occurring between hydrated lime and clay minerals. It was reported that kaolin required an addition of 4 - 6 % of lime for maximum strength development and the strength gain commenced immediately upon addition of lime. On the other hand, montmorillonite and illite minerals required lime in excess of 4 - 6 % before there was gain in strength. X-ray diffraction analysis indicated that lime addition caused an immediate attack upon kaolinite crystal edges which was accompanied by gain in strength. In the case of illite and montmorillonite, strength gain was delayed until lime was added in an amount which exceeded that required for saturation of the interlayer positions with calcium (Eades and Grim, 1960).

Studies have been made of the effect on soil- lime stabilization of the addition of small amounts of other chemicals. Favorable results have been reported from the addition of 1-2 % sodium hydroxide to clay soils stabilized with lime (Davidson *et al*., 1960). The increased alkalinity was thought to favor an accelerated attack on siliceous and aluminous compounds in the soil. The common ion effect may have suppressed ionization of the calcium hydroxide until sodium silicate had been formed. On eventual drop in pH, this may react with the calcium silicate to form cementitious compounds (Lambe *et al*., 1960). Confirmation of these earlier studies was reported by O'Flaherty and Gray (1974). Addition of metasilicate to lime stabilized soil led to a more rapid strength gain than was produced by Na_2SO_4 or NaOH; addition of these compounds however gave more favorable results than were obtained with lime alone.

The strength gain arises chiefly from chemical reactions between the lime, clay-grade minerals and amorphous constituent in the soil. When these are absent or present in small amounts, use has been made of lime together with a pozzolan. A pozzolan is defined as "a siliceous or alumino-siliceous material that in itself possesses little or no cementitious value but that in finely divided form and in the presence of moisture will chemically react with alkali and alkaline earth hydroxide at ordinary temperatures to form or assist in forming compounds possessing cementitious properties" (ASTM, 1980). Pozzolanic materials such as certain forms of volcanic ash and diatomaceous earth, occur naturally while calcine clays and shale, calcine bauxite waste and pulverized furnace fuel ash also known as fly ash are artificial pozzolanas. Fly ash has been extensively employed as a pozzolan in lime stabilization of soils. Osinubi (1995) reported improvement in the properties of black cotton soil stabilized with cement admixed with pulverized coal bottom ash. Similarly, Osinubi and Medubi (1998) reported improvement in the properties of soil-cement admixed with phosphatic waste. Also, Nicholson *et al*. (1994) reported that lime-fly ash admixture has shown tremendous potential as an economic method to update the geotechnical properties of tropical Hawaiian soil.

The effect of elapse time between mixing and compaction on the final strength was examined by (Mitchell and Hooper, 1961; Osinubi, 1998a, b; 1999b; Osinubi and Katte, 1997; 1999). It was reported that samples compacted within 1 hour after mixing had higher strength than those compacted after 24 hours. Osinubi and Nwaiwu (2006) reported a decrease in maximum dry density and CBR when compaction was delayed after mixing.

Yu (1975) and Bueusuesco (1990) have shown that pure lime stabilization although effective can be very expensive in large projects. Cement stabilization also has been shown to be unsuitable for stabilizing expansive soil because of the presence of montmorillonite which retard hydration of cement resulting in high percentage of cement required for adequate stabilization. This is of concern, especially in the developing world where the price of the stabilizer is rapidly on the increase. This has necessitated the need to look elsewhere for other materials/ pozzolan with stabilizing potentials.

More recent works (Osinubi, 1995; 1998a,b; 1999a,b; 2000; Osinubi and Eberemu, 2005; Osinubi and Stephen, 2005;; Osinubi and Alhaji, 2005; 2008; Osinubi et al., 2007a, b; 2008a, b) have focused on the search for cheaper and locally available materials with pozzolanic properties, a large percentage of which are agricultural wastes. Bagasse (the fibrous residue from the crushing of sugar cane) and husks from rice have been reported to be rich in silica. When burnt, their ash contains a substantial amount of amorphous silica which reacts with lime.

Mohammedbhai and Baguant (1985) reported that bagasse ash contains a large amount of silica and other relevant oxides which enhance good pozzolanic activity such as aluminum and iron oxide.

Stephen (2005) reported that while bagasse ash shows favorable potential for stabilizing black cotton soil, there may be need for the addition of other calcium-base additive which may provide the calcium needed for strength development. This was attributed to the presence of little calcium in the bagasse ash needed for pozzolanic reactions. Lime with its high calcium content is thought to be able to provide the needed Ca^{2+} for the required pozzolanic reactions for strength development.

CHAPTER THREE

MATERIALS, METHODS AND TESTS RESULTS

3.1 Materials

3.1.1 Black cotton soil

The black cotton soil was obtained from Deba in Gombe State in the North Eastern part of Nigeria. The soil was collected by method of disturbed sampling. The top soil was removed to a depth of about 0.5 m and the soil samples were taken below 0.5 m, sealed in plastic bags and put in sacks. This was done to avoid loss of moisture when transporting the soil. In the laboratory, the soil was pulverized to obtain particle passing sieve through British Standard No. 4 sieve, (4.75 mm aperture).

3.1.2 Bagasse ash

The bagasse ash used for this work was obtained from Anchau, Kaduna State.
The fibrous residue (after the juice has been extracted) of sugar cane was obtained from the local sugar manufacturing mills and burnt in the open atmosphere. The ash was collected after complete burning sealed up and transported to the laboratory. The ash was then passed through British Standard No. 200 sieve, (75µm aperture). The material passing the sieve was then mixed up in the percentages of 0, 2, 4, 6 and 8 % with the soil and lime to obtain the required sample for the tests.

The oxide composition of the ash was determined at the Center for Energy Research and Training (CERT), A. B. U. Zaria, using the method of Energy Dispersive X-Ray Fluorescence (EDXRF). The result is shown in Table 3.1.

Table 3.1 Oxide Composition of Bagasse Ash

Oxide	Concentration, %
CaO	2.25
SiO_2	63.47
Al_2O_3	16..55
Fe_2O_3	1.57
Mn_2O_3	0.26
K_2O	3.00
TiO_2	1.27

3.1.3 Lime

The lime used for this work was a hydrated type obtained from National Research Institute for Chemical and Leather Technology (NARICT), Zaria. Test conducted at CERT gave the oxide composition which is shown in Table 3.2.

Table 3.2 Oxide Composition of Hydrated Lime

Oxide	Concentration, %
CaO	43.93
SiO_2	37.71
Al_2O_3	11.67
Fe_2O_3	0.17
Mn_2O_3	0.11
K_2O	0.18
TiO_2	0.93

Table 3.3 shows typical oxide compositions of bagasse ash, lime and Portland cement.

Table 3.3: Typical Oxide Compositions of Bagasse Ash, Lime and Ordinary Portland Cement.

Oxide	Concentration, %		
	Bagasse Ash*	Lime*	OPC**
CaO	3.23	63.00	63.00
SiO_2	57.12	1.59	20.00
Al_2O_3	29.73	0.50	6.00
Fe_2O_3	2.75	0.61	3.00
Mn_2O_3	0.11	0.50	-
Na_2O+K_2O	-	Trace	1.00
K_2O	8.72	Trace	-
SO_3	0.02	-	0.02
TiO_2	1.10	-	-
Loss on ignition	17.57	26.87	2.00

* Czernin, 1962 **Stephen, 2005

There is a close agreement in the oxide composition of the bagasse ash used for this research and that reported in Table 3.3.

3.2 Methods and Tests Results

3.2.1 Natural moisture content

The natural moisture content of the soil as obtained from the site was determined in accordance with BS 1377 (1990) Part 2. The weighing container was cleaned and weighed to the nearest 0.01g (m_1)

The sample freshly collected, crumbled and placed loosely in the container and the container and sample are weighed together to the nearest 0.01g as $m_{2.}$ The container and the sample were placed in the oven and dried at 105 ^{0}C – 110 ^{0}C for 24 hours. The container and the sample were then removed and weighed dry to the nearest 0.01g as $m_{3.}$

The moisture content was then calculated as

$$W = \frac{(m_2 - m_3)}{(m_3 - m_1)} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where W is the moisture content in percentage.

The natural moisture content is shown in Table 3.4

3.2.2 Specific gravity

The determination of specific gravity was carried out according to BS 1377 (1990) test (B) for fine grained soils. The density bottle and the stopper were weighed to the nearest 0.001g (m_1). The air dried soil was transferred into the density bottle and the bottle, content and the cover was weighed as (m_2). Water was then added just enough to cover the soil, the soil in the bottle was gently stirred to remove any air bubble. The bottle was then completely filled up and covered. The covered bottle was then wiped dry and the whole weighed to the nearest 0.001g (m_3).

The bottle was subsequently emptied and filled completely with water wiped dry and weighed to the nearest 0.001g (m_4).

The specific gravity is calculated as:

$$G_s = \frac{(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

TABLE 3.4: Index Properties of Natural Soil

Property	Quantity
Natural moisture content, (%)	5.1
Liquid Limit, (%)	59
Plastic Limit, (%)	22
Plasticity Index, (%)	37
Linear Shrinkage, (%)	20
AASHTO classification	A-7-6
USCS classification	CH
Specific Gravity	2.35
Maximum Dry Density, (Mg/m^3)	
British Standard Light	1.47
West Africa Standard	1.55
British Standard Heavy	1.83
Optimum Moisture Content, (%)	
British Standard Light	21.5
West Africa Standard	18.7
British Standard Heavy	13.9
Unconfined Compressive Strength (kN/m^2)	
British Standard Light	173
West African Standard	343
British Standard Heavy	633
California Bearing Ratio, (%)	
British Standard Light	4
West African Standard	6
British Standard Heavy	9
Color	Grayish black
Dominant clay mineral	Montmorillonite

The result of the specific gravity of the natural soil is shown in Table 3.4 and Table 3.5 gives the result of the specific gravity values for the various soil-lime-bagasse ash mixes.

Table 3.5: Specific Gravity Values of Soil-Lime-Bagasse Ash Mixes

Bagasse Ash Content, %	Lime Content, %				
	0	2	4	6	8
0	2.35	2.31	2.36	2.28	2.23
2	2.31	2.32	2.31	2.31	2.3
4	2.33	2.31	2.31	2.27	2.25
6	2.27	2.3	2.25	2.26	2.26
8	2.25	2.3	2.3	2.29	2.21

3.2.3 Particle size analysis

The particle size analysis was carried out in accordance with BS 1377; 1990 Part 2. Wet sieving was conducted by weighing 200 g of the soil sample and soaking it overnight. The sample was then washed through BS sieve No. 200. The particle retained was dried in the oven overnight and sieving was carried out on the dried sample to obtain the particle size distribution

3.2.4 Atterberg limits Tests

The tests include the determination of the liquid limit, plastic limit and the plasticity index of the natural soil and the soil mixed with lime and admixed with bagasse ash in the various percentages.

The liquid limit test was determined in accordance with BS1377: 1990 Part 2: 4.5 and ASTMD4318. For the natural sample, 200 g of the material passing through sieve 425µm was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil water mixture was then placed in the cup of the Casagrande apparatus, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the center of the hinge. The cup was then lifted up and droped by turning the crank until the two parts the soil come into contact at the bottom of the groove. The number of blow at which this occured was recorded and a little quantity of the soil was taken and its moisture content was determined as before. This test was performed for well-spaced out moisture content from the drier to the wetter state. The values of the moisture content determined and the corresponding numbers of blows were then plotted on a semi-logarithmic paper and the liquid limit was determined as the moisture content corresponding to 25 blows.

This same procedure was repeated for each sample with lime and bagasse ash admixture for the percentages listed earlier and for each of the elapse time of 1 hour, 2 hours and 3 hours respectively. The procedure involved mixing the soil fraction passing 425 μm sieve and mixing it with lime and bagasse at optimum moisture content of the soil, sealed up and allowed to stand for the elapse time after which the test procedure was repeated. The result obtained for the natural soil is shown in Table 3.4 and Table 3.6(a) gives the results for the various percentages of soil-lime-bagasse ash mixes.

The plastic limit test was also performed in accordance to BS 1377: 1990 Part 2: 5.3 and ASTMD4318. A small portion of the soil sample was taken from that which was used for the determination of the liquid limit. (The portion was relatively drier than that used for the liquid limit). The ball of the soil was molded between the fingers and rolled between the palms of the hand until it has dried sufficiently. The sample was then divided into approximately four equal halves. Each of the parts was rolled into a thread between the first finger and the thumb. The thread was then rolled between the glass and the tips of the fingers of one hand. This continued until the diameter of the thread is reduced to about 3 mm in five to ten forward and backward movement of the hand. This procedure was continued until the thread shears both longitudinally and transversely. The crumbled soil was then put in the moisture content container and the moisture was determined as in the first case. The result for the natural soil is given in Table 3.4 and Table 3.6(b) gives the results of the various soil-lime-bagasse ash mixes.

Having determined the liquid limit and the plastic limit of the soil, the plasticity index is (PI) is calculated as the difference of the liquid limit and the plastic limit. The results are given in Table 3.6(c) for the various soil-lime-bagasse ash mixes.

$$PI = LL - PL \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

TABLE 3.6(a) Liquid Limit Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content,%				
		0	2	4	6	8
0	0	60.00	55.20	50.40	53.00	48.00
	2	57.00	59.00	51.00	50.00	47.00
	4	54.00	54.00	52.00	48.00	49.00
	6	52.00	51.00	50.00	46.00	50.00
	8	50.00	53.12	51.27	50.44	50.30
1	0	60.00	55.20	50.40	53.00	48.00
	2	57.00	59.00	51.00	50.00	47.00
	4	54.00	54.00	52.00	48.00	49.00
	6	52.00	51.00	50.00	46.00	50.00
	8	50.00	53.12	51.27	50.44	50.30
2	0	60.00	44.60	42.08	40.16	42.32
	2	55.00	44.16	43.24	38.64	37.72
	4	55.00	40.48	41.40	44.16	37.72
	6	50.00	38.64	39.56	42.32	36.80
	8	47.00	40.48	36.80	39.56	40.40
3	0	60.00	42.24	41.36	39.60	38.72
	2	51.00	42.24	39.60	47.52	42.24
	4	46.00	45.76	45.76	44.00	43.12
	6	43.00	45.76	44.88	39.60	43.12
	8	41.00	44.00	43.12	44.00	42.24

TABLE 3.6 (b) Plastic Limit Test Results for Soil – Lime – Bagasse Mixes

at Various Elapse Times

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	22.00	20.00	19.80	19.60	15.20
	2	21.00	20.00	18.60	17.90	20.30
	4	21.80	20.30	14.70	19.20	18.30
	6	19.50	20.90	14.70	15.80	17.70
	8	16.50	16.90	15.80	16.40	16.90
1	0	22.00	20.00	18.00	18.50	16.70
	2	20.50	20.10	13.90	13.60	13.20
	4	17.90	18.30	13.50	17.10	13.30
	6	16.40	17.50	11.00	12.20	13.80
	8	14.80	15.11	13.75	13.60	11.10
2	0	22.00	18.20	17.80	17.50	16.70
	2	17.90	17.60	16.30	15.50	13.80
	4	16.30	15.00	12.70	14.20	14.50
	6	15.80	16.10	14.90	10.90	11.90
	8	15.90	16.30	14.20	12.20	11.20
3	0	22.00	16.90	17.20	16.70	16.70
	2	18.20	17.90	16.10	11.20	15.40
	4	17.10	17.80	15.90	14.30	16.10
	6	15.00	18.40	12.70	12.40	11.80
	8	13.90	16.40	11.30	14.40	13.70

TABLE 3.6 (c) Plasticity Index Results for Soil – Lime – Bagasse Mixes at Various Elapse Times

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	38.00	37.21	40.04	40.08	34.36
	2	36.00	39.00	38.88	38.52	32.04
	4	32.20	33.70	34.76	36.56	34.84
	6	32.50	30.10	32.36	36.24	30.36
	8	33.50	33.10	35.44	33.12	31.32
1	0	38.00	33.20	35.40	35.94	35.82
	2	36.50	26.45	38.04	37.26	38.88
	4	37.10	31.10	36.24	43.32	35.34
	6	35.60	28.10	34.24	35.22	29.04
	8	34.20	29.54	31.80	32.70	31.42
2	0	38.00	27.80	32.74	31.99	30.74
	2	37.10	26.56	32.33	27.77	28.70
	4	38.70	25.48	30.44	35.95	27.86
	6	34.20	22.54	29.59	34.70	29.88
	8	31.10	24.18	27.12	32.83	29.24
3	0	38.00	25.34	28.99	27.48	26.42
	2	32.80	24.34	28.20	43.58	32.21
	4	28.90	27.96	32.83	35.64	32.42
	6	28.00	27.36	34.62	32.64	37.58
	8	27.10	27.60	36.18	35.52	34.25

3.2.5 Compaction

The compaction test was carried out for the soil in its natural state and when stabilized. All test were carried out according to BS 1377 (1990) Part 4: 3.3 using the British Standard light (standard Proctor), British Standard Heavy and the West African standard energy compaction in accordance with the Nigerian General Specification (1977).

2.5 kg of the soil sample was taken and mixed thoroughly with water. The water was added in an increment of between 5-6 % of the weight of the soil. The soil was then compacted into the mould 1000 cm^3, in three layers of approximately equal mass each layer being given 27 blows of the 2.5 kg rammer falling through a height of 300 mm for the British Standard light compaction, 27 blows of the 4.5 kg rammer in five layers for British Standard Heavy and 10 blows of 4.5 kg rammer in five layers for West African Standard compaction. The blows were uniformly distributed over the surface of each layer. The collar was removed and the compacted soil was leveled off to the top of the mould with a straightedge. The mould and the soil were then weighed to the nearest 1g (m_2)

The compacted soil was then removed from the mould and a representative sample was taken and the moisture content was determined as previously discussed. The remaining sample was crushed, water was added in the predetermined quantity and then subjected to the same procedure. A minimum of five determinations was conducted within which the optimum moisture content was obtained. This entire process was repeated for each increment of bagasse ash-lime-soil mix for the elapse time of 0, 1, 2, and 3 hours. The bulk density in Mg/m^3 calculated for each compacted layer as:

$$\rho = \frac{m_2 - m_1}{1000} \quad \text{..(5)}$$

Where m_1 = mass of mould and base (g)

m_2 = mass of mould base and soil (g)

The dry density in Mg/m^3 is calculated as

$$\rho_d = \frac{100\rho}{100+w} \text{..(6)}$$

Where w= moisture content.

The values of the dry density as obtained from the equation above was plotted against the moisture content and the maximum dry density MDD was deduced as the maximum point on the resultant curves. The corresponding moisture content was also taken as the optimum moisture content OMC. The results are given in Tables 3.7(a) and (b) to Tables 3.9 (a) and (b) for each compactive efforts used.

TABLE 3.7 (a) Maximum Dry Density Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSL Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	1.470	1.460	1.461	1.450	1.453
	2	1.460	1.480	1.470	1.490	1.455
	4	1.480	1.479	1.490	1.490	1.461
	6	1.470	1.460	1.460	1.480	1.460
	8	1.440	1.457	1.450	1.460	1.440
1	0	1.470	1.460	1.450	1.458	1.486
	2	1.460	1.457	1.463	1.438	1.438
	4	1.468	1.473	1.438	1.435	1.410
	6	1.459	1.451	1.415	1.434	1.434
	8	1.427	1.362	1.410	1.347	1.330
2	0	1.470	1.501	1.481	1.439	1.4387
	2	1.392	1.38	1.446	1.371	1.388
	4	1.326	1.38	1.358	1.371	1.330
	6	1.390	1.382	1.321	1.403	1.319
	8	1.386	1.359	1.368	1.350	1.324
3	0	1.470	1.528	1.386	1.415	1.441
	2	1.309	1.413	1.356	1.313	1.401
	4	1.331	1.394	1.361	1.352	1.384
	6	1.329	1.366	1.357	1.342	1.335
	8	1.329	1.362	1.350	1.335	1.315

TABLE 3.7 (b) Optimum Moisture Content Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSL Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	21.50	20.00	20.21	20.26	22.40
	2	23.20	22.50	21.50	23.20	23.50
	4	24.50	23.30	23.20	22.20	24.10
	6	23.10	23.40	24.60	24.30	23.12
	8	20.30	22.50	23.60	22.70	25.30
1	0	21.50	26.67	27.73	28.15	28.32
	2	29.42	28.68	28.84	30.13	27.86
	4	30.06	28.79	27.47	30.13	28.60
	6	28.85	26.96	28.10	30.12	28.75
	8	27.48	29.19	29.80	28.29	29.78
2	0	21.50	26.54	27.83	27.58	30.16
	2	32.17	29.70	31.66	30.54	28.81
	4	29.21	29.99	30.85	24.49	29.70
	6	30.40	30.79	32.52	27.86	30.41
	8	26.95	27.30	28.07	26.54	32.80
3	0	21.50	25.69	28.42	25.30	29.12
	2	35.97	26.63	29.49	30.59	28.79
	4	30.62	27.73	28.18	30.12	27.85
	6	27.73	27.42	28.51	29.13	28.89
	8	26.36	30.66	31.81	28.41	32.05

TABLE 3.8 (a) Maximum Dry Density Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (WAS Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	1.600	1.660	1.630	1.650	1.672
	2	1.539	1.510	1.571	1.588	1.602
	4	1.561	1.545	1.580	1.590	1.584
	6	1.527	1.554	1.560	1.560	1.583
	8	1.518	1.490	1.508	1.552	1.540
1	0	1.600	1.663	1.558	1.558	1.615
	2	1.588	1.512	1.512	1.485	1.481
	4	1.510	1.483	1.494	1.507	1.483
	6	1.478	1.507	1.404	1.500	1.455
	8	1.505	1.492	1.357	1.404	1.448
2	0	1.600	1.508	1.531	1.520	1.613
	2	1.425	1.464	1.467	1.462	1.546
	4	1.445	1.446	1.450	1.483	1.529
	6	1.414	1.359	1.449	1.451	1.528
	8	1.405	1.314	1.410	1.442	1.486
3	0	1.600	1.607	1.570	1.478	1.542
	2	1.477	1.490	1.549	1.435	1.478
	4	1.415	1.525	1.532	1.417	1.461
	6	1.400	1.534	1.531	1.332	1.460
	8	1.399	1.471	1.489	1.287	1.421

TABLE 3.8 (b) Optimum Moisture Content Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (WAS Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	18.70	18.00	18.60	16.30	17.50
	2	20.50	21.00	21.70	15.75	20.00
	4	20.50	20.00	18.00	18.20	21.50
	6	18.50	23.50	22.00	19.20	22.00
	8	20.00	19.40	19.50	20.00	20.50
1	0	18.70	19.57	20.74	21.54	22.32
	2	20.73	22.13	21.32	23.62	26.04
	4	20.04	21.46	21.85	23.62	21.60
	6	20.76	22.44	20.92	20.82	26.40
	8	22.45	21.42	22.36	21.04	23.40
2	0	18.70	22.73	17.67	20.61	24.56
	2	20.00	21.28	24.41	23.31	24.91
	4	22.62	22.86	23.79	25.86	26.93
	6	21.93	23.13	22.52	23.63	25.26
	8	22.93	21.04	24.38	28.08	26.88
3	0	18.70	22.61	17.17	24.30	25.49
	2	18.47	21.54	20.03	21.74	24.63
	4	19.46	25.12	25.61	27.00	24.69
	6	20.86	24.10	24.71	26.67	26.04
	8	22.60	24.37	27.75	26.19	29.13

TABLE 3.9 (a) Maximum Dry Density Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSH Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	1.830	1.790	1.766	1.785	1.736
	2	1.787	1.762	1.760	1.790	1.726
	4	1.760	1.750	1.730	1.716	1.703
	6	1.680	1.708	1.630	1.690	1.640
	8	1.685	1.628	1.620	1.650	1.590
1	0	1.830	1.766	1.754	1.761	1.700
	2	1.772	1.760	1.726	1.707	1.692
	4	1.744	1.730	1.715	1.661	1.600
	6	1.732	1.630	1.673	1.597	1.609
	8	1.691	1.620	1.595	1.588	1.522
2	0	1.830	1.692	1.683	1.678	1.701
	2	1.705	1.665	1.674	1.683	1.613
	4	1.685	1.654	1.593	1.613	1.552
	6	1.680	1.614	1.554	1.589	1.494
	8	1.580	1.538	1.481	1.551	1.558
3	0	1.830	1.676	1.628	1.607	1.651
	2	1.679	1.670	1.600	1.582	1.482
	4	1.760	1.642	1.643	1.604	1.540
	6	1.600	1.547	1.510	1.598	1.437
	8	1.600	1.537	1.490	1.415	1.480

TABLE 3.9 (b) Optimum Moisture Content Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSH Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	14.10	16.00	13.50	14.00	17.20
	2	19.40	17.80	15.00	15.00	17.10
	4	19.70	18.00	17.00	15.00	19.24
	6	17.50	18.00	17.80	16.00	17.15
	8	17.80	18.50	18.00	17.00	18.30
1	0	14.10	18.00	18.90	19.66	21.48
	2	19.63	19.76	15.35	21.84	21.83
	4	17.73	20.25	20.25	19.12	22.17
	6	19.62	18.23	21.60	20.02	19.69
	8	19.95	20.81	22.95	20.24	20.03
2	0	14.10	18.49	16.43	20.64	21.60
	2	16.72	19.48	22.87	20.52	23.71
	4	18.05	20.15	20.66	23.09	24.30
	6	18.41	21.15	22.85	20.58	21.87
	8	20.11	19.96	23.25	21.96	24.98
3	0	14.10	18.62	19.44	21.47	21.86
	2	17.80	22.05	24.00	22.63	23.60
	4	19.55	19.91	21.01	20.43	24.06
	6	20.03	21.41	22.00	24.57	26.29
	8	20.05	21.77	22.24	24.99	24.68

3.2.6 *Unconfined compressive strength*

The unconfined compression test was done in accordance with BS1377: 1990 Part 7. The test was carried out using the standard Proctor, the British heavy and the West African standard energy compaction. The sample was compacted in 1000 cm^3 mould after which it was extruded from the mould and trimmed into a cylindrical specimen of 40 mm diameter and 80 mm long. The specimen was each cured for 7 days, 14 days and 28 days respectively after which the sample was trimmed into a cylindrical specimen having diameter of 40 mm and length of 80 mm The specimen was then placed centrally on the lower platen of a load frame machine driven strain controlled at 0.10 %/min. Record was taken simultaneously of the axial deformation and the axial force at regular interval until failure of the sample occurred. The unconfined compressive strength of the sample was ascertained as the point on the stress- strain curve at which failure occurred. This procedure was repeated for the sampled treated with the stabilizer and the unconfined compressive strength was calculated from the following equation.

$$\delta = \frac{\left[R \times C_r \times (100 - E\%) \times 1000 kN/m^2\right]}{(100 \times A)} \qquad \text{...(7)}$$

Where $E\% = v / L_o$

E% = Strain percent

v = Amount of compression at any stage

R = Load ring reading at strain E

C_r = Mean calibration of load ring

L_o = Initial length of specimen

A_o = Initial cross sectional area

δ = Compressive stress at strain E

The unconfined compressive test results for the various lime-bagasse ash content at the different compactive efforts and elapse times are shown for the various curing periods in Tables 3.10 (a), (b) and (c) to Tables 3.12 (a), (b) and (c) respectively.

3.2.7 Durability

The durability assessment of the soil-stabilizer and the admixture was done by the immersion in water tests for the measurement of resistance to loss in strength. The resistance to loss in strength was determined as the ratio of the UCS of specimen wax cured for 7days, de-waxed top and bottom and then immersed in water for another 7days to the UCS of specimen wax-cured for 14 days. The results are shown in Tables 3.13 (a), (b) and (c).

TABLE 3.10 (a) Unconfined Compressive Strength (7 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSL Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	173.18	328.67	317.56	353.38	389.95
	2	219.36	370.12	382.08	408.92	419.71
	4	254.58	433.78	430.05	513.29	480.87
	6	300.22	369.54	400.65	372.74	467.14
	8	365.44	296.03	355.14	341.2	460.95
1	0	173.18	338.66	329.90	329.08	338.38
	2	222.74	301.79	329.04	345.09	340.70
	4	260.49	340.98	338.04	382.21	387.37
	6	297.30	334.27	366.46	368.11	436.92
	8	292.57	319.15	332.07	333.63	376.00
2	0	173.18	273.14	277.89	282.59	294.72
	2	228.88	324.83	311.32	347.78	377.44
	4	286.48	315.41	362.02	367.79	360.32
	6	294.35	335.34	344.08	348.58	412.30
	8	234.32	323.43	317.74	330.74	296.16
3	0	173.18	414.18	394.24	351.28	330.46
	2	251.26	210.42	302.66	278.56	224.94
	4	220.94	238.70	307.32	265.54	307.32
	6	401.70	207.26	232.82	427.98	431.32
	8	327.38	277.96	310.08	311.96	370.88

TABLE 3.10 (b) Unconfined Compressive Strength (14 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSL Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	173.18	358.68	383.4	385.87	298.16
	2	293.66	299.31	395.78	385.57	352.37
	4	314.63	438.02	458.85	450.19	496.94
	6	388.04	432.88	380.19	450.15	454.35
	8	314.63	333.93	371.03	385.87	415.55
1	0	173.18	343.57	308.18	383.39	287.82
	2	283.35	359.19	350.69	395.77	301.53
	4	337.92	376.69	404.57	434.99	429.69
	6	346.03	432.79	444.16	380.19	438.59
	8	260.63	300.53	380.69	371.02	401.13
2	0	173.18	370.11	328.59	294.81	366.72
	2	283.47	282.98	343.51	364.19	378.52
	4	303.71	346.30	360.27	387.03	416.02
	6	374.58	395.78	387.62	399.10	416.55
	8	289.07	296.82	287.42	364.19	354.85
3	0	173.18	294.43	314.42	269.79	348.96
	2	283.75	291.30	307.67	282.64	338.93
	4	297.27	305.75	322.69	322.00	332.75
	6	315.63	279.32	347.18	352.75	400.46
	8	298.18	218.47	325.03	296.46	309.05

TABLE 3.10 (c) Unconfined Compressive Strength (28 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSL Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	173.18	400.71	482.35	510.83	485.20
	2	309.20	371.63	393.40	494.71	494.70
	4	476.65	606.03	630.75	646.13	618.38
	6	476.65	581.27	494.70	630.75	519.45
	8	358.76	383.38	545.25	540.26	495.22
1	0	173.18	376.09	386.35	347.04	305.05
	2	337.03	333.93	459.05	442.09	488.06
	4	424.22	409.88	500.59	574.73	605.31
	6	428.99	457.98	463.29	458.51	512.49
	8	313.89	445.04	360.21	417.01	447.29
2	0	173.18	326.53	297.66	317.06	34.37
	2	248.46	322.36	354.81	333.89	436.14
	4	300.51	460.37	492.95	524.56	566.99
	6	429.17	442.13	367.53	457.94	422.74
	8	361.81	353.09	357.67	345	411.39
3	0	173.18	348.59	369.61	321.22	320.66
	2	312.38	300.3	326.09	409.2	408.49
	4	393.19	429.29	465.69	531.97	531.05
	6	397.61	412.29	434.01	468.17	504.61
	8	304.01	310.61	366.94	385.98	449.93

TABLE 3.11 (a) Unconfined Compressive Strength (7 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (WAS Compaction).

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	343.34	415.56	408.14	447.23	484.07
	2	494.50	500.88	408.14	628.90	664.38
	4	618.38	667.85	638.16	656.84	667.93
	6	591.41	667.85	753.05	740.69	725.17
	8	607.99	640.02	653.00	684.81	707.42
1	0	343.344	410.9094	425.4592	492.3458	509.5999
	2	474.6211	500.8781	425.4592	530.8923	652.6996
	4	581.1488	646.3992	635.7564	609.3149	661.4677
	6	555.8107	660.3651	700.512	675.2413	768.7149
	8	577.4643	584.2649	474.912	518.2477	745.3865
2	0	343.344	421.9404	437.2367	350.2109	402.6912
	2	455.0667	475.5202	560.0162	484.1135	490.8606
	4	464.2217	522.1828	567.5393	640.426	711.0378
	6	516.237	578.6818	590.8189	612.5034	647.1578
	8	501.1823	517.5066	585.7247	589.0135	572.5796
3	0	343.344	432.3746	402.6908	377.6784	437.2367
	2	379.6969	440.1188	490.8606	500.5734	560.0162
	4	522.1894	496.8239	618.6029	510.6438	681.0471
	6	433.5324	517.2028	563.0273	567.8607	590.8189
	8	461.3246	512.7434	498.1442	501.1823	514.852

TABLE 3.11 (b) Unconfined Compressive Strength (14 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (WAS Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	343.34	931.20	731.38	940.34	835.86
	2	685.67	768.78	835.86	974.74	961.24
	4	831.11	831.11	853.20	902.79	940.34
	6	664.89	890.48	988.66	905.12	1068.57
	8	849.58	879.55	890.48	887.03	1003.03
1	0	343.34	547.13	667.24	705.26	685.18
	2	510.53	636.43	682.16	697.76	783.06
	4	615.02	624.90	737.47	767.37	775.87
	6	546.87	648.32	790.15	763.31	940.88
	8	487.98	512.02	780.46	731.21	773.23
2	0	343.34	553.80	599.70	606.58	521.88
	2	543.05	599.90	599.66	620.15	714.74
	4	593.09	624.33	609.37	670.43	756.48
	6	505.54	628.65	705.52	718.32	656.25
	8	455.38	510.91	692.35	709.51	689.03
3	0	343.344	490.7513	464.0592	519.236	547.1254
	2	494.4228	523.5011	459.1266	530.8462	636.431
	4	532.5738	565.9471	587.6513	573.8878	624.8956
	6	498.6667	555.5236	601.2303	614.8797	648.3167
	8	421.9585	459.0899	481.1349	607.3372	611.8685

TABLE 3.11 (c) Unconfined Compressive Strength (28 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (WAS Compaction).

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	343.34	551.68	656.90	602.41	748.49
	2	621.31	728.36	977.21	997.22	1076.39
	4	712.21	761.61	920.75	1004.00	924.18
	6	612.83	904.76	988.07	1045.35	1180.60
	8	674.35	853.10	890.48	837.66	799.00
1	0	343.34	540.65	643.76	590.36	740.99
	2	596.40	713.79	957.66	977.28	1007.39
	4	640.99	746.38	902.33	983.92	1108.92
	6	576.05	837.62	968.31	1024.44	1168.77
	8	606.91	817.27	872.67	820.91	790.99
2	0	343.34	579.39	412.07	589.04	630.89
	2	524.10	696.02	850.04	932.29	938.51
	4	691.94	700.11	862.88	900.08	884.29
	6	524.86	764.96	715.06	919.89	948.94
	8	714.30	785.40	572.99	829.03	855.21
3	0	343.34	564.86	476.10	598.80	750.32
	2	596.46	479.27	728.26	861.11	913.67
	4	649.94	718.91	761.50	905.70	975.72
	6	588.32	688.00	780.80	944.48	785.20
	8	647.38	618.37	694.96	639.20	564.36

TABLE 3.12 (a) Unconfined Compressive Strength (7 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSH Compaction).

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	633.94	743.86	693.03	716.98	841.71
	2	785.86	960.70	816.29	815.08	946.57
	4	927.32	993.07	1084.88	851.29	951.62
	6	898.71	993.07	989.30	959.95	839.30
	8	826.62	868.04	979.28	887.53	1007.89
1	0	633.94	832.08	891.72	775.94	991.48
	2	864.45	810.26	864.45	993.81	987.35
	4	936.59	814.58	918.97	984.13	1114.23
	6	988.59	718.44	988.59	995.26	1079.86
	8	909.28	862.75	925.81	974.14	993.23
2	0	633.94	697.33	645.28	831.60	885.48
	2	711.13	864.45	907.45	938.24	992.36
	4	918.41	1000.05	947.73	928.64	1100.49
	6	949.38	988.59	968.71	965.94	1090.25
	8	949.38	909.25	715.14	963.75	981.30
3	0	633.94	714.10	715.14	963.75	981.30
	2	707.27	870.39	799.96	988.09	968.80
	4	834.89	953.35	1063.18	1159.18	1087.62
	6	808.84	955.39	969.52	949.96	1101.39
	8	743.96	833.30	1017.75	778.70	970.60

TABLE 3.12 (b) Unconfined Compressive Strength (14 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSH Compaction).

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	633.94	959.39	1001.49	934.03	1071.54
	2	925.31	1009.19	1133.41	1113.1	1127.92
	4	939.93	1281.87	1259.01	1270.81	1300.78
	6	1187.28	1145.58	1485.67	1346.92	1380.84
	8	1001.29	1291.167	1385.16	1212.05	1385.16
1	0	633.94	959.39	991.48	934.06	996.54
	2	915.038	908.27	1127.08	1168.86	1065.8
	4	1039.19	1113.68	1246.421	1316.92	1330.74
	6	1174.1	1211.03	1173.53	1206.59	1329.29
	8	990.18	1131.95	1371.31	1162.11	1315.9
2	0	633.94	849.93	722.72	993.78	900.41
	2	885.47	1067.84	1063.6	1074.08	1116.19
	4	1010.61	1139.79	1181.72	1167.42	1207.16
	6	1225.47	1140.49	1128.24	1028.33	1276.49
	8	1089.07	1062.24	916.93	1129.79	1074.08
3	0	633.94	909.72	847.18	799.79	914.87
	2	842.42	1085.06	1057.76	1066.4	1275.94
	4	1106.65	1118.13	1105.76	1325.78	1251.67
	6	1298.28	1133.55	1221.92	1235.79	1167.57
	8	1003.96	1087.07	1045.69	1000.64	1050.35

TABLE 3.12 (c) Unconfined Compressive Strength (28 Days Curing) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSH Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	633.94	1266.48	989.44	1076.508	1278.332
	2	989.28	1187.28	1147.76	1175.434	1044.806
	4	1187.28	1242.686	1306.008	1227.653	1385.2
	6	919.85	1242.686	1109.144	996.322	992.5872
	8	1305.488	1430.376	949.4282	1939.28	1044.806
1	0	633.94	948.7	1016.47	990.45	1160.87
	2	905.17	1014.72	1087.19	1350.59	1381.48
	4	1061.43	1266.87	1307.36	1348.82	1374.75
	6	931.25	1097.47	1417.07	1404.13	1420.53
	8	1036	1251.74	1242.22	1210.64	1321.69
2	0	633.94	1006.5	1046.03	977.19	1029.98
	2	968.99	1008.11	1100.32	1169.76	1211.38
	4	1110.11	1199	1293.44	1301.89	1169.23
	6	1214.69	1151.75	1157.83	1318.09	1202.69
	8	1155.99	1185.63	1375.79	1109.48	1302.95
3	0	633.94	1003.72	1000.62	1093.16	1090.63
	2	1006.5	989.73	1169.96	1181.149	1234.29
	4	1076.54	1167.88	1299.89	1394.17	1371.06
	6	1276.17	1131.86	1210.22	1240.61	1290.88
	8	1064.01	1041.06	1008.62	1192.77	1292.88

TABLE 3.13 (a) Unconfined Compressive Strength (7 Curing + 7 Days Soaking) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSL Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	10.22	75.72	58.28	52.71	50.75
	2	58.03	34.15	56.24	54.02	35.55
	4	78.28	60.93	109.44	58.21	118.47
	6	132.55	73.50	114.51	72.02	76.06
	8	54.87	54.46	63.04	47.77	92.46
1	0	10.22	31.75	26.20	19.78	14.74
	2	27.26	25.43	14.80	16.38	13.60
	4	39.94	50.82	17.92	36.02	19.72
	6	35.12	27.74	15.95	22.09	23.64
	8	26.38	23.29	18.54	17.14	53.47
2	0	10.22	23.72	15.64	11.88	30.95
	2	19.19	20.40	49.19	17.66	29.87
	4	36.69	25.80	15.71	18.35	14.69
	6	37.38	29.92	17.06	26.98	11.50
	8	21.71	24.43	11.09	12.24	27.64
3	0	10.22	21.35	37.86	29.03	27.25
	2	21.54	22.81	22.49	20.75	34.30
	4	23.69	22.59	38.92	39.77	23.23
	6	26.32	20.11	26.42	41.10	35.12
	8	40.40	19.79	47.39	34.24	37.86

TABLE 3.13 (b) Unconfined Compressive Strength (7 Curing + 7 Days Soaking) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (WAS Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	48.41	141.45	110.22	175.94	141.09
	2	96.89	135.38	111.34	165.02	197.34
	4	158.74	129.32	133.10	133.61	177.16
	6	96.08	158.51	143.85	140.11	183.69
	8	151.31	122.96	94.21	117.09	166.60
1	0	48.41	61.39	55.78	66.08	122.99
	2	54.42	70.33	88.20	88.27	113.70
	4	85.12	93.74	106.93	92.16	114.36
	6	100.41	93.75	116.47	103.96	100.86
	8	87.06	89.81	109.34	96.15	121.09
2	0	48.45	88.33	56.61	80.37	58.66
	2	66.85	84.71	71.00	95.01	82.91
	4	80.96	78.48	74.22	76.56	78.07
	6	76.74	86.57	88.19	73.48	83.80
	8	82.83	80.62	83.15	72.02	75.52
3	0	48.41	56.58	67.43	73.52	50.55
	2	60.57	70.99	95.27	79.41	58.62
	4	69.39	74.20	89.73	82.98	75.61
	6	59.74	92.05	96.32	93.58	77.21
	8	65.74	83.14	86.80	86.48	68.35

TABLE 3.13 (c) Unconfined Compressive Strength (7 Curing + 7 Days Soaking) Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSH Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	121.91	139.50	190.48	124.13	140.80
	2	142.41	137.25	194.95	158.17	179.34
	4	130.74	172.28	201.32	220.49	228.16
	6	208.72	160.50	189.72	185.87	180.48
	8	133.17	178.05	175.50	155.26	193.51
1	0	121.91	115.03	74.86	45.58	84.11
	2	90.86	121.07	88.14	51.31	100.19
	4	115.35	124.62	117.16	56.36	114.31
	6	103.09	128.61	106.79	62.50	117.24
	8	116.25	121.01	105.73	55.90	109.09
2	0	121.91	44.28	30.93	45.91	53.93
	2	85.18	47.73	45.95	58.75	54.02
	4	85.60	54.82	55.30	59.54	54.81
	6	75.49	60.79	58.22	69.21	63.44
	8	90.72	46.63	52.91	67.11	62.30
3	0	121.91	49.22	59.05	37.51	57.09
	2	89.04	62.17	68.75	47.77	86.25
	4	119.85	68.99	70.99	62.05	95.50
	6	118.92	64.05	85.41	49.56	86.52
	8	117.46	46.09	61.17	45.03	96.95

3.2.8 California bearing ratio

The California bearing ratio (CBR) value of a soil is an important parameter which is used to indicate the strength and bearing capacity of the soil. It is widely used in the design and assessment of the suitability of soil or otherwise for base and sub-base. Lime stabilized soils are often used for the construction of these pavements layer and also for embankment. The CBR is therefore a familiar test used to evaluate the strength of soils for these applications.

The effect of elapse time on CBR of the soil-lime-bagasse ash is shown in Figures 3.10 (a)-(c) for each of the compactive efforts. The reduction in CBR value might not be unconnected with the disruption of the hydration products in the process of compaction.

It should be noted here that the test was conducted immediately after compaction without first of all curing. Thus the values of CBR obtained here can be said to be the minimum that can be obtained for lime-bagasse ash stabilized black cotton soil used in this study.

TABLE 3.14 (a) California Bearing Ratio Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSL Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	4.53	9.20	9.53	11.25	7.84
	2	9.50	10.51	11.30	11.98	9.53
	4	9.53	10.70	12.71	13.30	11.57
	6	10.20	11.25	13.00	13.78	14.10
	8	13.77	12.77	10.72	14.89	9.58
1	0	4.53	10.27	9.12	11.52	12.77
	2	11.04	9.36	8.38	9.95	12.61
	4	11.38	8.95	8.14	8.95	13.29
	6	16.94	14.55	10.43	12.30	12.24
	8	22.25	19.28	11.86	15.72	10.68
2	0	4.53	8.73	7.03	6.82	8.94
	2	9.37	8.17	7.31	6.66	6.71
	4	9.37	7.58	6.27	6.50	8.11
	6	11.36	9.00	6.08	6.97	5.96
	8	12.95	10.99	7.32	8.09	9.01
3	0	4.53	8.89	6.46	4.03	7.23
	2	9.85	8.53	7.63	5.02	5.01
	4	10.17	8.17	6.17	6.01	5.84
	6	10.01	7.22	4.43	4.83	2.84
	8	10.16	8.20	6.17	4.95	10.38

TABLE 3.14 (b) California Bearing Ratio Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (WAS Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	6.01	16.38	16.96	15.78	13.96
	2	16.91	18.71	20.11	21.32	16.96
	4	20.51	20.09	24.23	20.23	20.59
	6	18.16	20.03	23.14	20.40	17.59
	8	16.96	22.73	21.94	23.12	19.16
1	0	6.01	18.28	16.23	20.51	17.22
	2	17.47	16.66	14.91	17.71	19.90
	4	25.61	15.93	14.49	21.76	23.65
	6	25.41	25.90	26.49	21.89	21.80
	8	19.81	16.98	16.70	17.91	19.01
2	0	6.05	15.53	12.51	12.13	15.90
	2	16.67	14.53	13.00	11.85	13.28
	4	19.68	13.49	15.54	11.57	14.44
	6	17.93	16.02	16.85	13.41	14.89
	8	18.30	19.55	14.82	14.40	20.03
3	0	6.05	15.82	11.50	7.17	12.87
	2	15.54	15.18	13.58	10.94	8.70
	4	16.00	14.54	10.98	10.70	10.40
	6	16.80	12.85	11.43	10.60	11.36
	8	18.08	14.60	10.98	18.71	15.48

TABLE 3.14 (a) California Bearing Ratio Test Results for Soil – Lime – Bagasse Mixes at Various Elapse Times (BSH Compaction)

Elapse Time (Hrs)	Bagasse Ash Content, %	Lime Content, %				
		0	2	4	6	8
0	0	9.32	20.46	21.19	25.02	17.44
	2	21.13	23.37	25.13	26.64	21.19
	4	29.05	26.27	31.52	31.55	27.45
	6	30.52	28.15	32.53	33.48	28.52
	8	28.68	33.13	30.48	33.90	26.82
1	0	9.32	27.41	24.34	30.74	28.79
	2	27.37	24.98	22.35	26.55	31.21
	4	40.41	27.17	24.72	33.54	40.34
	6	39.00	49.16	40.00	41.54	41.36
	8	54.95	47.38	37.31	43.95	38.79
2	0	9.32	19.40	15.63	15.16	19.87
	2	20.83	18.16	16.25	14.80	15.98
	4	24.79	17.98	18.60	15.42	19.24
	6	26.36	22.52	20.63	18.34	18.76
	8	29.17	28.50	20.66	20.99	27.10
3	0	9.32	19.77	14.37	8.96	16.08
	2	20.31	18.97	16.97	12.77	18.95
	4	22.33	19.38	14.64	14.26	16.62
	6	24.13	18.06	14.27	13.89	12.78
	8	26.36	21.28	16.01	22.08	24.14

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF RESULTS

4.1 Preliminary Tests

4.1.1 *Index properties of the natural soil*

The soil is predominantly fine-grained. It is greyish - black in colour with a liquid limit of 60 %, plastic limit of 22 % and plasticity index of 38 %. The soil was classified as CH or A-7-6 using the Unified Soil Classification System (USCS) and AASHTO classification, respectively. The soil has a free swell of about 40 %. The CBR values are 4, 6 and 9 % for British Standard light, West African Standard and the British Standard heavy compactive efforts, respectively. The soil is thus unsuitable for use as a sub-grade material.

4.1.2 Particle size distribution

The particle size distribution of the natural soil is shown in Fig. 4.1. The natural soil is primarily composed of about 73 % fine particles that are less than 0.075 mm in diameter.

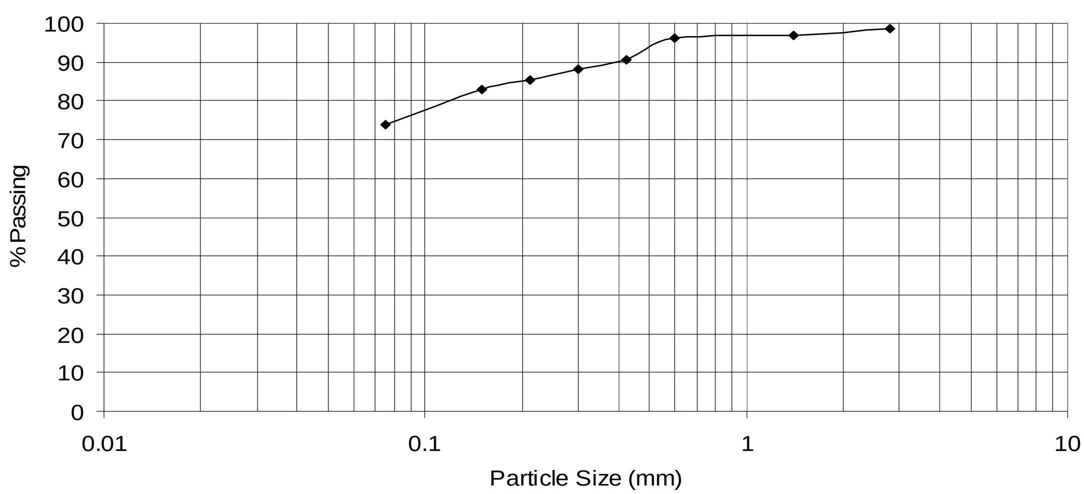


Fig. 4.1 Paticle Size Distribution of Natural Black Cotton Soil

4.1.2 Atterberg limits

The liquid limit for the natural soil is 60 %. However, this decreased to about 46 % with the addition of bagasse ash and lime as shown in Fig. 4.2.

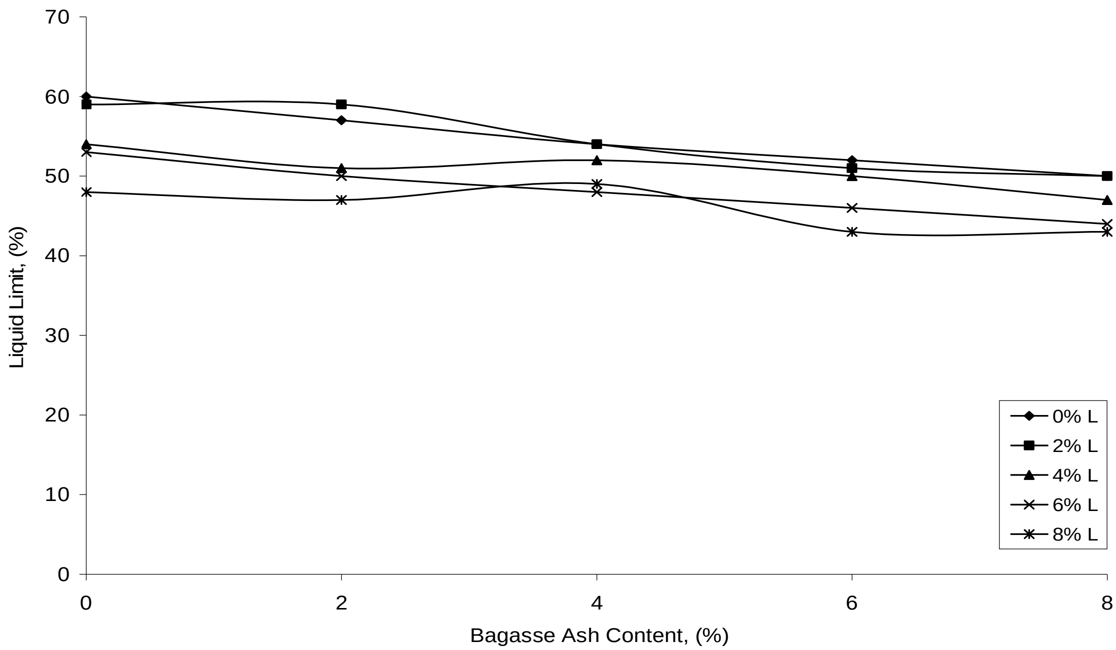


Fig. 3.2 Variation of Liquid Limit with Bagasse Ash Content at Various Lime Contents

In Fig. 4.2, liquid limit decreases with increase in bagasse ash and lime contents to a minimum value of 46 % at 8 % lime and 8 % bagasse ash treatments. At zero lime content, the decrease in liquid limit from 60 to about 55 % at 8 % bagasse ash content is not substantial. The reason for this may be attributed to the scarce Ca^{2+} in bagasse ash available for reaction. However it was observed that as the quantity of lime increased, the liquid limit further decreased. This can be attributed to the availability of abundant Ca^{2+} lime made available for cation exchange reaction with the clay mineral leading to the initial quick modification of the soil properties. As the amount of lime increased, there was an apparent reduction in the clay content and a corresponding increase in the coarse particles, and hence the soil surface area (Chen, 1975).

The effect of elapse time on the liquid limit is shown in Fig. 4.3 (a) for zero lime content. The liquid limit decreased with increases in elapse time and bagasse ash content. The greatest decline in liquid limit value to about 43 % (i.e., a decrease of about 28 %) was recorded for soil containing 8 % bagasse ash at 3 hours elapse time. Similar trends were observed when soil was treated with only lime (i.e., without bagasse ash admixture) as shown in Fig. 4.3 (b). A decrease of about 36.7 % was recorded when liquid limit decreased from 60 to 38 % at same elapse time and 8 % lime content. It should be noted that the reduction in liquid limit for soil-lime reaction was much more than that of soil-bagasse ash mixture. This may be attributed to the ion exchange reaction which is expected to be greater for lime than for bagasse ash because of the abundant Ca^{2+} available in lime than in bagasse ash.

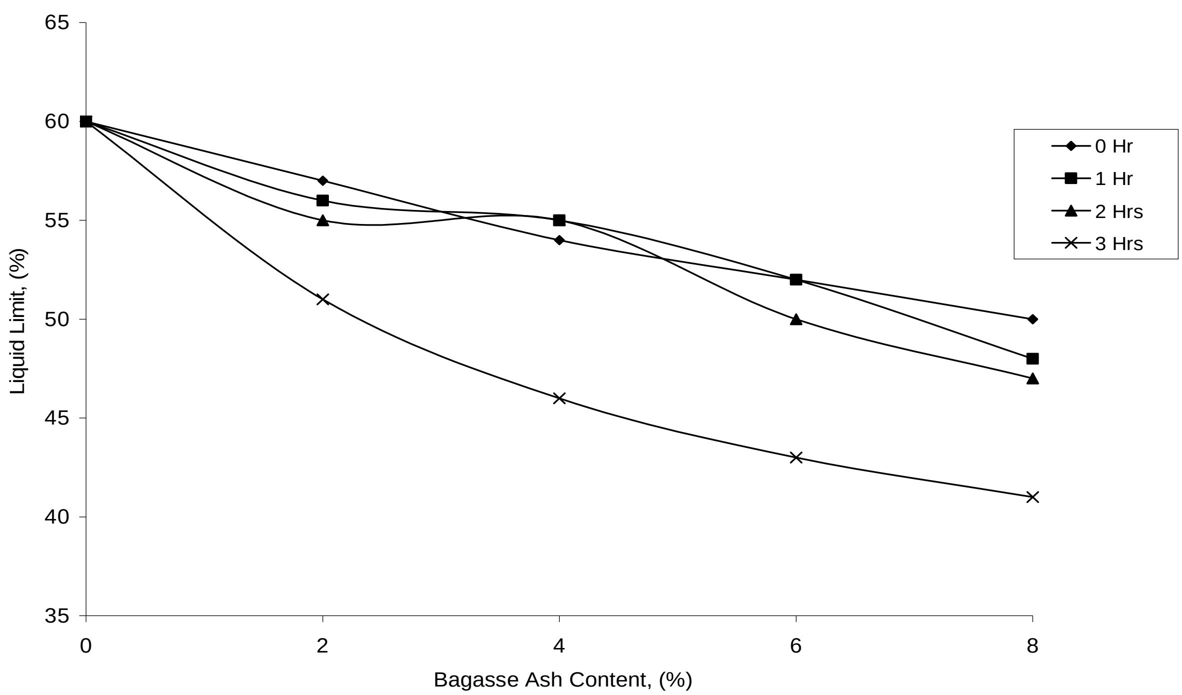


Fig. 4.3 (a) Variation of Liquid Limit with Bagasse Ash Content at 0% Lime Content

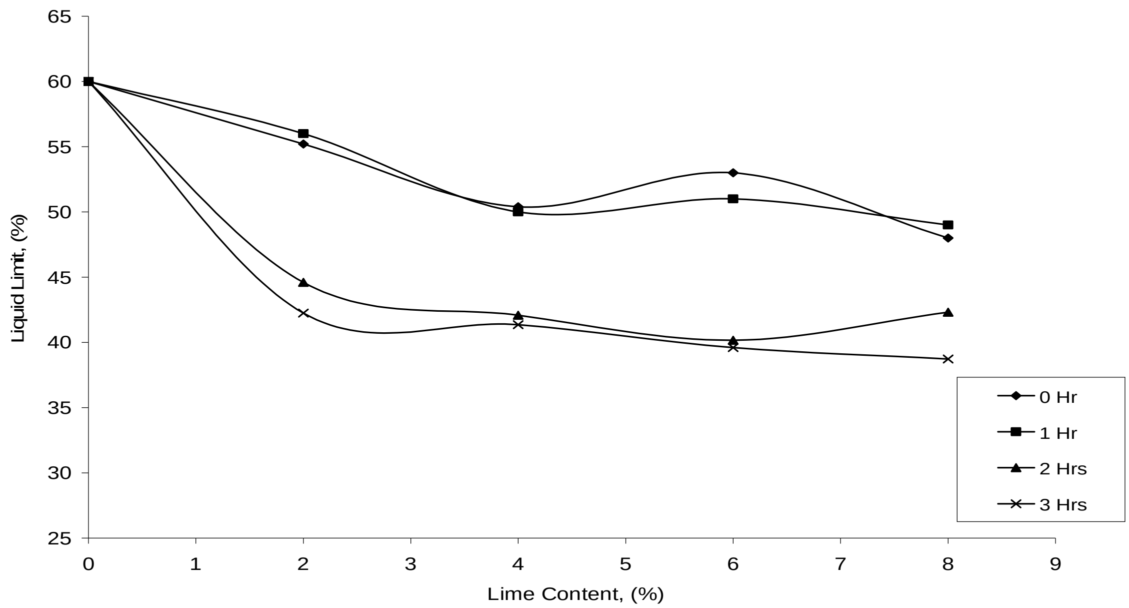


Fig. 4.3 (b) Variation of Liquid Limit with Lime Content at 0% Bagasse Ash Content

The effect of elapse time on liquid limit for the various soil-lime-bagasse ash mixes is shown in Fig. 4.4.

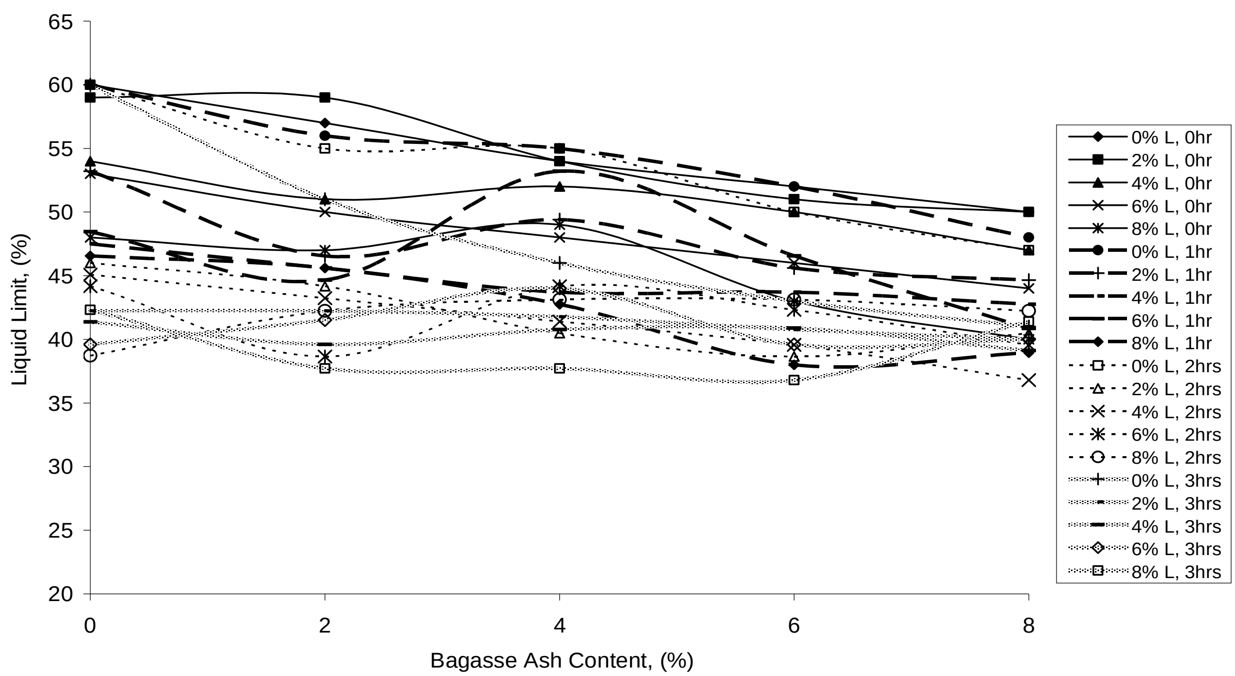


Fig. 4.4 Variation of Liquid Limit with Bagasse Ash Content at Various Lime Contents and Elapse Times

Liquid limit generally decreased with time and with increase in lime/bagasse ash contents as seen in Fig. 4.4. The least value was observed at 8 % lime content and 2 % bagasse ash content where the liquid limit decreased from about 60 to about 36 % after two hour. At the third hour, the liquid limit increased to about 40 % for the same lime-bagasse ash ratio. This gradual increasing trend of liquid limit at the third hour was observed with further addition of bagasse ash for all the lime content. It should be noted that the decrease in liquid limit with elapse time appeared to be critical in the first two hours. While the liquid limit decreased significantly at the third hour in the early stage, there was a gradual but steady increase in the liquid limit with further addition of lime at all bagasse ash contents. This is probably because the time lag between mixing and when the test was carried out, reaction between the clay minerals and the lime-bagasse ash was in progress thus resulting in the flocculation of the clay particles. At the testing stage, more water was required to break up the bond already formed and for the lubrication of the clay particles to achieve the flow required at the liquid limit.

The variation of the plastic limit with bagasse ash is shown in Fig. 4.5 at various lime contents. The plastic limit decreased with increasing bagasse ash treatment for all lime contents. The minimum reduction of about 10 % occurred in specimens containing 6 % lime and 8 % bagasse ash. This is not consistent with Ola (1983) who reported a decrease in plastic limit with increase in lime content. George (2006) however, reported a decrease in plastic limit of black cotton soil when treated with cement and bagasse ash. A similar observation was made by Stephen (2005) in investigating the potential of bagasse ash as stabilizer for black cotton soil.

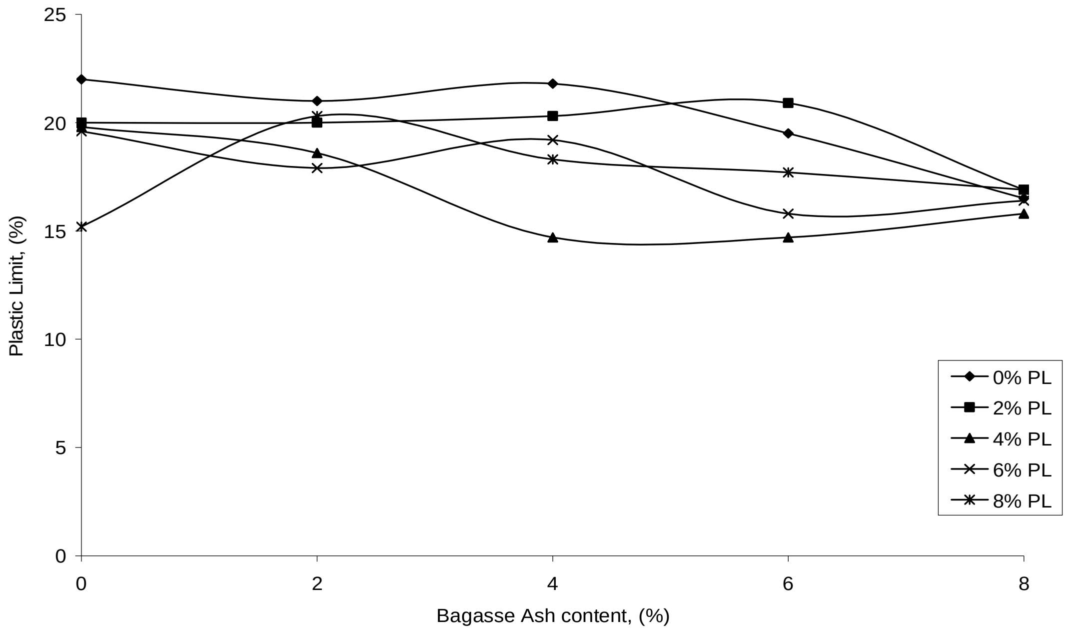


Fig 4.5 Variation of Plastic Limit with Bagasse Ash Content at Various Lime Contents

The effect of elapse time on the plastic limit of the stabilized soil is shown in Fig. 4.6. The plastic limit reduced from 22 to about 10 % after 3hour delay at 8 %lime and 6 % bagasse ash treatment. The reduction in plastic limit is consistent with the reports of Stephen (2005) and George (2006). This was probably primarily due to the immediate modification effect of lime on the soil with bagasse ash playing a secondary role.

The reduction in plastic limit was accompanied with a corresponding increase in the plasticity index of the soil for all lime and bagasse ash contents. Fig. 4.7 shows the variation of plasticity index with elapse time. The plasticity index reduced with elapse time from the natural soil value of 38 % to a minimum of 23 % at 8 % lime and 4 % bagasse ash content after 3 hours elapse time. This was probably due to cation exchange reactions that predominated at the early stage of the reaction and which resulted in the agglomeration and flocculation of the clay particles.

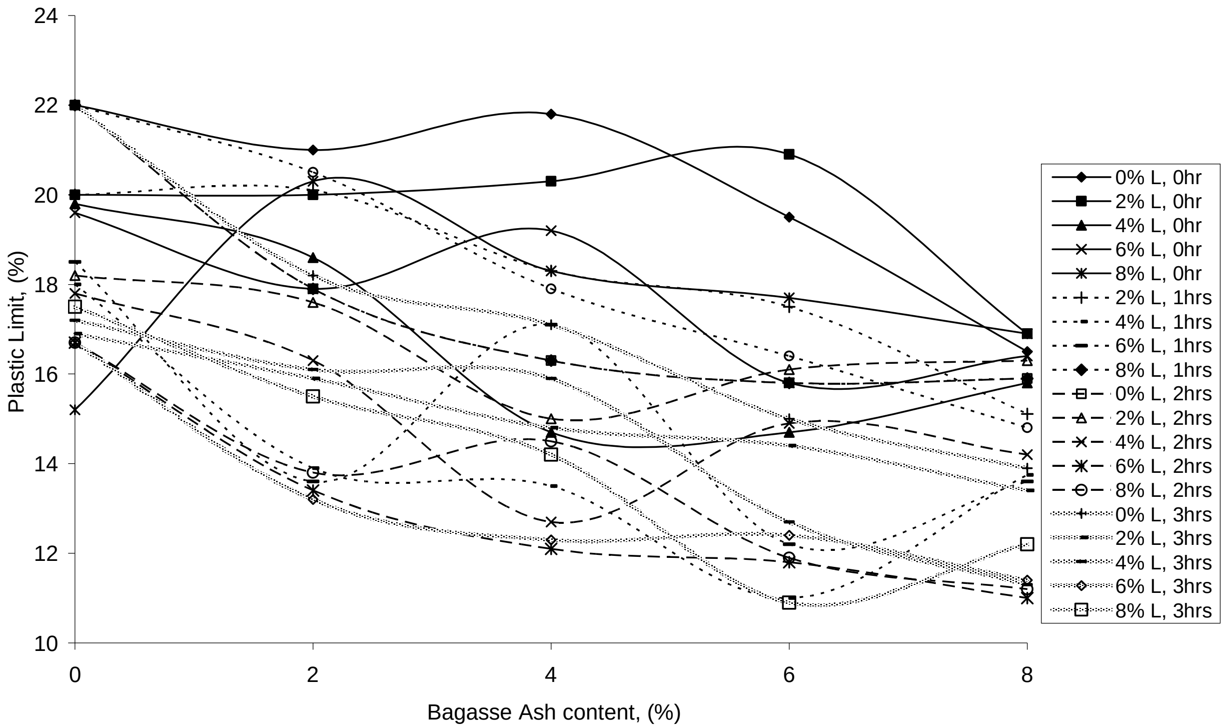


Fig 4.6 Variation of Plastic Limit with Bagasse Ash Content at Various Lime Contents and Elapse Times

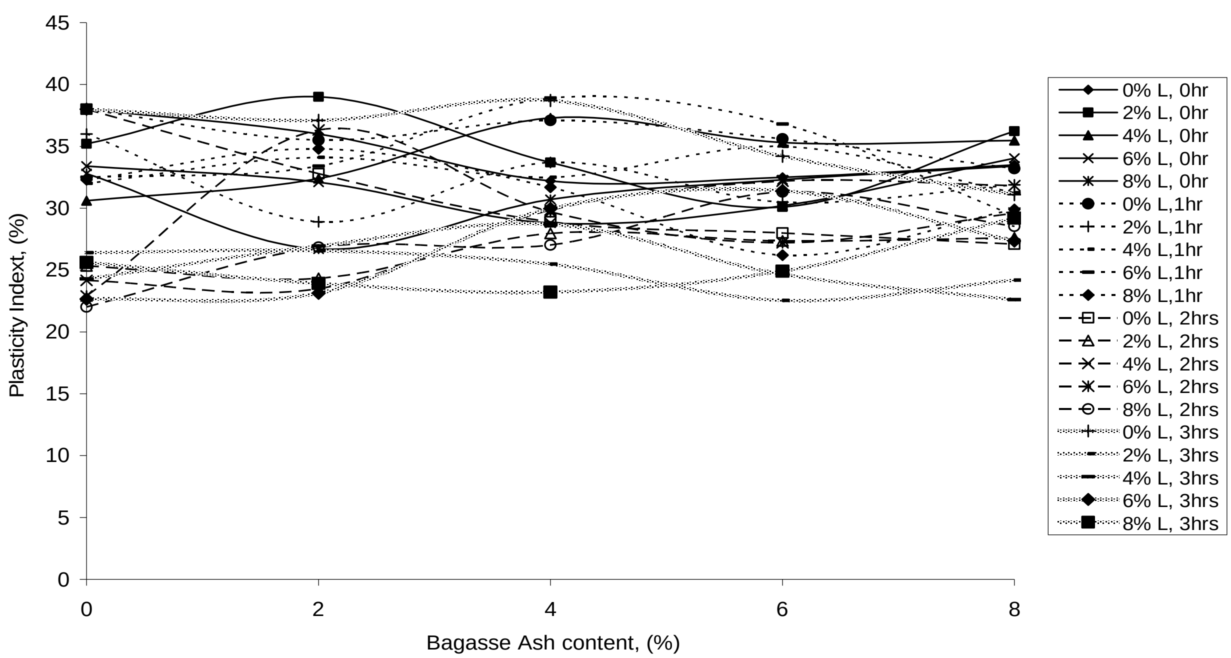


Fig 4.7 Variation of Plasticity Index with Bagasse Ash Content at Various Lime Contents and Elapse Times

4.1.3 Compaction characteristics

Stabilization of soils with lime has been reported to affect the compaction characteristic of the soils by decreasing their maximum dry densities and increasing the optimum moisture contents (Hausmann, 1990). This trend was reported by Osinubi (1999) to increase with the stabilizer content. Stephen (2005) reported a decrease in dry density and increase in optimum moisture content in the investigation of the potential of bagasse ash as a stabilizer for black cotton soils. George (2006) reported a similar observation when black cotton soil was stabilized with cement and bagasse ash.

In this study the effect of the addition of lime and bagasse ash was investigated. It was observed that for BS light compactive effort, there was an initial increase of the maximum dry density (MDD), up to 4 % bagasse ash content, after which the MDD decreases with further increase in bagasse ash content for all lime increment. For West African and BS heavy standard compactive efforts, the maximum dry density of the soil decreased with increasing amount of bagasse ash at all lime contents as shown in Figs. 4.8 (a), (b), and (c).

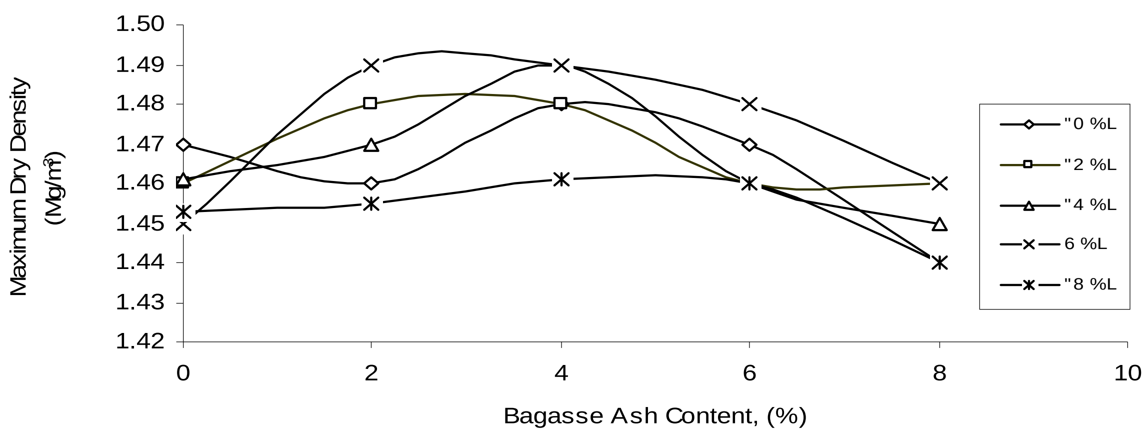


Fig.4.8 (a). Variation of Maximum Dry Density with Bagasse Ash Content (BSL Compaction)

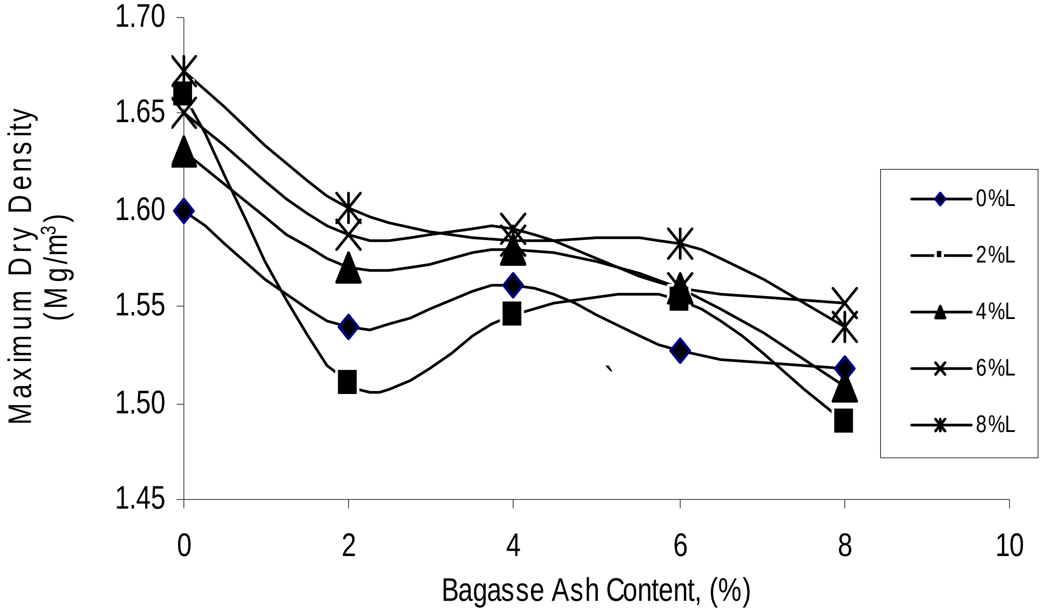


Fig. 4.8 (b). Variation 0f Maximum Dry Density with Bagasse Ash Content (WAS Compacyion)

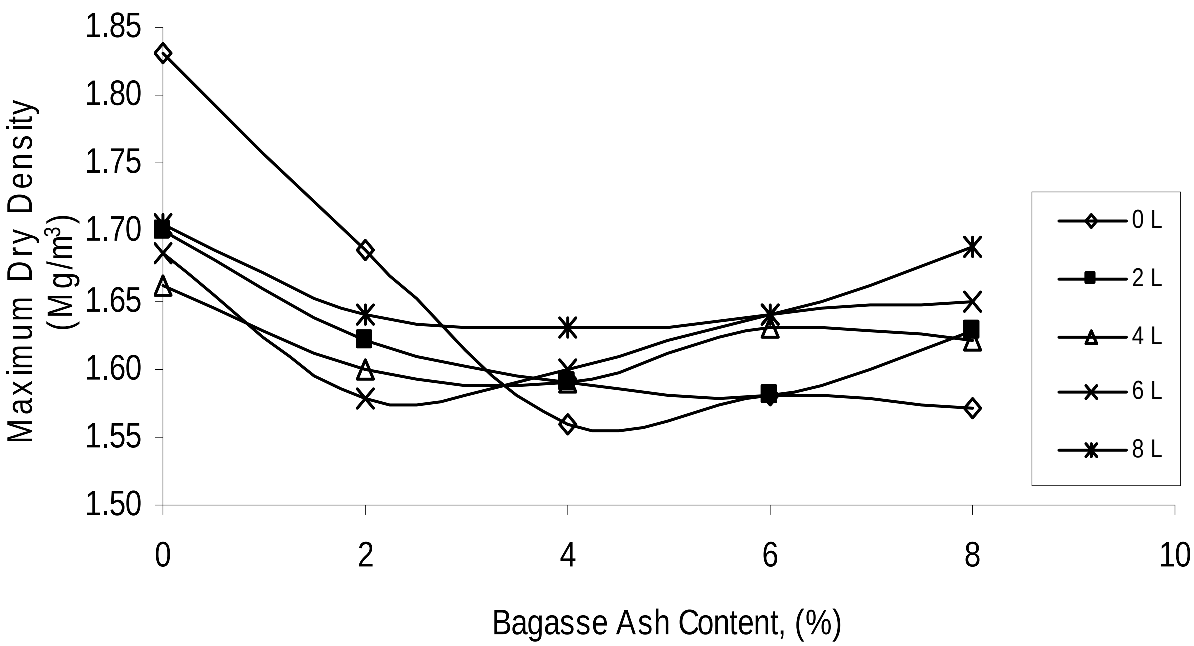


Fig. 4.8 (c)Variation of Maximum Dry Density with Bagasse Ash Content for (BSH Compaction)

Figs. 4.9 (a)-(c) show the effect of delay between mixing and compaction for the soil-lime-bagasse ash mixes. There was a further decrease in maximum dry density with increased delay between mixing and compaction for all the three energy levels (i.e., BS light, West African Standard and BS heavy compactive efforts). This may be attributed to the fact that when compaction is delayed, hydration products which bind particles in a loose state are formed. A disruption of these aggregations is required to densify the soil. Therefore, a portion of the compaction energy is used in overcoming the cementation hence the maximum density is reduced with increasing elapse time. The magnitude of reduction is expected to be dependent on time and the rate at which hydration products are formed.

The maximum dry density (MDD) reduced from 1.48 to 1.34 Mg/m^3 after 3 hours elapse time for specimens containing 6 %lime/8 % bagasse ash compacted at the energy of the BSL. Similarly, the MDD reduced for WAS and BSH from 1.60 Mg/m^3 to 1.29 Mg/m^3 and 1.83 Mg/m^3 to 1.42 Mg/m^3 at the same lime/bagasse ash treatment, respectively, after 3 hours.

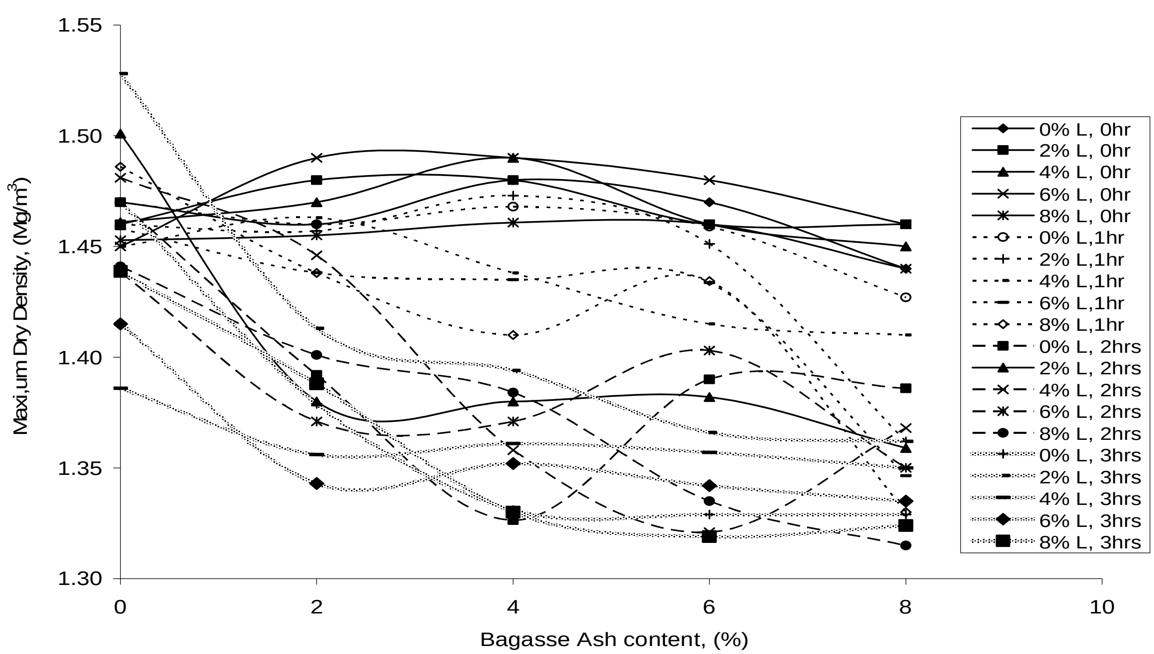


Fig 4.9 (a) Variation of Maximum Dry Density with Bagasse Ash Content at Various Lime Contents and Elapse Times (BSL Compaction)

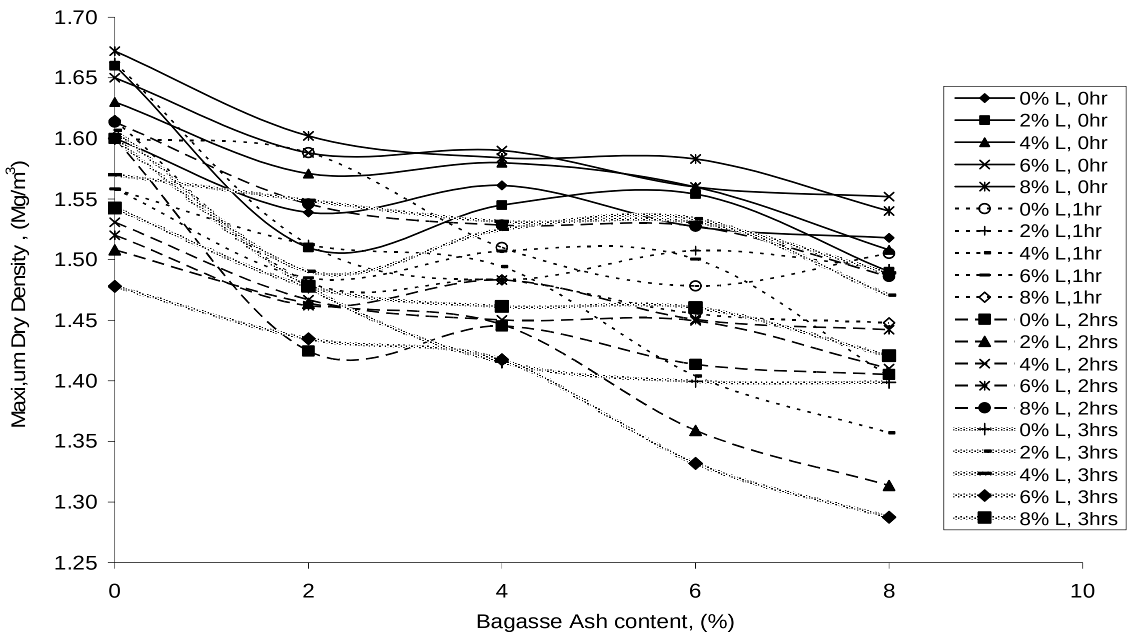


Fig 4.9(b) Variation of Maximum Dry Density with Bagasse Ash Content at Various Lime Contents and Elapse Times (WAS Compaction)

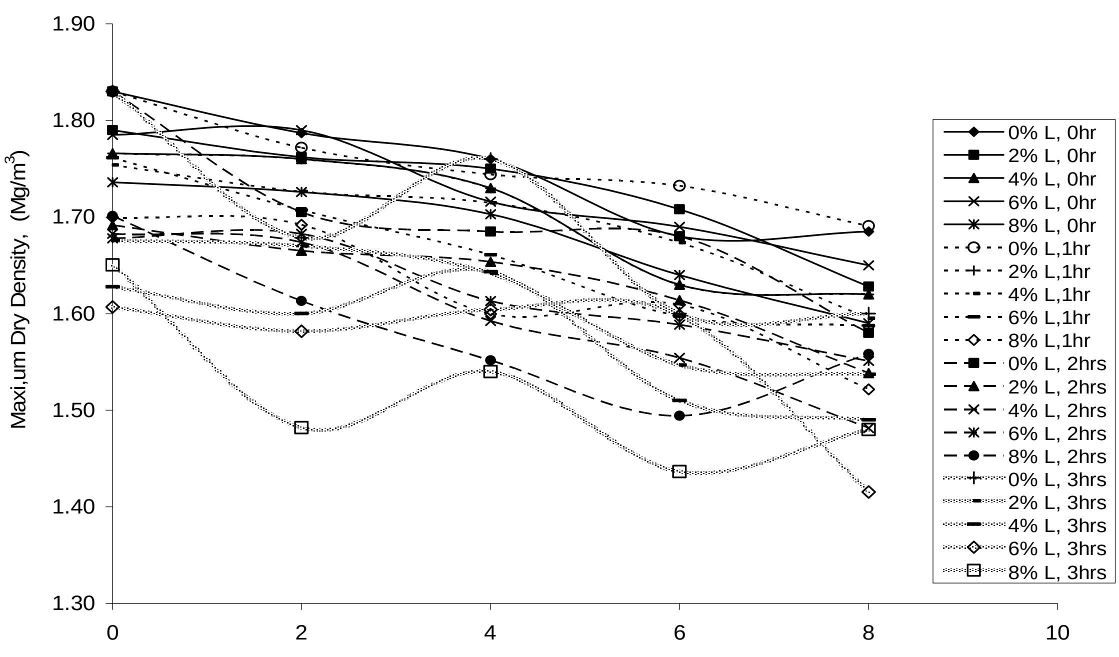


Fig 4.9(c) Variation of Maximum Dry Density with Bagasse Ash Content at Various Lime Contents and Elapse Times (BSH Compaction)

Other probable reasons for the drop in MDD may be due to the product of cation exchange reaction between lime-bagasse ash and the soil minerals which resulted in the flocculated and agglomerated clay particles. These particles occupied larger spaces that led to a corresponding decrease in the dry density (Ola 1977; Lees et al. 1982). Also the decrease in MDD at higher bagasse ash content was probably due to the replacement of soil particles in a given volume with particles of lime and bagasse ash of comparatively low specific gravity (Lees et al. 1982). As expected, higher dry densities were achieved with greater effort for all lime-bagasse ash content used in this study.

The variation of optimum moisture content (OMC) with bagasse ash and lime contents is shown in Fig. 4.10 (a) - (c). The effect of elapse time on the OMC for British Standard Light, West African and British Standard Heavy compactive efforts are shown in Fig. 4.11 (a)-(c). It can be observed that there is a continuous increase of the OMC with increasing bagasse ash and at all lime contents for all the compactive efforts used.

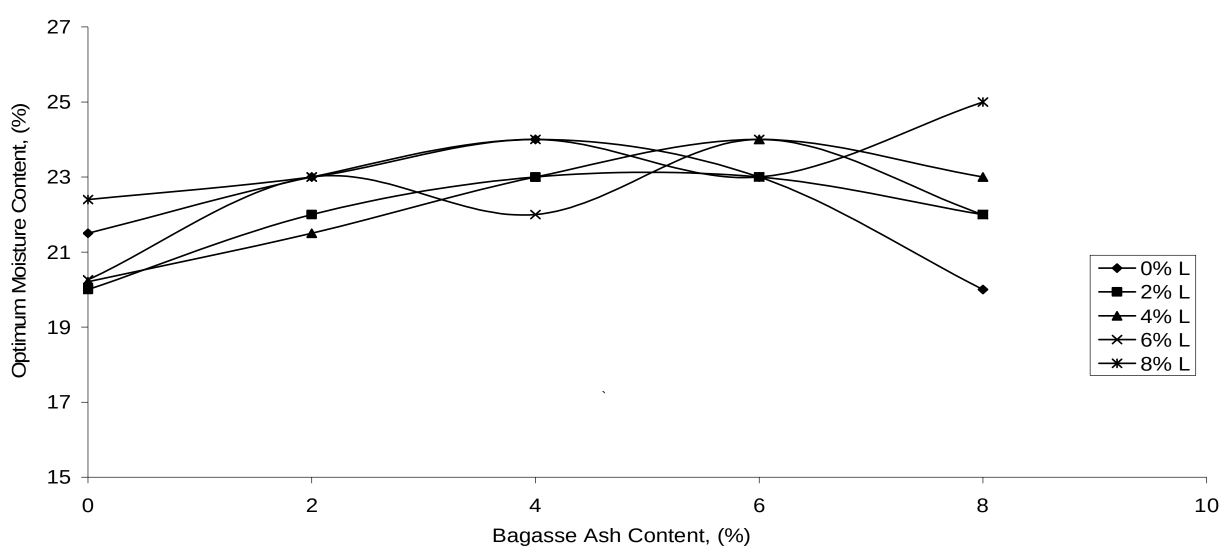


Fig. 4.10 (a) Variation of Optimum Moisture Content with Bagasse Ash (BSL Compaction)

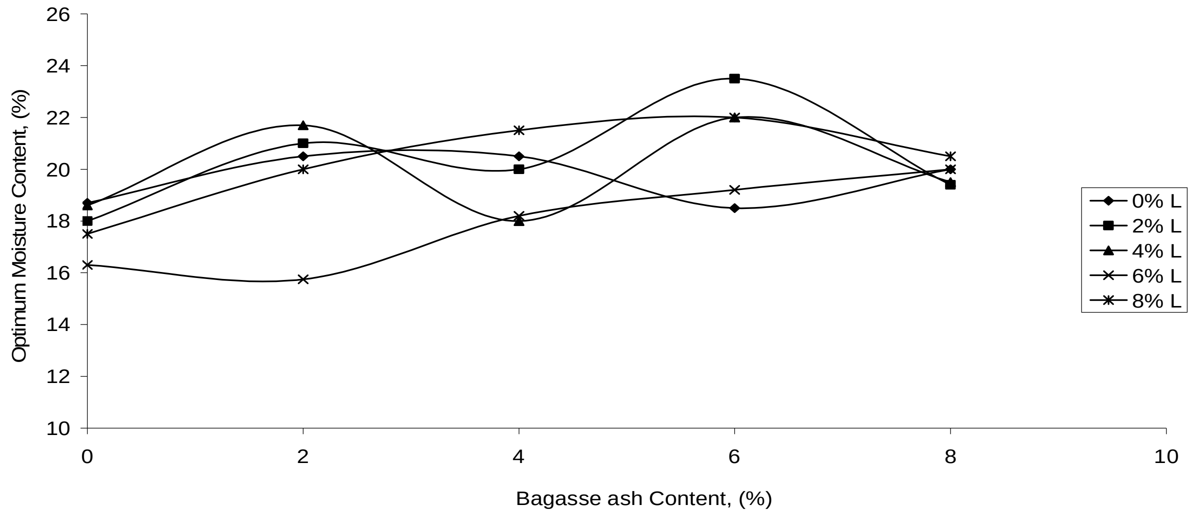


Fig. 4.10 (b) Variation of Optimum Moisture Content with Bagasse Ash (WAS Compaction)

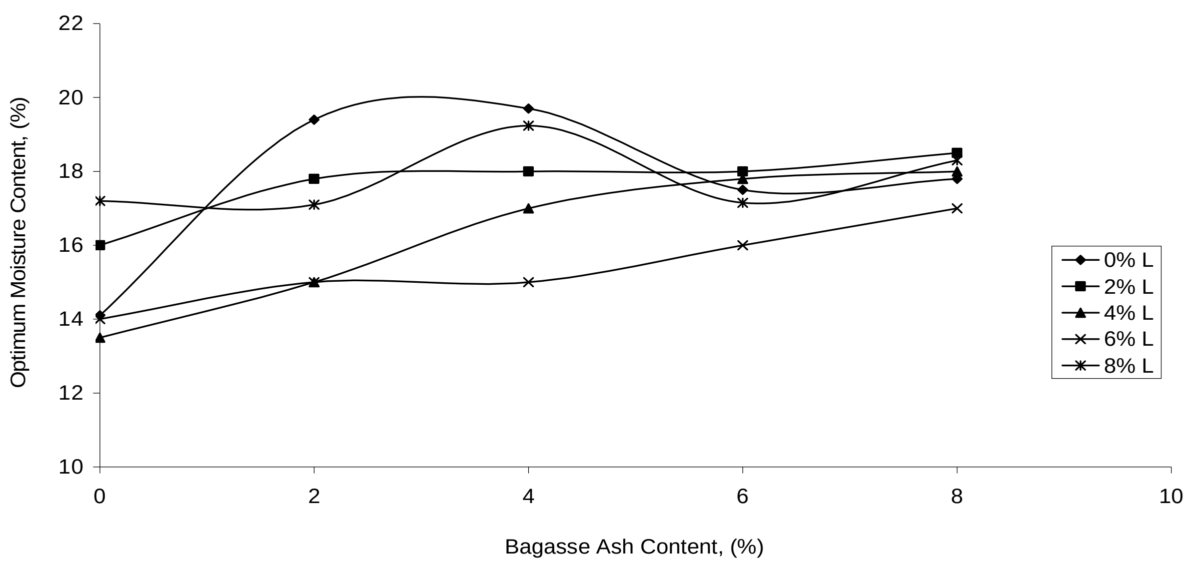
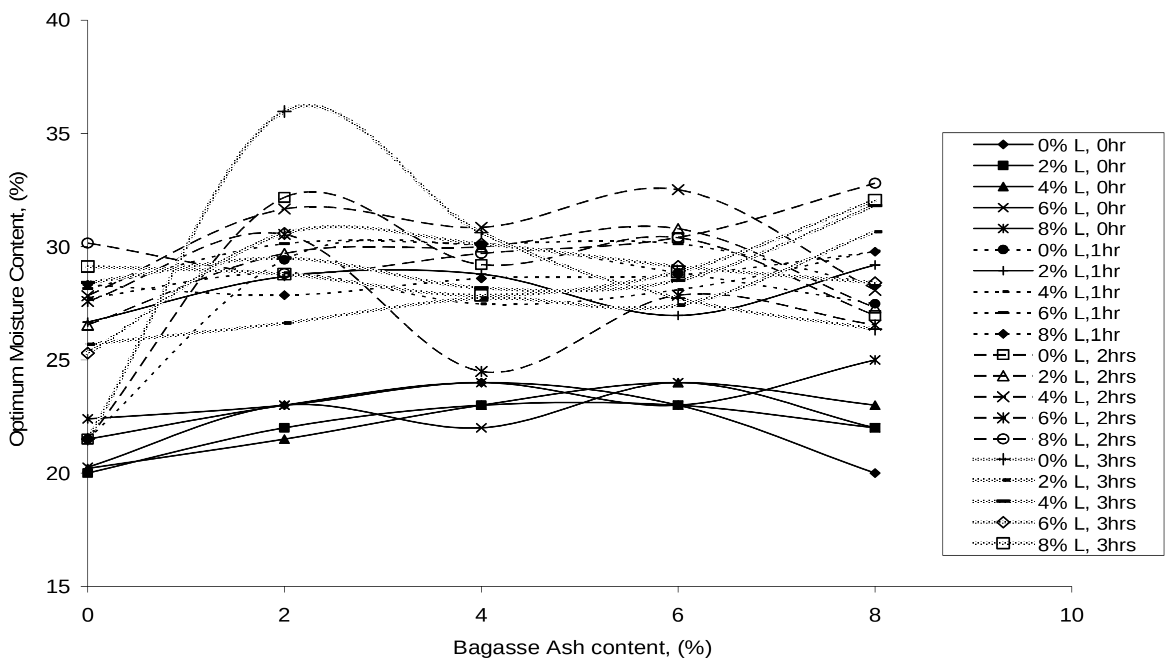


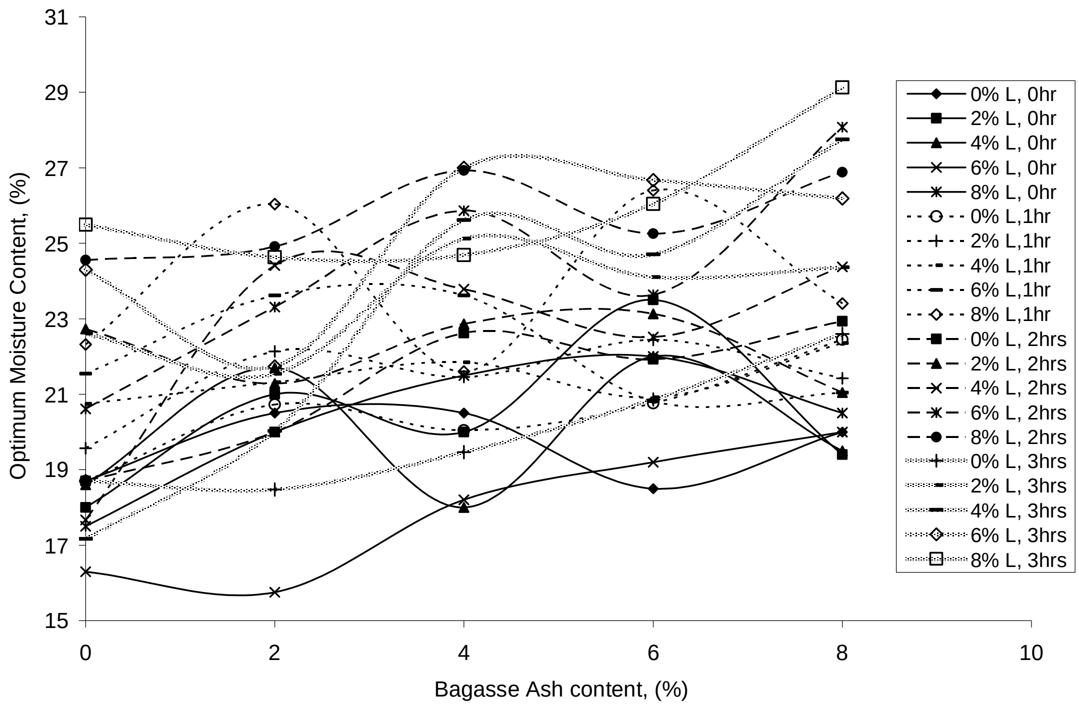
Fig. 4.10 (c) Variation of Optimum Moisture Content with Bagasse Ash (BSH Compaction)

This gradual increase in OMC with increasing bagasse ash content further increased with the addition of lime and with delay between mixing and compaction. The trends of decreasing MDD and increasing OMC for lime stabilized soil have been reported by Osinubi (1999). Stephen (2005) reported a similar observation for black cotton soil treated with bagasse ash.

An explanation offered for the trend reported above for lime stabilized soil is that the increasing desire for water is somewhat commensurate to the increasing amount of lime, as more water is required for the dissociation of lime into Ca^{2+} and OH^- ions to supply more Ca^{2+} for the cation exchange reaction. Another reason may be the increasing surface area caused by increasing amount of lime and bagasse ash addition which requires more water to lubricate the entire matrix of soil-lime-bagasse ash to enhance compaction, in addition to the water needed for the reactions mentioned previously. OMC was lower for higher compaction energies because it was easier at higher efforts to break down flocculated aggregates, destroy shear planes and eliminate larger pores.



4.11(a) Variation of Optimum Moisture Content with Bagasse Ash Content at Various Lime Contents and Elapse Times (BSL Compaction)



4.11(b) Variation of Optimum Moisture Content with Bagasse Ash Content at Various Lime Contents and Elapse Times (WAS Compaction)

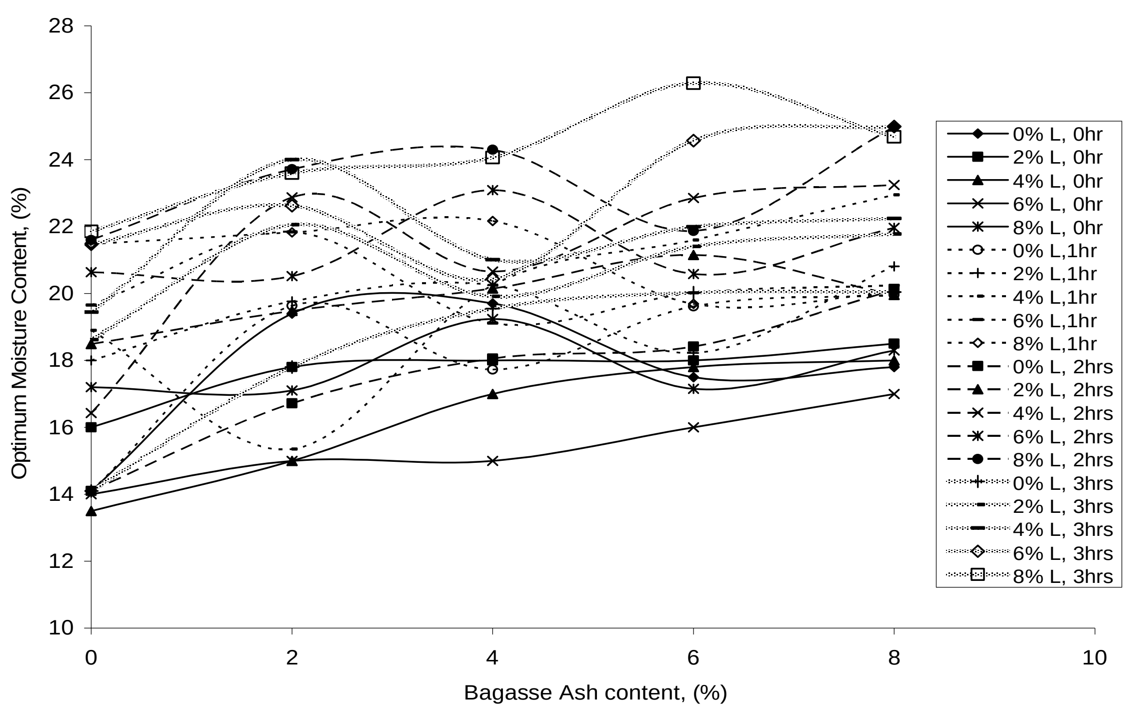


Fig 4.12 Variation of Optimum Moisture Content with Bagasse Ash Content at Various Lime Contents and Elapse Times (BSH Compaction)

Figures 4.11(a), 4.11(b) and 4.12 show the variation of optimum moisture content with elapse time. There was an increase in optimum moisture content, (OMC), up to a value of about 32 % at 6 % lime and 8 % bagasse ash content from the natural moisture content of 21 % for British standard light compactive effort at three hours elapse time. Similarly there was an increase in the OMC from 18 % to 26 % for West African standard at 6 % lime and 8 % bagasse ash content after three hours elapse time. At the British standard heavy compactive efforts, an increase was observed from 13 % to 24 % at 6 % lime and 8 % bagasse ash after three hours elapse time.

4.1.4 Unconfined compressive strength

The unconfined compressive strength (UCS) of a soil is an important factor in the evaluation of the design criteria for use as a pavement material. The addition of lime to soil apart from the immediate effect of improving the workability of the soil also in most cases tend to increase the strength of the soil and therefore, it becomes a cost effective and efficient material for use in embankment, earth fill etc.

The gain in strength is primarily due to the formation of various compounds such calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes. The exact products, however, vary with the kind of clay mineralogy and the reaction conditions, including temperature, moisture and curing conditions.

The effects of bagasse ash on the strength of soils were investigated by Stephen (2005) and Mustapha (2006). The strength gain of black cotton soil with bagasse ash was shown to be minimal when compared with lime. This was attributed to the low amount of Ca^{2+} contained in bagasse ash. However, the abundance of Ca^{2+} contained in the lime provides sufficient Ca^{2+} for the required pozzolanic reactions for strength development.

The variation of the unconfined compressive strength of soil - lime mixture with bagasse ash content compacted at British Standard Light energy level and cured for 7, 14 and 28 days are shown in Fig. 4.13. It can be observed that the unconfined compressive strength increases with increasing curing period for all lime contents. For soil treated with 6 % lime and 8 % bagasse ash, strength increased from about 410 kN/m^2 at 7 days to 540 kN/m^2 at 28 days curing. The 7, 14 and 28 days strength development for the West Africa standard and British standard Heavy energy levels are shown in Fig. 4.14 and Fig. 4.15.

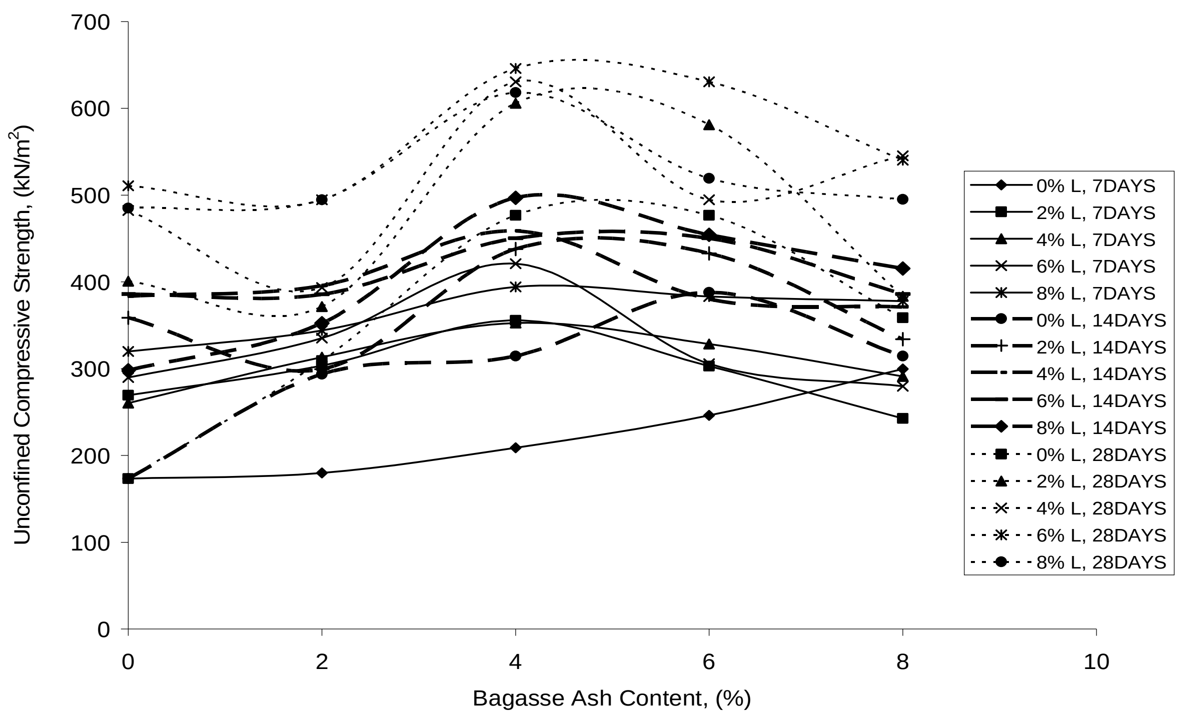


Fig. 4.13 Variation of UCS with Bagasse Ash Content for Various Curing Periods and Lime Contents (BSL Compaction)

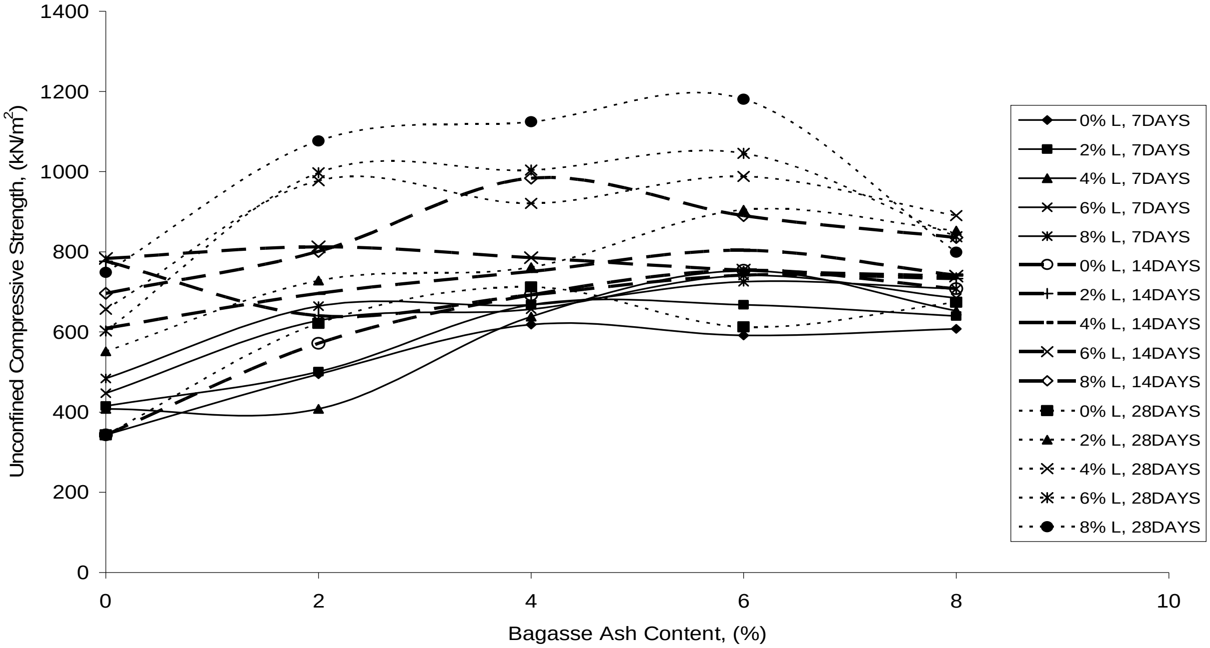


Fig. 4.14 Variation of UCS with Bagasse Ash Content for Various Curing Periods and Lime Contents (WAS Compaction)

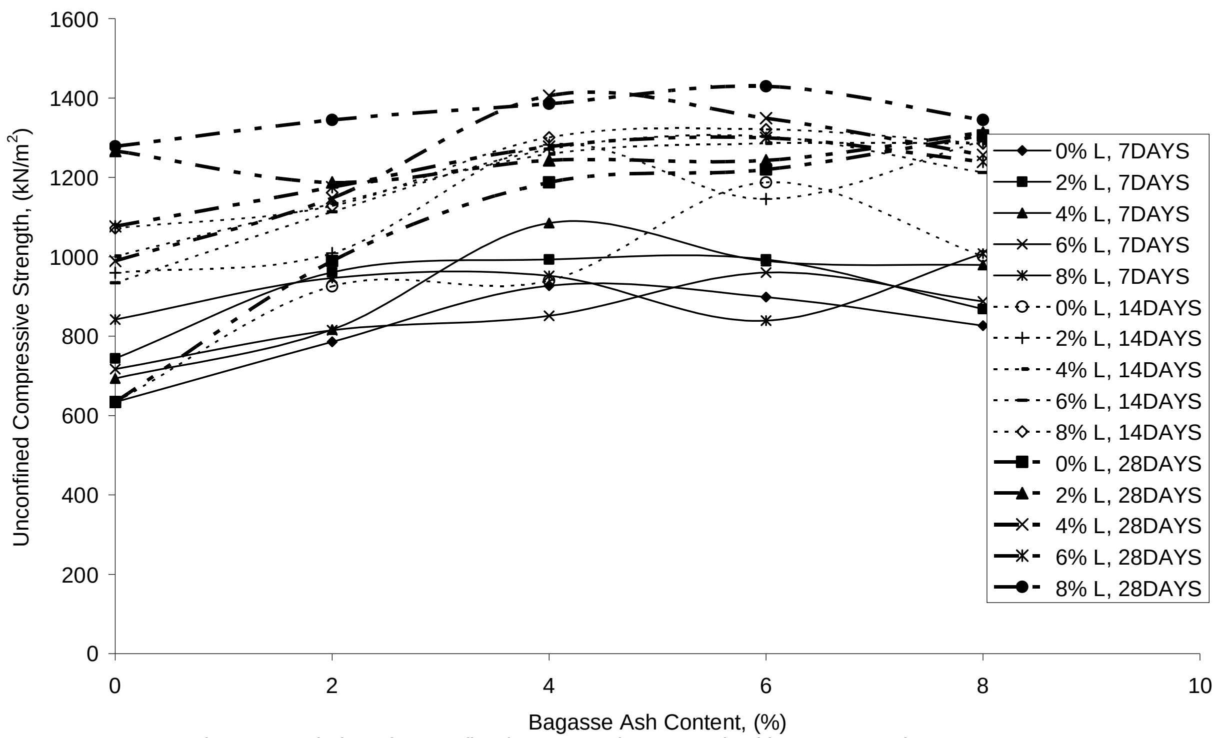


Fig. 4.15 Variation of Unconfined Compressive Strength with Bagasse Ash Content for Various Curing Periods and Lime Contents (BSH Compaction)

There was an increase of UCS from about 680 kN/m^2 at 7 days to about 850 kN/m^2 at 28 days for WAS and from 1160 kN/m^2 to about 1330 kN/m^2 for BSH at 6 %lime/8 %bagasse ash. Although there is no established strength criterion for soil-lime/bagasse ash mix, but using the UCS value of 1034.25kN/m^2 normally utilized as criterion for adequate lime stabilization (see Ola, 1983; Osinubi, 1998a; 1999a), the samples stabilized with 6%lime/8%bagasse ash did not achieve the required strength at 7 days curing period. However, 28 day UCS value of 1330 kN/m^2 which was achieved at the BSH compactive efforts, exceeded the requirement. The strength development of the soil-lime-bagasse ash mix increased with curing period for all lime and bagasse ash contents. This is consistent with reports by other researchers (Osinubi et al., 2007a,b; 2008a,b). Pozzolanic reactions between the additives and the soil minerals resulted in the production of compounds such calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) which are responsible for strength gain. These reactions are slow for lime and can go on for days, months or even years resulting in a long term gain of strength. The peak strength gains recorded at 28 days curing for specimens prepared at the three compactive efforts substantiate the foregoing that strength development of soil - lime/bagasse ash mixture is a slow process and a longer period may be required to achieve higher strength values.

The effect of delay between mixing and compaction (elapse time) is shown in Figures 4.16 (a)-(c); 4.17 (a)-(c) and 4.18 (a)-(c) for BSL, WAS and BSH compactive efforts, respectively. It can be observed in all the curves that there is a general decline in UCS with elapse time. This was expected and is consistent with other reports on lime stabilization (Mitchell and Hooper, 1961). The reduction in strength may be attributed to the destruction of the cementation bond formed during the soil-lime-bagasse ash reaction over the period of time between mixing and compaction. The destruction of this matrix during compaction results in reduction of the soil density and consequently, reduction in strength of the compacted soil. There was an average of about 17 – 25 % decrease in strength for an elapse time of 3 hours.

The value of unconfined compressive strength of the soil in its natural state was 173, 343 and 633 kN/m^2 respectively for BSL, WAS and BSH compactive efforts. This strength increased as lime and bagasse ash were added for each of the compactive efforts and with curing period. However, strength decreased with elapse time for all compactive efforts. There was a decrease in UCS from a value of 410 kN/m^2 to 311 kN/m^2 at 6 % lime and 8 % bagasse ash after 3 hours elapse time, for BSL compactive effort for 7 days curing period. At the same energy level for 14 and 28 days curing periods, the strength decreased from 510 and 540 kN/m^2 at 6 % lime -4 % bagasse ash to 360 and about 380 kN/m^2 respectively. At the energy level of West Africa standard, the UCS values decreased from a peak value of 680, 750 and 850 kN/m^2 to 490, 600 and 620 kN/m^2 at 6 % lime-8 % bagasse ash content at 7, 14 and 28 days respectively after three hours elapse time. Similarly a decrease from maximum UCS value of 1160, 1210 and 1330 kN/m^2 to 780, 960 and 1020 kN/m^2 at 6 % lime-8 % bagasse ash content respectively were recorded at 7, 14 and 28 days after three hours elapse time.

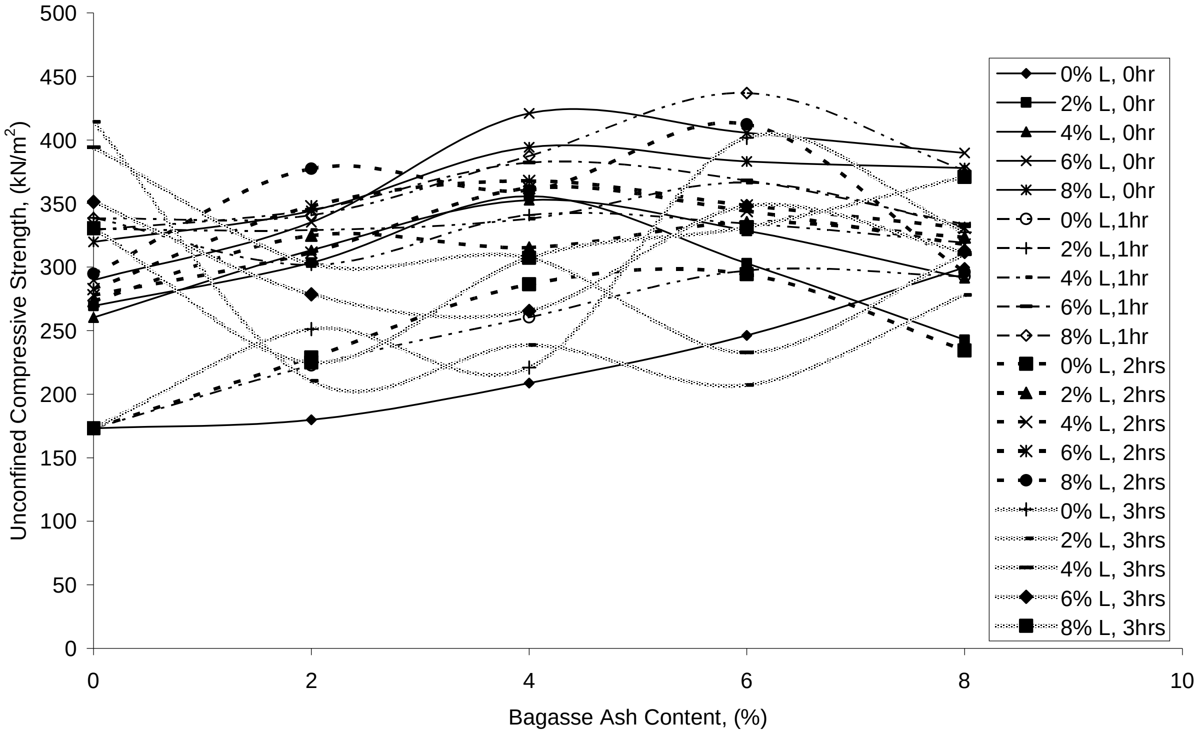


Fig. 4.16 (a) Variation of Unconfined Compressive Strength (7 Days Curing) with Bagasse Ash Content at Various Elapse Times (BSL Compaction)

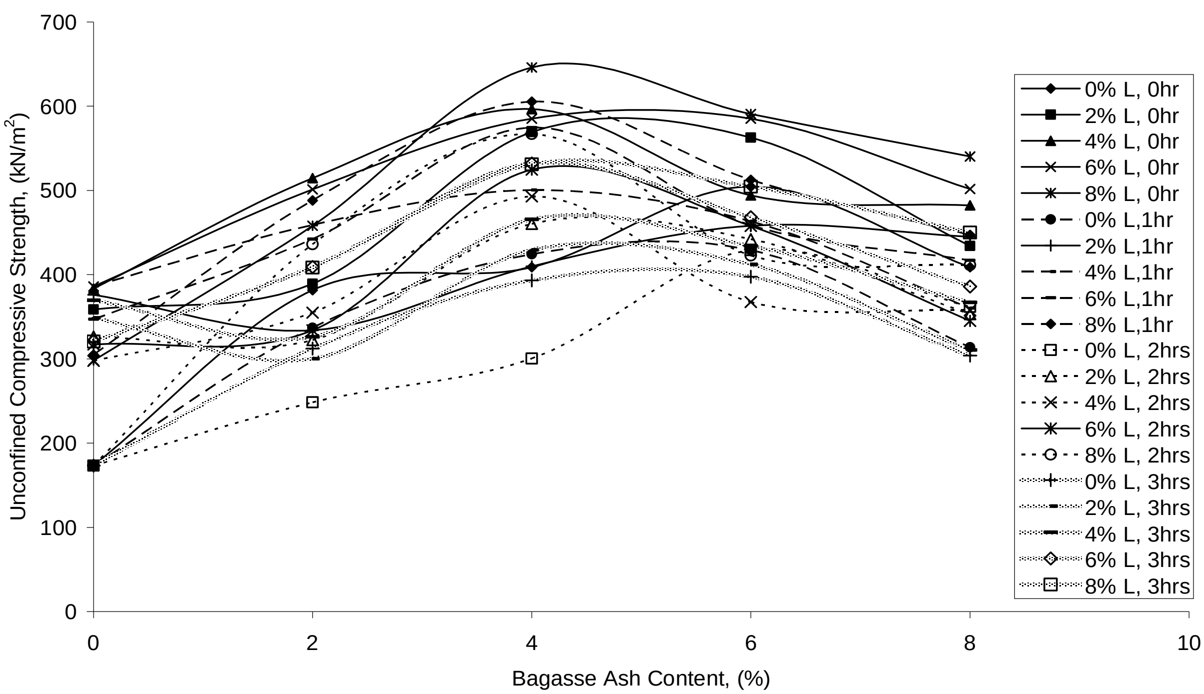


Fig. 4.16 (b) Variation of Unconfined Compressive Strength (14 Days Curing) with Bagasse Ash Content at Various Elapse Times (BSL Compaction)

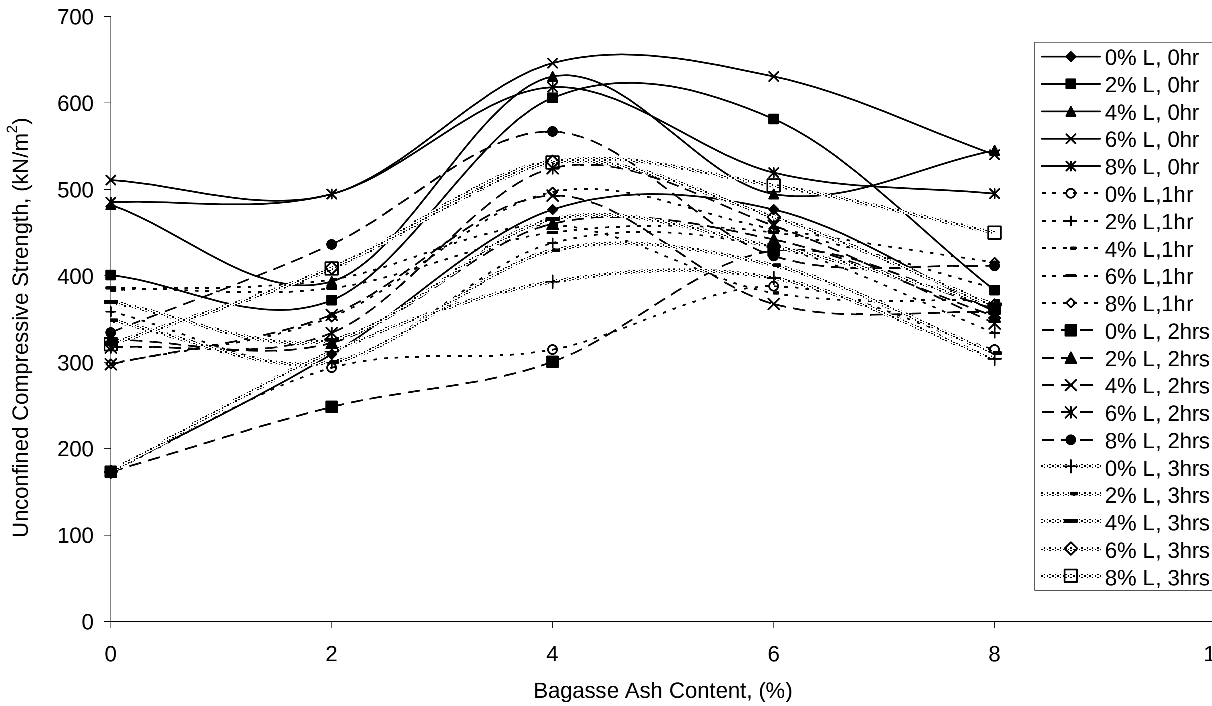


Fig. 4.16 (c) Variation of Unconfined Compressive Strength (28 Days Curing) with Bagasse Ash Content at Various Elapse Times (BSL Compaction)

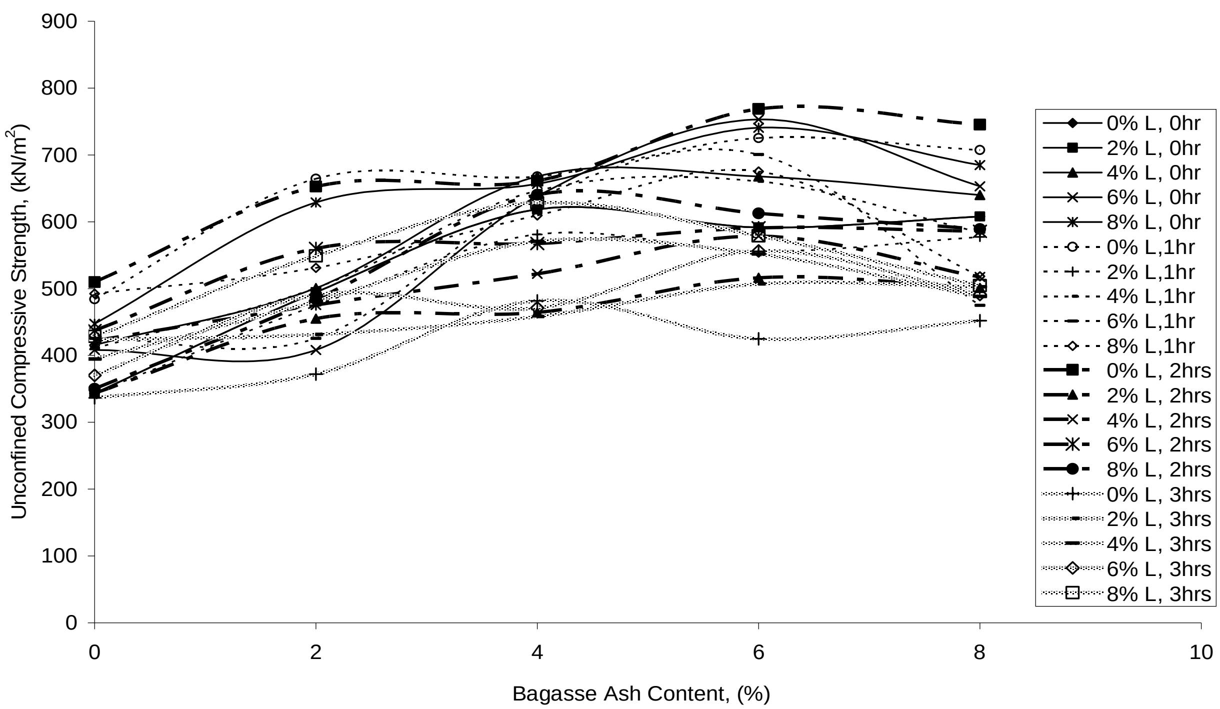


Fig. 4.17 (a) Variation of Unconfined Compressive Strength (7 Days Curing) with Bagasse Ash Content at Various Elapse Times (WAS Compaction)

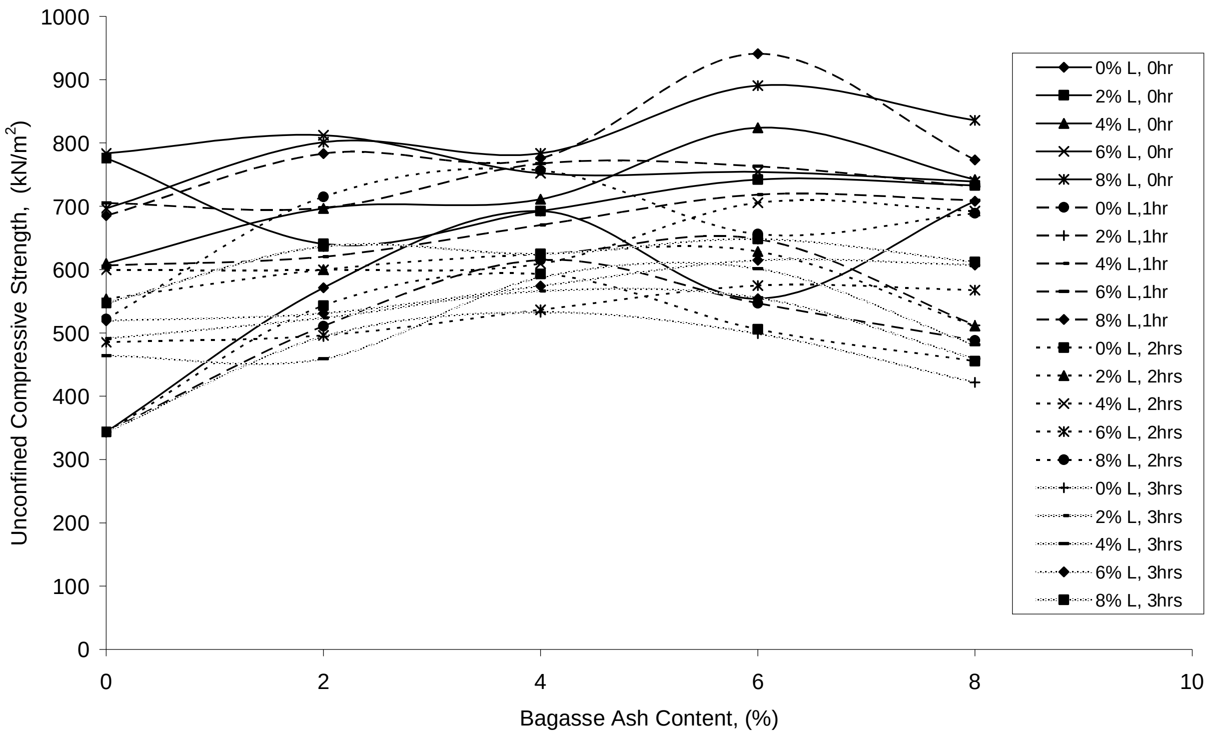
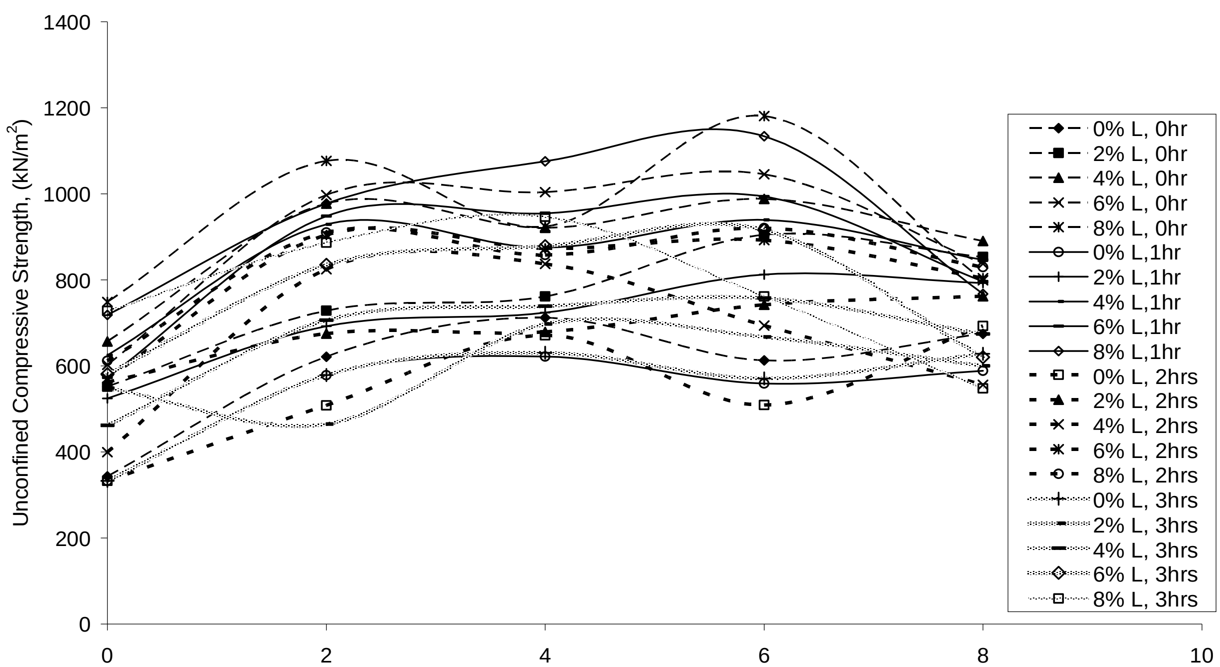


Fig. 4.17 (b) Variation of Unconfined Compressive Strength (14 Days Curing) with Bagasse Ash Content at Various Elapse Times (WAS Compaction)



Bagasse Ash Content, (%)

Fig. 4.17 (c) Variation of Unconfined Compressive Strength (28 Days Curing) with Bagasse Ash Content at Various Elapse Times (WAS Compaction

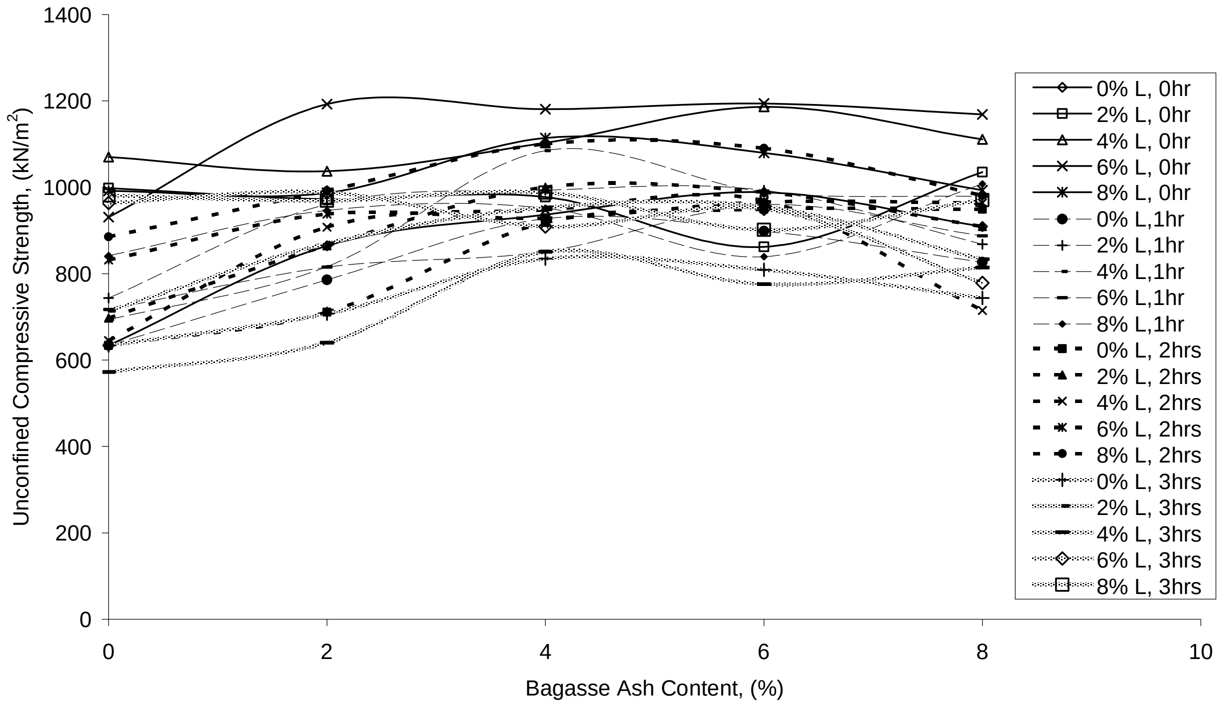


Fig. 4.18 (a) Variation of Unconfined Compressive Strength (7 Days Curing) with Bagasse Ash Content at Various Elapse Times (BSH Compaction)

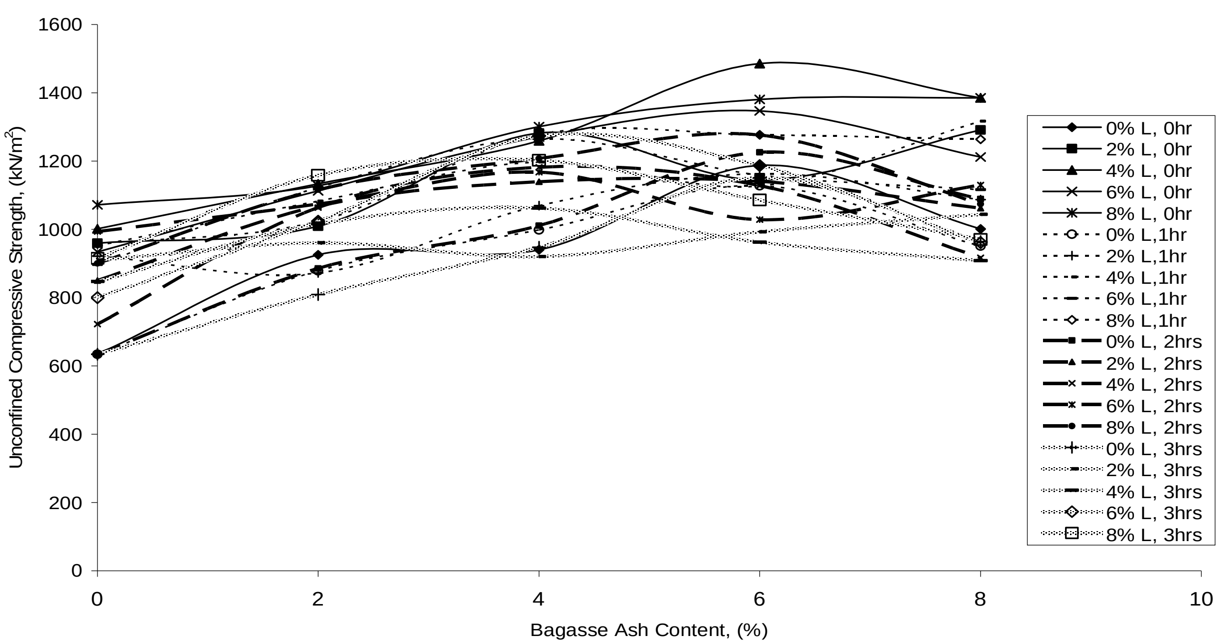


Fig. 4.18 (b) Variation of Unconfined Compressive Strength (14 Days Curing) with Bagasse Ash Content at Various Elapse Times (BSH Compaction)

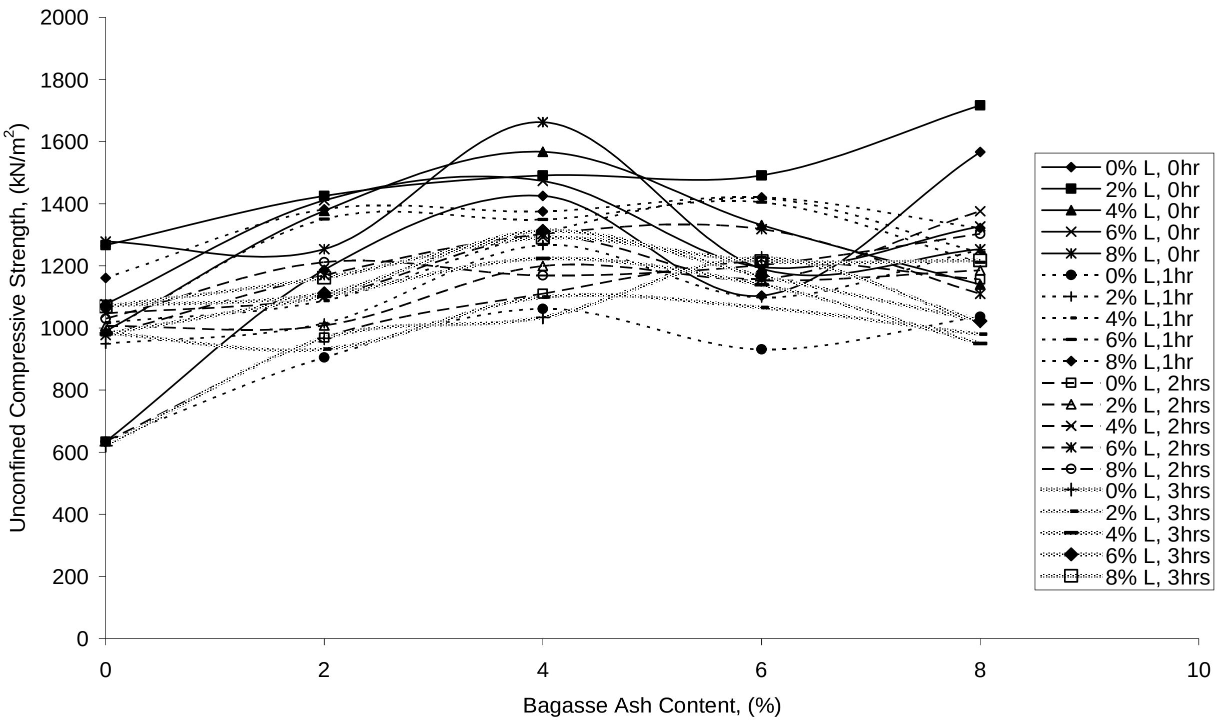


Fig. 4.18 (c) Variation of Unconfined Compressive Strength (28 Days Curing) with Bagasse Ash Content at Various Elapse Times (BSH Compaction)

4.1.6 Durability

A stabilized soil is usually accepted on the basis of meeting strength and durability requirements. The durability assessment is based on the ratio of the UCS of specimen wax cured for seven days de-waxed top and bottom and immerse in water for another seven days and specimen waxed cured for 14 days. Conventionally, an allowable 20 % loss in strength is recommended for a specimen cured for seven days and immersed in water for four days (see Ola, 1974; Osinubi, 1998a; 1999a).

Figures 4.19 (a)-(c) show the ratio of the UCS of specimen cured for 7 days and immersed in water for another 7 days and the UCS of specimen cured for 14 days. The effect of elapse time is also shown in Figures 4.20 (a)-(b).

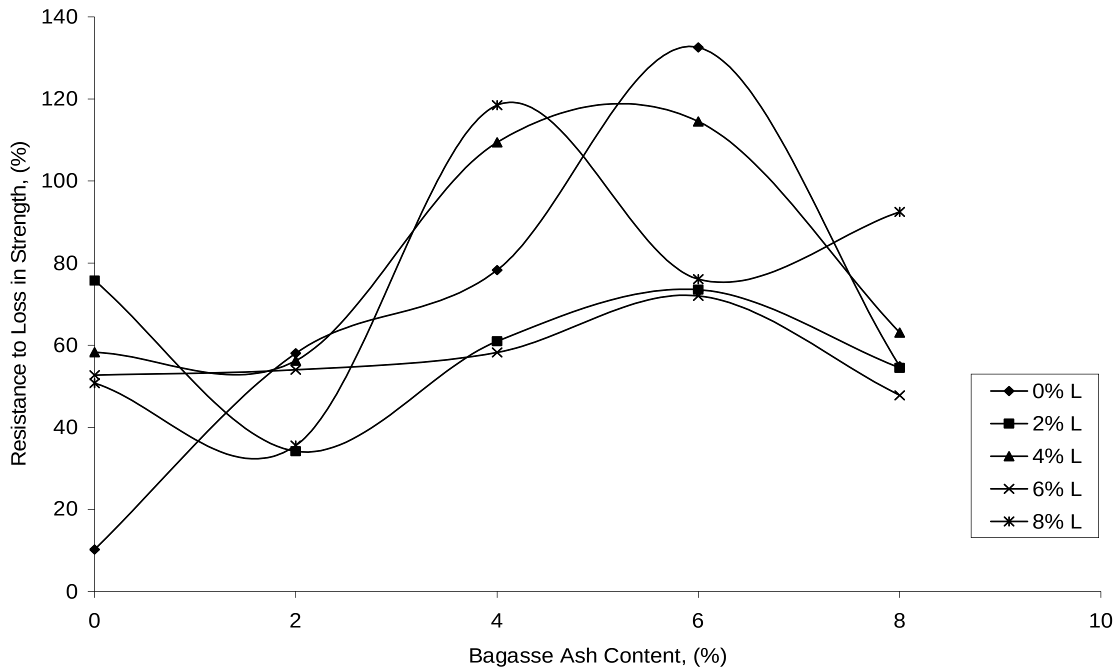


Fig. 4.19 (a) Variation of the Ratio of UCS of 7 Days Cured + 7 days Soaked and 14 Days Cured Specimen with Bagasse ash Cotent for Various Lime Contents (BSL Compaction)

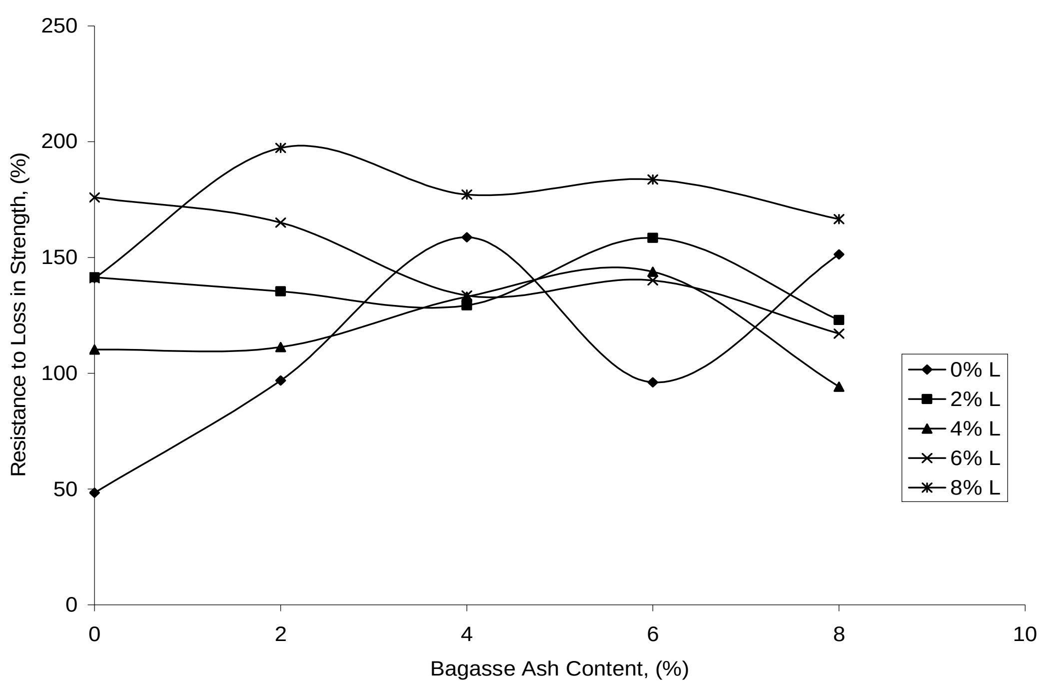


Fig. 4.19 (b) Variation of the Ratio of UCS of 7 Days Cured + 7 days Soaked and 14 Days Cured Specimen with Bagasse ash Cotent for Various Lime Contents (WAS Compaction)

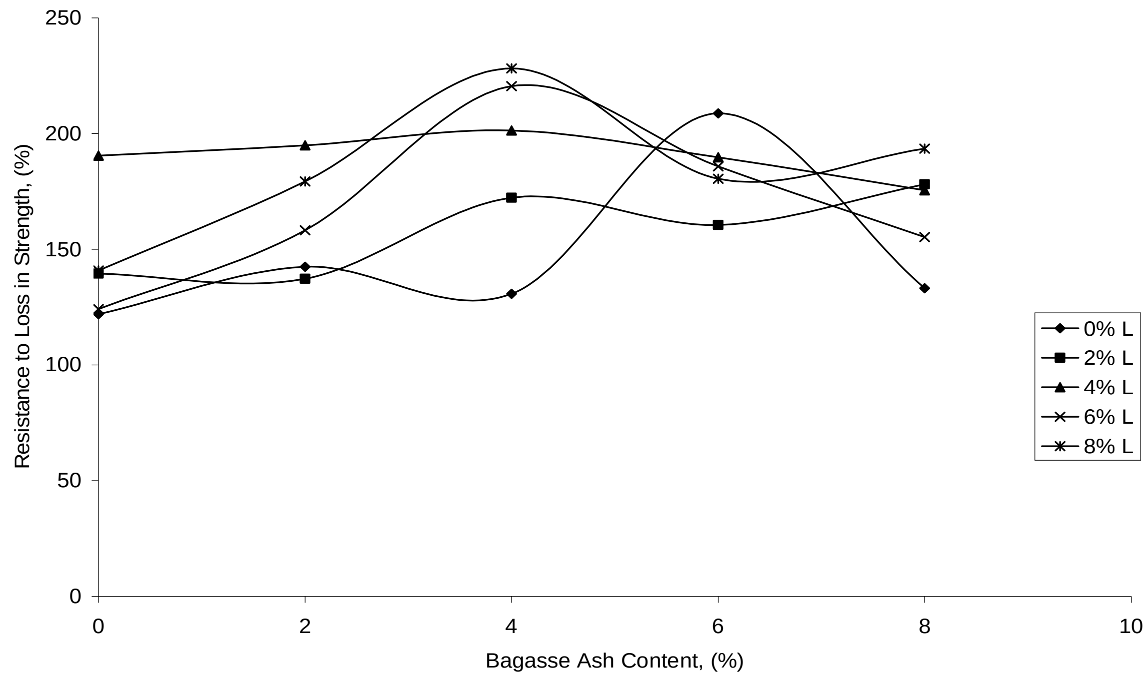


Fig. 4.19 (c) Variation of the Ratio of UCS of 7 Days Cured + 7 days Soaked and 14 Days Cured Specimen with Bagasse ash Cotent for Various Lime Contents (BSH Compaction)

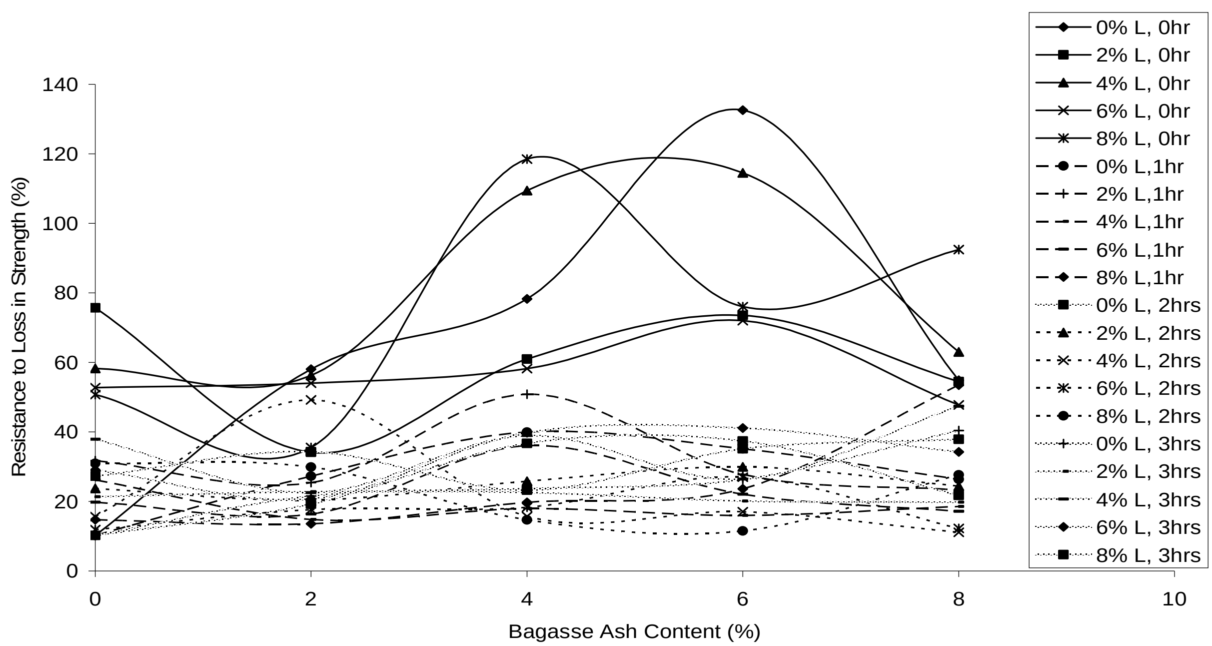


Fig. 4.20(a) Variation of the Ratio of UCS of 7 Days Cured + 7 days Soaked and 14 Days Cured Specimen with Bagasse ash Cotent for Various Lime Contents (BSL Compaction)

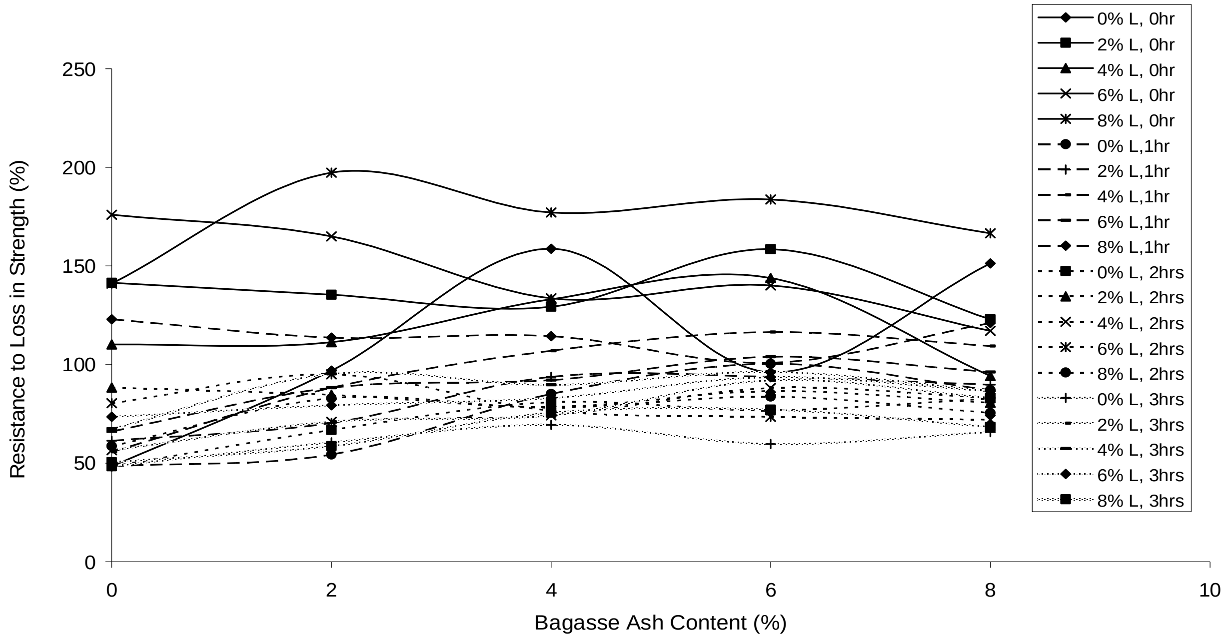


Fig. 4.20 (b) Variation of the Ratio of UCS of 7 Days Cured + 7 days Soaked and 14 Days Cured Specimen with Bagasse ash Cotent for Various Lime Contents (WAS Compaction)

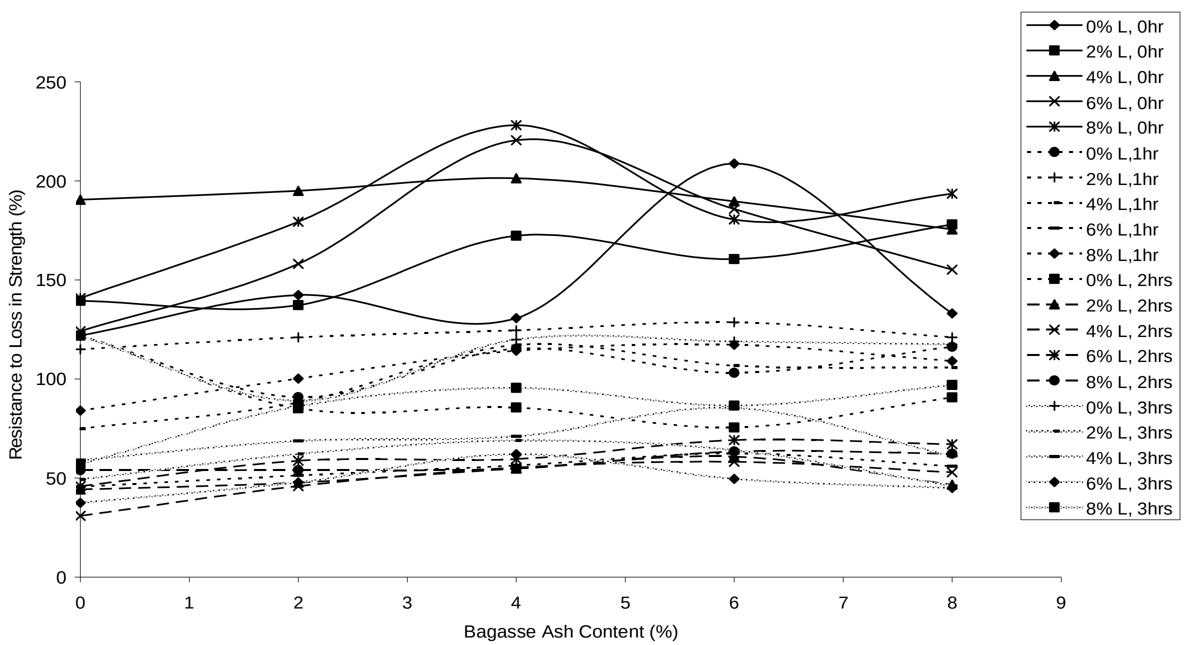


Fig.20 (c) Variation of the Ratio of UCS of 7 Days Cured + 7 days Soaked and 14 Days Cured Specimen with Bagasse ash Cotent for Various Lime Contents (BSH Compaction)

Durability assessment of the soil-lime-bagasse ash mix showed a decline in the resistance to loss in strength of the mixes with elapse time for all compactive efforts. There was however some increase in the UCS value of the mixes with increase in lime/bagasse ash content. A peak value of 50 % was attained at 6 % lime/8 % bagasse ash for BSL compactive effort. This declined to 20 %after three hours. Similarly, peak values of 120 and 200 % were attained for WAS and BSH energy levels respectively at 6 % lime/8 % bagasse ash treatment. These values decreased to 58 and 60 % after three hours elapse time. The resistance to loss in strength values of tested specimens fell far short of the acceptable conventional 80 % accepted as minimum reported by Ola (1974).

4.1.7 *California bearing ratio*

The California bearing ratio (CBR) value of a soil is an important parameter used to indicate its strength and bearing capacity. It is widely used in design and to assess the suitability of soil or otherwise for base and sub-base. Lime stabilized soils are often used for the construction of these pavement layers and also for embankment. The CBR is therefore a familiar test used to evaluate the strength of soils for these applications. According to TRB (1982), CBR "is not appropriate for characterizing strength of cured soil-lime mixtures" and can only be used as a comparison, and has little practical significance or meaning as a measure of strength and stability other than as a relative indicator test.

The Nigerian General Specifications (1997) recommended a CBR value of 180 % to be attained in the laboratory for cement stabilized material to be constructed by the mix-in-place method, while it did not state the value for lime-treated soil.

Usually, a minimum CBR value of 60-80 % is required for bases and from 20-30 % for subbase both when compacted at optimum moisture and 100 % West Africa Standard (Gidigasu, 1982). However, the minimum conventional CBR values for lime-treated soils of 40, 80, and 100 % (standard Proctor/British Standard Light) for subbase, base (lightly trafficked roads) and base (heavily trafficked roads), respectively, are adopted in evaluating the strength of soil-lime specimens

The variation of CBR of soil-lime bagasse ash mixtures with bagasse ash for the various lime contents and compactive efforts are shown in Figs. 4.21(a)-(c). The CBR test results recorded for the stabilized soil in this work were generally low and decreased with delay in time between mixing and compaction.

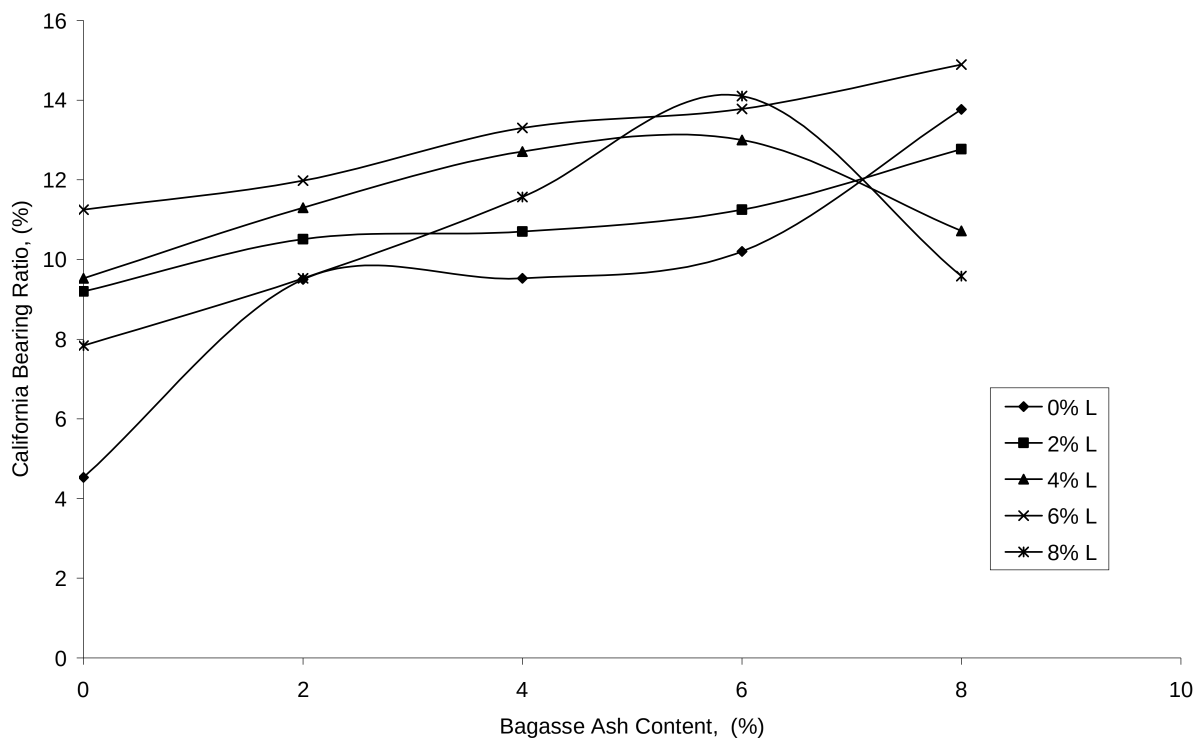
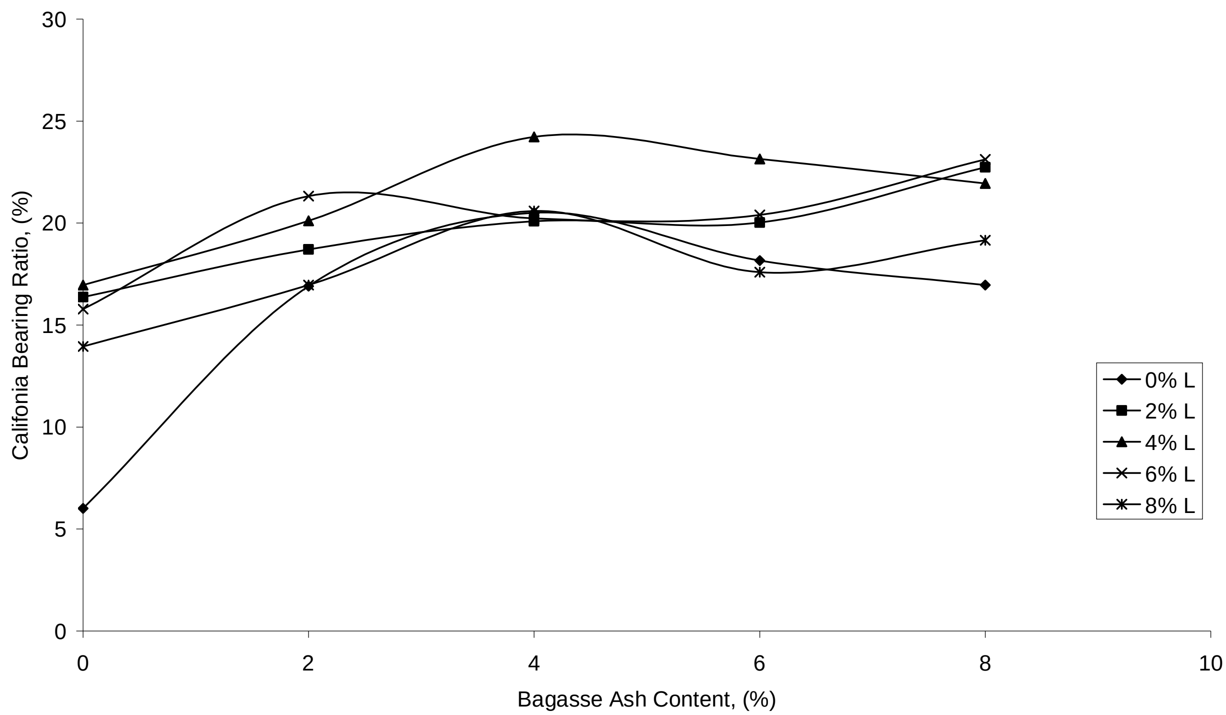
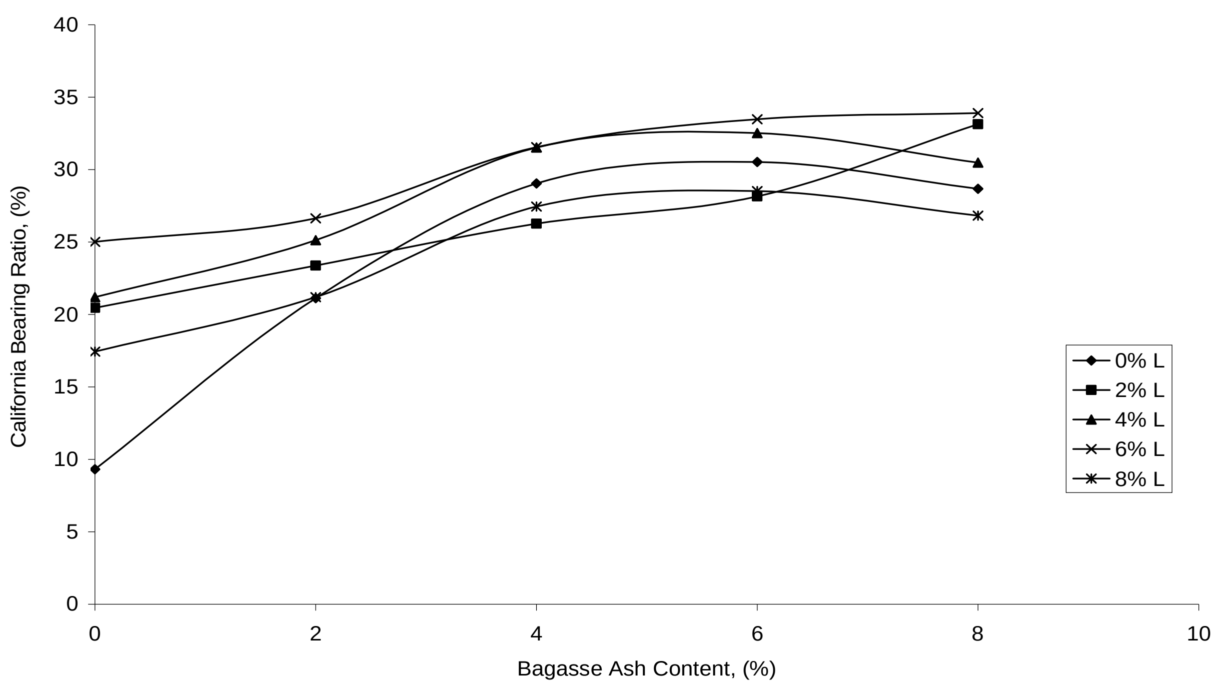


Fig. 4.21 (a) Variation of California Bearing Ratio with Bagasse Ash Content at Various Lime Contents (BSL Compaction)



4.21(b) Variation of California Bearing Ratio with Bagasse Ash Content at Various Lime Contents (WAS Compaction)



4.21(c) Variation of California Bearing Ratio with Bagasse Ash Content at Various Lime Contents (BSH Compaction)

The highest CBR value of 35 % was recorded at the British Standard Heavy compactive effort for soil treated with 6 % lime/ 8 % bagasse ash. This was an increase of about 25 % above 9 % which was the CBR value of the natural soil at this energy level. From this value, there was a steady but gradual decrease with elapse time. At the West African Standard and British Standard Light compactive efforts, maximum CBR values of 24 and 14 %, respectively, were recorded. These values showed increases of about 18 and 10 % over the CBR values of 6 and 4 % for the natural soil compacted at the energy levels of the WAS and BSL, respectively (see Figures 4.21 (a)-(c)). None of the mixes fulfilled any of the requirements for its use as base or subbase.

The effect of elapse time is shown in Figures 4.22 (a)-(c) for each of the compactive efforts. The CBR values decreased with elapse time.

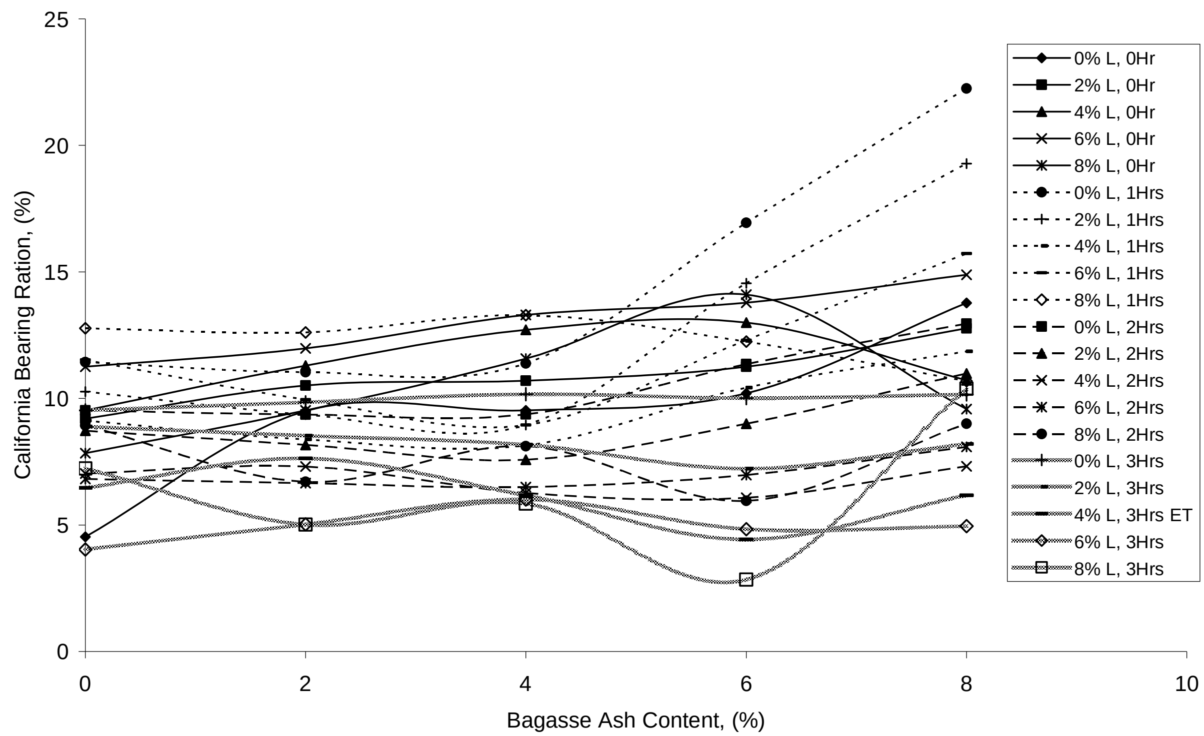


Fig. 4.22 (a) Variation of California Bearing Ratio with Bagasse Ash Content at Various Lime Contents and Elapse Times (BSL Compaction)

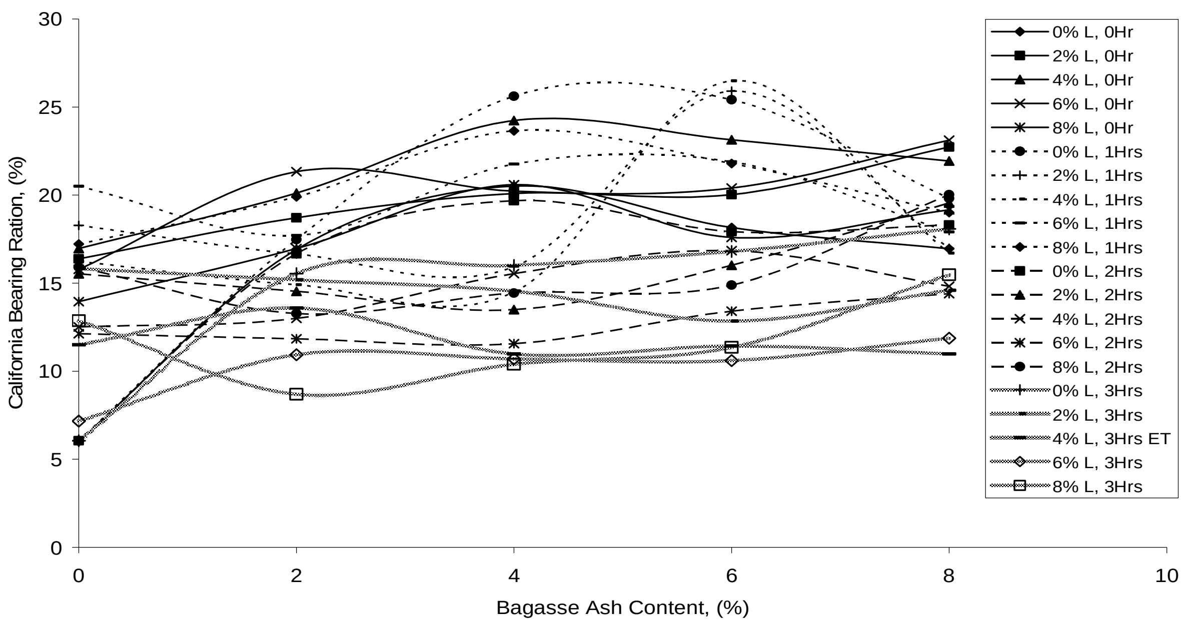


Fig. 4.22(b) Variation of California Bearing Ratio with Bagasse Ash Content at Various Lime Contents and Elapse Times (WAS Compaction)

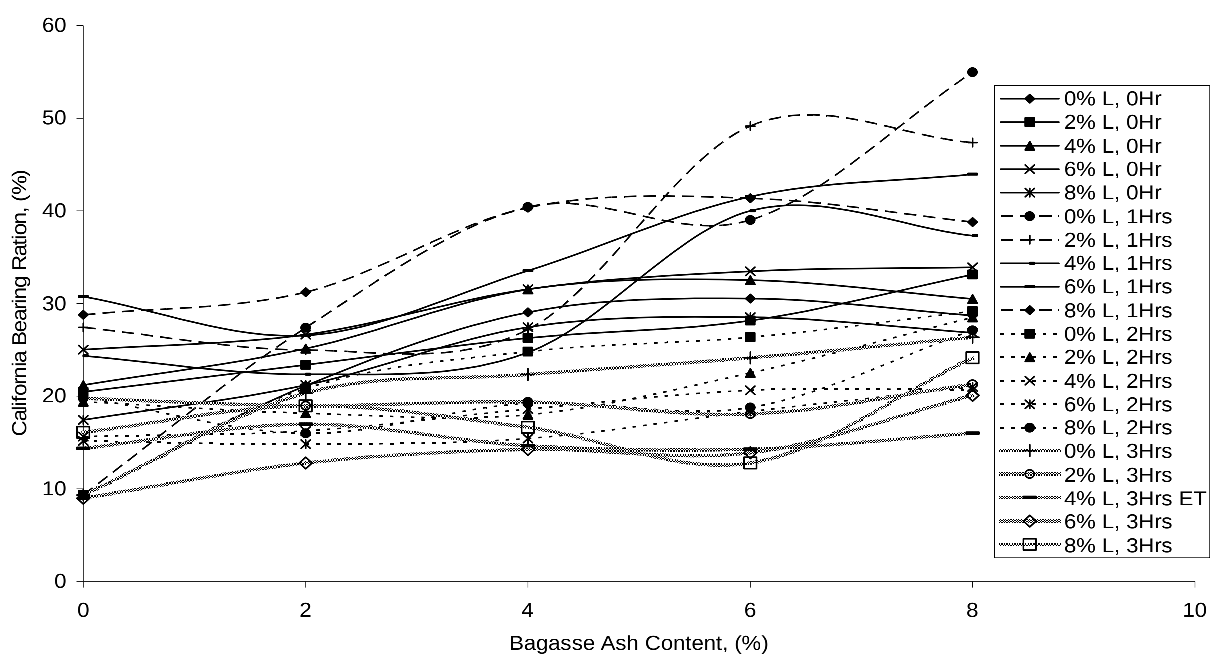


Fig. 4.22 (c) Variation of California Bearing Ratio with Bagasse Ash Content at Various Lime Contents and Elapse Times (BSH Compaction)

The CBR value of the soil decreased from 14 % at zero hour to 5 % after three hours elapse time at 6 % lime/8 % bagasse ash treatment and compaction at the energy of the British Standard light. Similarly, the CBR values declined for the West African Standard and British Standard heavy compactions from 24 % to 11 % and 35 to 20 % at 6 % lime-8 % bagasse ash treatment, respectively after three hours elapse time.

The reduction in CBR values was probably due to the disruption of the hydration products in the process of compaction. The hydration product bound the soil together, however the process of compaction after delay disrupted this aggregation thereby resulting in lower densities and consequently lower strengths.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research was conducted to investigate the effect of delay between mixing and compaction on the geotechnical properties of black cotton soil-lime-bagasse ash mixes. The problem soil was treated with additives in stepped concentration of 0, 2, 4, 6 and 8 % by dry weight of the soil.

The natural soil was classified as CH and A-7-6(28) using the Unified Soil Classification System (USCS) and AASHTO soil classification, respectively. It was established that delay between mixing and compaction affect the properties of the soil-lime-bagasse ash mix.

The natural soil had a liquid limit of 60 %, plastic limit of 22 % and plasticity index of 38%. The liquid limit of the soil reduced from 60 to 37 % at 8 % lime/2 % bagasse ash treatment at three hours elapse time. The plastic limit reduced from 22 to 11 % at 8 %lime/6 % bagasse ash treatment after three hours elapse time. The plasticity index decreased with elapse time and a minimum value of 23 % was obtained from a maximum value of 38 % at 8 % lime/ 4 % bagasse ash treatment after three hours elapse time.

Generally, maximum dry density (MDD) increased with higher compactive effort but decreased with higher lime/bagasse ash treatment as well as elapse time between mixing and compaction. The MDD of the natural soil compacted at the energies of the British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH) were 1.47, 1.60 and 1.83 Mg/m^3, respectively. For specimens treated with 6 % lime/8 % bagasse ash and compacted at the energy levels of BSL, WAS and BSH three hours after mixing, the MDDs reduced from the natural values obtained for soil to 1.34, 1.29 and 1.42 Mg/m^3, respectively.

A general trend of increasing optimum moisture content (OMC) with increasing lime/bagasse ash treatment as well as elapse time between mixing and compaction for all the compactive efforts was observed. For specimens compacted at the energy levels of the BSL, WAS and BSH the OMCs increased from 21, 18 and 13 %, respectively for the natural soil to 32, 26 and 24 %, respectively, when specimens were treated with 6 % lime/8 % bagasse ash and compacted 3 hours after mixing.

The 7 day unconfined compressive strength (UCS) values of the soil in its natural state were 173, 343 and 633 kN/m^2 for specimens prepared at the BSL, WAS and BSH compactive efforts, respectively. UCS values increased with higher lime and bagasse ash treatments for all the compactive efforts and curing periods considered. However, UCS of specimens decreased with elapse time for all compactive efforts. There was a decrease in 7 day UCS from a value of 410 to 311 kN/m^2 for specimen treated with 6% lime/8% bagasse ash and compacted at the BSL energy level 3 hours after mixing. At the same energy level for 14 and 28 days curing periods, the UCS decreased from 510 and 540 kN/m^2 to 360 kN/m^2 and 380 kN/m^2 respectively when specimens were treated with 6 % lime/8 % bagasse ash. At the same lime-bagasse ash ratio, the peak UCS for West African Standard energy level decrease from 680, 750 and 850 kN/m^2 to 490, 600 and 620 kN/m^2, and from 1160, 1210 and 1330 kN/m^2 to 780, 960 and 1020 kN/m^2 at the British Standard heavy energy level at 7, 14 and 28 days curing periods after three hours elapse time respectively.

Although, there is no established strength criterion for soil-lime/bagasse ash mix, using the 7 day UCS value of 1034.25 kN/m^2 normally utilized as criterion for adequate lime stabilization, it is observed that sample stabilized with 6 % lime/8 %bagasse ash did not achieve the required strength. The strength at 28 days however showed that the strength development of lime/bagasse ash is a slow process and a longer period would be required to attain the specified strength.

Durability assessment of the soil-lime-bagasse ash mix showed a decline in the resistance to loss in strength of the mixes with elapse time for all compactive efforts. There was however some increase in the UCS value of the mixes with increase in lime/bagasse ash content. A peak value of 50 kN/m^2 was attained at 6 % lime/8 % bagasse ash for BSL compactive effort. This declined to 20 kN/m^2 after three hours. Similarly, peak values of 120 and 200 kN/m^2 were attained for WAS and BSH energy levels at 6 % lime/8 % bagasse ash treatment. These values decreased to 58 and 60 kN/m^2 after three hours elapse time. The resistance to loss in strength values of tested specimens fell far short of the acceptable conventional 80 %, as reported by Ola (1974).

The CBR of the soil increased with increase in lime/bagasse ash content for all compactive efforts. Peak values of 14, 24, and 35 % were achieved at 6 % lime/8 % bagasse ash treatments for compaction BSL, WAS and BSH energy levels, respectively. These values represent increases of about 10, 18 and 25 % over the values of the natural soil of 4, 6, and 9 % respectively. The CBR values also showed gradual and steady decreases in values with elapse time. A decrease from 14 to 5 % after three hours elapse time was observed at 6 % lime/8 % bagasse ash treatment for BSL energy level. At the WAS and BSH compactive efforts, decreases from 24 to 11 % and 34 to 20 %, respectively, at 6 % lime/8 % bagasse ash treatment after three hours were recorded. None of these mixes fulfilled 30 % soaked CBR requirement for sub-base reported by Gidigasu and Dogbey (1980) as well as Osinubi (2001).

5.2 Recommendations

Based on the results obtained from this study, it is recommended that an optimal mix of 6 % lime/8 % bagasse ash be used for the treatment of black cotton soil compacted at British Standard heavy energy level. The delay between mixing and compaction should not exceed one and half hour.

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