EFFECT OF ELAPSED TIME AFTER MIXING ON THE PROPERTIES OF LIME – IRON ORE TAILINGS STABILIZED BLACK COTTON SOIL

BY

ANNAFI,BABATUNDE QAUDRI

DEPARTMENT OF CIVIL ENGINEERING,
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

AUGUST, 2021

EFFECT OF ELAPSED TIME AFTER MIXING ON THE PROPERTIES OF LIME – IRON ORE TAILINGS STABILIZED BLACK COTTON SOIL

BY

ANNAFI, BABATUNDE QAUDRI
P16EGCV8104

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING,
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY,
ZARIA NIGERIA

AUGUST, 2021

DECLARATION

The work in this dissertation titled **"**EFFECT OF ELAPSED TIME AFTER MIXING ON THE PROPERTIES OF LIME – IRON ORE TAILINGS STABILIZED BLACK COTTON SOIL**"** was accomplished in the Department of Civil Engineering by me. All information gotten from the published writings has been properly recognized and referenced. This work or portion thereof has never been submitted for award of degree or diploma at this or any other institutions.

ANNAFI, QAUDRI BABATUNDE

______________	________________	________________
Name of Student	Signature	Date

CERTIFICATION

This Dissertation titled **“**EFFECT OF ELAPSED TIME AFTER MIXING ON THE PROPERTIES OF LIME – IRON ORE TAILINGS STABILIZED BLACK COTTON SOIL**”** by ANNAFI QAUDRI BABATUNDE,satisfy the conditions for award of the degree of Master of Science (Civil Engineering) of Ahmadu Bello University, Zaria and is hereby approved for its literary presentation ad contribution to knowledge.

Prof. K. J. Osinubi

……………………………………. ………………….. ……………..

Chairman, Supervisory Committee Signature Date

Prof. A. O. Eberemu

……………………………………. ………………….. ……………..

Member, Supervisory Committee Signature Date

Dr. J. M. Kaura

……………………………………. ………………….. ……………..

Head of Department Signature Date

Prof. S. A. Abdullahi

……………………………………. ………………….. ……………..

Dean, School of Postgraduate Studies Signature Date

DEDICATION

This work is dedicated to the memory of my late parents Alh. Abdul Raheem Qaudri and AlhajaHafsatAnnafiQaudri for their immense love and for the very good solid educationalfoundation provided for me. I also wish to dedicate it to my dear sister Sakirat Annafi.

ACKNOWLEDGEMENTS

All praises; glorifications and adorations to Almighty Allah. The Lord of the universe for His infinite mercy on me throughout the work and always. My special appreciation goes to my supervisors Prof. K. J. Osinubi and Prof. A. O. Eberemu for their guidance, patience and words of encouragements at all times. I wish to appreciate my childhood friend, Prof. M. A. Ajibikeof Water Resources and Environmental Engineering departmentwho practically pushed me to commence the course at the time.

To the two most valuable women (my wives) in my life Mrs. Hannafi, Olufunmilayo. O. and Engr. Dr. Sholadoye, I. O. for standing by me all through laboratory works; write up and till date in the course of this work; I say a BIG Thanks to you two. My children, my warriors, thank you for your understanding and encouragement throughout the period of study and for providing me an avenue to ease out the stress.

Special thanks to the staff at Soil Mechanics Laboratory department of Civil Engineering A. B. U, Zaria, for their supports in various forms. My special appreciation to Mr. L. Idris, for the exceptional cooperation shown during my time in the laboratory.

I cannot but appreciate my colleagues for all their love, admiration and supports: MessrsT. Igboro, I. M.,Kanyi, T. Abdulmumin, C. I. Igbokwe, M. Ibrahim and A. Saeed thank you all.

ABSTRACT

The black cotton soil (BCS) used in the study was classified as A-7- 6(14) soil group of the American Association State Highways Transportation Officials (AASHTO) soil classification system and CH soil group in the Unified Soil Classification System (USCS). The study focused on the effect of elapsed time (i.e., 0, 1, 2 and 3 hours) after mixing on the properties of black cotton soil (BCS) treated with lime and iron ore tailings (IOT) in stepped concentration of 0, 2, 4, 6 and 8 % as well as 0, 2, 4, 6, 8 and 10 % by dry weight of soil, respectively. Tests were carried out on the natural and treated soil to determine index properties, compaction characteristics, unconfined compressive strength (UCS) and durability as well as California bearing ratio (CBR). Specimens were prepared using three (3) compactive efforts (i.e., British Standard light, BSL, West African Standard, WAS or 'Intermediate' and British Standard heavy, BSH).The results obtained show that the maximum dry density (MDD) of the BCS increased from 1.47, 1.55 and 1.63Mg/m^{3}for the natural soil to 1.60, 1.67 and 1.79 Mg/m^3 at 6 % lime / 10 % IOT treatment for BSL, WAS and BSH compaction, respectively. The corresponding optimum moisture content (OMC) values decreasedwith higher compactive effort and IOT content from 25.6, 20.3 and 19.0 % to 15.2, 15.8 and 16.8 % at 4 and 8 % lime / 10 % IOT treatment for BSL, WAS and BSH compaction, respectively.Peak UCS values of 2,696.51, 3,628.88 and 3,888.93 kN/m^{2}were obtained at 8 % lime/ 8 % IOT treatment within 0 -2 hours elapsed time after mixing for BSL, WAS and BSH compaction, respectively. Thereafter,the UCS values decreased with higher elapsed time after mixing for the lime and IOT contents considered. Peak CBR values of 147.5 %, 172.21 % and 229.31 % were obtained at 8 % lime / 8 % IOT treatment within 0 - 2 hours elapsed time after mixing for BSL, WAS and BSH compaction. However, CBR (un-soaked and soaked conditions) values decreased with higher elapsed time after mixing for the lime and IOT contents considered. The resistance to loss in strength increased with elapsed time. Durability value of 98.2 % was obtained at 3 hours elapsed time for BSL compaction from 96.1 % at 1 hour elapsed time after mixing.Microanalysis of specimens showed that the crystalline hydration products contributed to the strength of the treated soil. Statistical two - way analysis of variance (ANOVA) ofthe tests results show that effects of lime and IOT on the properties of BCS were significant. It is recommended that

BCS treated with 8 % lime / 8 % IOT when compacted with WAS and BSH energy and maximum 2 hours elapsed time after mixing be used as sub base and base material in the construction of low-volume roads.

TABLE OF CONTENTS

Contents **pages**

List of Tables

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BS	British Standard
BSH	British Standard heavy
BSL	British Standard light
CAH	Calcium Aluminate Hydrates
CBR	California bearing ratio
CSH	Calcium Silicate Hydrates
E	Young Modulus
Fcal	F -calculated
Fcrit	F –critical
G_S	Specific gravity
IOT	Iron ore tailings
LL	Liquid Limit
ρ_b	Bulk Density
ρ_d	Dry Density
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
OPC	Ordinary Portland cement
PI	Plasticity Index
PL	Plastic Limit
SEM	Scanning electron microscopy
USCS	Unified Soil Classification System
WAS	West African Standard

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Rapid urbanization and industrialization has made soil improvement a serious issue in the construction industry especially in areas where large deposits of poor soils are located. A soil improvement technique is the one that enhance the indicator and engineering properties of soft soils (Shaia*et al.,* 2016).

Black cotton soils occupy an estimated 104,000 km^{2}in the north-eastern part of Nigeria. They are a product of weathering of shaly and argilaceous deposits and volcanic rocks. They have extra montmorillonite with ensuing exhibition of expand- contract characteristics and inclination to excessively expand and shrink with adjustment in water content. The shrink – swell nature of the earth when in contact with water could result to pavement failure manifesting as disposition, cracks, and depressions. Building roads on soft soil is problematic since there is possibility of expanding and contracting with adjustment in water due to the presence of montmorillonite (Ola, 1983; Meshida*et al.,* 2013; Amadi, 2014; Hadi*et al.,* 2017).

Natural hazard such as earthquakes and flood cause damages to structures but expansive soils typically black cotton soil, cause more damage to light buildings and roads built on them. (Jones and Holtz, 1973; Ramesh *et al.,* 2013; Shailendra and Hemant, 2015). The use of these soils as sub grade materials is problematic because of their engineering and index properties. (Nelson and Miller, 1992; Pedarla, *et al.*, 2011; Ahmed *et al*., 2017; Ikeagwuani and Nwonu, 2019).

The plasticity index (PI) is one principal variable used in categorization of incompressible soils and it is the liquid limit value minus plastic limit value. Shrinkage limit (SL) is the water content where further loss of moisture will not result in any more volume reduction. Shrinkage effects can be seen as cracks in the soils and can negatively affect the performance of the soil. Liquid limit is widely accepted as an assessment of the toughness to cut - off the soil that is mushy. (Sowers *et al.*, 1959; Ramesh *et al.*, 2013). There is enhancement in the plasticity, workability and stability properties of fine grained soil with inclusion of small quantities of lime (Diamond and Kinter, 1965; Bell, 1988a.b, 1996; Pei *et al.*, 2015; Firoozi*et l.*, 2017; Jayashree and Roja, 2019).

The engineering properties of expansive soils can be improved upon with little proportion of lime and other admixtures. This methodof soil improvement isemployedin many building construction such as main road, railroad and airport works to enhance sub grades and sub-bases. Usually, inclusion of lime and cement to weak soils for improvement has become needful for construction works (Ola, 1983; Balogun, 1991; Matawal and Tomarin, 1996; Shailendra and Hemant, 2015; Vaibhav and Shrikant, 2017; Ayininuola and Balogun, 2018; Pastor *et al.*, 2019) but the cost is usually very high.

Several pavements in Nigeria fail because of soil with insufficient strength. Therefore improving engineering properties of soil especially black cotton soils becomes a great concern to transportation engineers. In an attempt to enhance the engineering characteristics of weak soil, to make them satisfactory for construction works, several researchers (Osinubi and Medubi, 1997a, b; Osinubi, 2000; Cokca, 2001; Medjo and Riskowiski, 2004; Osinubi and Eberemu, 2005; 2009; Osinubi and Stephen, 2006; Moses, 2006, 2008; Alhassan and Mustapha, 2007; Osinubi*et al.*, 2007a,b, 2009; Osinubi and Alhassan, 2008; Ali and Koranne, 2011; Kumar and Prasanna, 2012; Kanalli *et al.*, 2015; Ravi *et al.*, 2016; Etim*et al.*, 2017; Ayininuola and Balogun, 2018; Jayashree and Roja, 2019) have studied the use of possible agro-industrial waste materials that can be beneficially reused to enhance the characteristics of weak soils.

Tailings are waste products of mining industries which are made up of silicon oxide particles and powdery ore. Storage and handling of these tailings is a serious environmental concern. Safe disposal and utilization of the tailing is also a technological challenge.Nigeria is a rapidly growing nation with ample inorganic wealth. The iron ore reserve at Itakpe in Ajaokuta, Kogi State, Nigeria, has an approximate savings of about 182.5 million metric tonnes. The conception is to process a minimum of 24,000 tonnes of ore per day (Elinwa and Maichibi, 2014).

Iron Ore Tailings (IOT) is the waste from refining of mined iron ore at Itakpe, Kogi state, Nigeria which is about 3,072 tonnes/day (Ajaka, 2004; 2009). The proper disposal of the waste is important in order to reduce the nuisance it poses. Iron ore tailings can beused as a secondary source of about 20-22% iron minerals and also in concrete works as supplementary materials (Elinwa and Maichibi 2014).The creation of artificial tailing ponds or dumpsites creates a negative environmental impact such as air and water pollution, and deforestation (Ghose and Sen 1999; Shailendra and Hemant, 2015; Etim*et al.*, 2017). The tailings have to be disposed so as to free the seized land and make clean the polluted environment.

A study carried out by Ishola (2014) on IOT modification of lateritic soil showed that the additive IOT could not alone achieve the required result. Researchers such as Yisa, (2014),Yohanna, *et al.*, (2014), Etim, *et al.*, (2014) and Samadou, (2015) also stabilized black cotton or lateritic soil blending iron ore tailings (IOT) with lime or cement. Lime has been confirmed to be a supplement that beneficially enhances the engineering characteristics of fine-grained soils. It decreases the softness and shrink–swell characteristics as well as enhancing the stability of the soil. (Katti*et al.*, 1966; Katti and Kulkarni, 1996; Nadgouda and Hegde, 2010; Shailendra and Hemant, 2015; Etim*et al.*, 2017). It has also been confirmed that the extent of dispersed double layers was reduced with inclusion of lime due to increase in the combining power of transposable ion or the electrolyte cluster (Sridharan and Jayadeva 1982; Nadgoudaand Hegde, 2010; Ramesh *et al.*, 2013; Amruta *et al.*, 2015; Etim, *et al.*, 2017).

On construction site, compaction and final shaping should follow immediately after mixing/placing is done. It is not always so as there are occasional hold – up between mixing/placing and compaction due to unexpected situations (Okonkwo, 2009). Elapsed time or delay time is the interval between mixing/placing and compaction of the soil with the modifier so as to produce desired and workable characteristics for the weak soil (Trindade, 2005; Osinubi*et al.*, 2012; Sani *et al.*, 2014; Eberemu*et al.*, 2015).

1.2 Statement of the Problem

Industrial and agricultural wastes cause air and water pollution as well as occupying useful land; therefore management of waste such as tailings is a serious issue not just for pollution control, but preservation of the environment. Tailings are stacked forming embankment that can be eroded, cut down or completely breach and collapse (Toland, 1977; Ghose, 1997; Sen and Ghose 1997; Ramesh *et al.*, 2013; Shivam*et al.*, 2017; Etim*et al.*, 2017). The processing of iron ore produce huge amount of tailings (Ajaka 2009; Adepoju and Olaleye, 2001).

Mine tailings (e.g., iron ore tailings, IOT) can be beneficially used in civil engineering works thereby reducing the disposal issues and environmental menace (Pebble Project, 2005; Sabat*et al.*, 2015; Vaibhav and Shrikant, 2017; Etim*et al.*, 2017). The index characteristics of black cotton soil can be improved with mine tailings (Ramesh, *et al.*, 2013; Etim*et al.*, 2017). However in the field, during construction most times, delay time after mixing/placing is unavoidable because of any of the following reasons: sudden rain; breakdown of compaction equipment after mixing; insufficient workers; poor transportation etc. This elapsed time after mixing before compaction might affect the reaction within the black cotton soil- lime- iron ore tailings mixture thus leading to changes in properties.

1.3 Justification for the Study

The waste from mining industries has to be managed by finding cost effective and economic way to utilize or re – use this waste thereby reducing problems associated with waste disposal. The creation of these artificial tailing ponds or dump sites generates issues of environmental contamination and great effect on farm (Ghose and Sen, 1999; Shailendra and Hemant, 2015; Sabat*et al.*, 2015; Etim*et al.*, 2017). When the tailings are not taken care of, the environment will be polluted and land with other useful resources cannot be conserved.

Improvement in soil properties by soil stabilization has been attributed to the soil – lime reaction (Clare and Cruchley 1957; Locat*et al.*, 1990; 1996; Pei *et al.*, 2015). The chemical changes taking place in the soil properties for soil – lime mixes can be explained with the cation exchange, effervescent and pozzolanic reaction that occurred between soils – lime mixes (O'Flaherty, 2002). Cation exchange is assumed accountable for the change in plasticity of the soil, and magnitude of this change is influenced by the soil silicate layer. Montmorillonite soils show greater change, the effect in illite - chlorite is intermediate and effect in kaolinite soil is less (Hitt and Davidson, 1960; Nadgouda and Hegde, 2010).

Research works by Mohammedbhai and Baguant (1990), Cokca (2001) as well as Medjo and Riskowski (2004) have revealed that industrial and agro - industrial wastes can favorably enhance the behaviour of soils.

Similarly, Kamon and Katsumi (1994), Yorimichi and Kazuhiko (1999), Rezende, and Carvalho (2003); Phanikumar and Sharma (2004); Qian *et al.* (2011); Kumar (2012); Sivrikaya*et al*. (2013); Ugama*et al.,*(2014); Kanalli*et al.,*(2015); Ravi *et al.,*(2016); Etim*et al.,*(2017),carried out studies on the use of factory wastes such as batholiths; verdantiqut and other stone wastes to modify/stabilize soft soils. The authors reported that factory wastecould improve the properties of expansive soils when used in such soil modification or stabilization either as a stand-alone or as admixture. The stabilization/modification improves the properties of soil through reactions like cation exchange; aggregation of soil particles and formation of cementitious silicate and aluminate hydrates (Bell, 1988a, b). Shivapullaiah*et al.*(1996) confirmed fly ash decreased plasticity and swelling nature of clayey soils.

Studies have been carried out using IOT alone (Ishola, 2014; Yisa, 2014; Samadou, 2015) and as admixture (Yohanna, *et al.,* 2014; Etim*et al.*, 2014) in lime or cement modification / stabilization of black cotton soil. However, little attention has been given to study of the allowable delay between mixing the soil with the additives and subsequent placement and compaction.

This study focused on the improvement of lime stabilized black cotton soil using IOT as admixtures invarying percentages with elapsed time (0 to 3 hours) after mixing and subsequent determination of the optimum quantity of the lime-iron ore tailings blend at maximum allowable delay time required to improve the soil properties. The technique minimizes the environmental problems associated with disposal of iron ore tailings.

1.4 Aim and Objectives

The aim of the research was to assess the effect of elapsed time after mixing on the properties of lime – iron ore tailings stabilized black cotton soil when used for road works.

The specific objectives of the study include:

i. Characterizations of the natural and the treated black cotton soil.
ii. Evaluation of the effect of 0 hour - 3 hours elapsed time after mixing on thewater-density relationships for the various compaction delays at different compaction energies (i.e, British Standard light(BSL), West African Standard(WAS) and British Standard heavy (BSH) considered
iii. Evaluation of the effect of 0 hour to 3 hours elapsed time after mixing on strengthcharacteristics (i.e., California bearing ratio (CBR) and unconfined compressive strength(UCS) and durability of the stabilized soil.
iv. Determination of the maximum allowable delay time after mixing for the optimallystabilized soil.
v. Statistical analysis of tests results using 2 – way analysis of variance (ANOVA)
vi. Determination of the microanalysis of optimally treated soil using Scanning Electron Microscope (SEM)

1.5 Scope of the Study

The scope of work includes the establishment of the strength properties of black cotton soil stabilized with 2 to 8 % lime and admixed with 2 to 10 % iron ore tailings at 0, 1, 2 and 3 hours elapsed time after mixing. All tests were done in accordance with BS1377 (1990) and BS 1924 (1990) for the natural soil and treated soil, respectively.

CHAPTER TWO

LITERATURE REVIEW

2.1 Black Cotton Soil

Black cotton soil is a typical example of a weak soil (Tomlinson, 1999; Osinubi*et al.*, 2010; 2012; Harish, 2017;Adewuyi and Moatshe, 2019; Pardakhe and Ban, 2019) and is found in the north-eastern part of Nigeria, part of northern and southern Africa, etc. The soil is also found in India, Australia, South west of the United States of America and Israel (Plait, 1953; Ola, 1978; Osinubi *et al.*, 2011; Mohammed*et al.*, 2017; Ikeagwuani and Nwonu, 2019).

Sedimentary rock from volcanic eruption, which are located in North America, South Africa and Israel together with the igneous rocks located in Nigeria, India, parts of USA and Israel are the parent rocks for the formation of expansive soils (Plait, 1953; Medjo and Riskowiski, 2004; Ikeagwuani and Nwonu, 2019). There are many names and definitions for black cotton soil but technically, it is a dark grey/black soil having high clay content of over 50% with montmorillonite being the principal clay mineral and very expansive (Morin, 1971; Osinubi*et al.*, 2010, 2012; Dinesh *et al.*, 2017; Harish, 2017). The soils have the tendency to expand and shrink with changes in water content due to the clay particles. The expansion and contraction of black cotton soil cause damages to footings of structures placed on it, thus durability and safety of the structures cannot be guaranteed. The abnormal settlement of footings due to very little resistance to pressure has to be checked hence lots of works and energy on the enhancement of expansive soil especially when wet has been put into its study.

2.2 Iron Ore Tailings

Iron ore geological conserve in Nigeria is an iron – bearing quartzite deposit totaling 200 million tonnes (Umar and Elinwa, 2005; Ajaka, 2009).The iron ore deposit at Itakpe Nigeria with an approximate storage of about 182.5 million metric tonnes made up of quartzite, magnetite and hematite (Soframine, 1987). This deposit is vital to the national growth of iron and steel production in Nigeria.However, other silico-ferruginous formations along Lokoja- Okene-Kabba triangle of Ajabonoko Hill and ChokoChoko are homogeneous to those at Itakpe (Ajaka, 2009).

Beneficiation of iron ore produce iron ore tailings as a waste. The process of improving the percentage iron content of the ore leads to production of large quantities of tailings (Olubambi and Potgieter, 2005; Ajaka, 2009; Adepoju and Olaleye, 2001) which are dumped as wastes. Table 2.1 shows constituent of Itakpeiron ore tailings and Table 2.2 shows some properties of tailings from Itakpe in Nigeria.

Table 2.1 Constituents of the Itakpe tailings.
a.

Chemical component	Fe_2O_3/Fe_3O_4	SiO_2	Others
Average composition %	22	78	2

(Soframine, 1987)

b.

Oxide	**Percentage by mass IOT***	**Percentage by mass IOT****	**Percentage by mass IOT*****
SiO_2	71.00	45.64	61.477
Fe_2O_3	15.00	47.7	0.2312
Al_2O_3	2.62	3.36	20.6630
CaO	01.20	0.607	11.8924
MgO	0.30	0.393	4.1640
Na_2O	1.20	0.405	
TiO_2	0.20	0.24	
K_2O	0.08	0.607	
SO_3	0.03	-	
Others	_	_	1.6295

*(Elinwa and Maichibi, 2014); ** (Ishola, 2014);***Adedayo and Onitiri,(2012)

Table 2.2: Physical Properties of Itakpe Iron Ore Tailings

Parameter	IOT
Specific gravity	3.51
Loose bulk density (kg/m3)	1650
Loss of ignition (%)	**-**
Specific surface (m2/g)	**-**
Soundness (mm)	**-**
Moisture Content (%)	**0.2**
pH	**13.11**

(Elinwa and Maichibi, 2014)

2.3 Pozzolan

Pozzolan is a silicate, or aluminate-like substance that is not cementitous on its own but in a powder or liquid form in the presence of moisture undergoes chemical reaction with calcium hydroxide to yield cementitious composites like calcium silicate and calcium aluminate hydrates. (Amadi and Osu, 2016). The constituents of Itakpe tailings from two sources with higher percentage of Silicon oxide and Aluminum oxide which are common features of pozzolans are summarized in Table 2.1 in agreement with the properties listed in ASTM. C – 618-12a (2013).

2.4 Stabilization

Stabilization as an improvement technique is the processes of improving the index and engineering properties of the natural soil. In pavement construction, the principal goal of stabilization is to improve the strength hence stability of the soil, thereby cutting cost by using nearby materials.

Soil stabilization involves the changes or control of any property of a soil and not just about increase or decrease of the properties (Osinubi and Katte, 1997; Al - Swaidani*et al.,* 2016). This changes or control of the soil characteristics can be chemical and physical with the main goal being improving the load carrying ability of the soil, its resistance to weathering process and soil permeability. The durability of any construction work is based on the fitness of the subsoil. Therefore, problematic nature of unstable soils necessitate soil stabilization technique which makes sure the soil stability is good enough to effectively carry the imposed load; saves time and money compared to cutting and replacement of unstable soils.

The soil – water reaction is one main factor that determines the safety of structures placed on them (Alhassan, 2008b; Osinubi*et al.,* 2011; Amadi, 2014; Yin *et al*., 2018; Jiang *et al*., 2019). Therefore making weak soils meet the required geotechnical design is important. Alternative idea is to enhance the available soil to meet the required standards (Alhassan and Mustapha, 2007; Alhassan, 2008a; Osinubi*et al.,* 2011; Amadi, 2014;Yin *et al*., 2018; Jiang *et al*., 2019).

2.4.1 Mechanical Stabilization

It is a stabilization process that brings changes in soil gradation through compaction, cutting and replacing bad soil with granular materials or mixing with other soils. Sub grade that is wet and soft can be covered or replaced with granular material up to a given depth. The granular layer when compacted spreads the wheel loads over large area. For the granular material layer to effectively serve as working platform, it shall meet the following conditions (Thomson, 1977; Office of Geotechnical Engineering, 2008; Onyelowe, 2012; Afrin, 2017;Ikeagwuani and Nwonu, 2019):

i. The granular materials must be thick enough to distribute pressure over the wet soils.

ii. Materials used for backfilling must not rut under wheel load.

iii. Compaction of backfilling materials should be according to the specifications.

2.4.2 Chemical stabilization

This is an improvement technique that changes the physical and chemical characteristics of a soil with inclusion of chemicals like lime, fly ash, Bitumen, cement or any of these combined. The basic process by which chemicals stabilize sub-grade materials include (Thomson, 1977; Office of Geotechnical Engineering, 2008; Onyelowe, 2012; Al – Swaidani *et al*., 2016; Firoozi *et al*., 2017):

i. The soil particles combine and become bigger; increase in internal friction among combined particles; increased resistance to shear stressand decrease in plasticity and potentials to contract or expand.

ii. Water absorption and chemical reaction will make compaction easy and good.

2.5 Benefits of Soil Stabilization

The option to stabilize a wet – soft subgrade will reduce/ remove the cost of cutting and cart away to spoil of the bad soil replacement with good soil. Stabilization also reduce the delays from weather and solve problems associated with disposal of waste which is our main concern.

Other Benefits of soil stabilization include: (National Lime Association 2001)

i. Resilient modulus improved appreciably.

ii. Shear strength is improved appreciably

iii. There is continuous gain of strength with time

iv. Durability in long term even under severe environmental conditions.

v. Lime stabilized layers structurally can create a cost effective alternative in pavement design of short term while in the long term lime stabilization gives results that bring about cost reduction in maintenance.

2.6 Previous Work on Soil Stabilization

Studies had been done using industrial waste to strengthen weak soils. Many researchers have made efforts in improving weak soil using binders, industrial and agricultural waste and combination of both (Mohammedbhai and Baguant, 1990; Osinubi, 1998a, b; Osinubi and Medubi, 1997a, b; Osinubi*et al.*, 2009; Oyekan *et al*., 2013; Salahudeen *et al*., 2014; Pravin and Mahiyar, 2014;Maneli *et al*., 2015;Ikeagwuani, 2016; Dalal *et al*., 2017; Etim *et al*., 2017; Patil *et al.*, 2019). Ingles and Metcalf, (1972) as well as Kedzi (1979) recommended 2 - 3 % of hydrated lime for soil modification, While Yoder and Witczak (1975) as well asPortelinha*et al.* (2012) recommended 0.5 - 4 % lime for the same process. Eades and Grim (1960, 1996), and Sherwood (1993) recommended 4 - 6 % for Kaolinite, about 8 % for illite and montmorillonite. Ola (1978) established a linear relationship between the strength of lime – stabilized black Cotton soil and up to 10 % lime content. Akawwi and Al- Kharabsheh (2002),Nadgouda and Hegde (2010) used 3.5 – 5 % quicklime to stabilize Amman's expansive soils.

Akwuete lateritic soil was stabilized using 4 - 6 % cement admixed with 10% bagasse ash(Onyelowe, 2012). Kiran and Kiran (2013) reported that the strength characteristics of black cotton soil stabilized using bagasse ash with binders improved itsengineering characteristics at 8% bagasse ash and 8 % cement optimum treatment.Ikeagwuani,2016 reported that there were significant improvements in the compressibility characteristics of the black cotton soil when a combination of 16%SDA and 4% lime of the weight of black cotton soil were added to it.

The influence of the waste materials added for different compaction levels and curing periods improved the CBR and UCS values significantly(Maneli *et al*., 2015). UCS of the stabilized BCS meets the specification for sub-base material at 97% and 100% compaction for all the curing periods.

A study of theinfluence of compactive efforts on cement-bagasse ash treatment on expansive black cotton soil by Moses and Osinubi (2013) showed that 8 % cement / 4 % bagasse ash was optimal blend treatment for sub-base materials. Etim, *et al.* (2014) studied the effect of lime- iron ore tailings (IOT) blend on the expansive nature of black cotton soil. The findings showed increased maximum dry density (MDD) value as compactive efforts and IOT content increase and decreasing OMC was observed with higher IOT content. However, an optimal blend of 8 % lime / 8 % IOT treatment was recommended for sub-grade using British Standard heavy energy.

Yohanna, *et al.* (2014) recommended an optimal treatment of 4 % cement / 6 % IOT to improve properties of black cotton soil for sub grade materials.Yisa, *et al.* (2014) and Samadou (2015) both studiedthe effect of iron ore tailings on lateritic soil and black cotton soil respectively. Their results showed that IOT cannot be used as a stand-alone additive, but as an admixture in either lime or cement stabilization. Yisa*et al.* (2014) reported IOT enhanced the characteristics of the lateritic soil, while Samadou(2015) recommended an optimal 10 % IOT treatment to enhance the characteristics of black cotton soil using very high compactive effort (BSH).

The effect of elapsed time after mixing on the properties of cement- locust bean waste ash modified lateritic soilwas studied byAbdullahi (2011). The author reported that an optimal mix of 2 % cement / 6 % LBWA can be used to modify lateritic soil at an optimum 2 hours elapsed time after mixing.On the other hand, Nwadiogbu (2012) studied the effect of elapsed time after mixing on lateritic soil modified with lime and locust bean waste ash.Theauthor recommended that the delay between mixing and compaction should not exceed 2 hours for an optimal 2 % lime / 6 % LBWAtreatment of lateritic soil used as sub-base materials.

CHAPTER THREE

MATERALS AND METHODS

3.1 Materials

3.1.1 Black Cotton Soil

The soil used was obtained from Deba- Gombe township road, 100 m from Yamaltu/Deba Local Government Secretariat, Deba, Gombe State, Nigeria; located between latitude 10^{o}13' and 10^{o} 2' North and longitude 11^{o} 23' and 11^{o} 38' East, on the geographical map of Nigeria. The samples were carefully taken at depths representative of the soil stratum about 0.5m from an open excavation. The samples were taken to the Soil Mechanics Laboratory of the Department of Civil Engineering in Ahmadu Bello University, Zaria. Air-dried and crushed specimen passing through B.S. No.4 sieve (4.76 mm aperture) was used for the various tests carried out.

3.1.2 Iron ore tailings

The iron ore tailings (IOT) was collected from the premises of the National Ore Mining Company, Itakpe in Kogi State, Nigeria (Longitude 6° 16 E Latitude 7° 39'N).The tailing was sieved and samples passing through Sieve No. 200 with 75µm opening were used.

3.1.3 Lime: lime was sourced from the open market at Kaduna, Kaduna State.

3.2 Methods

3.2.1 Natural moisture content

The natural moisture content of the soil was ascertained in accordance with BS 1377 (1990) Part 2. Weighing containers were cleaned and weighed on weighing balance of 0.01g accuracy. The empty container was weighed as M_1. The collected fresh sample was crumbled and put inside weighed container and the container plus sample was weighed as M_2. The containers with the fresh sample were put in an oven for 24 hours to dry at 105 – 110^{o}C. The oven dried sample were brought out and weighed as M_3 to the nearest 0.01g. The average of the three containers of the oven dried samples gives the natural moisture content of the soil computed by Equation. (3.1)

$$w\ \% = \frac{(M_2 - M_3)}{(M_3 - M_1)} \times 100 \qquad (3.1)$$

Where;

w is the moisture content (%), M_{1} - the weight of empty container (g), M_{2} - the weight of container + fresh soil (g) and M_3 - the weight of container+ dried soil (g)

3.2.2 Specific gravity

Specific gravity was ascertained in accordance with BS 1377 (1990) test (B) for soft soils. The density bottles with the stopper were weighed (M_1). The air dried soil was put into the density bottle, and the bottle plus content with the cover were weighed as M_2. The density bottle plus soil was filled with water and the mixture stirred to remove air bubbles. The density bottles with the solution was dried with cloth and weighed as M_3. The density bottle was emptied and filled with water alone and was weighed as M_4. The experiment was carried out using three(3) bottles per samples and an average taken. The specific gravity for the sample was computed using Equation. (3.2):

$$G_s = \frac{(M_2 - M_1)}{(M_4 - M_1)(M_3 - M_1)} \qquad (3.2)$$

Where;

$G_s$is the Specific gravity, M_1- the weight of empty density bottle (g), M_2- the weight of density bottle + dried soil (g), M_3 - the weight of density bottle + soil + water (g) and M_4 - the weight of density bottle filled with water (g).

3.2.3 Sieveanalysis of the Natural Soil

3.2.3.1 Wet sieving

Hydrometer Method

The test was carried out in accordance with BS 1377(1990) Part 2. This is the procedure for the determination of the particle – size distribution in a soil for the fraction is that finer than No.200 sieve (0.075mm). Incomplete dispersion of soil clays results in low values for clay and values for silt and sand. 200 gof the oven dried soil sample was weighed, wet sieved to remove clay and silt particles using BS No. 200 (0.075 mm) sieve under tap water. The percentage passing 75 micron sieve is transfer into 1000ml measuring cylinder and distilled water added to make the volume to 1000 ml. The percentage retained on 75 micron sieve was put in the oven to dry. The washing was done carefully to avoid damage to the sieves and the sample was put in an oven to dry at 105 ˚C. The oven-dried samples were transferred unto BS sieves arranged in descending order and then shaken for at least 10 minutes manually. After sieving, the retained sample on every sieve was weighed and % passing was calculated.

3.2.3.2 Dry sieving

The particle size analysis was done in accordance with BS 1377: 1990 Part 2. A part of the dried soil sample passing sieve no. 40 (425 μm aperture) was used in carrying out dry sieving test. The 200g of the dried sample was mixed with the optimum moisture content obtained from compaction test and air drying it in the laboratory for 48 hours. Dry sieving was carried out on the dried sample and the results plotted to get the particle size distribution.

3.2.4 Atterberg limits

The Atterberg limits tests carried out are liquid limits, plastic limits and the plasticity index for the natural and treated soil. The tests were carried out in accordance with Test 1(A) BS 1377 (1990) Part 2.

3.2.4.1 Liquid limit

200g of air-dried soil that passed BS No. 40 sieve (425 μm apertures) was used for liquid limit. The sample with required percentages of the additives were put on flat glass plate and mixed with water thoroughly to give homogeneous paste. A part of the soil mixture was put in the cup of Casgrande apparatus and levelled off parallel to the base with spatula. Grooving tool was drawn through the centre of the hinge to divide the portion into two parts. The cup was lifted up and dropped by turning the crank till the two parts closed at the bottom of the groove. The number of blows at which the groove closed up are recorded and sample of the soil remove for moisture content. The determined moisture content was plotted against the number of blows and the liquid limit was the moisture content corresponding to 25 blows.

The soil fraction passing 425μm sieve was mixed with lime and iron ore tailings for the percentages earlier stated at the optimum moisture content, sealed up in a polythene bag left to stand for the elapsed time of 0; 1; 2 and 3 hours after which the test procedure was repeated.

3.2.4.2 Plastic limit

A part of the mixture used for the liquid limit test was retained for the plastic limit test. The portion of the soil was formed into ball and rolled in between palms of the hands to become dried. The dried sample was divided into four parts. Each part was spun on the glass plate into thread of about 3mm diameter till it breaks.

3.2.4.3 Plasticity index

The plasticity index (PI) of the soil is the liquid limit (LL) minus the corresponding plastic limit (PL). The plasticity index was calculated using Equation (3.3) as:

$$PI = LL - PL \qquad (3.3)$$

Where:PI - the Plasticity Index (%), LL - the Liquid Limit (%) and PL - the Plastic Limit (%)

3.2.5 Compaction

3.2.5.1 Maximum dry density

Compaction test were done for the natural and treated soil using British standard light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) energies.

3000g of the air-dried sample were weighed and poured into a wider metallic pan, crushed to smaller particles and water added in varying water content at an increment of 8% equivalent added for every compaction.

For British Standard light (BSL), the soil sample were compacted in 3 layers with 27 blows using 2.5kg rammer dropping from a height of 300mm for each of the layers in 1000cc mould. The blows were spread all over the sample surface and collar removed after completion of the blows to the last layer. The top was levelled with a spatula and the mould with the soil sample weighed. Two representative samples were taken at both faces of the compacted sample for moisture content. The compacted soil was extruded from the mould into the large wide tray and crushed again before adding another water content and procedure were repeated until the weight of the compacted soil dropped. For the elapsed time for the natural and stabilized soil, the additives (lime and iron ore tailings) were added in their stated percentages to the black cotton soil and water content added. Each of the soil samples were tied in a black cellophane bag and allowed to stay for 0, 1, 2 and 3 hours before compaction was carried out on them.

In West African Standard (WAS) compaction, the same procedure was followed except that 10 blows were applied using 4.5kg rammer dropping from a height of 450mm for 5 layers in 1000cc mould. And for British Standard heavy (BSH), the same process as WAS except that the blows were 27 for the 5 layers.

The plotted graph gave the maximum dry density and the corresponding optimum moisture content. The bulk density is given by Equation (3.4)

$$\rho_b = \frac{M_s}{V_s} \quad (3.4)$$

Where:

ρ_b-Bulk density (kg/m³), M_s- Weight of compacted soil (kg) and $V_s$is thevolume of Mould (cm³).

The dry unit weight was determined using the expression in Equation (3.5)

$$\rho_d = \frac{\rho_b}{1-w} (3.5)$$

Where: ρ_d- the Dry density (Mg/m³), ℓ_b - the Bulk density (kg/m³) and the moisture content (w) was determined using Equation (3.1)

3.2.5.2 Optimum moisture content (OMC)

The corresponding values of moisture contents at maximum dry densities (MDD) deduced from the graph of dry density against moisture contents, gives the optimum moisture content (OMC).

3.2.6 Strength characteristics

3.2.6.1 Unconfined compressive strength

The unconfined compressive strength (UCS) tests were carried out on the natural and stabilized soil samples in accordance with BS 1377; 1990 Part 7. Both natural and stabilized were compacted with the energy level in a 1000 cm^3 mould using appropriate optimum moisture content. The soils with admixtures in varying % were prepared with their appropriate optimum moisture content (OMC). The samples were left to stay for their various elapsed time of 0, 1, 2 and 3 hours in various cellophane bags before carrying out compaction in a 1000 cm^3 mould using BSL; WAS and BSHcompactive effort. Cylindrical specimen of 38mm diameter and 76mm length were used to extrude the compacted soil and each was waxed for 7 days, 14 days and 28 days to cure. The waxed samples were dewaxed at the end of curing period, put on the plate of the compression testing machine and a compressive force was applied. The axial deformations and forces at regular interval before failure were taken and recorded. The recorded data were plotted on the stress – strain curve and the UCS were determined as the point of failure. The UCS was calculated usingEquations (3.6) and (3.7).

$$\delta = \frac{[R \times C_e \times (100 - E\%) \times 1000\, kN/m^2]}{100 \times A_o} \tag{3.6}$$

Where:

$$E\% = \frac{v}{L_O} \tag{3.7}$$

E% - the Strain per cent, v - the amount of compression at any stage, R - the Load ring reading at strain E, C_{r-} the Mean calibration of load ring, L_{o-} the Original length of specimen, A_{o-} the Original cross sectional area and δ- the Compressive stress at strain E.

3.2.6.2 California bearing ratio

California bearing ratio (CBR) is the ratio of the plunger exerted force to the penetration depth into the specimen. The California bearing ratio (CBR) were done on the natural and lime/IOT treated black cotton soil according to BS 1377 (1990) and BS 1924 (1990).

5000 g of the soil sample were blended with lime/IOT in the stated percentages at their appropriate optimum moisture contents and put in various nylon bags for 0, 1, 2 and 3 hours. Each of the sample was then placed in BS mould of 2350 cm^3 and compacted using BSL, WAS and BSH energies. For BSL, the layers are three (3) and 62 blows from 2.5kg rammer; while for WAS, the layer are five (5) with 25 blows from 4.5kg rammer and BSH has 5 layers with 62 blows rammer. The base plates were removed and the compacted specimens placed in sealed plastic bags for 6 days during and after the sixth day, the specimens were immersed in water for 24 hours before testing according to Nigerian General Specifications (1997).

The base plates were replaced and the specimens placed on the lower plate of the CBR testing machine. The plunger was then made to penetrate the specimen at a given rate until the specimen failed. The mould was then inverted, base plate removed and the procedure repeated for the other surface of the specimens.

From the values of the penetration and force recorded, a curve of force against penetration was obtained. The CBR value was calculated at penetration 2.5 mm and 5.0 mm; the greater of the two values or their means where the value are within 10 % of each other. The CBR was calculated using Equation. (3.8)

$$CBR(\%) = \frac{\text{Measured Load}}{\text{Standard Load}} \times 100 \qquad (3.8)$$

Where, standard load = 13.24 KN at 2.5mm penetration

= 19.96 KN at 5.0mm penetration

3.2.7 Durability assessment

The durability assessment of the natural and treated soils when subjected to harsh field condition was assessed by the resistance to loss in strength, when immersed in water. It was demonstrated as the ratio of UCS of the specimen wax-cured for 7 days, de-waxed top before being soaked for another 7 days to the UCS of the specimen cured for 14 days.

3.2.8 Microanalysis

Research in soil microstructure has shown growing interest in recent year. The image of soil microstructure shows some micro-parameters such as porosity and soil particle orientation degree (Wei, 2010). The scanning electron microscope (SEM) observations were done on air-dried samples of 8 - 10 mm in diameter, broken and covered by a layer of gold to prevent electrisation. The viewing of the surface of the fracture was made by scanning electron microscope using rays of dynamic electrons to create different indications on the solid specimens. The photographs were taken at: x4800 and x5300 magnifications. The lesser magnified images were used to decide the assessable pore space parameters, while the x5300 magnified images made it possible to distinguish the microstructure qualitatively, among other things to decide the types of contacts.

3.2.8.1 Sample preparation and launching

Soil sample was collected, sieved through BS No 4 and compacted using British standard light (BSL) energy level and cured for 7 and 28 days respectively. Specimens were placed and secured onto the stage which is controlled by a goniometer. The SEM created a 2 -dimensional image which show dimensional spatial variations in their properties. Areas ranging from approximately 1 cm to 5 microns in width were as imaged in a scanning mode using conventional SEM techniques (magnifications ranging from 20X to approximately 30,000X, spatial resolution of 50 to 100 nm). Vital parts of all SEM include the following: Gun (Electron Source), Electron Lenses Sample Stag, Detectors for all signals of interest.

3.2.9 Statistical Analysis

The methods of analysis used in this research are:

1. Graphical method using Microsoft excel software package.
2. Two-way analysis of variance (ANOVA) without replication using the Microsoft excel software package.

3.2.9.1 Graphical Method

In the graphical method, graphs were used to show the connection between two variables. An individualistic variable usually is plotted on the X-axis and a dependant variable on the Y- axis. The graphs were plotted using the Microsoft excel package.

3.2.9.2 Two - way analysis of variance (ANOVA) without replication

Analysis of variance (ANOVA) checks statistically the notable difference of means of two or more group. ANOVA checks the effect of one or more factors by differentiating the means of different samples (Singh, 2018). According to Zar (1999) two-way ANOVA on the other hand would not only be able to assess both time and treatment in the same test, but also whether there is an interaction between the parameters. A two-way test creates three p-values, one for each parameter independently, and one measuring the interaction between the two parameters.

In this method, the aim of the analysis was to find out if there was any significant effect on the various black cotton soils – lime – iron ore tailing mixtures with respect to the various treatments and elapsed time.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Index Properties

4.1.1 Black cotton soil

The natural black cotton soil is fine-grained and dark grey in colour with 67.9 % passing No. 200 sieve, liquid limit of 60.3%, plastic limit of 32.6% and plasticity index of 27.7%.The soil classifies as CH soil in the Unified Soil Classification System, USCS (ASTM, 1992) or A-7-6(19) according to AASHTO soil classification system (AASHTO, 1986). The properties of the natural soil are summarised in Table 4.1. In its natural state, the soil cannot be used in engineering works such as highway construction and therefore requires improvement (Butcher and Sailie, 1984; Osinubi and Medubi, 1997a, b; Nadgouda and Hegde, 2010; Shailendra and Hemant, 2015). Detailed tests results are given in Tables A – G in the Appendix.

Table 4.1: Properties of the natural black cotton soil

Property	Quantity
Percentage passing BS No 200 sieve, (%)	67.90
Natural moisture content, (%)	11.90
Liquid limit, (%)	60.34
Plastic limit, (%)	32.62

Plasticity index, (%)	27.72
Specific gravity	2.29
AASHTO classification	A-7-6(14)
USCS	CH
Maximum Dry Density, (Mg/m^3)	
British standard light	1.47
West African standard	1.55
British standard heavy	1.63
Optimum moisture content, (%)	
British standard light	25.62
West African standard	20.32
British standard heavy	19.0
Unconfined Compressive Strength, (kN/m^2)	
British standard light	163.31
West African Standard	554.25
British standard heavy	557.49
California Bearing Ratio, (Unsoaked) (%)	
British standard light	2.54
West African standard	3.08
British standard heavy	5.44
California Bearing Ratio (24 hours soaking), (%)	
British standard light	1.18
West African standard	1.63
British standard heavy	2.72
Colour	DarkGrey

4.1.2 Additives

Iron ore tailings is a pozzolana and is classified as Class N according to ASTM C618-132a.The cementing characteristics of IOT are dependent on its oxide composition. The amount of CaO in IOT was found to be very low compared to that in the lime. The silicon dioxide in IOT on the other hand is higher than that in lime. However, the total amount of calcium oxide in lime and IOT was used in the stabilization process of the deficient natural black cotton soil. The comparatively high silicon and aluminium oxides in IOT also aided those in lime to provide the required improvement of the properties of the natural soil. The chemical compositions of the additives used reported by Ovuarume (2011) and Ishola (2014) are summarized in Table 4.2

Table 4.2: Chemical compositions of lime and iron ore tailings

	Composition by weight (%)	
Oxide	***Lime**	****Iron ore tailings**
Lime (CaO)	54.92	0.607
Silica (SiO_2)	0.35	45.64
Alumina (Al_2O_3)	0.60	3.36
Sodium (Na_2O)	0.02	0.405
Potassium (K_2O)	0.04	0.607
Sulphur trioxide ($S0_3$)	0.06	-
Titaniumdioxide (TiO_2)	-	0.24
Manganese oxide (MnO)	0.09	0.067
Iron Oxide (Fe_2O_3)	0.14	47.7
Magnesium oxide (MgO)	-	0.393
Vanadium (V) oxide (V_2O_5)	0.05	-
Loss on Ignition	43.67	3

* Ovuarume (2011).
**Ishola (2014)

Effect of Lime and Iron Ore tailings on the Properties of Black Cotton Soil

4.1.2 Specific gravity

The variation of specific gravity of black cotton soil – lime mixtures with iron ore tailings is shown in Fig.4.1. The results obtained show an increase in the specific gravity values with increasing percentage of the additives (lime and iron ore tailings). The value of specific gravity of the soil increased from 2.29 for the natural soil to 2.38 at 0% lime /10 % IOT and 2.49 at 8 % lime / 10 % IOT blend. Similar trend of increase was observed for the various percentages of additives in the black cotton soil –lime- IOT mixtures considered.

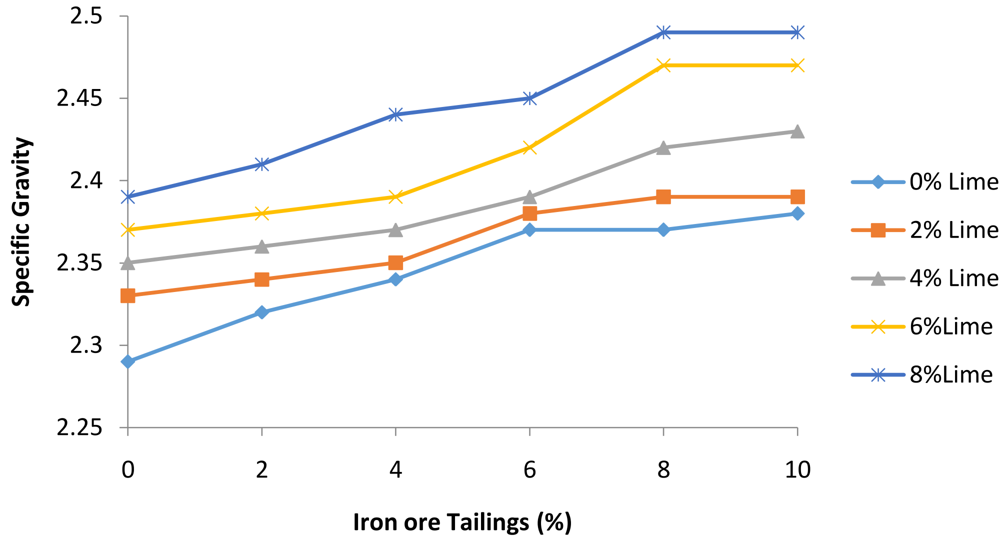


Fig. 4.1: Variation of specific gravity of black cotton soil- lime mixtures with iron ore tailings contents.

The increase in the specific gravity of the black cotton soil- lime-iron ore tailing mixture could be as a result of the high specific gravity of lime and IOT - 3.31 replacing the soil with low specific gravity of 2.29. The specific gravity of IOT obtained is within the range reported by other researchers (Mittal and Morgenstern, 1975; Crowder *et al.*, 2000; Garand *et al*., 2000; Haile.*et al*, 2000; Qiu and Sego, 2001; Demers and Haile, 2003; Etim*et al*., 2017). Detailed test results are shown in Appendix A.

The two – way analysis of variance (ANOVA) test on specific gravity results summarized in Table 4.3 shows that the effects of lime and IOT were statistically significant, with lime having a more pronounced effect.

Table 4.3: Two –way analysis of variance on specific gravity

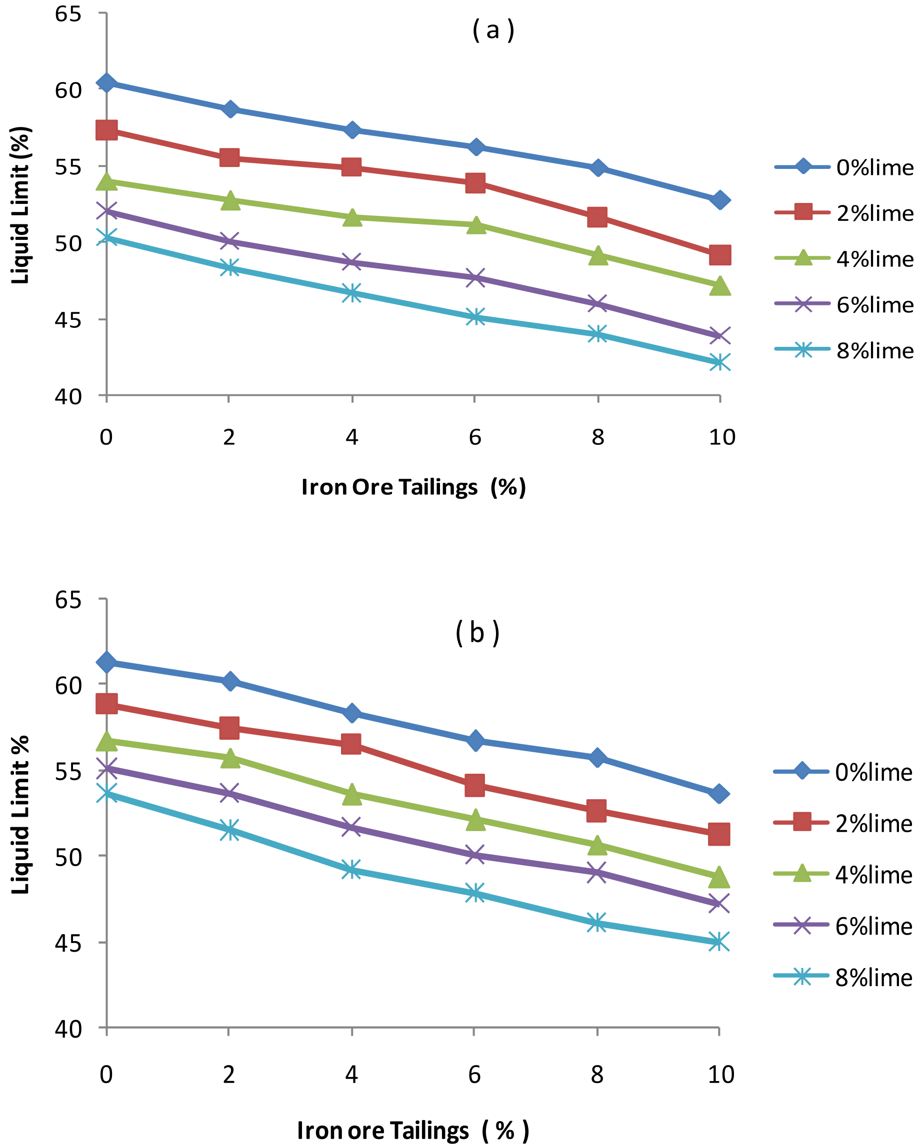
Property	Time	S.O.V	D.F	F_{CAL}	P – Value	F_{CRIT}	Remark
Specific Gravity	2 hours	Lime	4	85.4399	2.79E-12	2.8661	F_{CAL}>F_{CRIT} ,Significant Effect
	2 hours	IOT	5	54.5924	5.67E-11	2.7109	F_{CAL}>F_{CRIT} ,Significant Effect

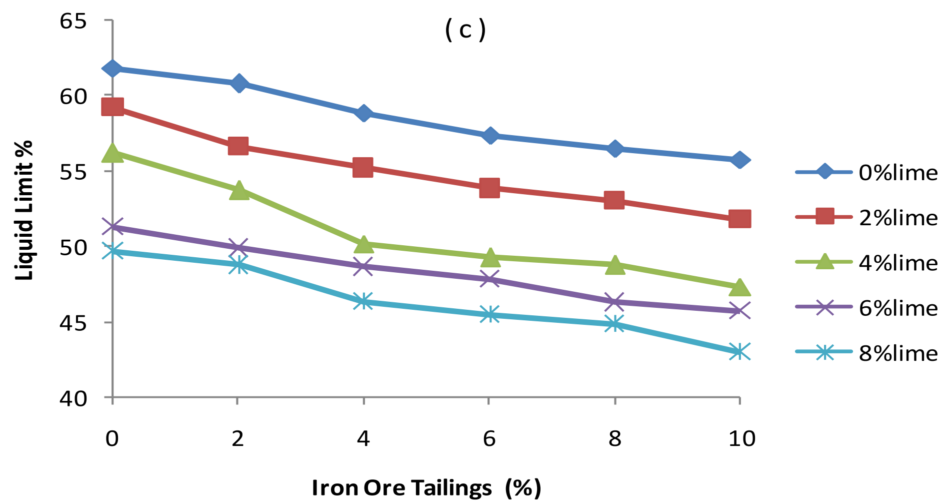
S.O.V –Source of Variations

4.2 Atterberg limits

4.2.1 Liquid limit

The variation of liquid limit of black cotton soil – lime mixtures with iron ore tailings (IOT) is shown in Fig. 4.2a-d. Generally liquid limit of the black cotton soil-lime-iron ore tailings mixtures irrespective of the hourly delay decreases with increase in the lime and iron ore tailing content. The decrease may be attributed to the reduction of the silts and clay fractions in the soil from agglomeration and flocculation of the clay particles. This is as a result of cation exchange reactions where by Ca^{2+} in the additives reacted with ions of lower valence in the clay structure. This finding is in agreement with the findings reported by Obeahon (1992), Osinubi and Alhassan (2008a),Ramesh *et al.* (2013);Osinubi*et al.* (2015) as well as Etim*et al.* (2017). The addition of lime and iron ore tailings introduced calcium for its strength which caused a decrease in the repulsive force of the soil mixture; thereby needing more water to take the soil to its dynamic shear strength (Osinubi, 1995). In other words, calcium ion (Ca^{2+}) and hydroxides (OH^-) produced by addition of lime to soil water system combine with silica (SiO_2) and alumina (Al_2O_3) in the clay fraction to form calcium silicate hydrate and calcium aluminate hydrates (Bell, 1996). The experimental studies reported in literature (Nelson and Miller, 1992; Lawton, 1996; Feng, 2002; Al-Rawas *et al*., 2002; Amadi and Okeiyi, 2017) generally show that the addition of lime to clay soils reduces the liquid limit. Similar trend was reported by Al-Refeaiand Al-Karni, (1999),Phanikumar *et al*. (2004). Detailed test results are shown in Tables B1 - 11 in the Appendix B.





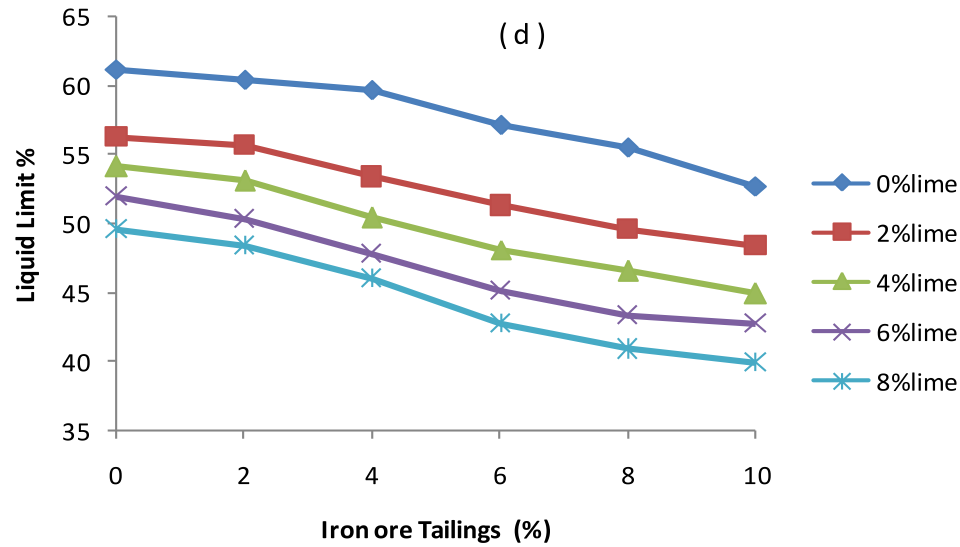
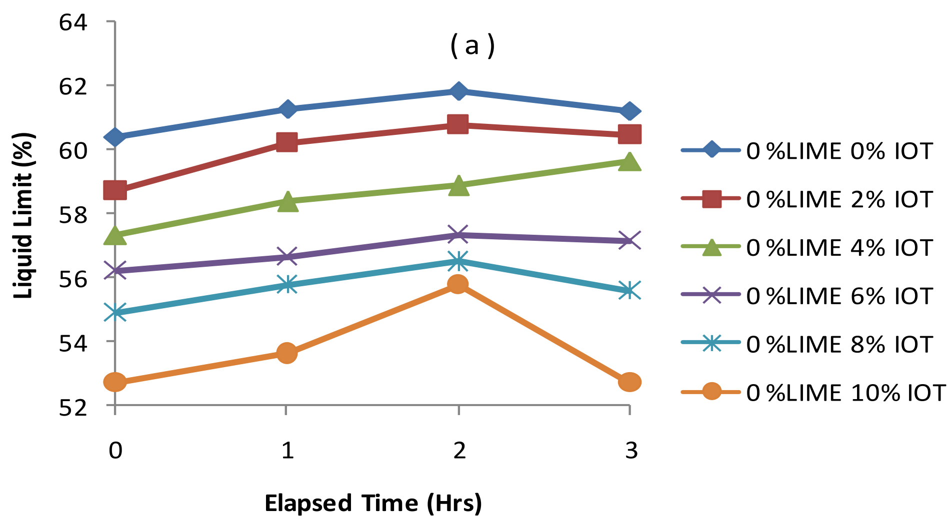


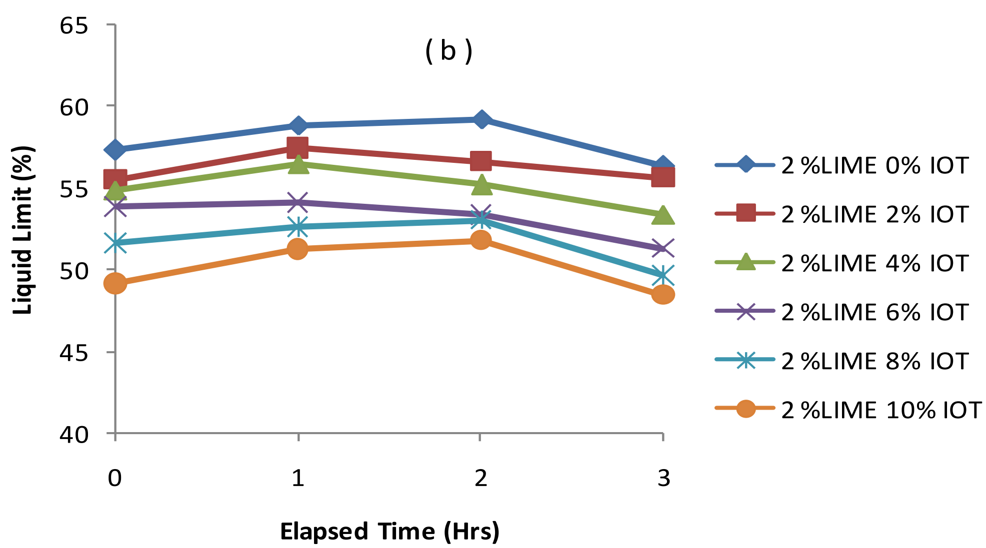
Fig.4.2: Variation of liquid limit of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours.

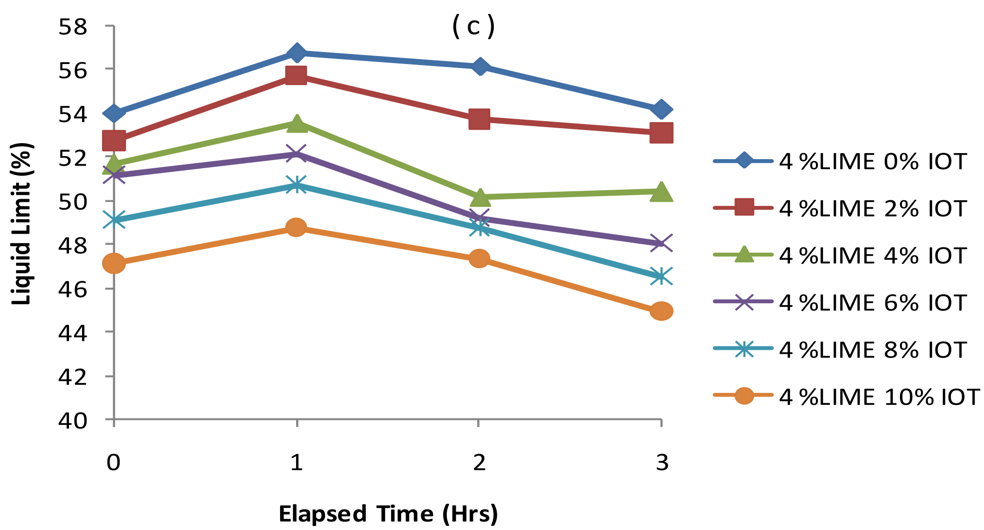
4.2.1.1 Effect of elapsed time

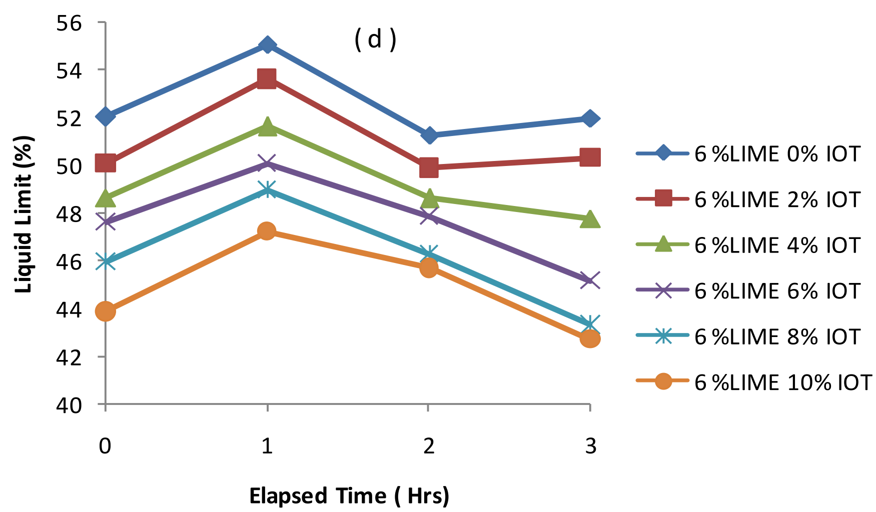
The effect of elapsed time after mixing on the liquid limit of black cotton soil – lime – iron ore tailings (IOT) mixtures with elapsed time after mixing for varying additive content is shown in Fig. 4.3a-e. There was an increase in the liquid limit between 0 and

1hour delay for all the blends. This may be due to formation of coarser aggregate and a more flocculated particle arrangement which may be as a result of the increasing calcium for strength and consequent needs for water to bring the soil to its dynamic strength (Osinubi, 1995; Amadi and Okeiyi, 2017; Bessaim *et al*., 2018). After 1hr elapsed time after mixing,the liquid limit decreased for delays up to 3hrs except for the specimen containing 0 – 2%lime that recorded increases up to 2hrs before decreasing at 3hrs elapsed time after mixing.









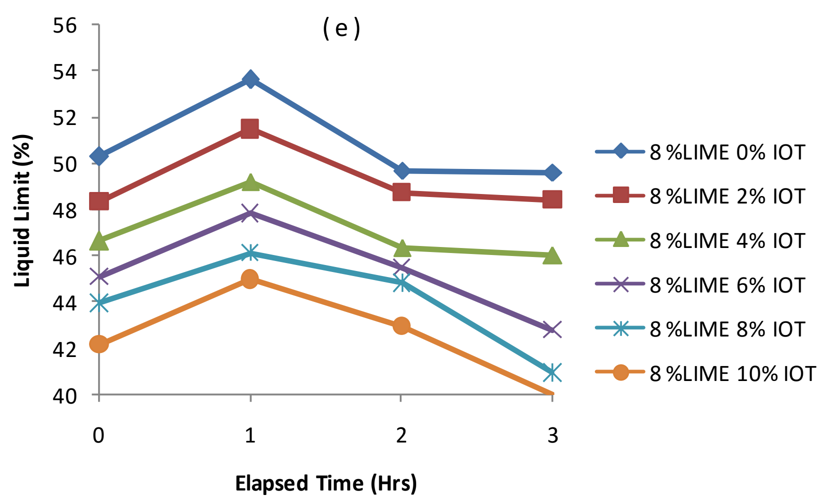


Fig.4.3: Variation of liquid limit of black cotton soil – lime – iron ore tailings (IOT) mixtures with elapsed time after mixing for varying additive content: (a) 0 % lime – up

to 10 % IOT (B) 2 % lime - up to 10 % IOT (c) 4 % lime – up to 10 % IOT (d) 6 % lime – up to 10 % IOT (e) 8 % lime – up to 10 % IOT

The result of the two – way analysis of variance (ANOVA) performed on the tests results of effect of elapsed time on the liquid limit result is presented in Table 4.4. For the elapsed time, it shows that the effects of elapsed time after mixing (F_{CAL} = 34.1737> F_{CRIT} = 3.2874) for Time and (F_{CAL} = 73.1103> F_{CRIT} = 2.9013) on the black cotton soil-lime-iron ore tailing were statistically significant with IOT having a more pronounced effect. Detailed test results are shown in TablesB1 – 11in Appendix B.

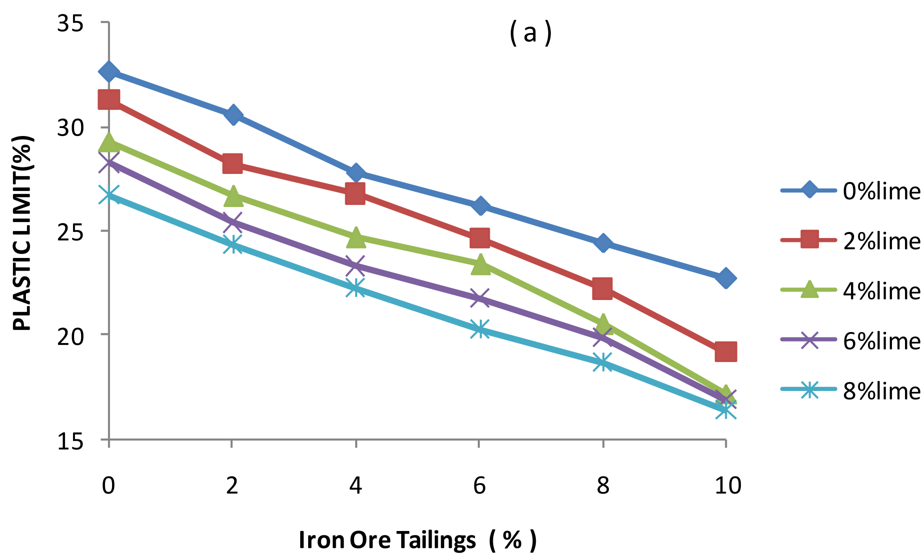
Table 4.4: Two –way analysis of variance on the effect of elapsed time after mixing on liquid limit of black cotton soil -lime-iron ore tailings mixtures.

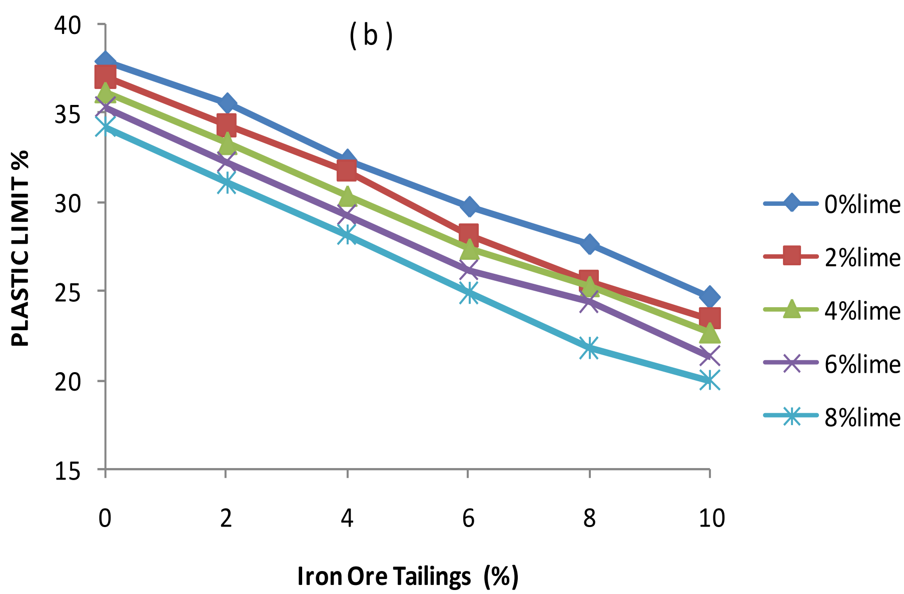
Property	**%Lime**	**S. O.V**	**D.F**	**F_{CAL}**	**P-Value**	**F_{CRIT}**	**Remark**
Liquid Limit	0	Time	3	10.4486	0.00058	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	98.3050	6.42E-11	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	2	Time	3	23.8622	5.81E-06	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	91.1025	1.11E-10	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	4	Time	3	18.6577	2.53E-05	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	60.1461	2.17E-09	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	6	Time	3	32.2592	8.74E-07	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	57.0999	3.14E-09	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	8	Time	3	34.1737	6.02E-07	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	73.1103	5.41E-10	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect

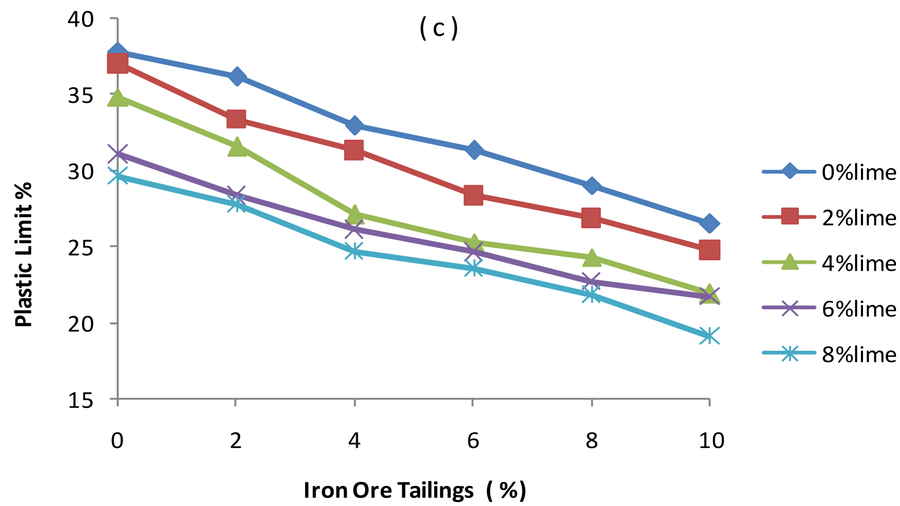
4.2.2 Plastic limit

The variation of plastic limit of black cotton soil – lime – IOT mixtures at 0 - 3 hours elapsed time after mixing is shown in Fig. 4.4a – d. Generally, the plastic limit of black cotton soil decreased with increase in lime and IOT content. The plastic limit of black cotton soil – 8%lime 10% IOT mixture decreased from 32.6% to 16.4% for 0 hour; from 38% to 19.9% for 1 hour; from 37.8% to 19.1% for 2 hours; and from38.6% to 20.2% for 3 hours elapsed time after mixing. Similar trend was reported by Osinubi (1995); Ochepo

(2008); Amadi, (2010), Ramesh *et al*.(2013); Osinubi *et al*.(2015); and Etim, *et al*., (2017). The decrease in plastic limit might not be unconnected with the cation exchange reaction along with flocculation-agglomeration of clay particles from the addition of the additives (i.e, lime and IOT). Detailed test results are shown in Tables C1 – 11 in Appendix C.







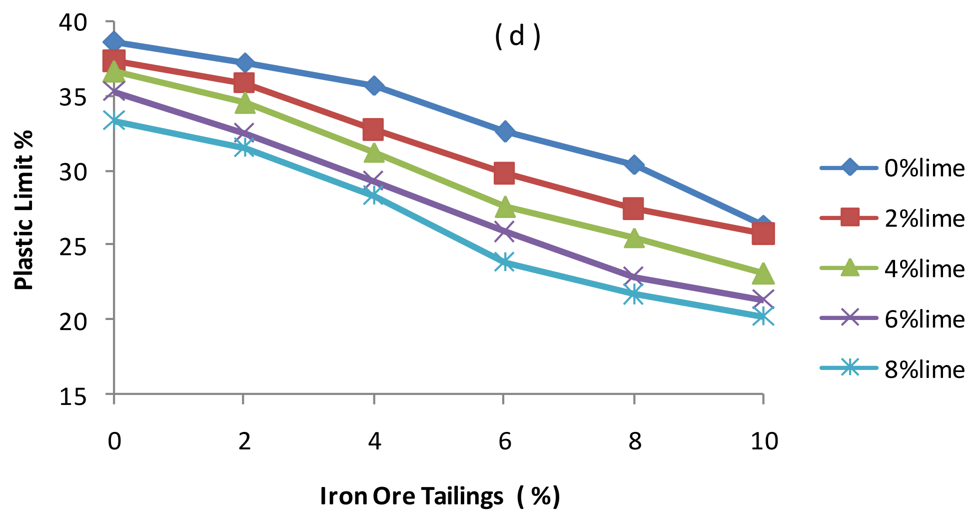
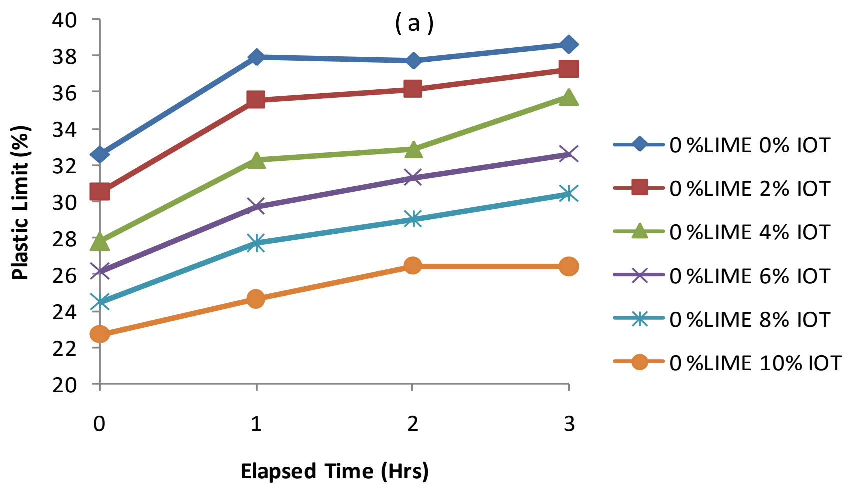


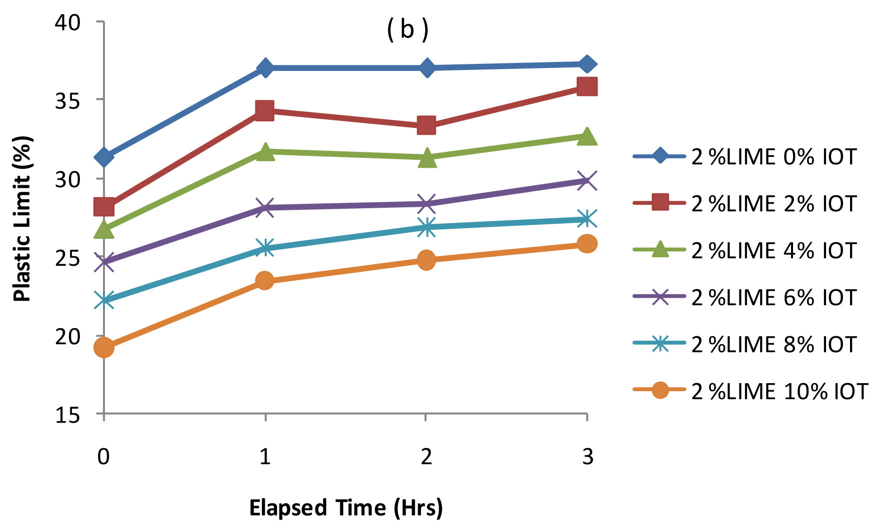
Fig.4.4: Variation of plastic limit of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours.

4.2.2.1 Effect of elapsed time after mixing

The variation of plastic limit of black cotton soil – lime mixtures with iron ore tailings content for 0 - 3 hours elapsed time after mixing is shown in Fig. 4.5a-e. There was a general increase in plastic limit (PL) for up to 1 hour elapsed time after mixing for the lime / IOT blends considered. This could probably be attributed to the continuous effect of lime (i.e., flocculation and agglomeration) on the black cotton soil – IOT mixtures.

The PL values decreased at 2 hours elapsed time after mixing except for the mixtures with 0% and 2% lime content before increasing at 3hours elapsed time after mixing. The increase in PL might also be as a result of the increased curing period that could have triggered the cation exchange; flocculation- agglomeration and carbonation reactions to take place from the addition of the additives (lime and IOT). Similar trend was reported by other researchers (Alhassan, 2006; Mustapha, 2006; Abdullahi, 2011; Nwadiogbu, 2012; Amadi and Okeiyi, 2017; Etim *et al*., 2017; Bessaim *et al*., 2018).





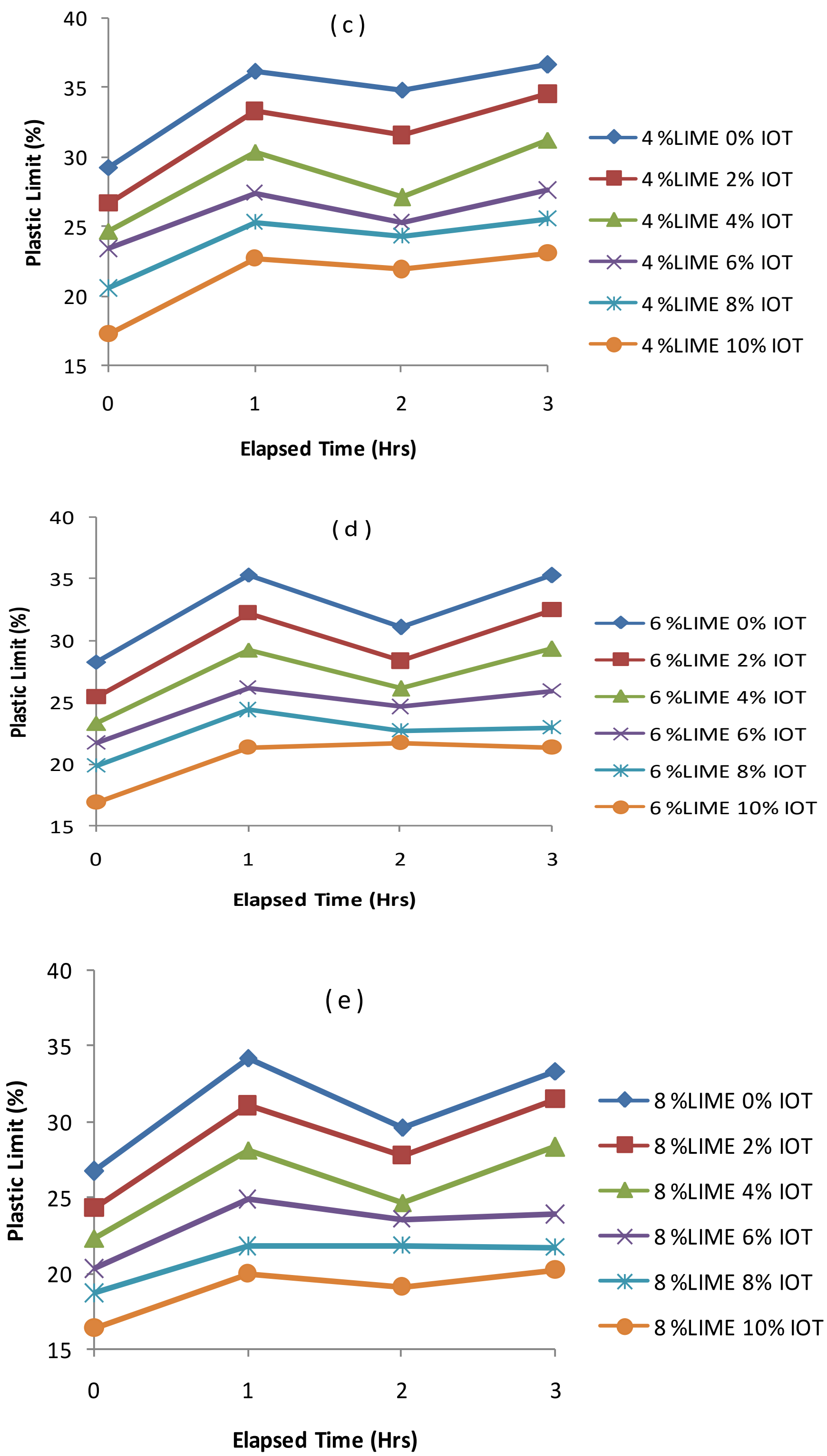


Fig. 4.5: Variation of plastic limit of black cotton soil – lime - iron ore tailings (IOT) mixtures with elapsed time after mixing for varying additive content:(a) 0 % lime – up to 10 % IOT (b) 2 % lime –up to 10 % IOT (c) 4 % lime – up to 10 % IOT (d) 6 % lime – up to 10 % IOT (e) 8 % lime – up to 10 % IOT.

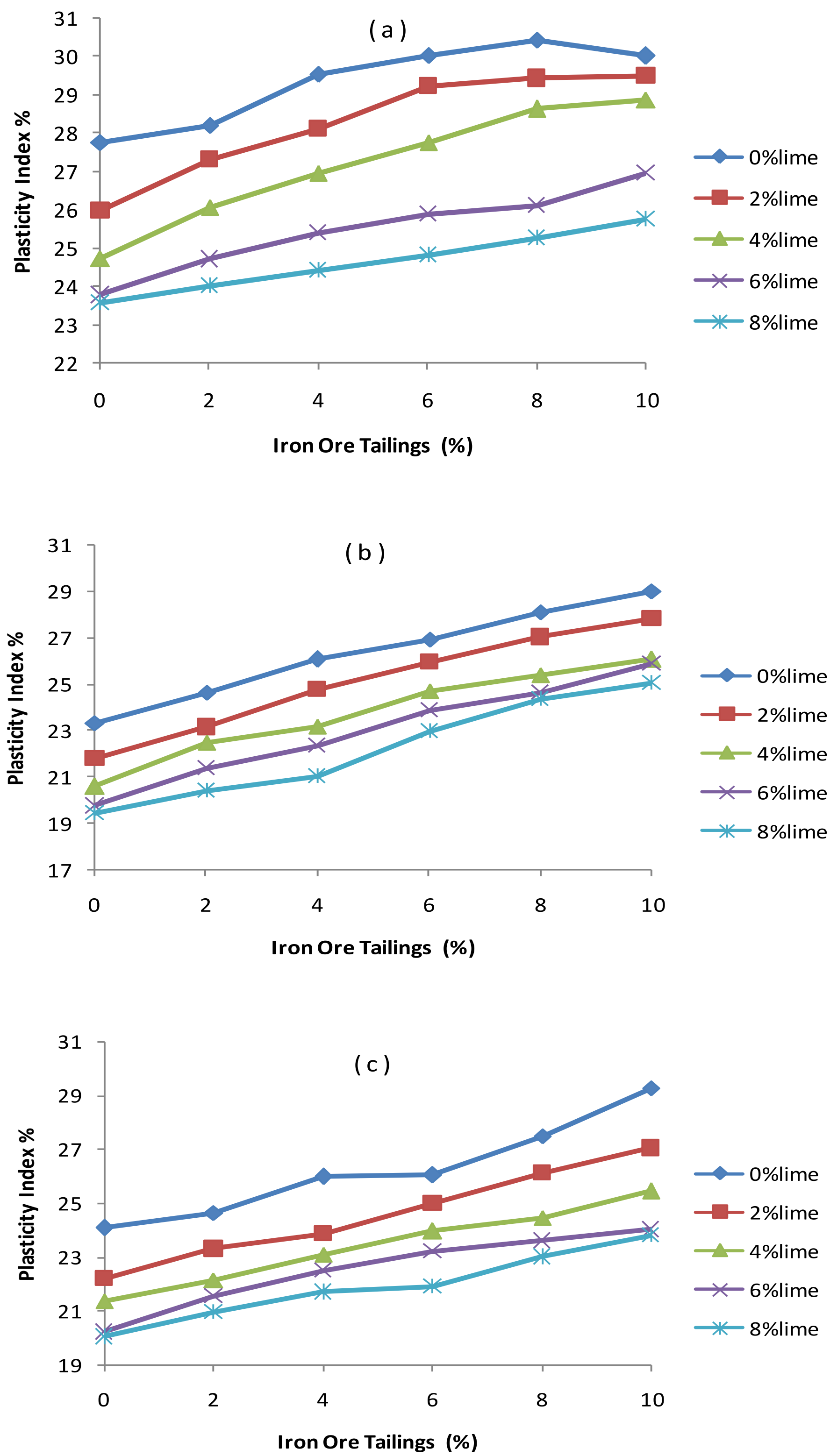
The results of the two- way analysis of variance (ANOVA) is presented in Table 4.5 it shows that elapsed time after mixing for 0, 2, 4, 6 and 8 % lime (F_{CAL} 78.155; 111.704; 73.446; 38.715; and 31.698 respectively >F_{crit} =3.2874) as well as 0, 2, 4, 6 and 8 % IOT (F_{CAL} 141.099; 223.97; 148.295; 80.258; 75.948, respectively> 2.9013) had significant effects on black cotton soil. Detailed test results are shown in Tables C1 – 11 in Appendix C.

Table 4.5: Two –way analysis of variance (ANOVA) on effect of elapsed time on the plastic limit of black cotton soil-lime-iron ore tailings mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
Plastic	0	Time	3	78.1546	2.2E-09	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
Limit		IOT	5	141.0987	4.63E-12	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	2	Time	3	111.7035	1.74E-10	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	223.97	1.55E-13	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	4	Time	3	73.446	3.4E-09	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	148.2947	3.21E-12	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	6	Time	3	38.7153	2.66E-07	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	80.2584	2.77E-10	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	8	Time	3	31.6975	9.78E-07	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	75.9477	4.12E-10	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect

4.2.3 Plasticity index

Generally the plasticity index of black cotton soil increased with increase in IOT and decreased with increase in lime content. Variation of plasticity index of black cotton soil – lime – IOT mixtures at 0 - 3 hours elapsed time after mixing is shown in Fig. 4.6a - d. This reduction in plasticity index for the increase in lime contents could be as a result of replacement of the finer soil particles by the lime- IOT mixtures. The reduction in plasticity index is in agreement with the findings reported by Yisa (2014) and Nwadiogbu (2012) which indicate improvement of the natural soil.


(a)
(b)
(c)
Plasticity Index %
Iron Ore Tailings (%)
0%lime
2%lime
4%lime
6%lime
8%lime
31
30
29
28
27
26
25
24
23
22
21
19
17
0
2
4
6
8
10

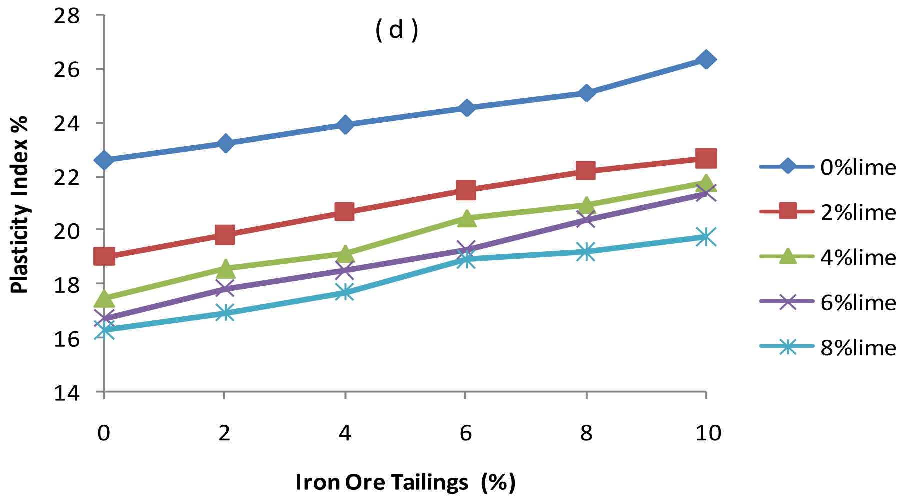
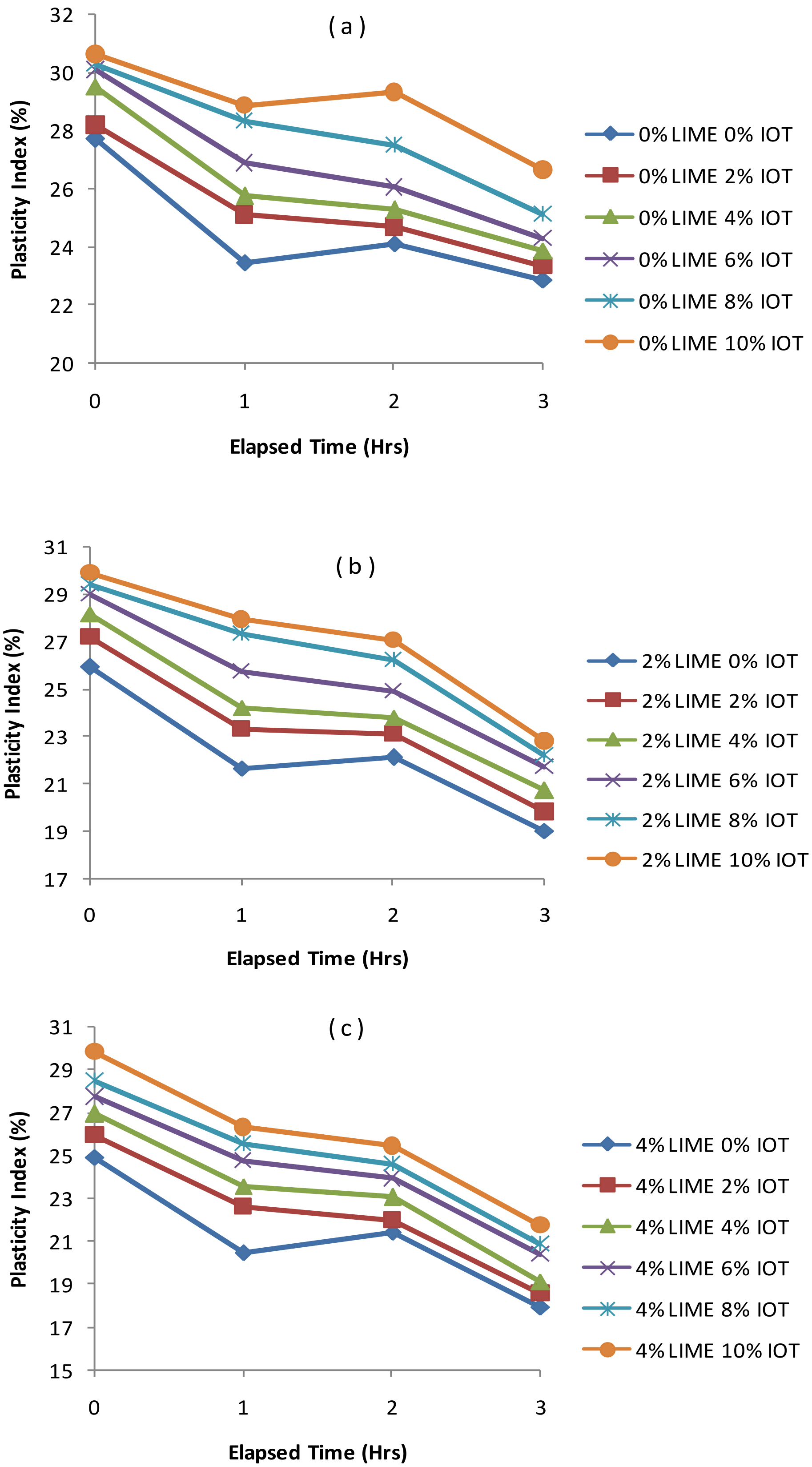


Fig.4.6: Variation of plasticity index of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours.

4.2.3.1 Effect of elapsed time after mixing on plasticity index

The variation of plasticity index of black cotton soil – up to 8 % lime – up to 10 % iron ore tailings mixtures with elapsed time after mixing is shown in Fig. 4.7a – e. Generally, the plasticity index decreased with elapsed time from 0 to 3 hours after mixing. The changes from 1 hour to 2 hours was almost steady for all the black cotton soil –lime – IOT blend considered before decreasing at 3 hours elapsed time after mixing. The plasticity index decreased from 30.6 % to 22.9 % for 0 % lime; 29.9 % to 19.1 % for 2 % lime; 29.8 % to 17.9 % for 4% lime; 27.0 % to 17.0 % for 6 % lime; and 25.8 % to 16.3 % for 8 % lime at 10 % IOT - 0 hour and 0 % IOT at 3 hours. This reduction in the plasticity index was reported by Nwadiogbu (2012); Yisa, (2014); Oluyemi – Ayibiowu and Ola, (2015); Sefene, (2020) and Kuppusamy and Krishnamurthy, (2020).


(a)
Plasticity Index (%)
Elapsed Time (Hrs)
0% LIME 0% IOT
0% LIME 2% IOT
0% LIME 4% IOT
0% LIME 6% IOT
0% LIME 8% IOT
0% LIME 10% IOT
(b)
Plasticity Index (%)
Elapsed Time (Hrs)
2% LIME 0% IOT
2% LIME 2% IOT
2% LIME 4% IOT
2% LIME 6% IOT
2% LIME 8% IOT
2% LIME 10% IOT
(c)
Plasticity Index (%)
Elapsed Time (Hrs)
4% LIME 0% IOT
4% LIME 2% IOT
4% LIME 4% IOT
4% LIME 6% IOT
4% LIME 8% IOT
4% LIME 10% IOT

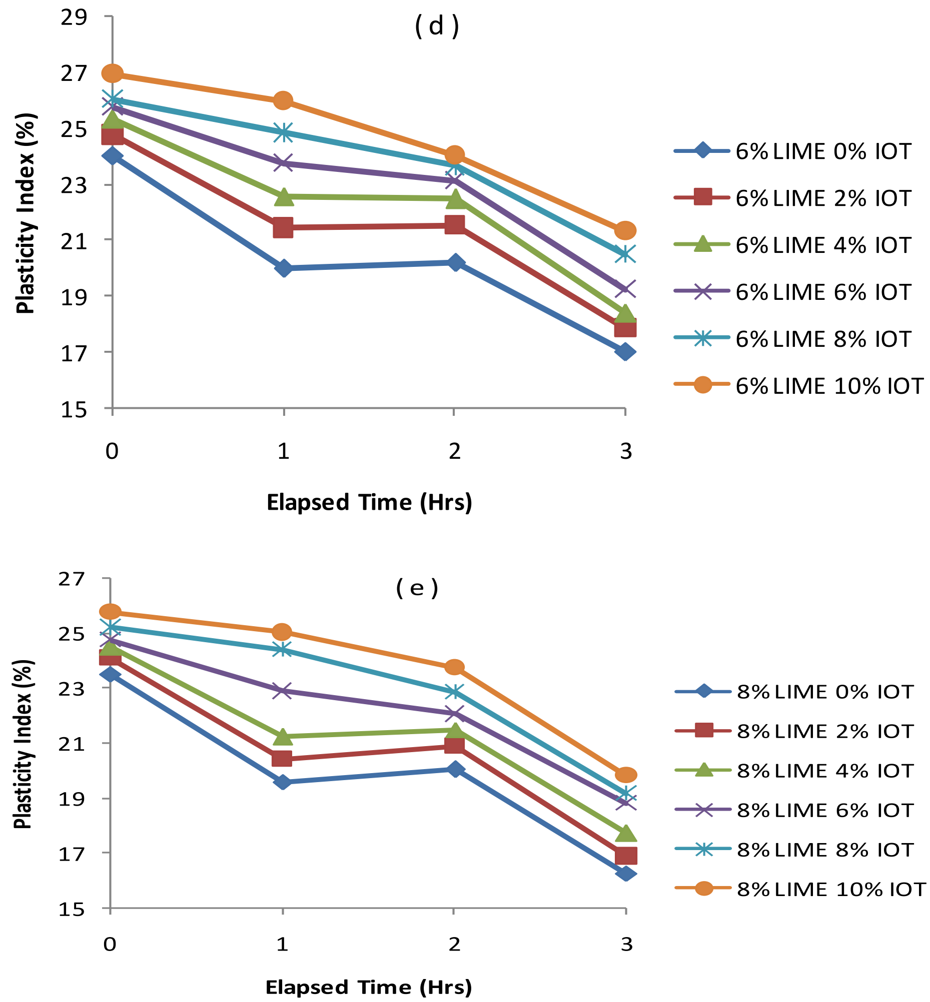


Fig.4.7: Variation of plasticity index of black cotton soil –lime iron ore tailings (IOT) mixtures with elapsed time after mixing for varying additive content: (a) 0% lime – up to 10 % IOT (b) 2 % lime – up to 10 % IOT (c) 4% lime – up to 10 % IOT (d) 6% lime – up to 10 % IOT (e) 8% lime – up to 10 % IOT

The two-way analysis of variance (ANOVA) on test results is presented in Table 4.6, it shows that the effect of elapsed time after mixing (F_{CAL}= 117.8075 > F_{CRIT} = 3.2874) and iron ore tailings content (F_{CAL} = 21.9561> F_{CRIT} = 2.9013) at 8% lime were statistically significantly with the effect of elapsed time being more pronounced than that of iron ore tailing for all the lime content considered, but much more for 4% lime. Detailed test results are shown in Tables D6 – 11 in Appendix D.

Table 4.6: Two –way analysis of variance (ANOVA) on effect of elapsed time on the plasticity index of black cotton soil-lime-iron ore tailings mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value09	F_{CRIT}	Remark
Plasticity Index	0	Time	3	76.7929	2.49E-	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	29.775	2.79E-07	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	215.4179	1.49E-12	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	53.6454	4.87E-09	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	408.1432	1.35E-14	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	84.0072	2E-10	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	143.537	2.87E-11	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	33.1806	1.35E-07	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	117.8075	1.19E-10	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	21.9561	2.07E-06	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

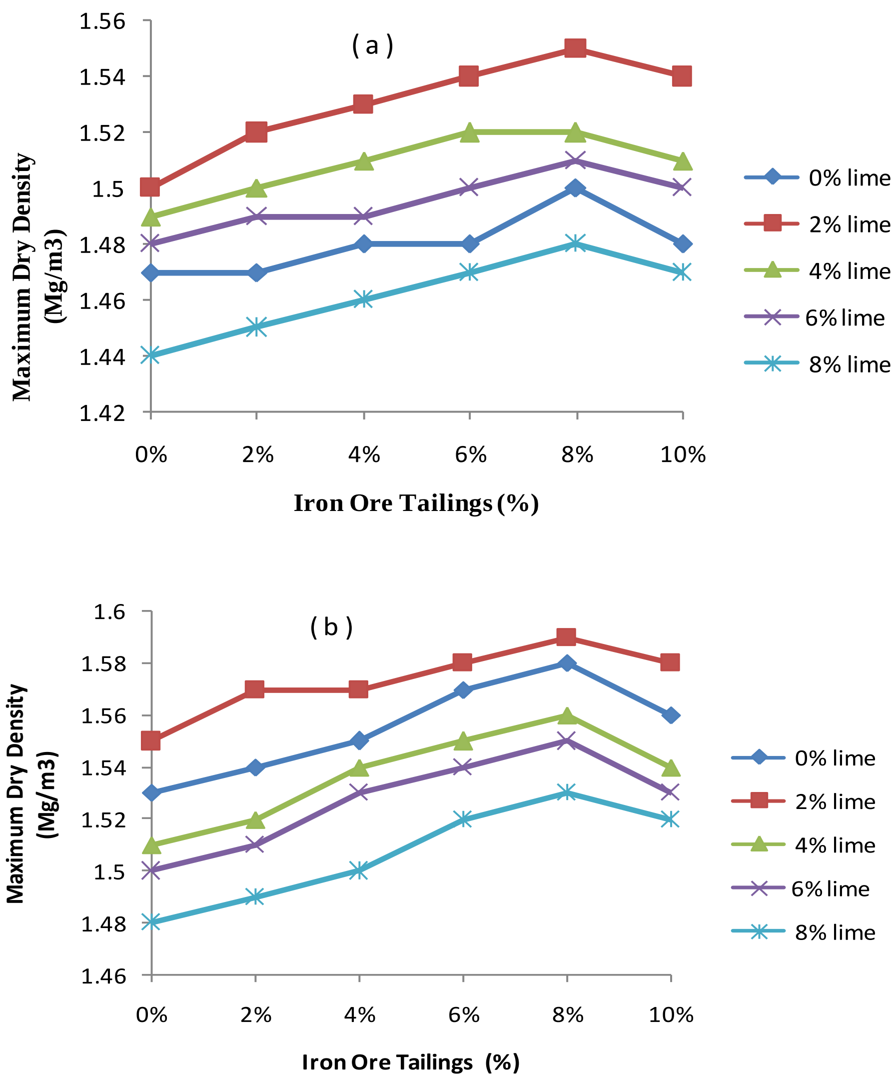
4.3 Compaction Characteristics

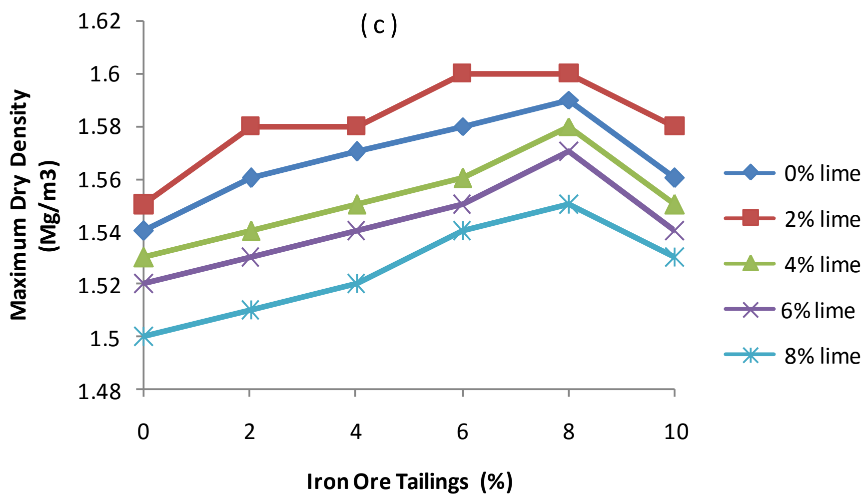
Many of the engineering properties of a soil are dependent on the moisture and density at which the soil is compacted (Osinubi and Toro, 1997; Bulinski and Sergiel, 2014; Surrendra and Sanjeev, 2017). Therefore, it is necessary to achieve the desired relative density of 95 % or more on field relative to that obtained in the laboratory.

4.3.1 Maximum dry density

The variation of maximum dry density of black cotton soil – lime mixtures with iron ore tailings content for 0 - 3 hours elapsed time after mixing is shown in Figs: 4.8a – d; 4.9a – d and 4.10a – d for the BSL, WAS and BSH compactive efforts, respectively. Generally, maximum dry density (MDD) of black cotton soil mixtures increased with increase in the IOT content for the three compactive efforts considered in the study. For BSL compaction, MDD increased up to 8 % IOT content but decreased at 10 % IOT content. However, it was observed that MDD decreased with higher lime content. Similar trends were recorded for WAS and BSH compactions. Peak MDD values 1.60 Mg/m^3 at 2% lime / 8 % IOT; 1.68 Mg/m^3 at 4 % lime/ 8% IOT and 1.79Mg/m^3 at 6% lime/ 10% IOT treatment were recorded for BSL, WAS and BSH compaction, respectively.

The increase in MDD recorded for thecompactive efforts considered may be due to flocculation and agglomeration of the clay particles primarily due to cation exchange and in addition the particles filling the voids within the soil matrix (Moses, 2008; Oriola and Moses, 2010; Etim*et al*., 2017). The increase in MDD could also be as a result of IOT which has a higher specific gravity (3.35) replacing the soil particles which has a lower specific gravity (2.29) thus resulting in the formation of a mixture with higher specific gravity and higher MDD as reported by Ishola (2014) and Osinubi*et al*. (2016).





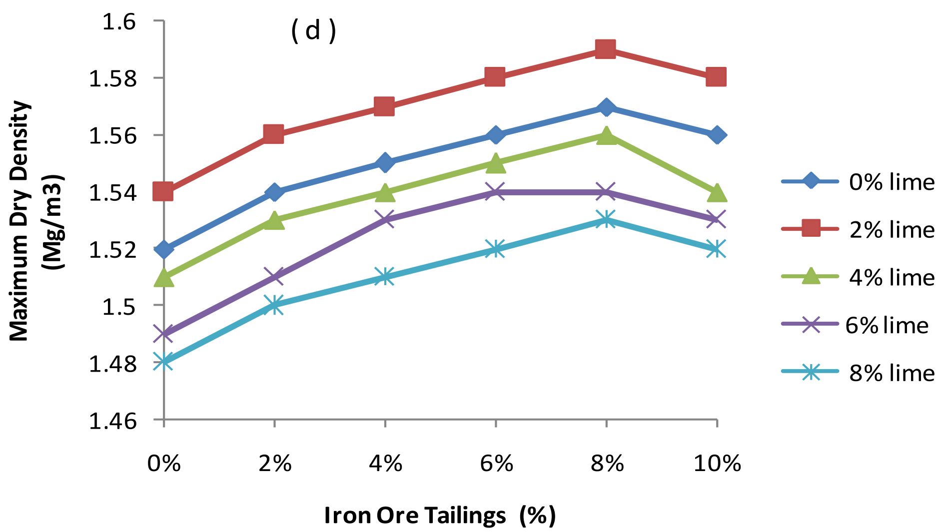
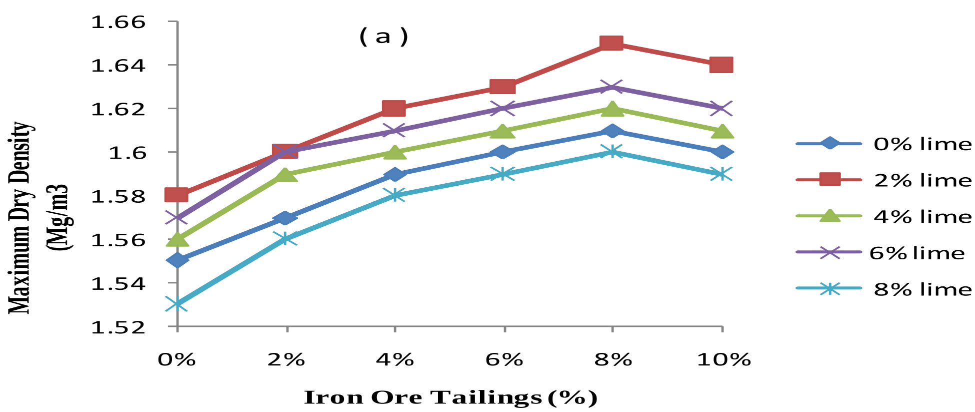


Fig. 4.8: Variation of maximum dry density of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours (BSL compaction).



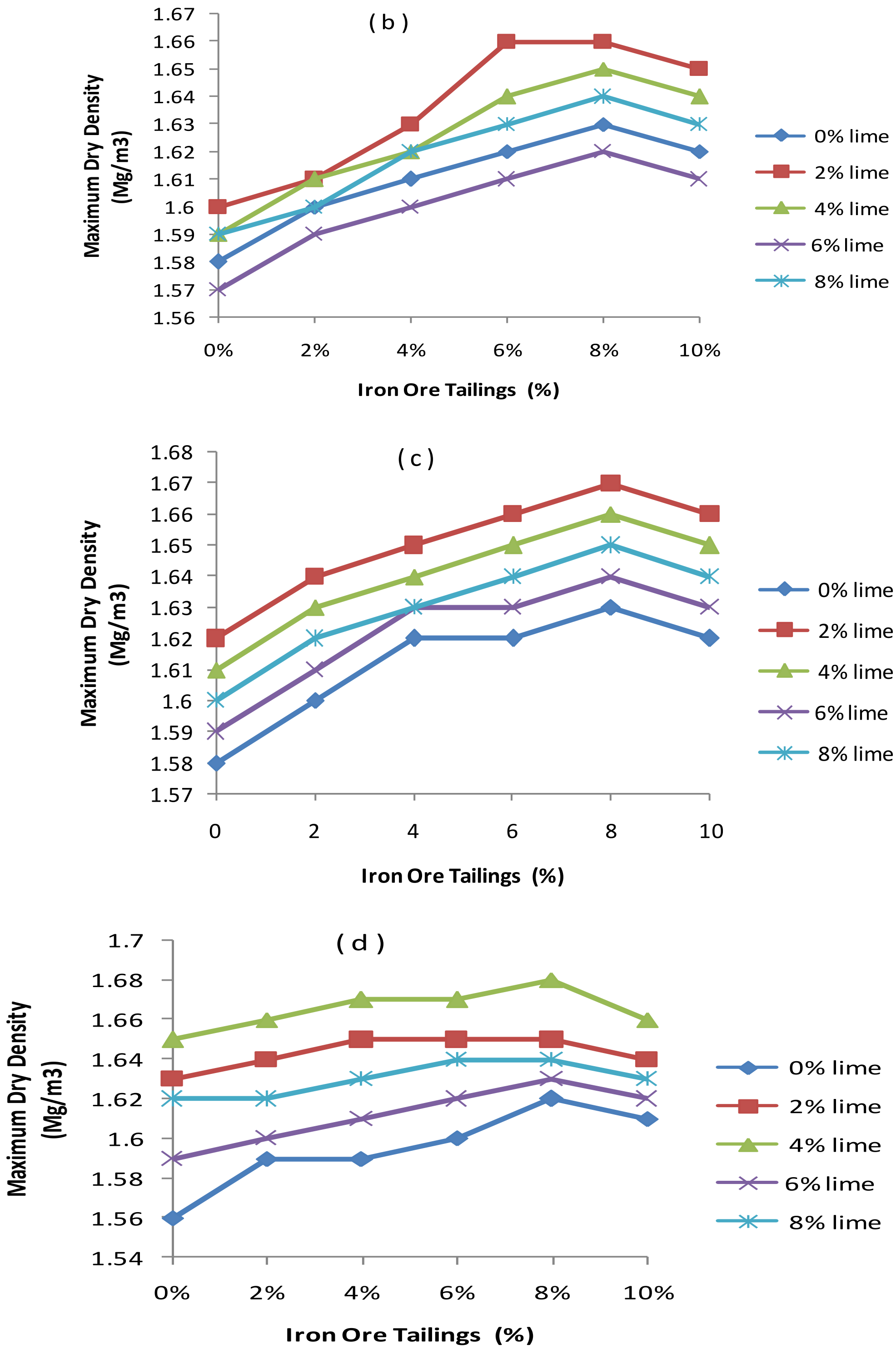
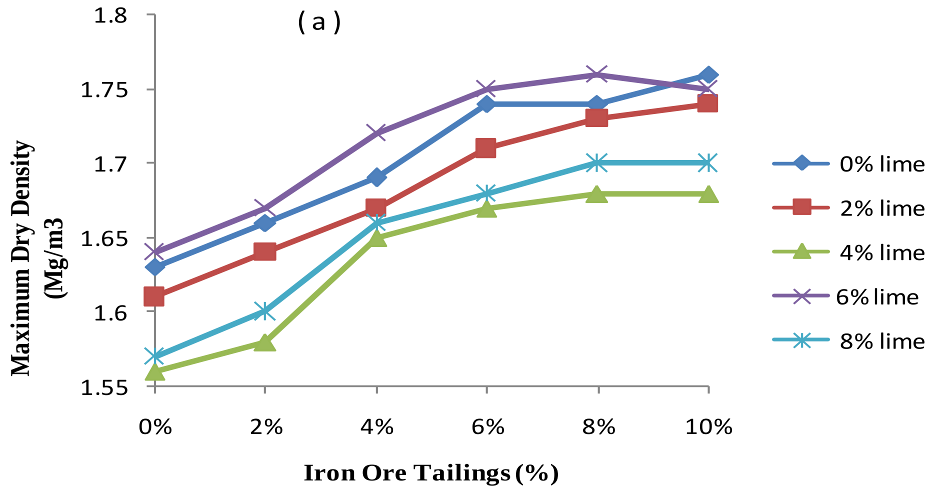
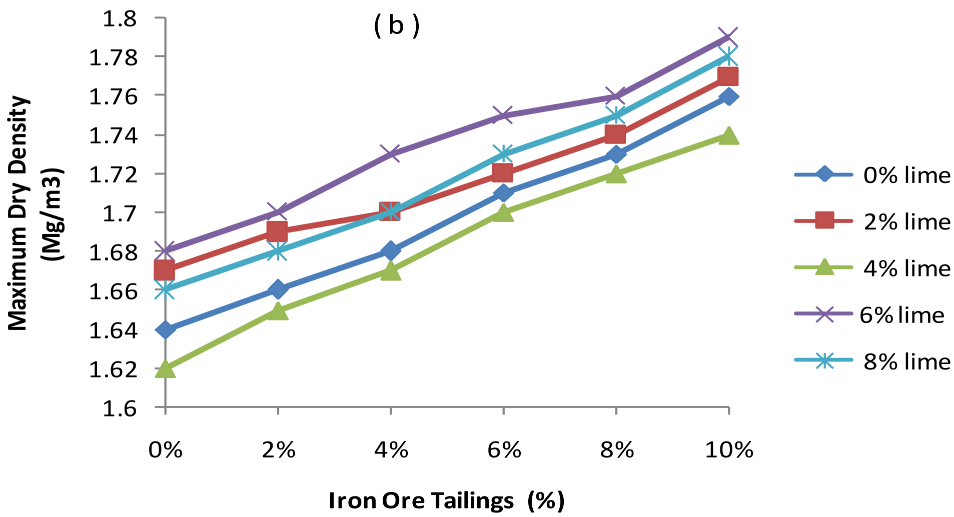
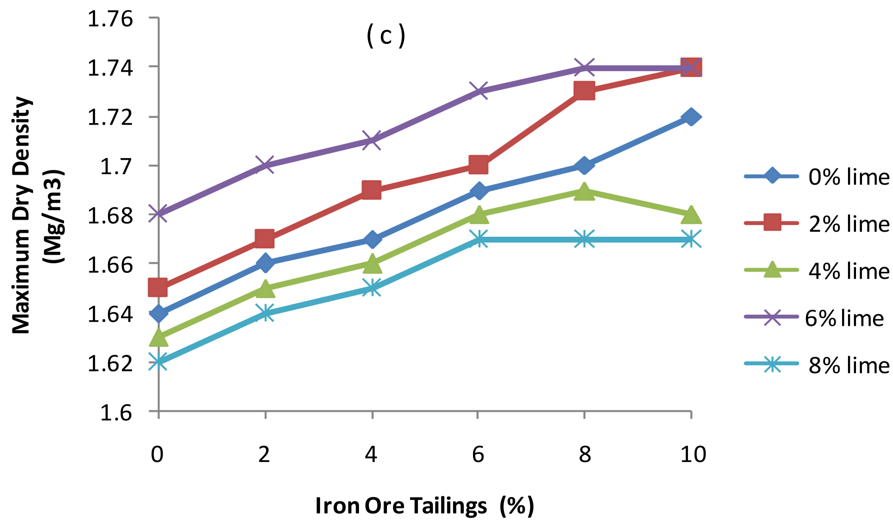


Fig.4.9: Variation of maximum dry density of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours(WAS compaction).


(a)
Maximum Dry Density (Mg/m3
1.8
1.75
1.7
1.65
1.6
1.55
0%
2%
4%
6%
8%
10%
Iron Ore Tailings (%)
0% lime
2% lime
4% lime
6% lime
8% lime


(b)
Maximum Dry Density (Mg/m3)
1.8
1.78
1.76
1.74
1.72
1.7
1.68
1.66
1.64
1.62
1.6
0%
2%
4%
6%
8%
10%
Iron Ore Tailings (%)
0% lime
2% lime
4% lime
6% lime
8% lime


(c)
Maximum Dry Density (Mg/m3)
1.76
1.74
1.72
1.7
1.68
1.66
1.64
1.62
1.6
0
2
4
6
8
10
Iron Ore Tailings (%)
0% lime
2% lime
4% lime
6% lime
8% lime

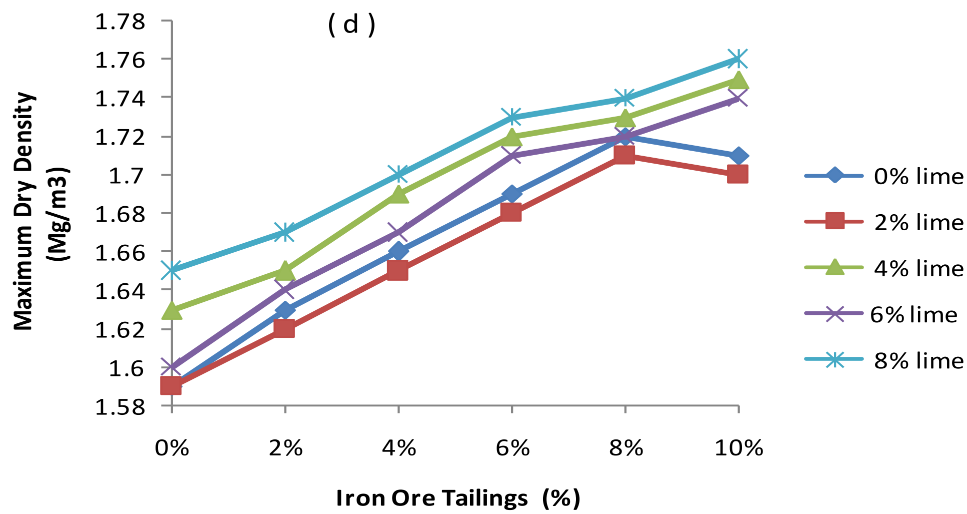
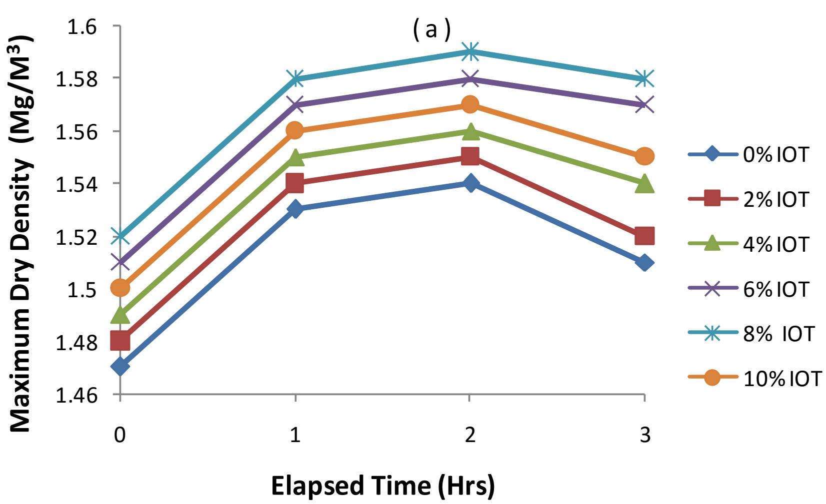


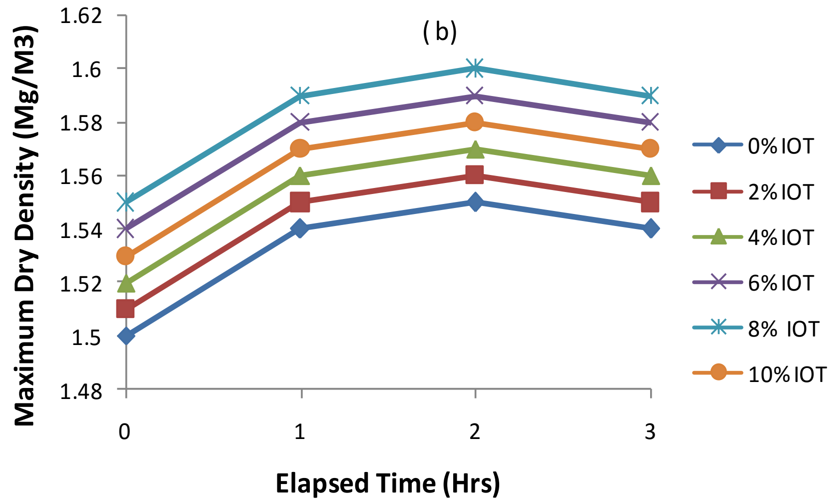
Fig.4.10: Variation of maximum dry density of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours (BSH compaction).

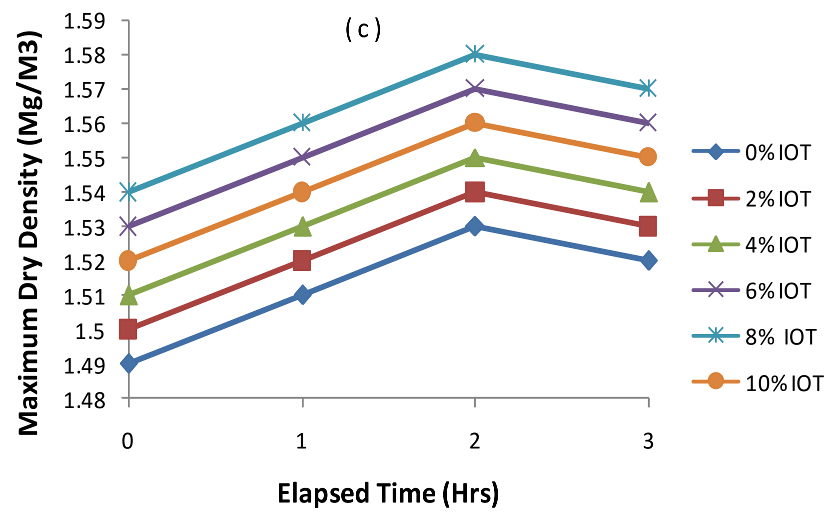
4.3.1.1 Effect of elapsed time after mixing on maximum dry density

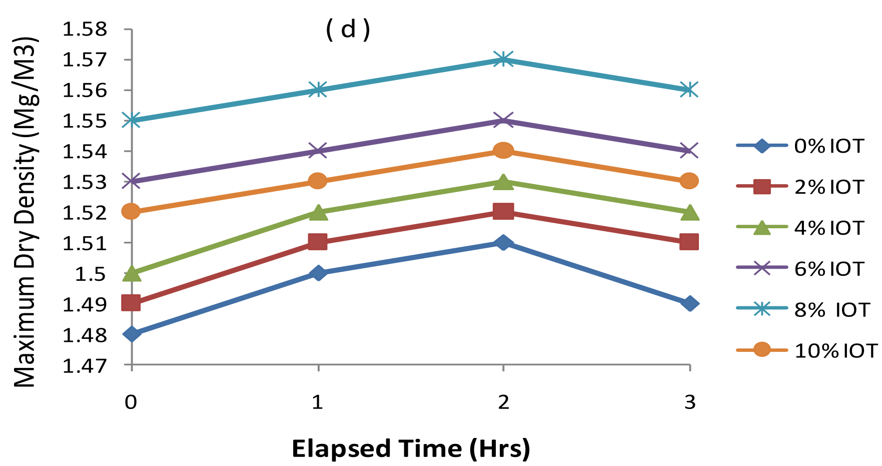
The variation of maximum dry density with elapsed time for black cotton soil treated with lime and admixed with IOT for BSL; WAS and BSH compaction energy is shown in Fig. 4.11 – 4. 13. On the other hand, Fig. 4.14 shows the variations of the MDD with the elapsed time after mixing for the three energy level considered. All the three energy level increased sharply from 0 – 1 hour and thereafter increased to 2 – 3 hours with BSL dropping slightly at 3 hours. Generally, the MDD increased for up to 2 hours elapsed time after mixing for all the lime and IOT treatments considered before decreasing at 3 hours elapsed time after mixing for BSL compaction. The same trend was observed for WAS compaction except for 4% and 8% lime content treatment increasing from 0 – 3 hours. For BSH compaction, the MDD increased for up to 1 hour elapsed time after mixing except for 0% lime and thereafter decreased at 3 hours elapsed time after mixing except for 4% and 8% lime treatments that increased after decreasing at 2 hours elapsed time after mixing. Similar trend was reported by Abdullahi (2011) and Nwadiogbu (2012).Etim *et al*., (2014); Yohanna *et al*, (2014) as well as Osinubi *et al*. (2015) reported similar trend of increasing maximum dry density.Furthermore, Nwadiogbu, (2012) and Abdullahi, (2011) reported increase in MDD with the elapse time after mixing in their respective studies.

The increase in MDD recorded for all the compactive efforts, may be due to flocculation and agglomeration of the clay particles primarily due to cation exchange and in addition the particles filling the voids within the soil matrix (Osinubi, 2008a; Moses, 2008; Oriola and Moses, 2010). The increase in MDD could also be as a result of IOT which has a higher specific gravity (3.35) replacing the soil particles which has a lower specific gravity of 2.29 thus resulting in the formation of a mixture with higher specific gravity and higher MDD as reported by Ishola (2014), as well as Osinubi *et al*. (2015). Detailed test results are given Tables E13 -19; E39 – 45 and E65 – 71in Appendix E.




(b)
Maximum Dry Density (Mg/M3)
1.62
1.6
1.58
1.56
1.54
1.52
1.5
1.48
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(c)
Maximum Dry Density (Mg/M3)
1.59
1.58
1.57
1.56
1.55
1.54
1.53
1.52
1.51
1.5
1.49
1.48
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(d)
Maximum Dry Density (Mg/M3)
1.58
1.57
1.56
1.55
1.54
1.53
1.52
1.51
1.5
1.49
1.48
1.47
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT

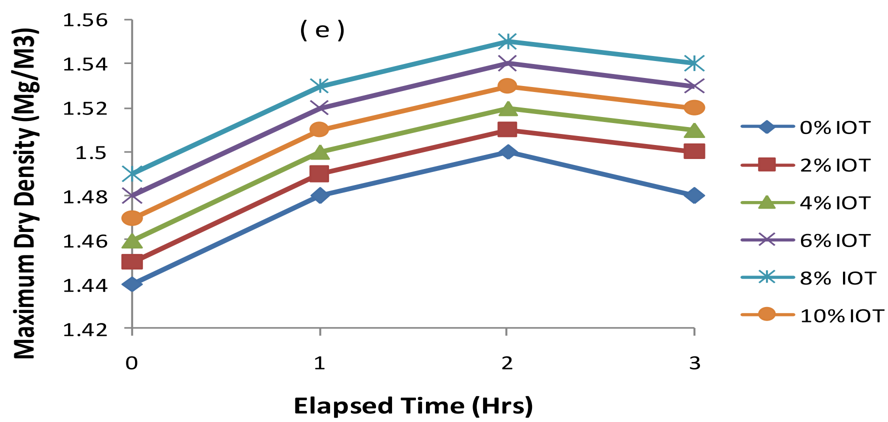
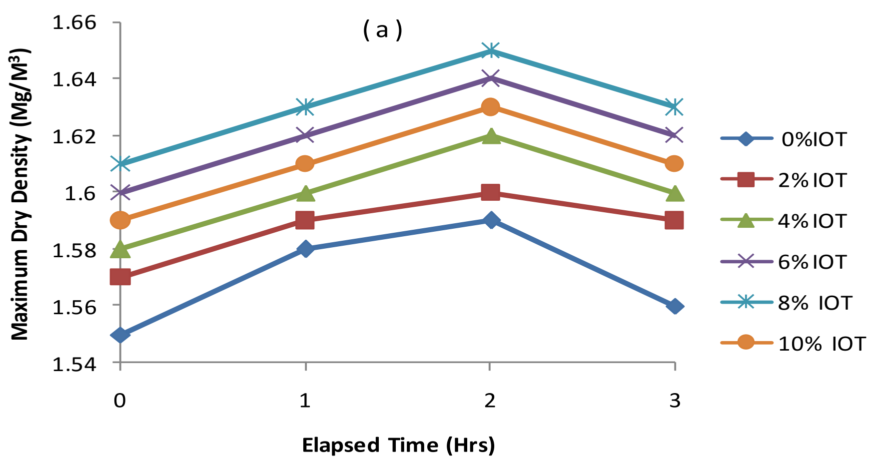
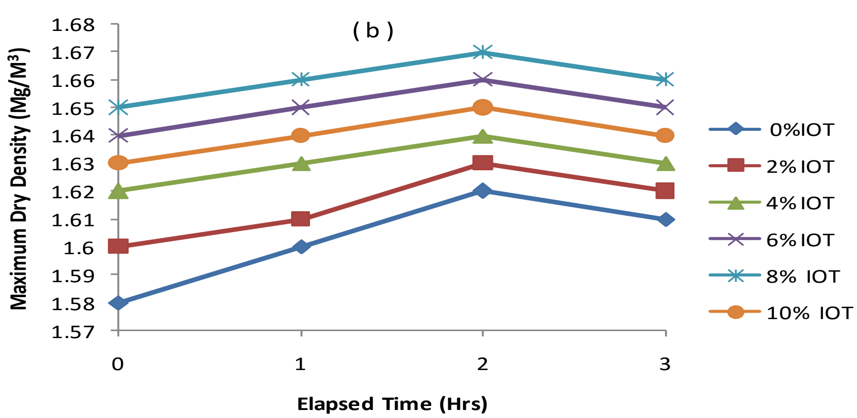


Fig. 4.11: Variation of maximum dry density of black cotton soil- iron ore tailings mixtures with elapsed time after mixing for varying lime content: (a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSL compaction).





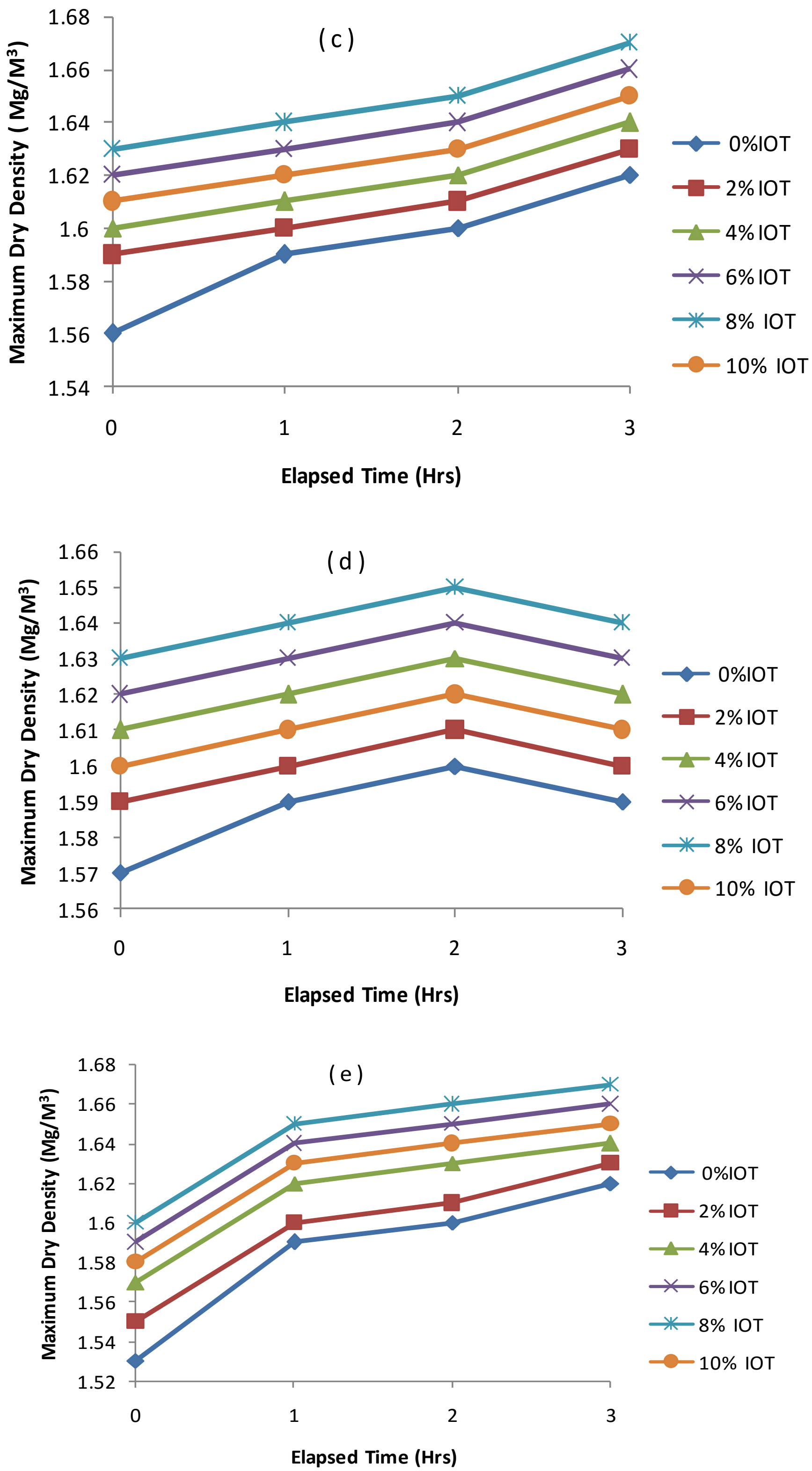
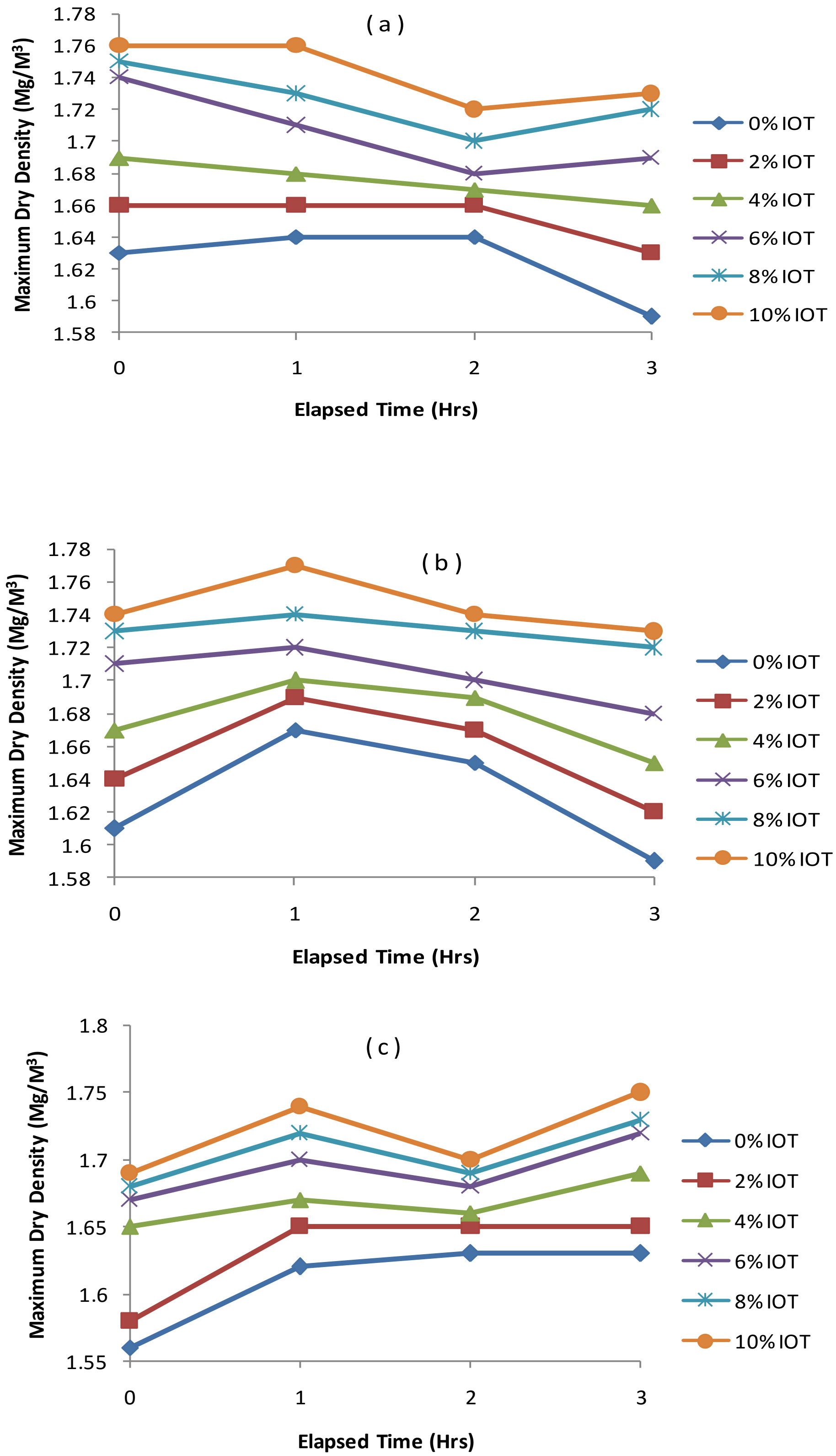
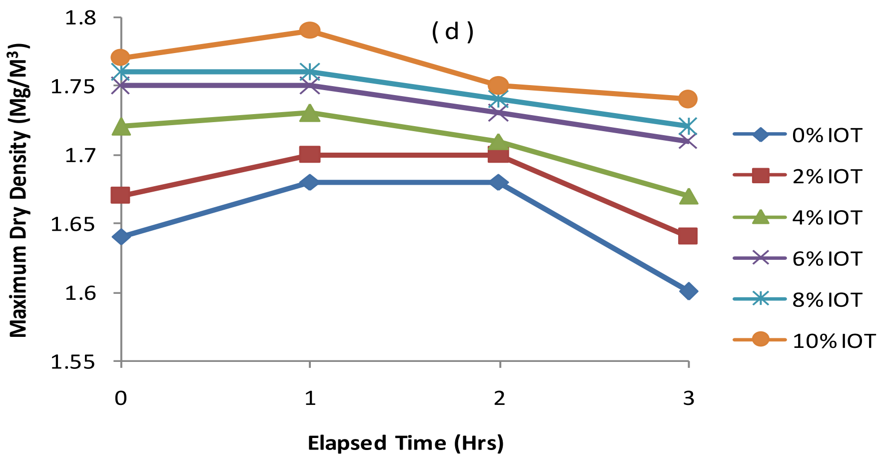


Fig. 4.12: Variation of maximum dry density of black cotton soil- iron ore tailings mixtures with elapsed time after mixing for varying lime content: (a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (WAScompaction)


(a)
(b)
(c)
Maximum Dry Density (Mg/M³)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT



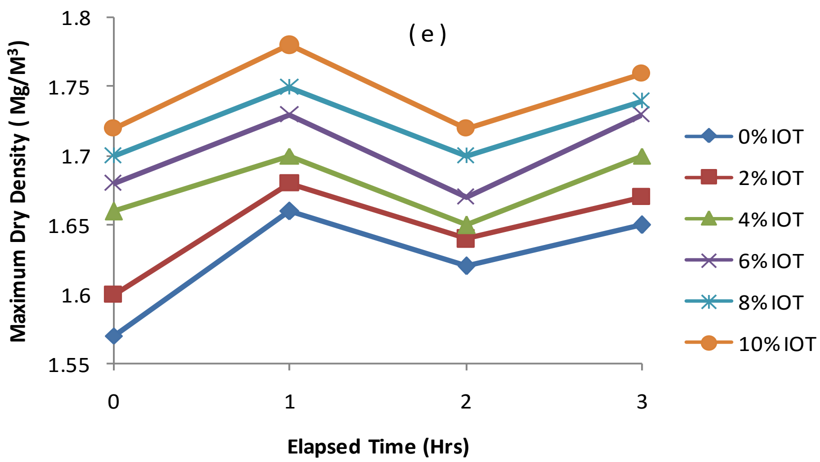


Fig.4.13. Variation of maximum dry density of black cotton soil- iron ore tailings mixtures with elapsed time after mixing for varying lime content: (a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSHcompaction)

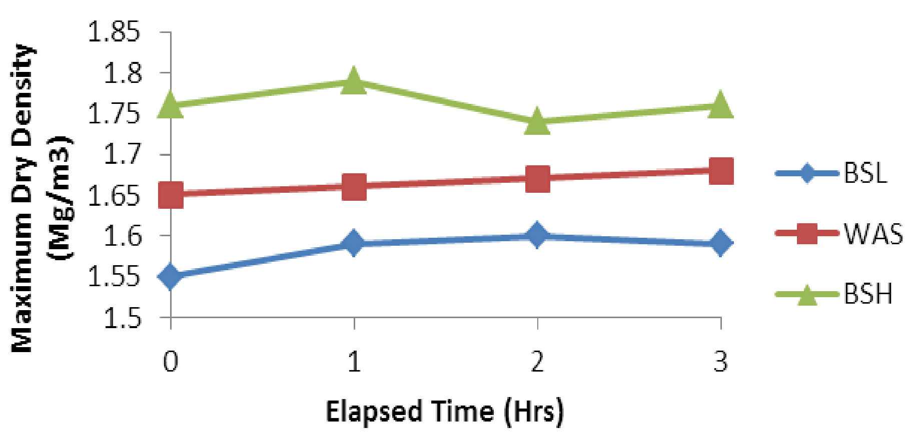


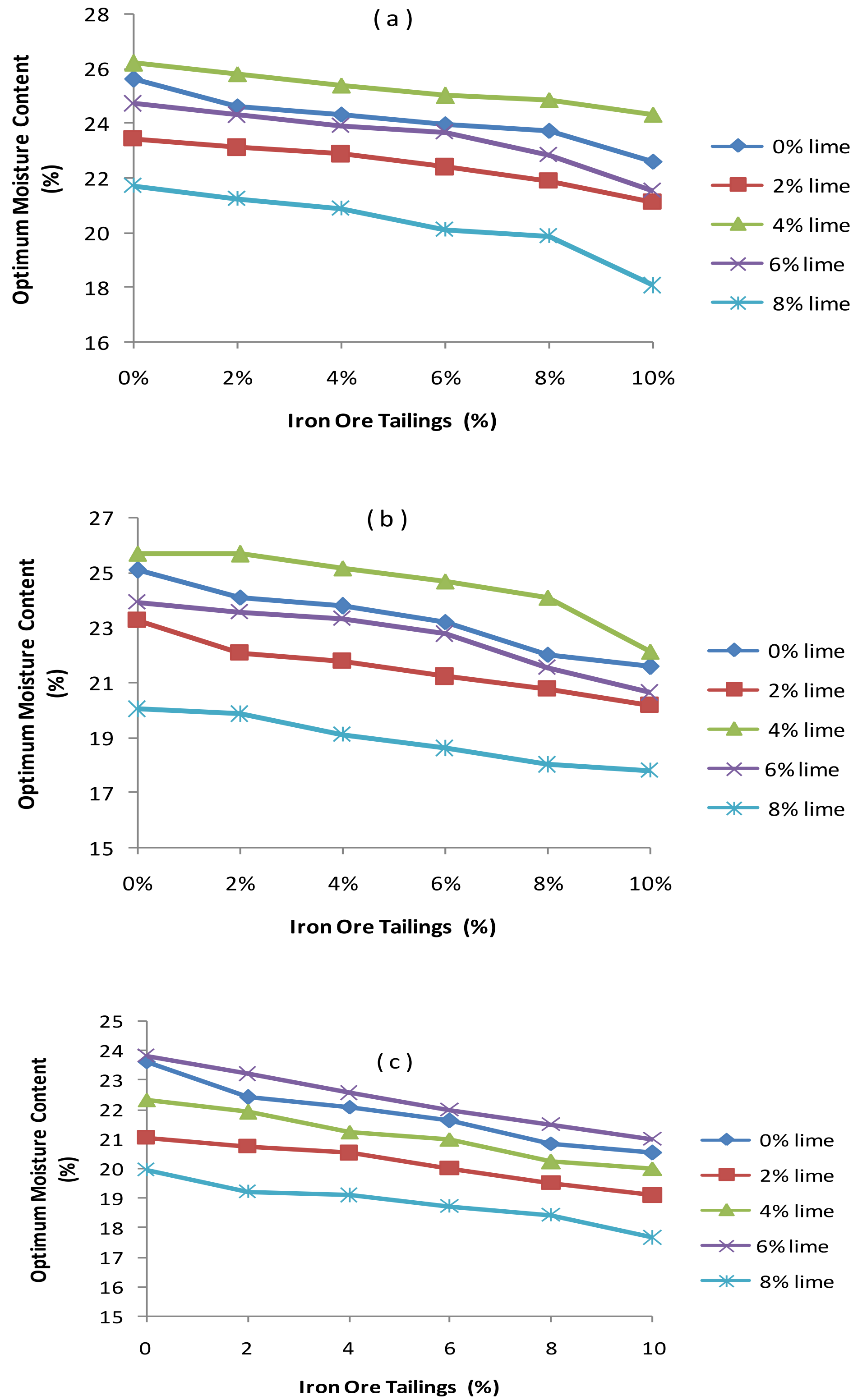
Fig. 4.14: Variation of peak maximum dry density of black cotton soil with elapsed time after mixing.

The two–way analysis of variance (ANOVA) test carried out on the MDD results for BSL;WAS and BSH compaction are presented in Appendix E – (Tables E6, E32 and E58). From the table, it shows that the effect of lime and Iron ore tailing are statistically significant; for lime (F_{CAL}= 135.16; 271.00 & 62.58> F_{CRIT}= 2.8661) and Iron ore tailing (F_{CAL}=70.375; 322.667 & 54.517> F_{CRIT}= 2.7109) respectively.Detailed test results are given Tables E6 -19; E39 – 45 and E65 – 71in Appendix E.

The two –way analysis of variance (ANOVA) test carried out on the MDD result with regard to elapsed time after mixing shows that the effect of time (F_{CAL}= 977.0; 494.79 and 40.242> F_{CRIT}= 3.2874) and IOT (F_{CAL}= 361.00; 158.106 and 60.145>F_{CRIT}=2.9013) are statistically significant for BSL; WAS and BSH compactions respectively. Details are found TablesE19; E45; and E71in Appendix E.

4.3.2 Optimum moisture content

The variation of optimum moisture content (OMC) of black cotton soil – lime mixtures with iron ore tailings content for 0 - 3 hours elapsed time after mixing are shown in Figs. 4.15 - 4.17. Generally, optimum moisture content (OMC) of black cotton soil mixtures decreased with increase in the IOT content for the three compactive efforts (i.e., BSL; WAS and BSH) considered in the study. For BSL compaction, OMC value of 25.62 % for natural soil decreased to 15.2 % at 8 % lime 10 % IOT blend .Similar trends were recorded for WAS and BSH compaction with the OMC value of the natural soil being - 20.3 % and 19.0 % respectively and decreased to 15.8 % and 16.8 % at 8 % lime 10 % IOT (Firoozi *et al*., 2017)


(a)
Optimum Moisture Content (%)
Iron Ore Tailings (%)
0% lime
2% lime
4% lime
6% lime
8% lime
(b)
Optimum Moisture Content (%)
Iron Ore Tailings (%)
(c)
Optimum Moisture Content (%)
Iron Ore Tailings (%)

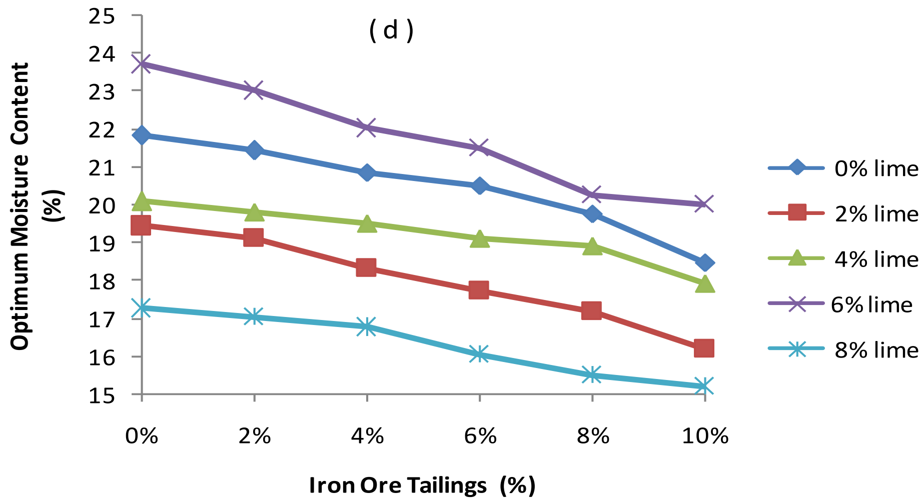
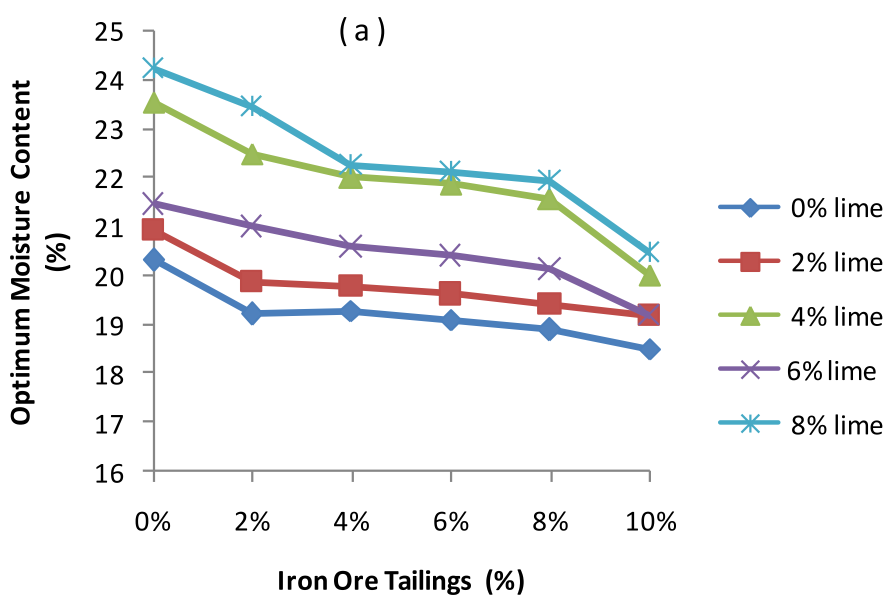


Fig. 4.15: Variation of optimum moisture content of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours and (d) 3 hours (BSL compaction).



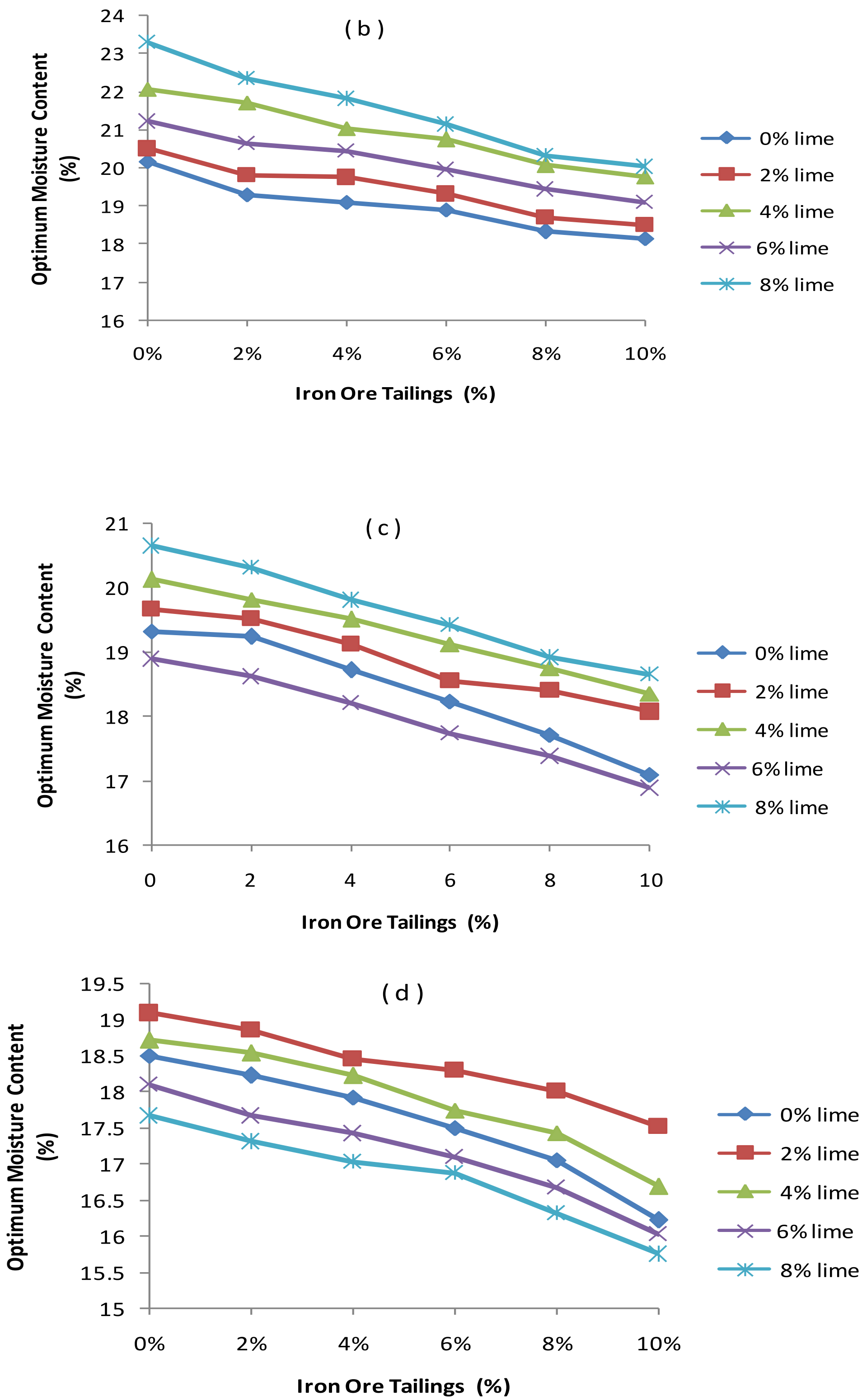
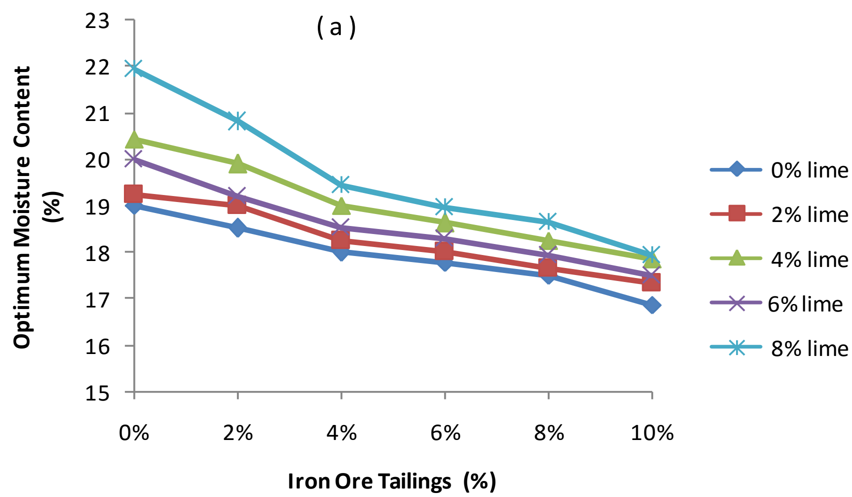
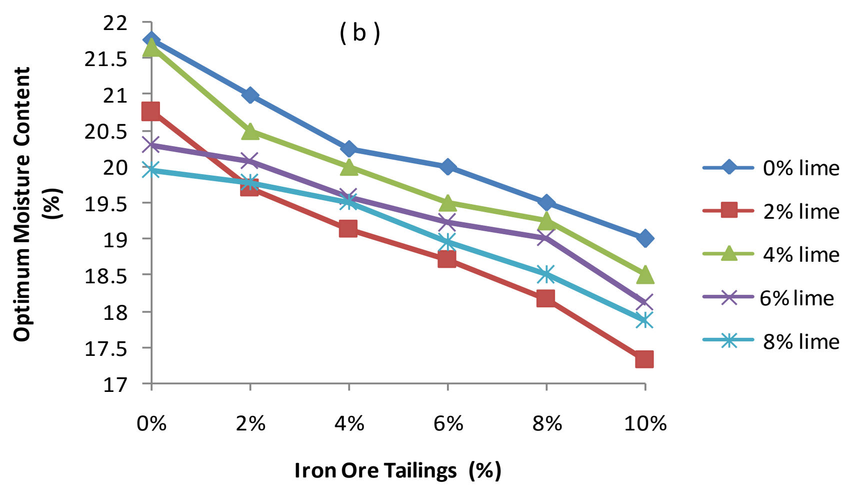
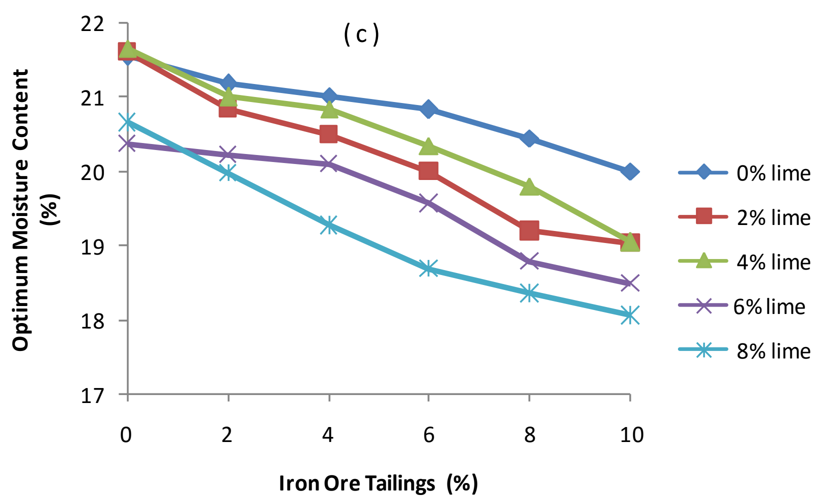


Fig. 4.16: Variation of optimum moisture content of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours and (d) 3 hours (WAS compaction).


(a)
Optimum Moisture Content (%)
23
22
21
20
19
18
17
16
15
0%
2%
4%
6%
8%
10%
Iron Ore Tailings (%)
0% lime
2% lime
4% lime
6% lime
8% lime


(b)
Optimum Moisture Content (%)
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
0%
2%
4%
6%
8%
10%
Iron Ore Tailings (%)
0% lime
2% lime
4% lime
6% lime
8% lime


(c)
Optimum Moisture Content (%)
22
21
20
19
18
17
0
2
4
6
8
10
Iron Ore Tailings (%)
0% lime
2% lime
4% lime
6% lime
8% lime

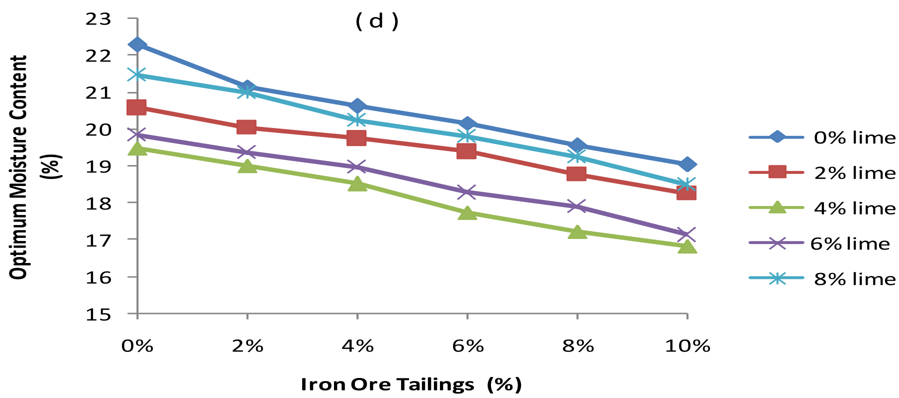
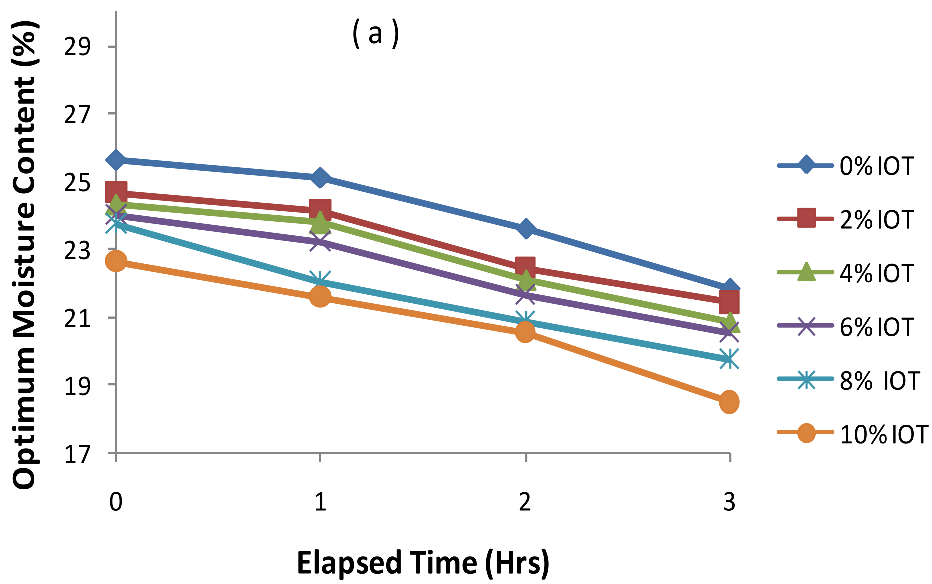
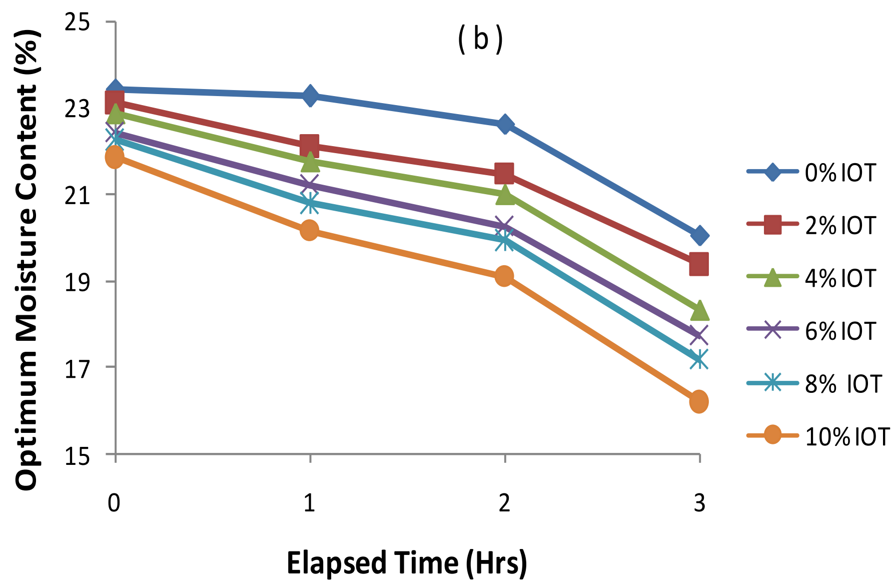


Fig. 4.17: Variation of optimum moisture content of black cotton soil – lime mixtures with iron ore tailings content for varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours and (d) 3 hours (BSH compaction).

4.3.2.1 Effect of elapsed time after mixing on optimum moisture content

The variation of optimum moisture content with elapsed time for black cotton soil treated with lime and admixed with IOT for BSL; WAS and BSH compaction energiesare shown in Fig. 4.18 - 4.20.The variation of optimum moisture content with the elapsed time after mixing for the three energy levels consideredis shown Fig. 4.21. Generally, the OMC of specimens decreased for up to 3 hours elapsed time after mixing for all the lime and IOT treatments considered after mixing for BSL and WAS compaction. For BSH compaction, the OMC increased for up to 2 hours elapsed time after mixing and thereafter decreased at 3 hours elapsed time after mixing.The decrease in the OMC could be as a result of an enhanced cation exchange reaction due to combination of free lime product and the IOT admixture. This reaction resulted in the decrease in the thickness of the double layer thereby causing flocculation. As the clay flocculated under this action, water, which had become separated from the particles concentrated in the voids between the bonded particles thus decreasing the OMC Mustapha (2006). Also, the observed decrease in OMC may not be unconnected to self – desiccation in which all the water was used up thus resulting in low hydration. When there was no water movement to or from the soil-lime- iron ore tailing matrix the available moisture was used up in the hydration reaction until too little was left to saturate the solid surfaces and hence the relative humidity within the paste decreased (Osinubi, 1998a; Okonkwo, 2009; Moses *et al*., 2012; Etim *et al*., 2017). Detailed test results are given in Tables E20 – 26; E46 – 52; E72 -78 in Appendix E.





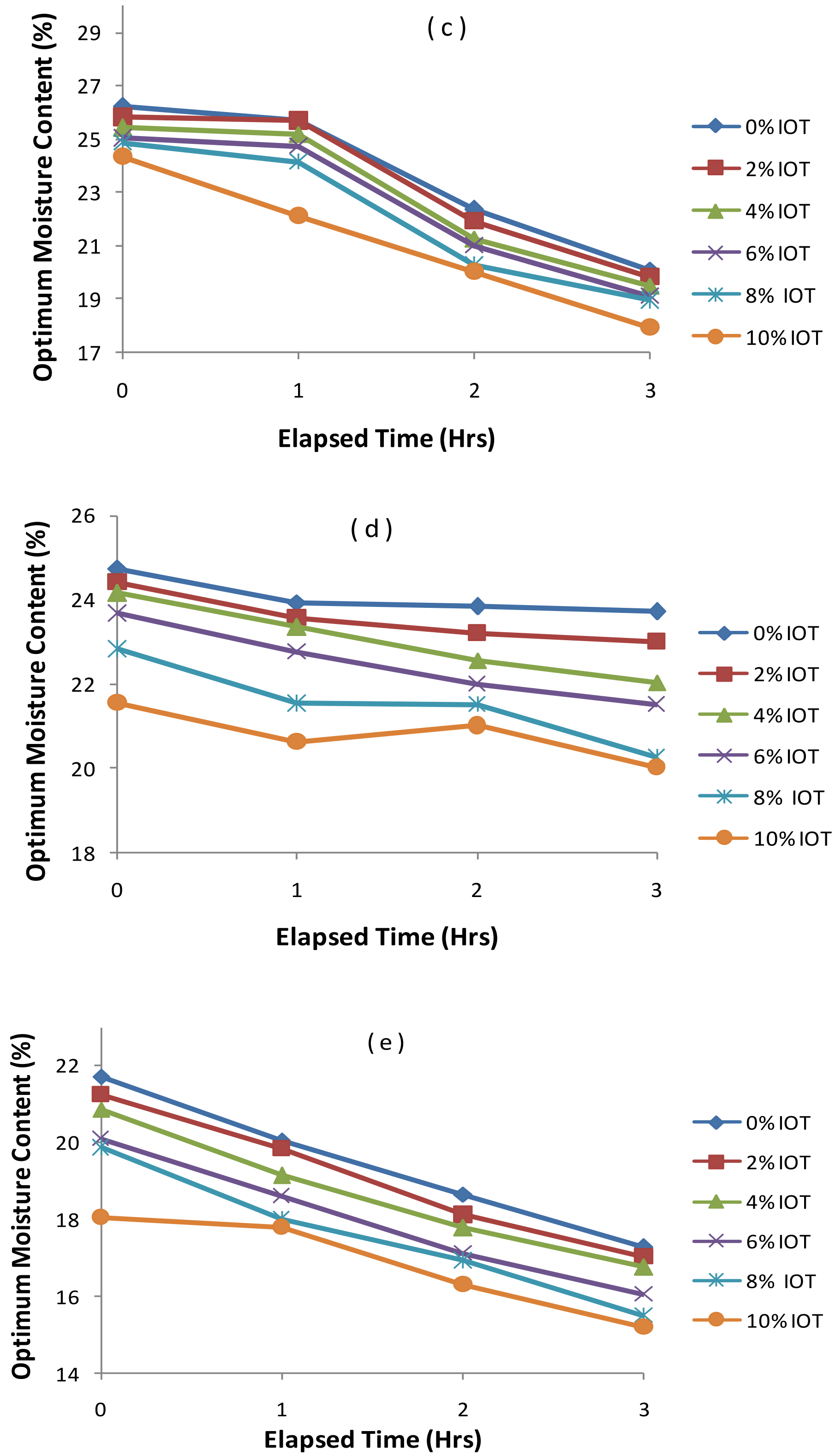
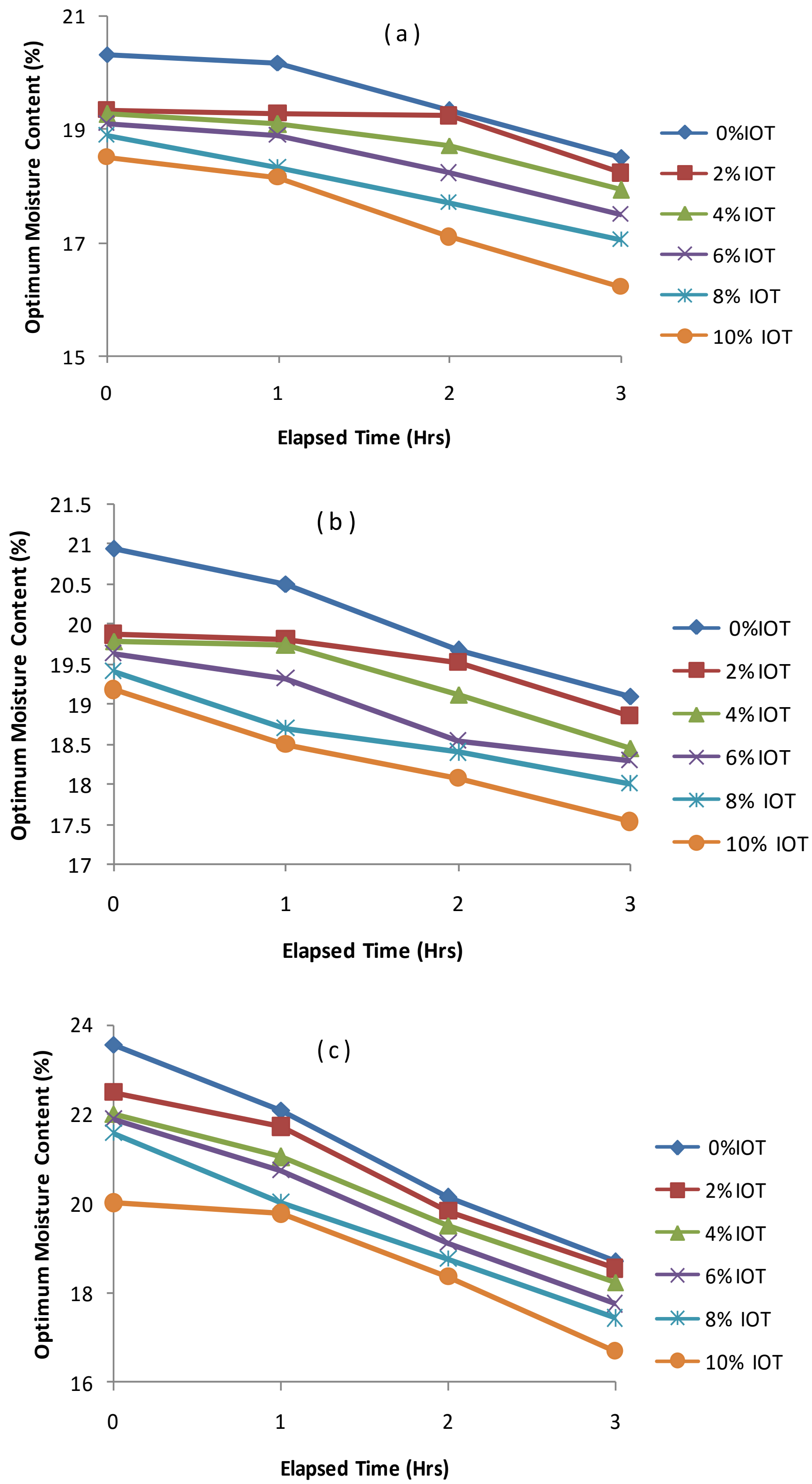


Fig. 4.18: Variation of optimum moisture content of black cotton soil – iron ore tailings mixtures with elapsed time after mixing for varying lime content: (a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSL compaction).


(a)
Optimum Moisture Content (%)
Elapsed Time (Hrs)
21
19
17
15
0
1
2
3
0%IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT
(b)
Optimum Moisture Content (%)
Elapsed Time (Hrs)
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
0
1
2
3
0%IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT
(c)
Optimum Moisture Content (%)
Elapsed Time (Hrs)
24
22
20
18
16
0
1
2
3
0%IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT

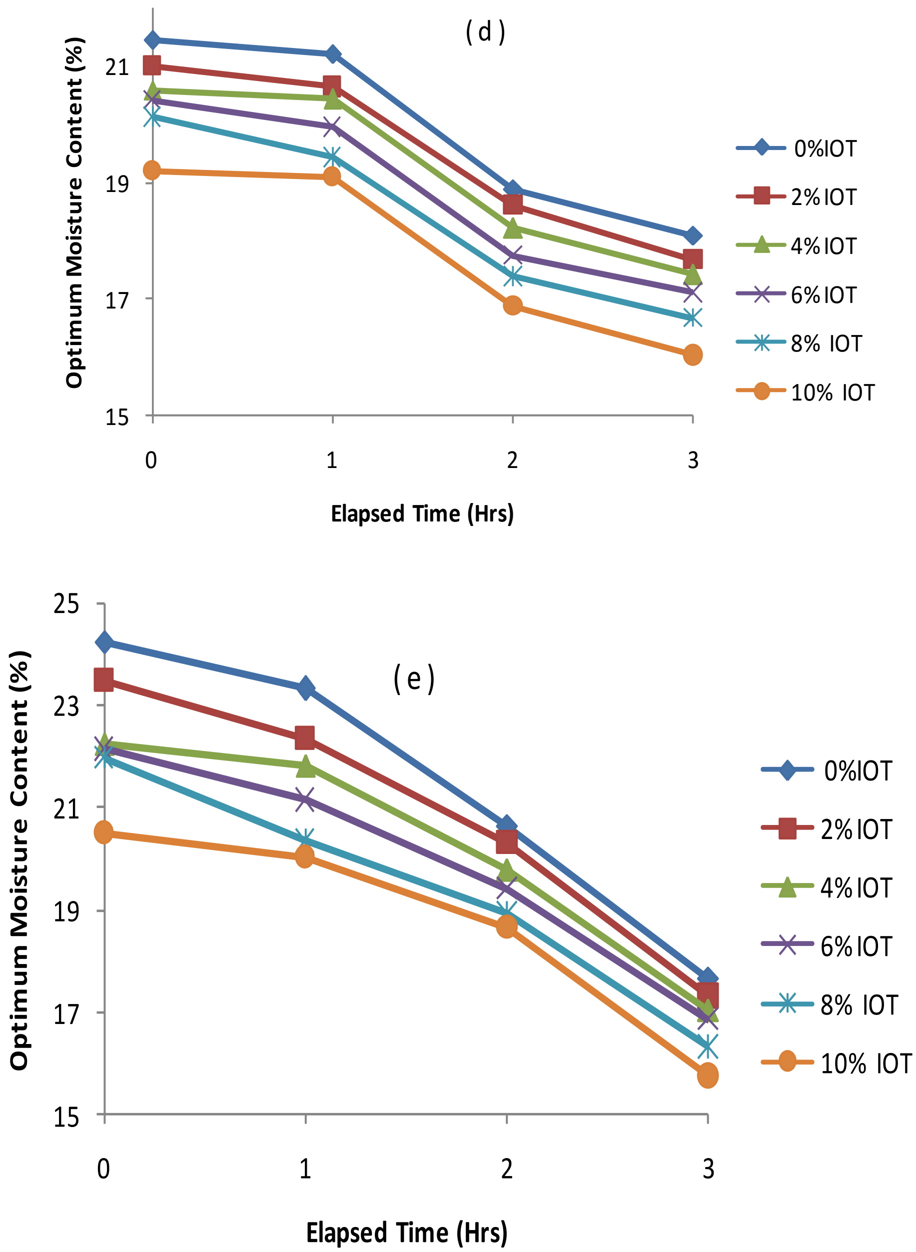
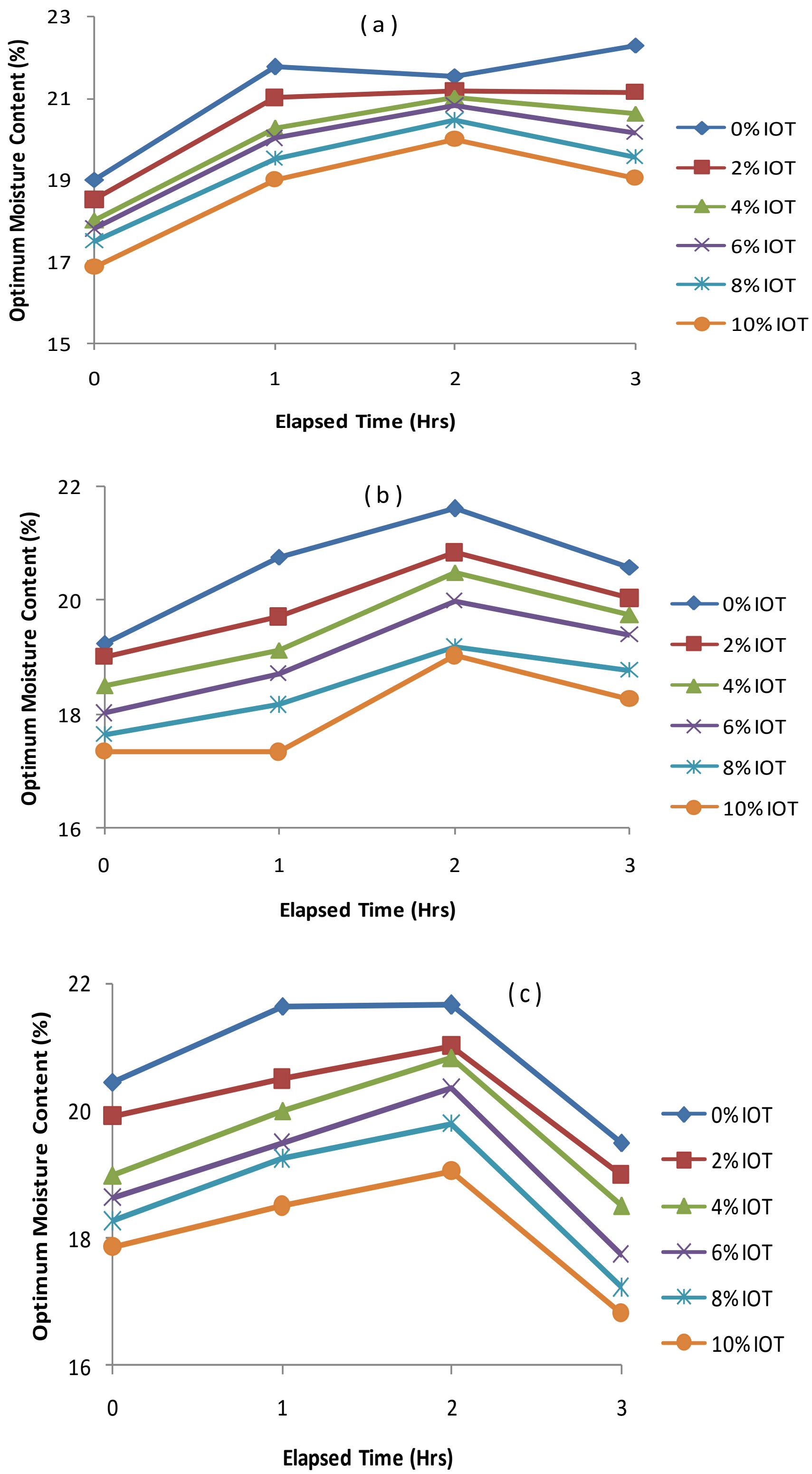
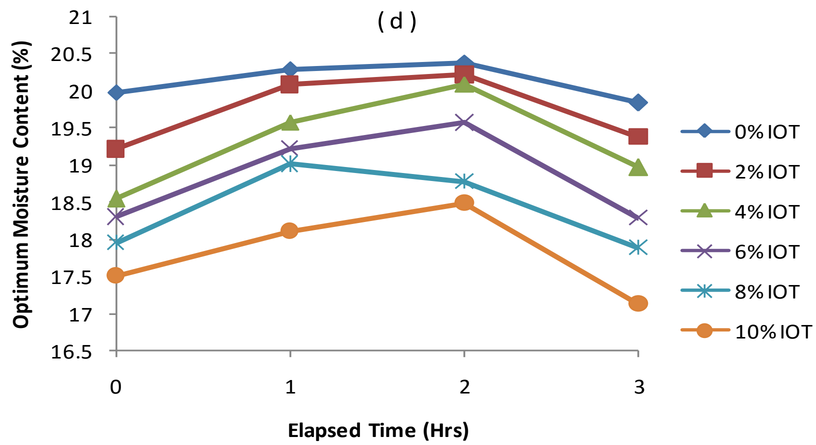


Fig. 4.19: Variation of optimum moisture content of black cotton soil – iron ore tailings mixtures with elapsed time after mixing for varying lime content: (a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (WAS compaction).


(a)
Optimum Moisture Content (%)
23
21
19
17
15
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT
(b)
Optimum Moisture Content (%)
22
20
18
16
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT
(c)
Optimum Moisture Content (%)
22
20
18
16
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT



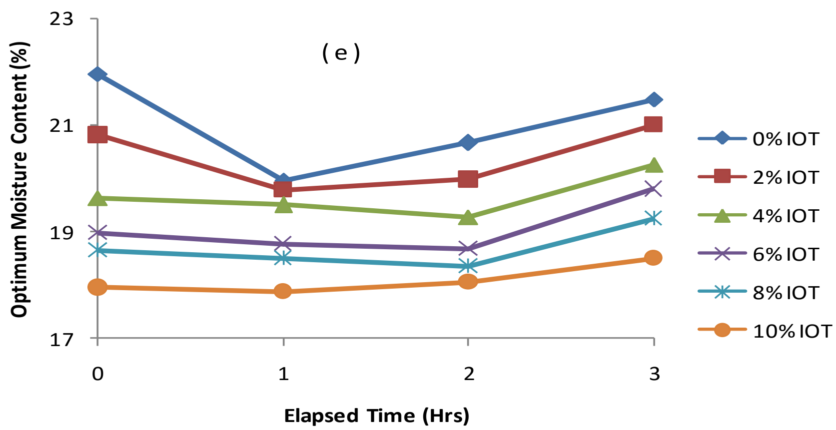


Fig. 4.20:Variation of optimum moisture content of black cotton soil – iron ore tailings mixtures with elapsed time after mixing for varying lime content: (a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSH compaction).

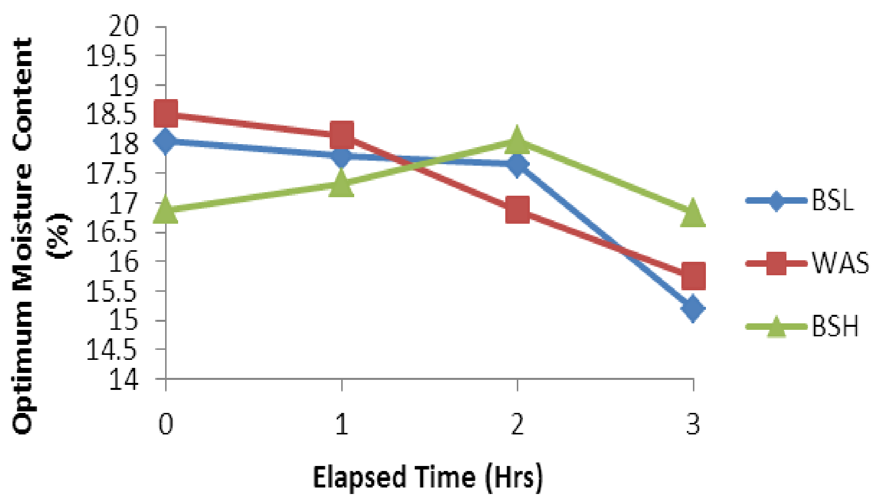


Fig. 4.21: Variation of peak optimum moisture content of black cotton soil – lime – iron ore tailings mixtures with elapsed time after mixing.

The result of the two - way analysis of variance (ANOVA) performed on OMC results with regards to elapsed time after mixing shows that the effect of time (F_{CAL}=202.837; 266.004; 35.618 > F_{CRIT} = 3.2874) and IOT (F_{CAL}= 41.917; 28.494; 64.005 > F_{CRIT}= 2.9013) are statistically significant for BSL; WAS and BSH compactions, respectively. For lime and IOT effect on BSL; WAS and BSH; Lime (F_{CAL}= 246.501; 192.113 & 42.920>F_{CRIT}=2.8661) and IOT (F_{CAL}=88.461; 196.359 &56.359>F_{CRIT}= 2.7109) respectively. For the elapsed time on BSL; WAS and BSH. Detailed results are as shown in Tables E20 – 26; E46 -52 and E72 -78 in Appendix E.

4.4 Strength Characteristics

4.4.1 Unconfined compressive strength

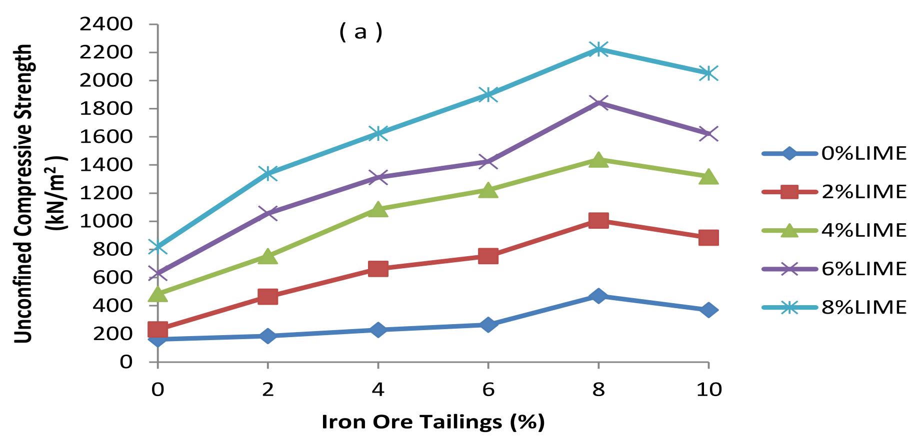
Over the years, unconfined compressive strength (UCS) test has been the most common and suitable method of evaluating the strength of stabilized soil. It is the main test recommended for the determination of the required amount of additive to be used in the stabilization of soil (Singh, 1991). According to Ola (1983), it is an important factor in the evaluation of the design criteria for the use of soil as a pavement material.

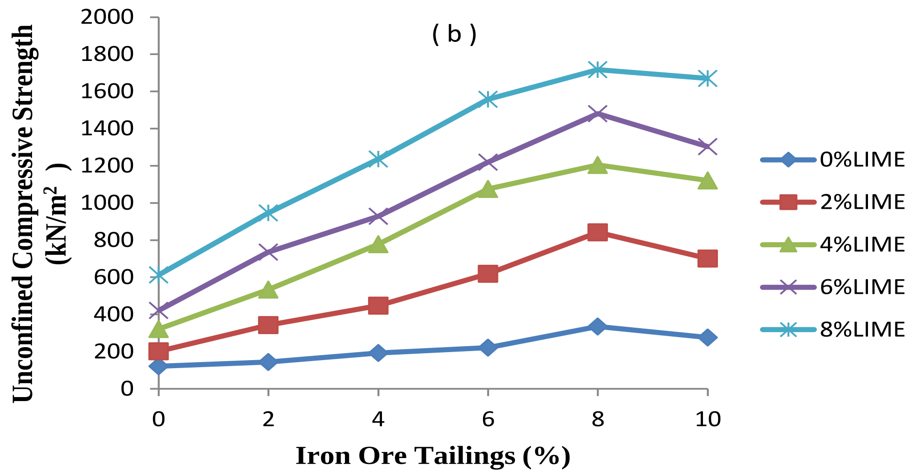
The variation of unconfined compressive strength with IOT for various lime mixtures using BSL; WAS and BSH compactive efforts are shown in Fig. 4.22, 4.23 and 4.24, respectively,for 7, 14 and 28 days curing period with the 2hours and 3hours elapsed time after mixing before compaction for each effort.

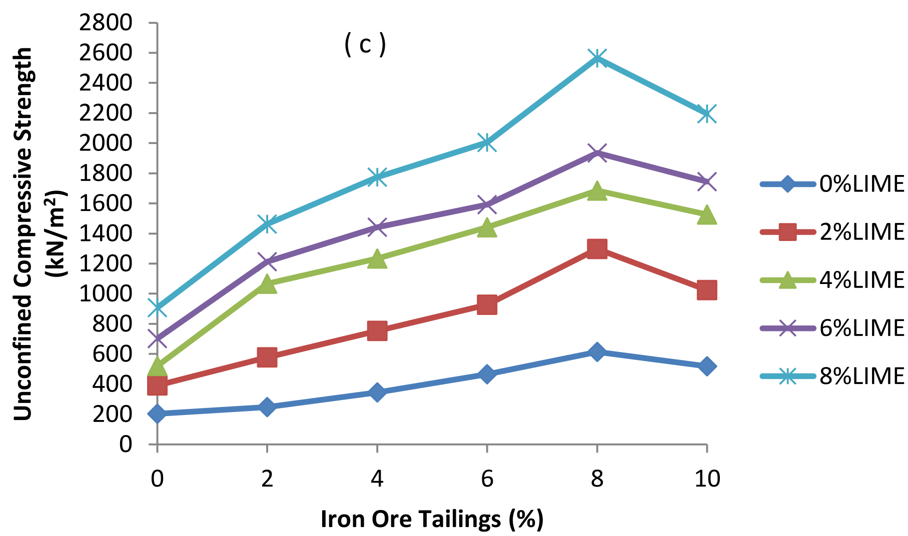
The increase in UCS values (or the gain in strength) was as a result of development of substances like calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes, leading to the strength development (Ingles and Metcalf, 1972; Ola, 1983; Negi *et al*., 2013; Maneli *et al*., 2015; Firoozi *et al*., 2017). The exact products, however, vary with the kind of clay mineralogy and the reactions, including temperature, moisture and curing conditions (Mitchell and Hooper, 1961; Ingles and Metcalf, 1972; Broms, 1984; Tamer, 2016). This reaction continued in the presence of moisture and could have been the reason for the increase in UCS of specific lime content with varied IOT with increased curing period.

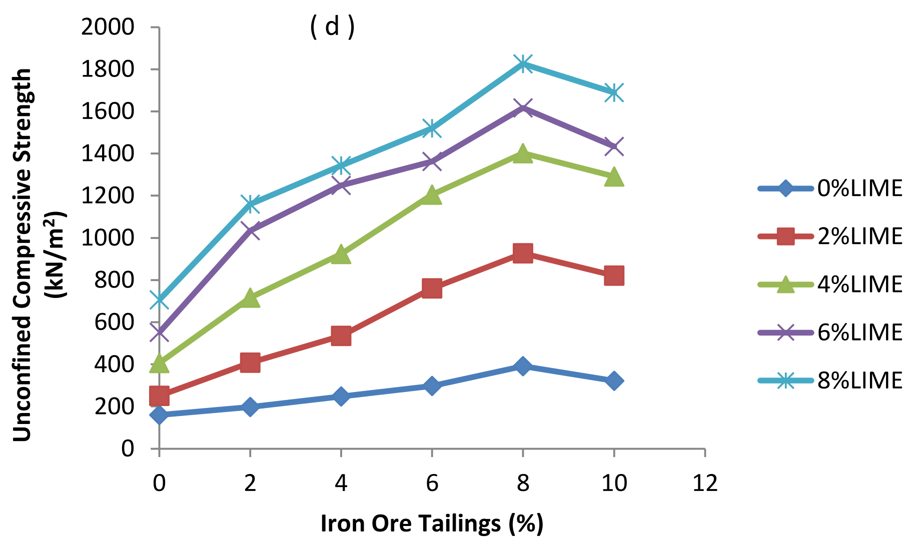
For BSL compaction at 7, 14 and 28 days curing period, peak UCS values recorded are 2,223.82 kN/m^2; 2,564.81 kN/m^2; and 2,696.51 kN/m^2, respectively at 8 % lime 8 % IOT treatment. For the same treatment when specimens were prepared with WAS compactive effort, 7, 14 and 28 days UCS values are 2,627.6kN/m^2 ;2,990.19kN/m^2 and 3,628.80kN/m^2, respectively. For BSH compaction, the same trend was observed.

Peak UCS values of 3,021.93 kN/m$^{2;}$ 3,661.18 kN/m^2 and 3,888.92 kN/m^2 at 7, 14 and28 days, respectively (Maneli *et al*., 2015; Firoozi *et al*., 2017; Ikeagwuani and Nwonu, 2019; Syed *et al*., 2020).




(b)
Unconfined Compressive Strength (kN/m2)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
2
4
6
8
10
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME


(c)
Unconfined Compressive Strength (kN/m2)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
0
2
4
6
8
10
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME


(d)
Unconfined Compressive Strength (kN/m2)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
2
4
6
8
10
12
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME

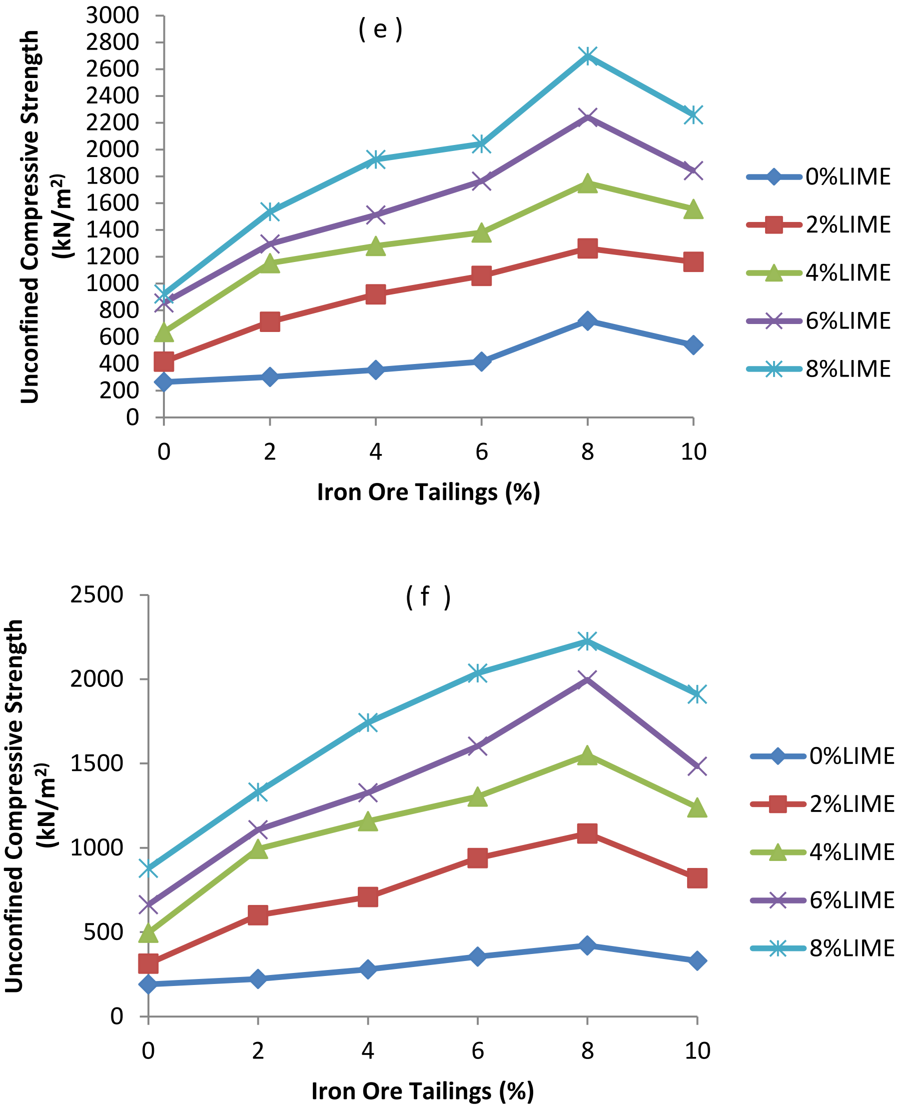
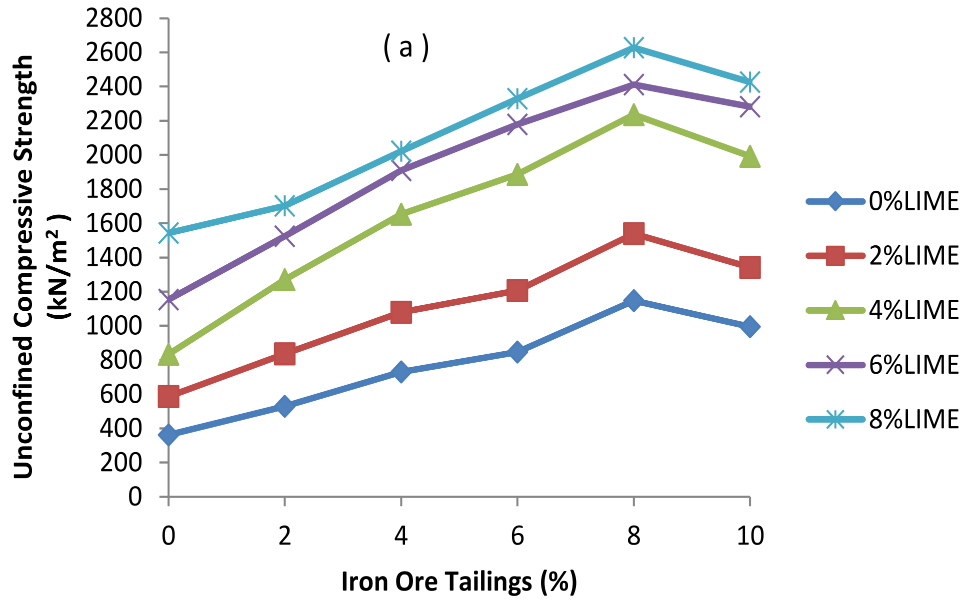
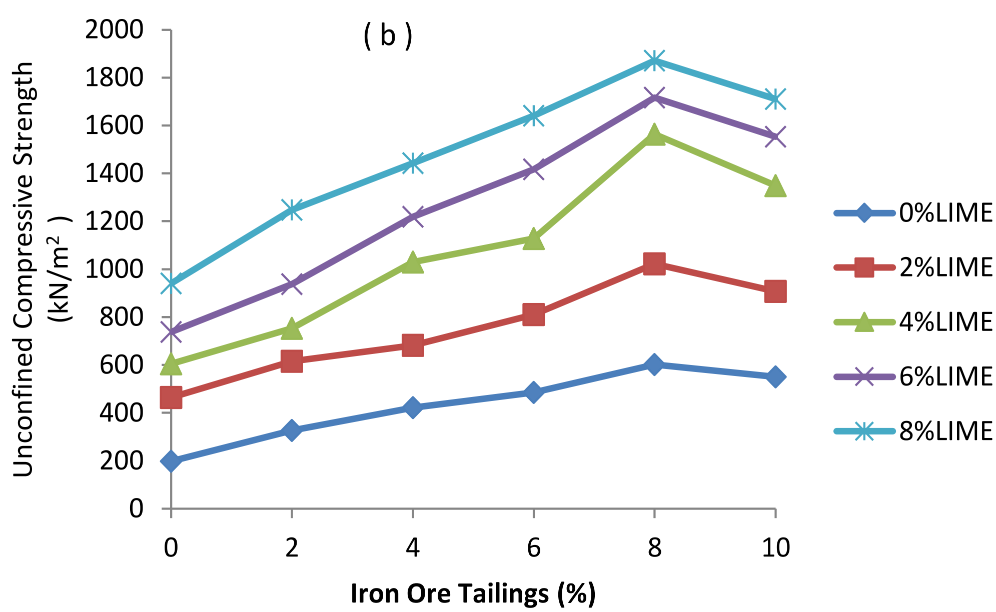
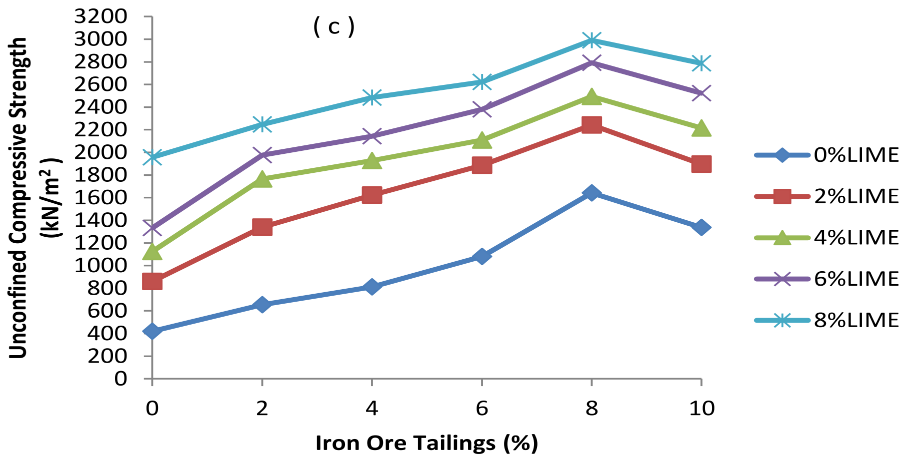


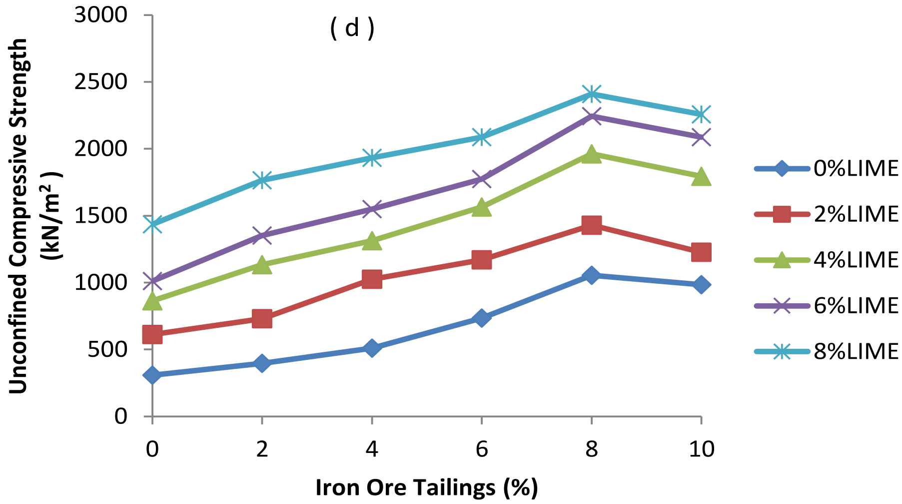
Fig.4.22: Variation of unconfined compressive strength of black cotton soil – lime mixtures with iron ore tailings for varyingcuring period and elapsed time after mixing: (a) 7 days – 2 hours (b) 7 days – 3 hours (c) 14 days – 2 hours (d) 14 days – 3 hours (e) 28 days - 2 hours (f) 28 days – 3 hours (BSL compaction).

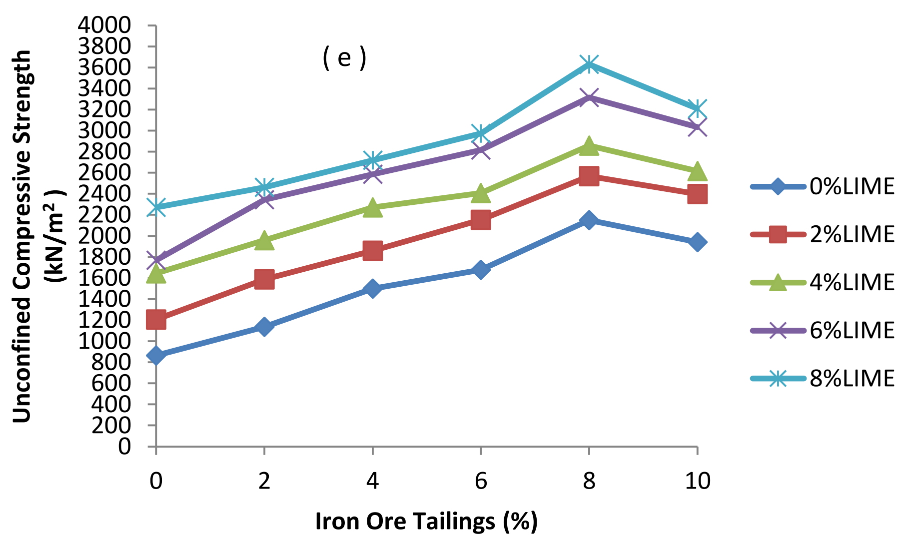
The UCS values for BSL effort and 7 days cured increased from 85.63 kN/m^2 for the natural soil to peak value of 2223.82 kN/m^2; for 14 days – 124.21kN/m^2 to 2564.81 kN/m^{2}and 28 days – 163.31 kN/m^2 to 2696.51 kN/m^2 all at 8% lime 8% IOT treatment. There was reduction in the UCS values for all the lime treatment at 10% IOT content across the curing periods. The highest peak value for BSL effort is 2696.51 kN/m^2 at 8% lime 8% IOT and 28 days curing.






(c)
Unconfined Compressive Strength (kN/m²)
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME


(d)
Unconfined Compressive Strength (kN/m²)
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME


(e)
Unconfined Compressive Strength (kN/m²)
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME

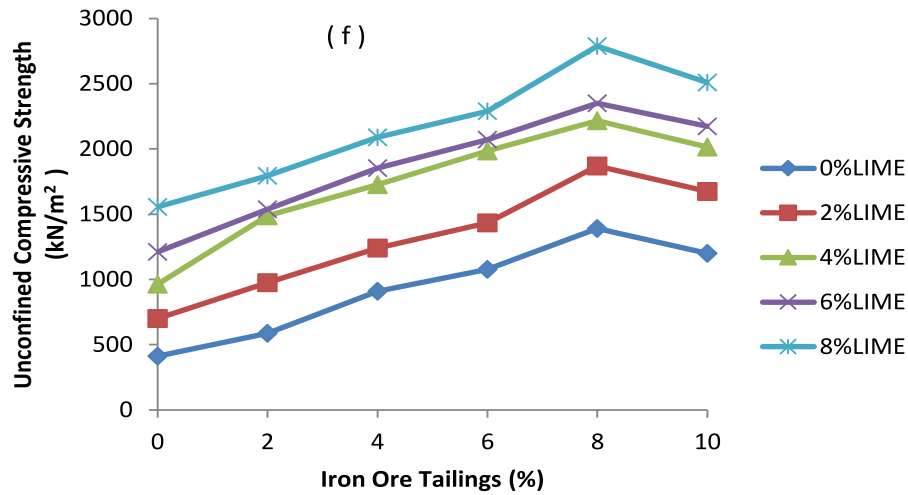
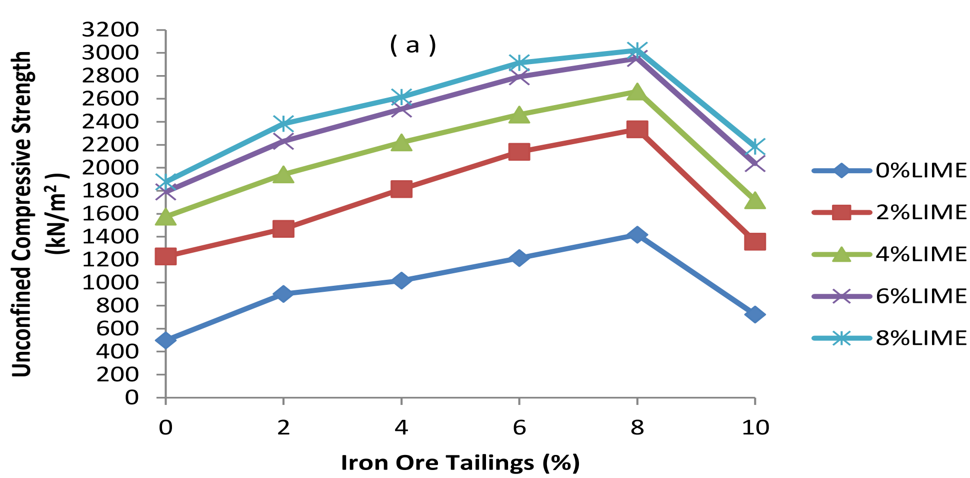
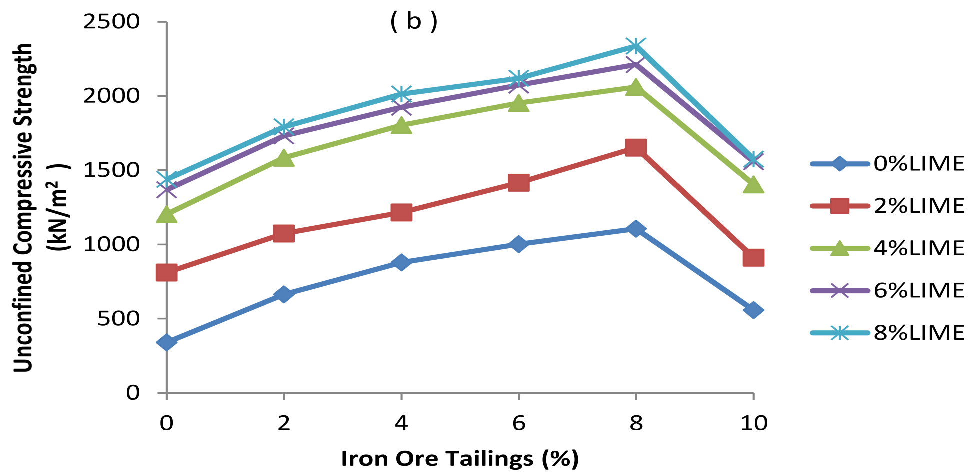
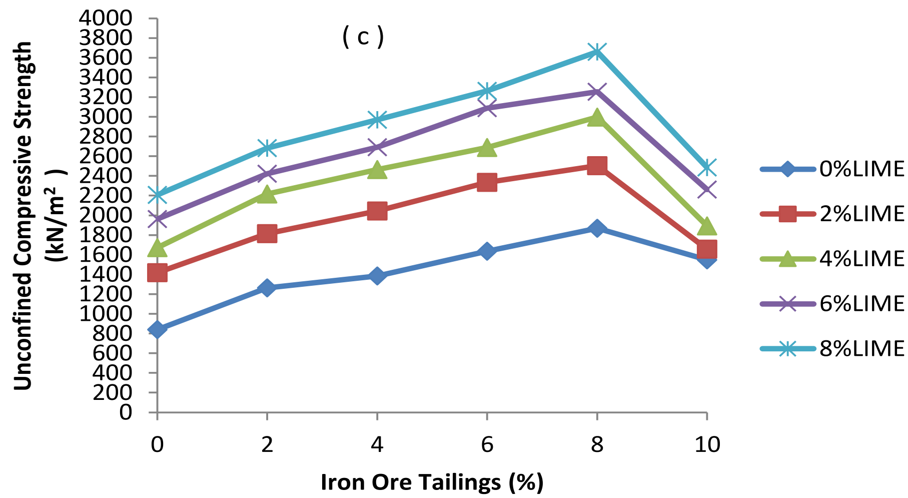


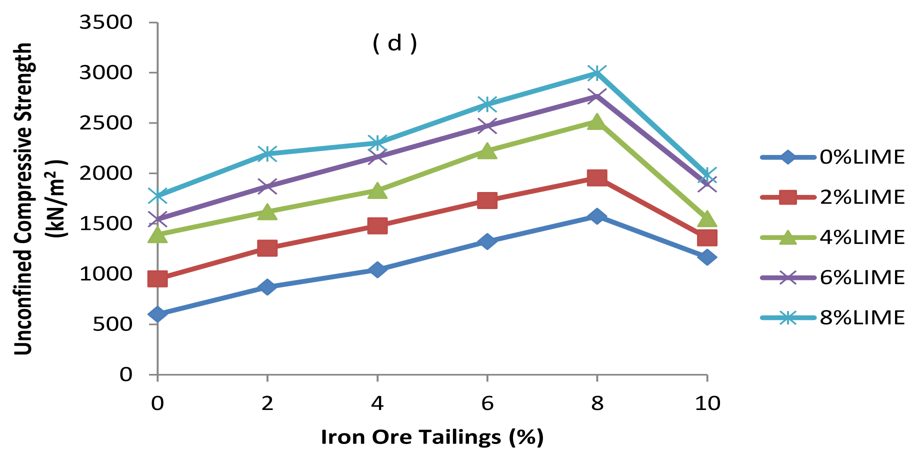
Fig.4.23: Variation of unconfined compressive strength of black cotton soil – lime mixtures with iron ore tailings for varyingcuring period and elapsed time after mixing: (a) 7 days – 2 hours (b) 7 days – 3 hours (c) 14 days – 2 hours (d) 14 days – 3 hours (e) 28 days - 2 hours (f) 28 days – 3 hours (WAScompaction).

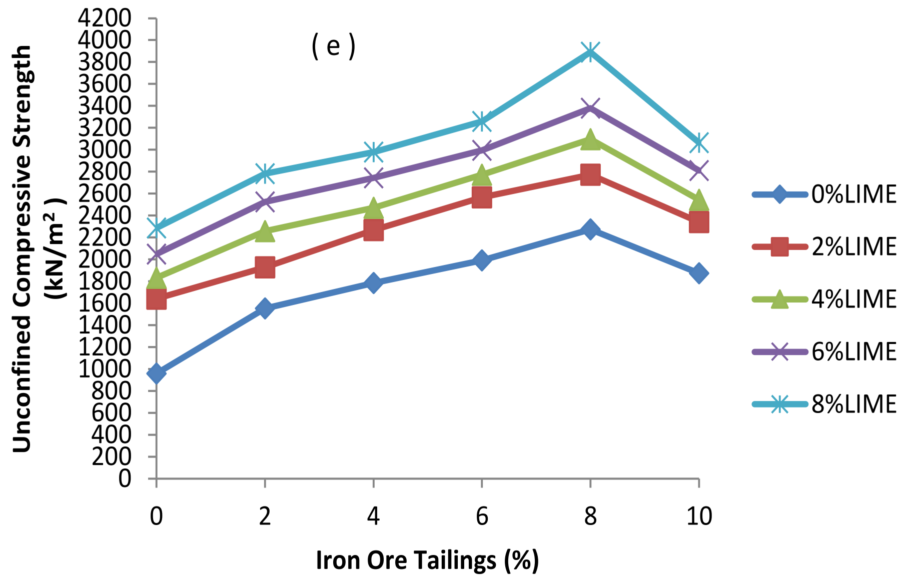
For WAS compactive effort, the trend observed is similar to that recorded for BSL compaction for all the treatments and curing periods considered. The peak values for UCS compared to the curing period and its natural soil value are as follow:7 days- 188.60 kN/m^2 to peak value of 2,627.6kN/m^2, 14 days-258.44 kN/m^2 to peak value of 2,990.19 kN/m^2, 28 days-554.25 kN/m^2 to peak value of 3,628.80 kN/m^2.




(b)
Unconfined Compressive Strength (kN/m2)
2500
2000
1500
1000
500
0
0
2
4
6
8
10
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME


(c)
Unconfined Compressive Strength (kN/m2)
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME


(d)
Unconfined Compressive Strength (kN/m2)
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME



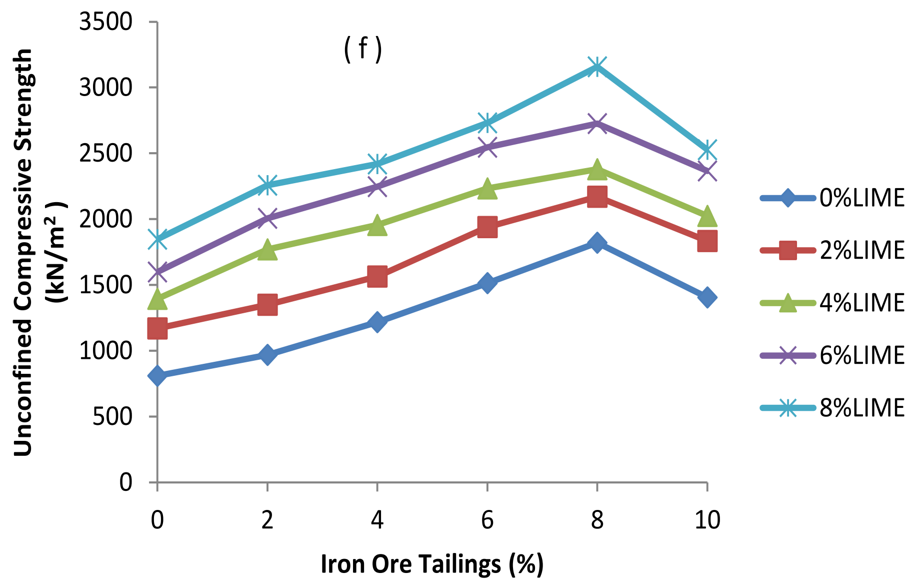


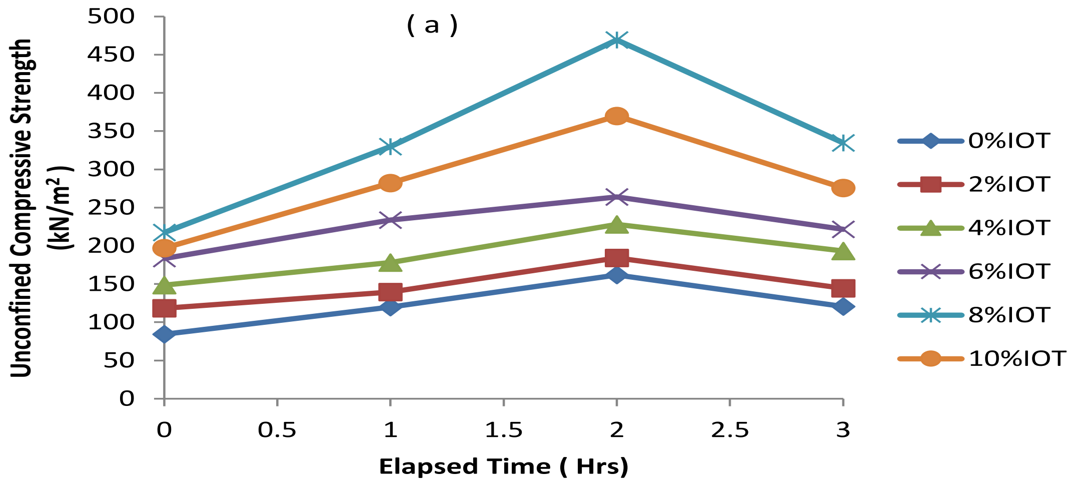
Fig.4.24:Variation of unconfined compressive strength of black cotton soil with iron ore tailings for varying curing period and elapsed time after mixing: (a) 7 days – 2 hours (b) 7 days – 3 hours (c) 14 days – 2 hours (d) 14 days – 3 hours (e) 28 days - 2 hours (f) 28 days – 3 hours (BSH compaction).

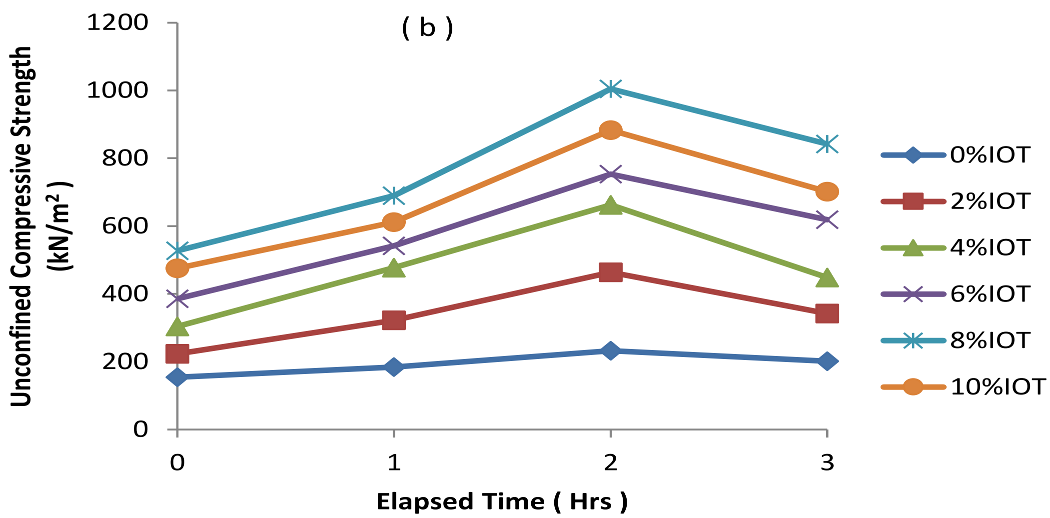
The UCS trend for BSH compactive effort is similar to that recorded for BSL compaction and the peak values are: 7 days – 196.43 kN/m^{2}to 3,021.93 kN/m^2, 14 days – 423.80kN/m^{2}to 3,661.18 kN/m^2, 28 days – 557.49 kN/m^{2}to 3,888.92 kN/m^2.

All the compactive efforts recorded decreases in the UCS values at 10% IOT content for all the lime treatment. The decrease in strength with the IOT content could be as a result of excess IOT yielding lower valence cations that cannot be neutralized with the available higher valence cations. This reaction increased the affinity of H^+ which caused a reduction in strength (Osinubi*et al.*, 2007a; Etim *et al*., 2017).

4.4.1.1 Effect of elapsed time after mixing on unconfined compressive strength

The variation of unconfined compressive strength of black cotton soil with elapsed time for various IOT mixtures at various percentages of lime using BSL; WAS and BSH efforts for 7; 14 and 28 days curing period are shown in fig.4.25 – 4.27; fig. 4.27 – 4.30 and fig. 4.31 – 4.33 respectively. Also fig. 4.34 - 4.36 shows the variation of peak values of unconfined compressive strength with elapsed time for various lime – IOT treatment at 7; 14 and 28 days respectively for BSL; WAS and BSH. Considering effects of the elapse time on the UCS test for all compaction energy level which are BSL; WAS and BSH; the UCS value increases and peaked at 2 hours and dropped to 3 hours.


(a)
Unconfined Compressive Strength (kN/m²)
500
450
400
350
300
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(b)
Unconfined Compressive Strength (kN/m²)
1200
1000
800
600
400
200
0
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT

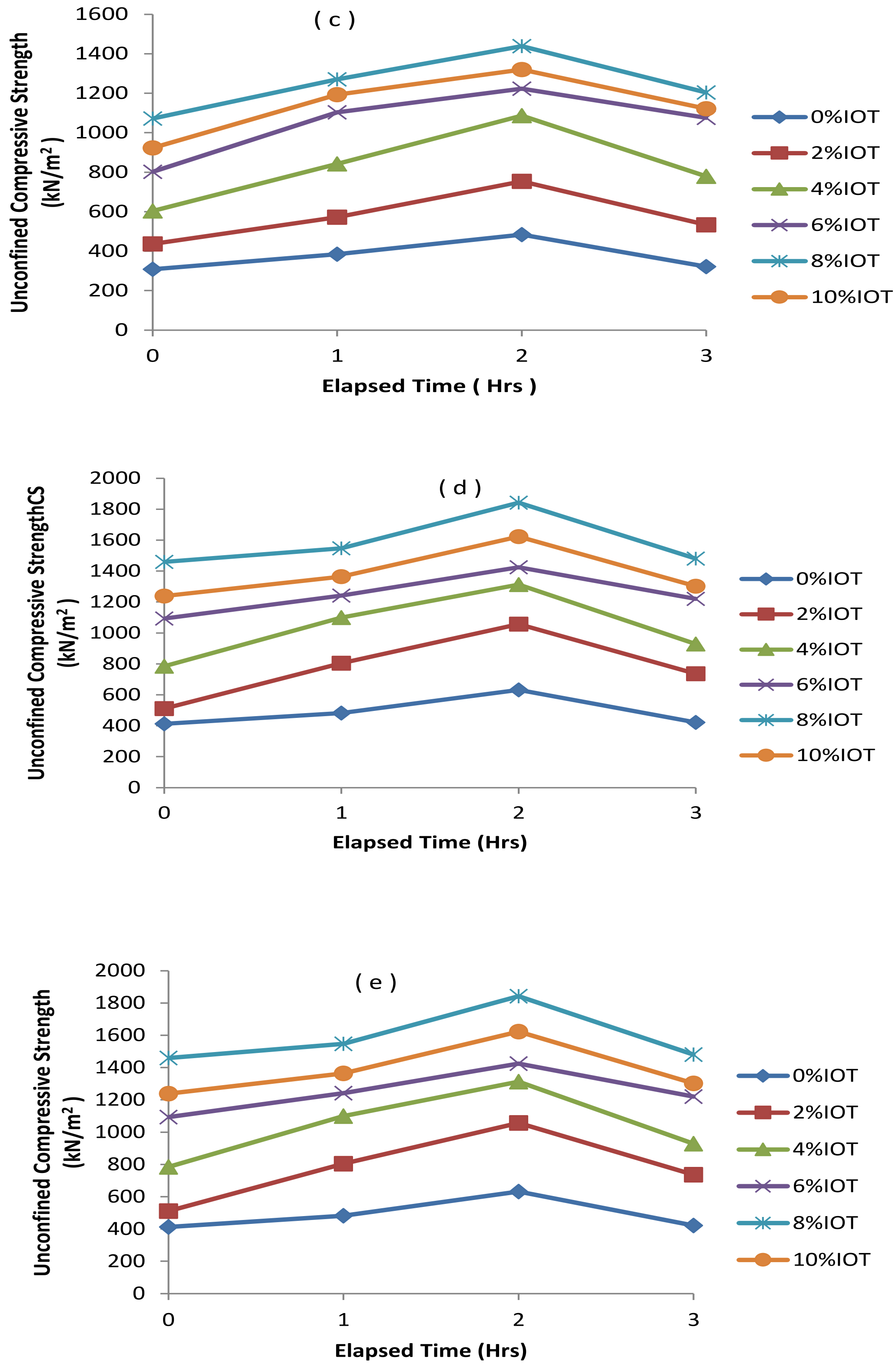
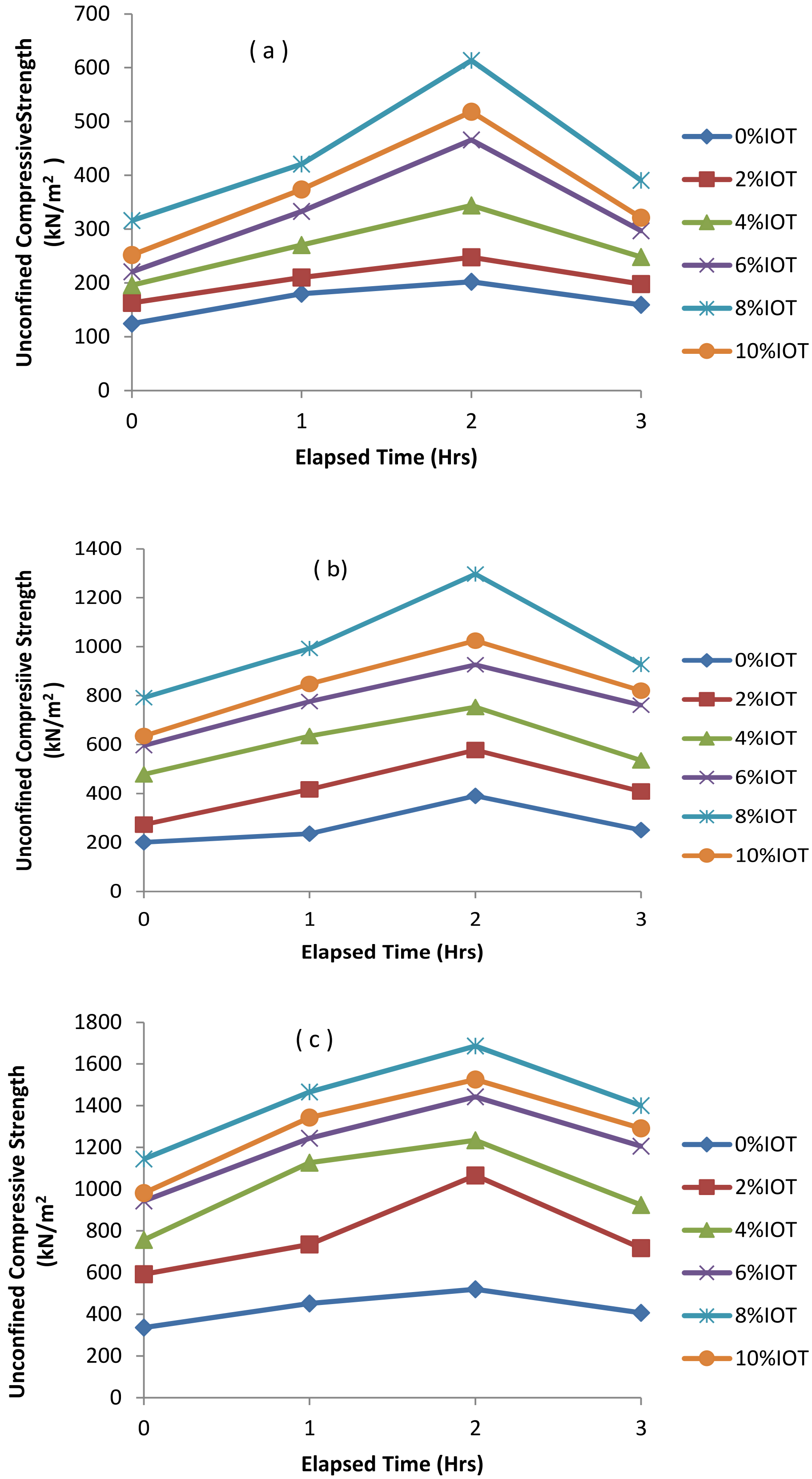
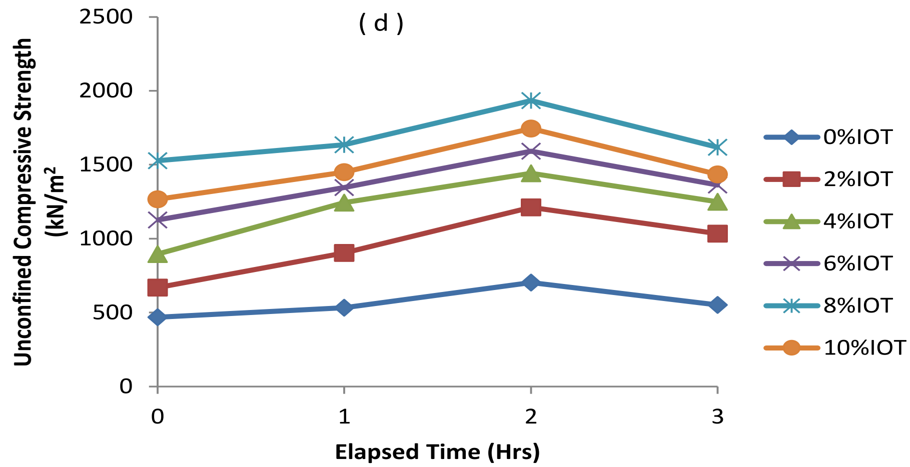


Fig. 4.25: Variation of unconfined compressive strength (7 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSL compaction)


(a)
Unconfined CompressiveStrength (kN/m²)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT
(b)
Unconfined Compresive Strength (kN/m²)
Elapsed Time (Hrs)
(c)
Unconfined Compressive Strength (kN/m²
Elapsed Time (Hrs)



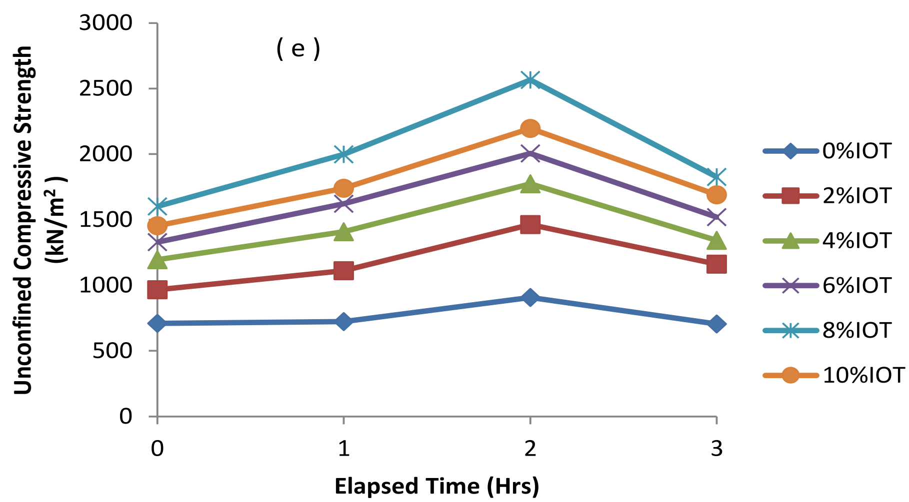
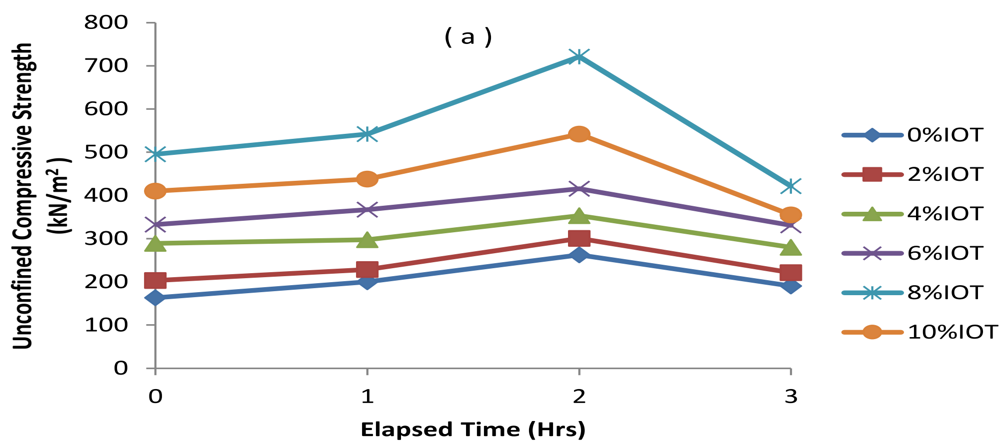
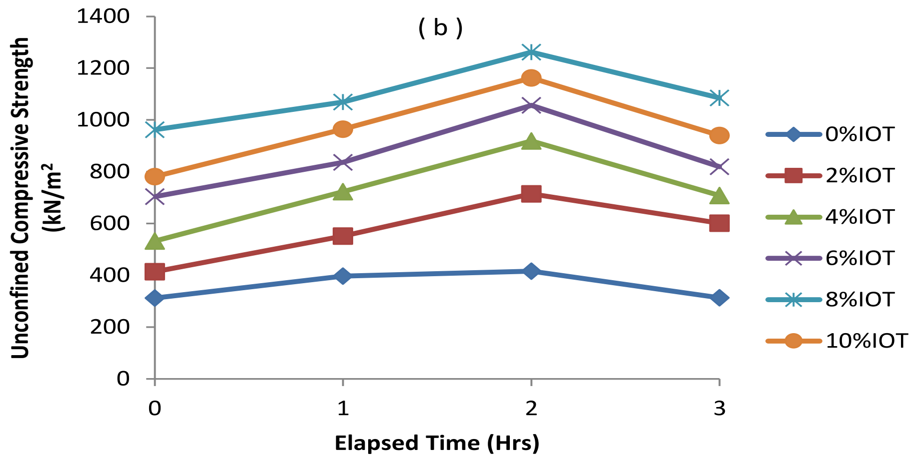
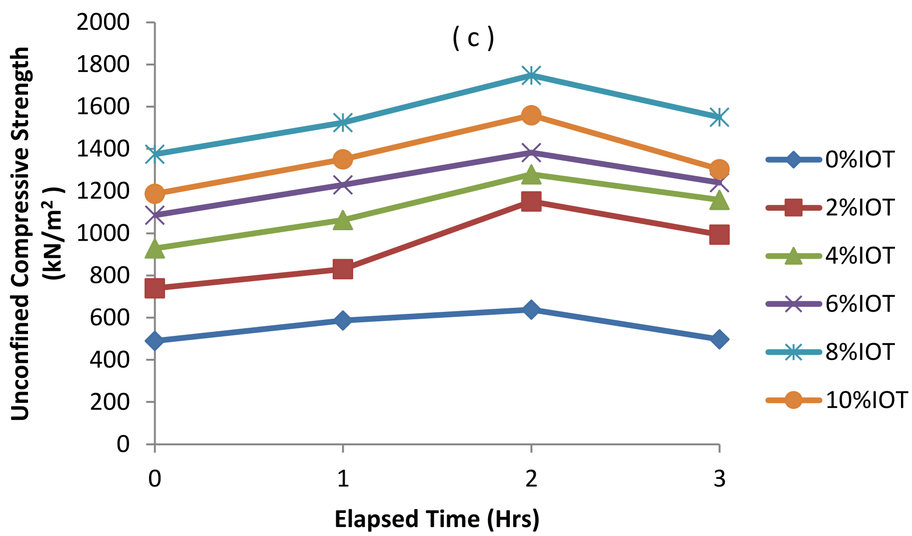
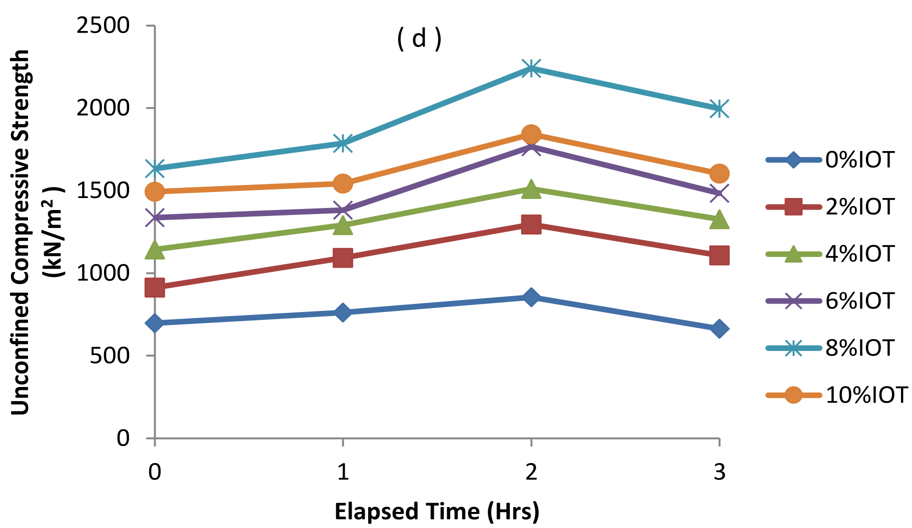


Fig. 4.26: Variation of unconfined compressive strength (14 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSL compaction)




(b)
Unconfined Compressive Strength (kN/m²)
1400
1200
1000
800
600
400
200
0
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(c)
Unconfined Compressive Strength (kN/m²)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(d)
Unconfined Compressive Strength (kN/m²)
2500
2000
1500
1000
500
0
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT

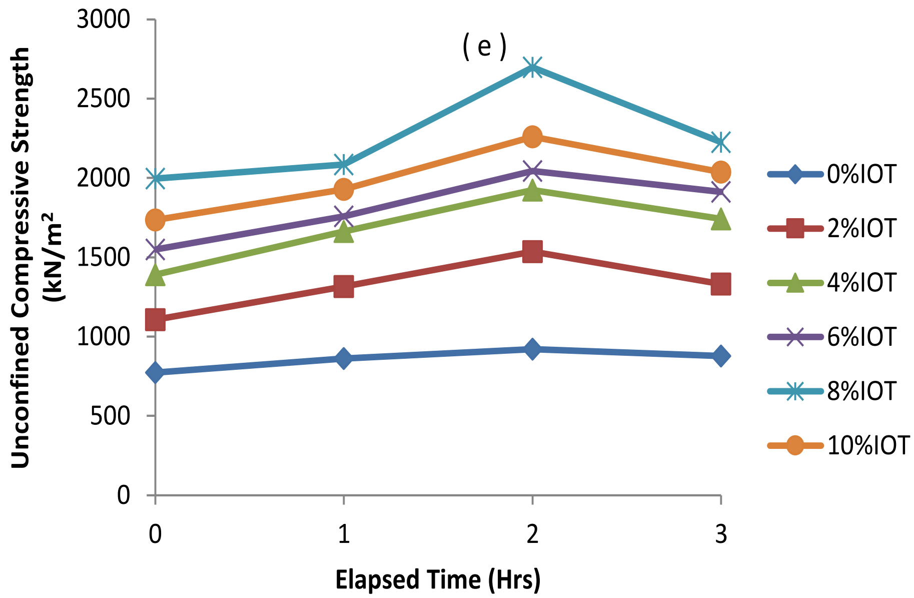
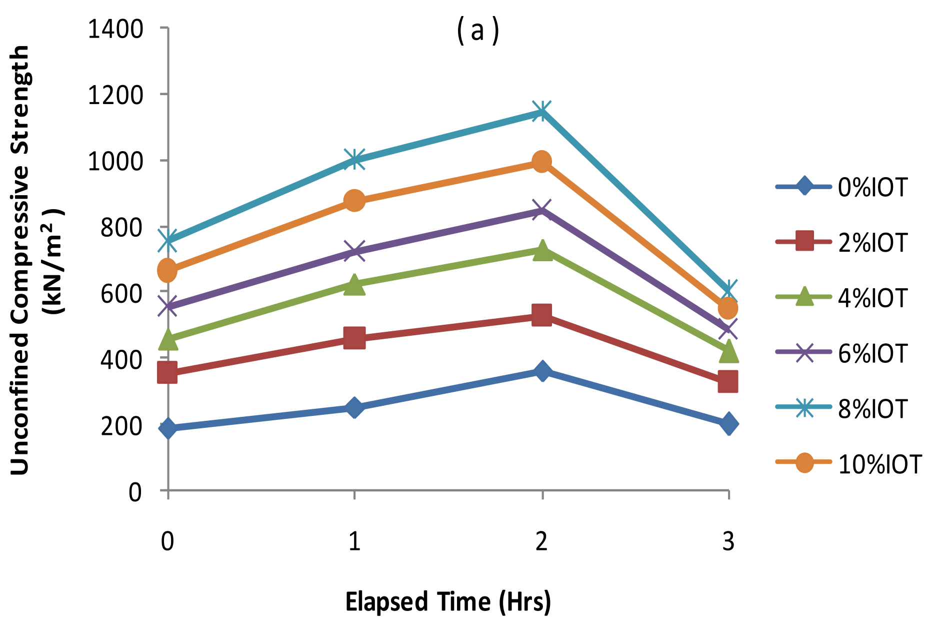
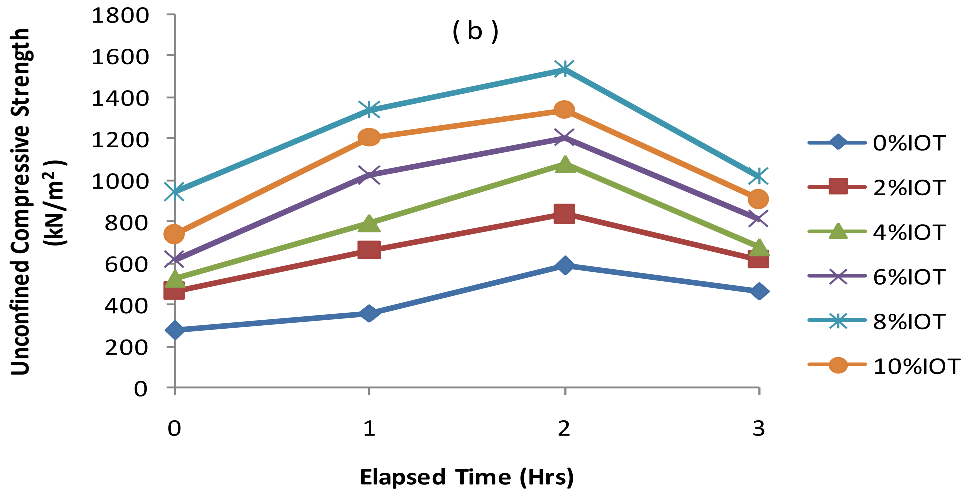
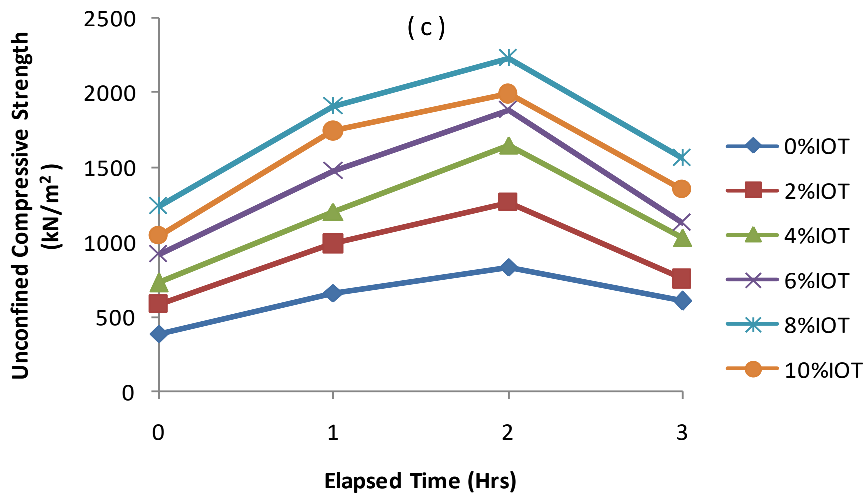
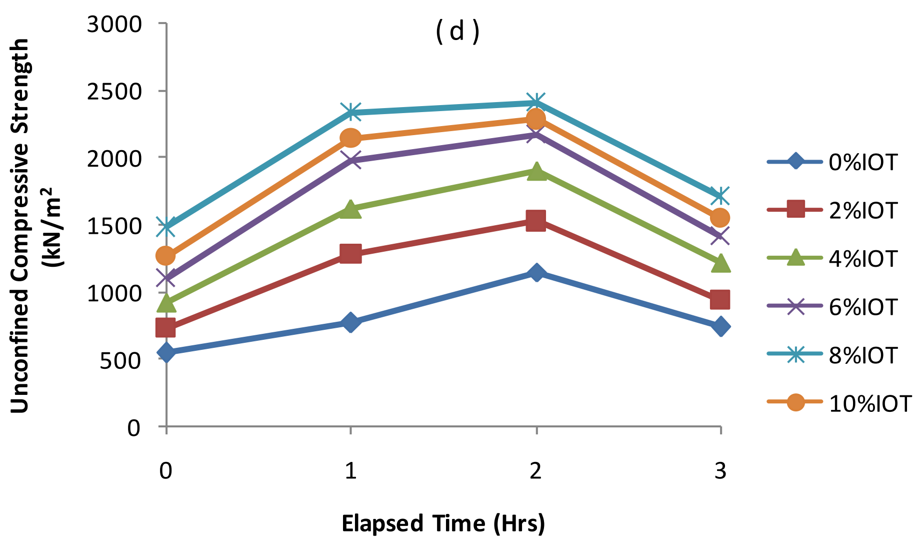


Fig. 4.27: Variation of unconfined compressive strength (28 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSL compaction)




(b)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(c)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(d)
Unconfined Compressive Strength (kN/m²
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT

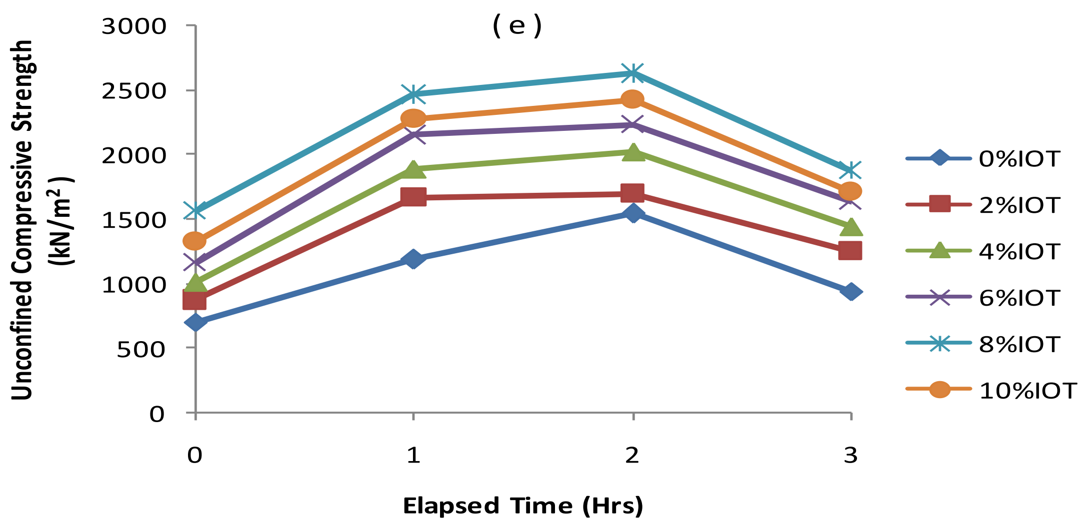
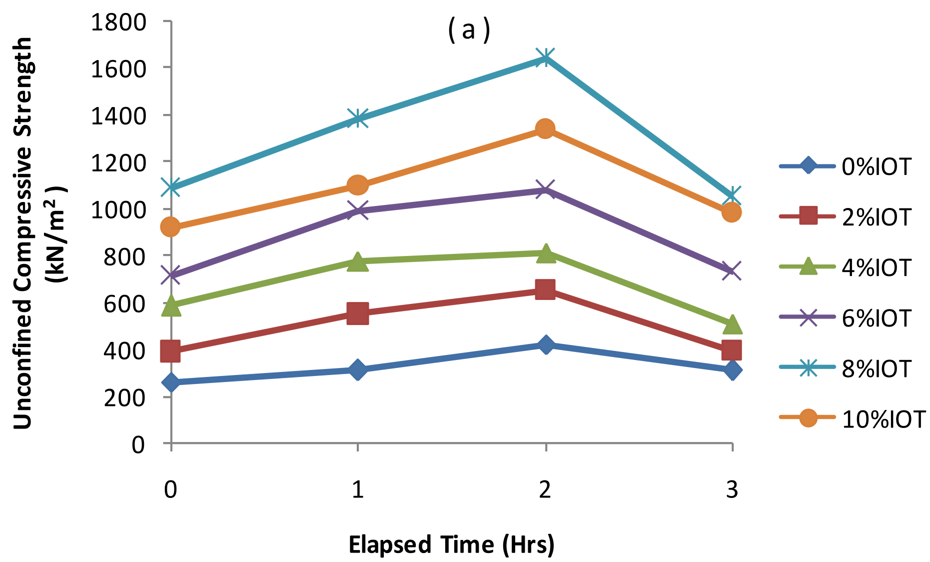
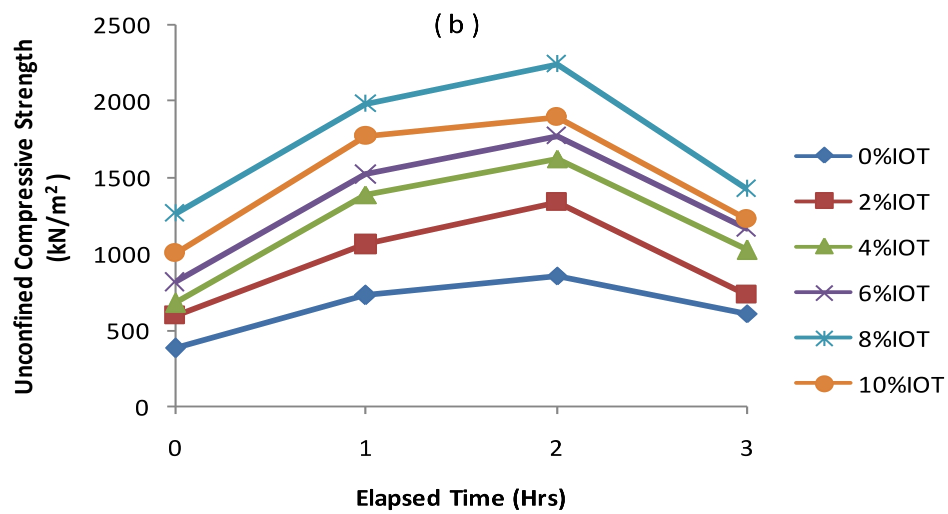
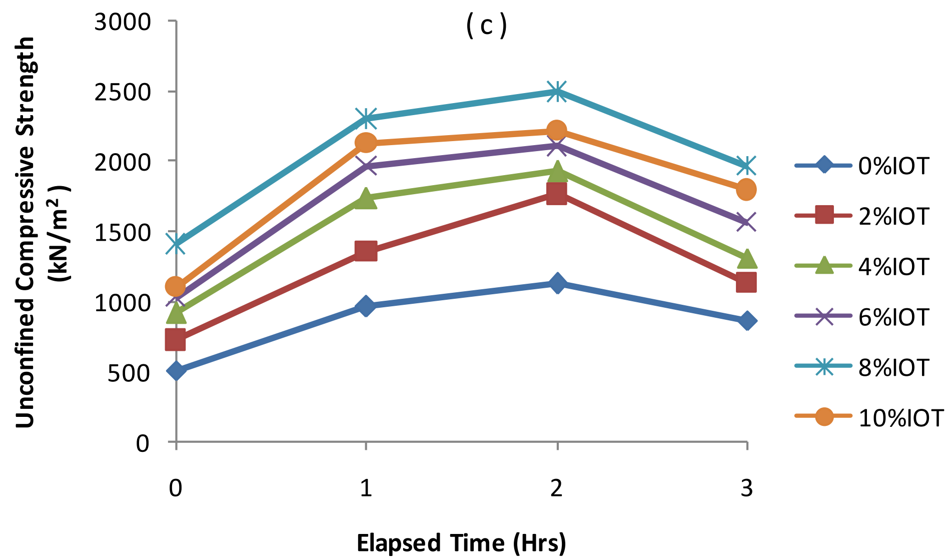
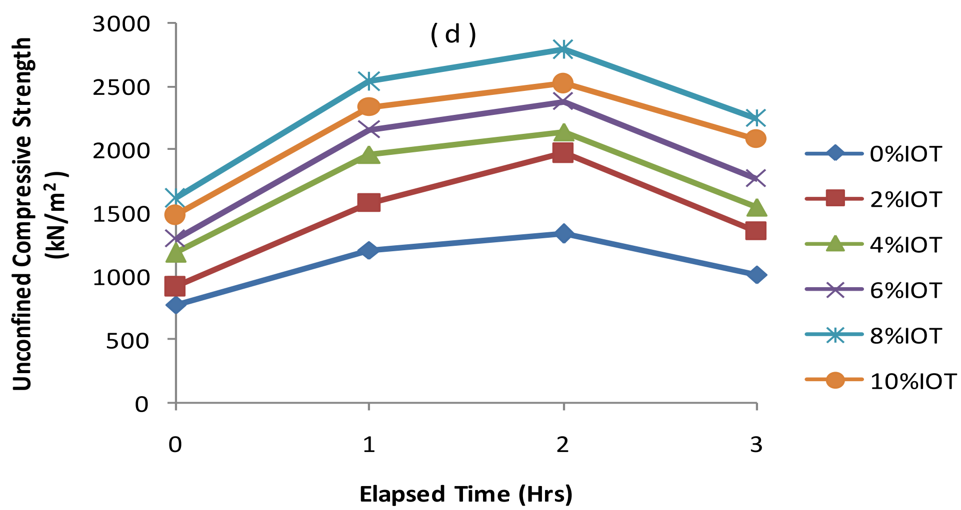


Fig. 4.28: Variation of unconfined compressive strength (7 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (WAScompaction)




(b)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(c)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(d)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT

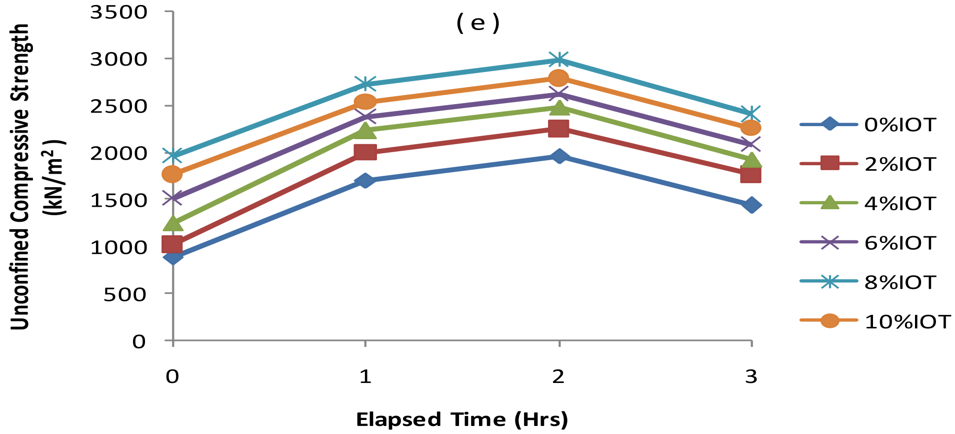
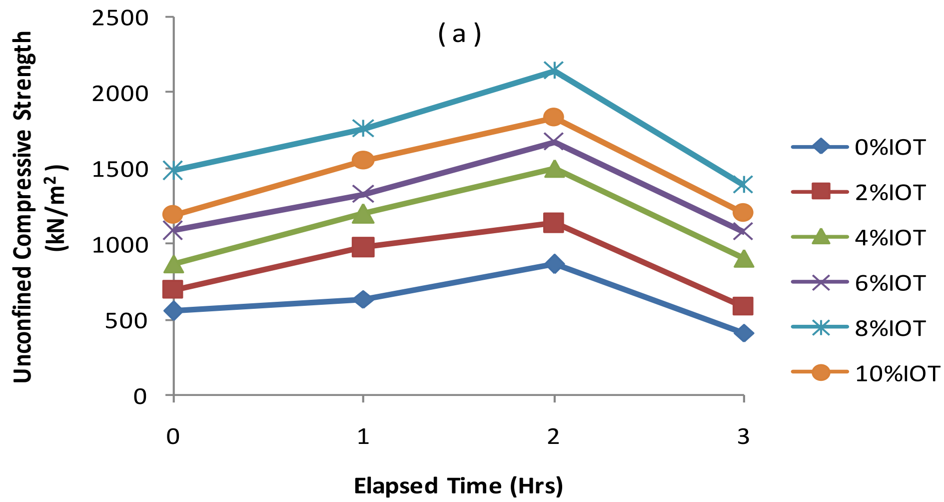
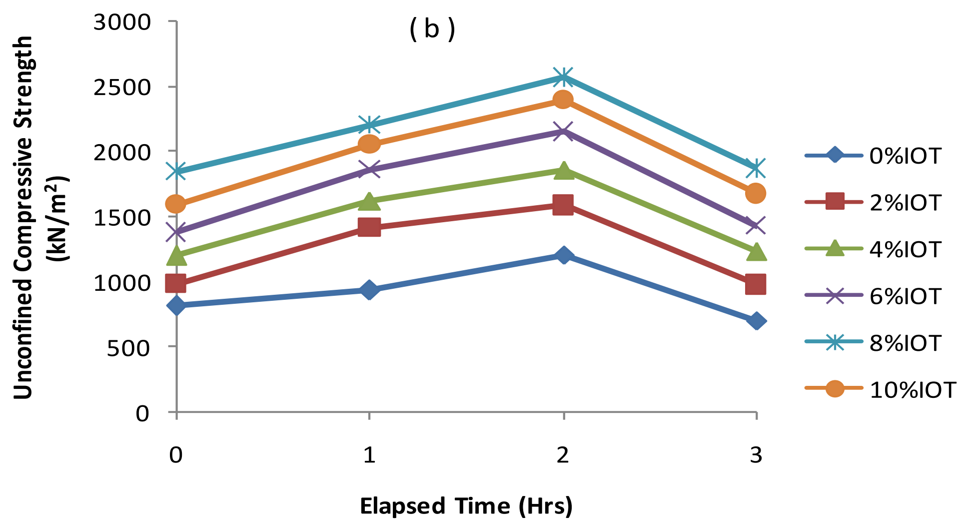


Fig. 4.29: Variation of unconfined compressive strength (14 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (WAScompaction)





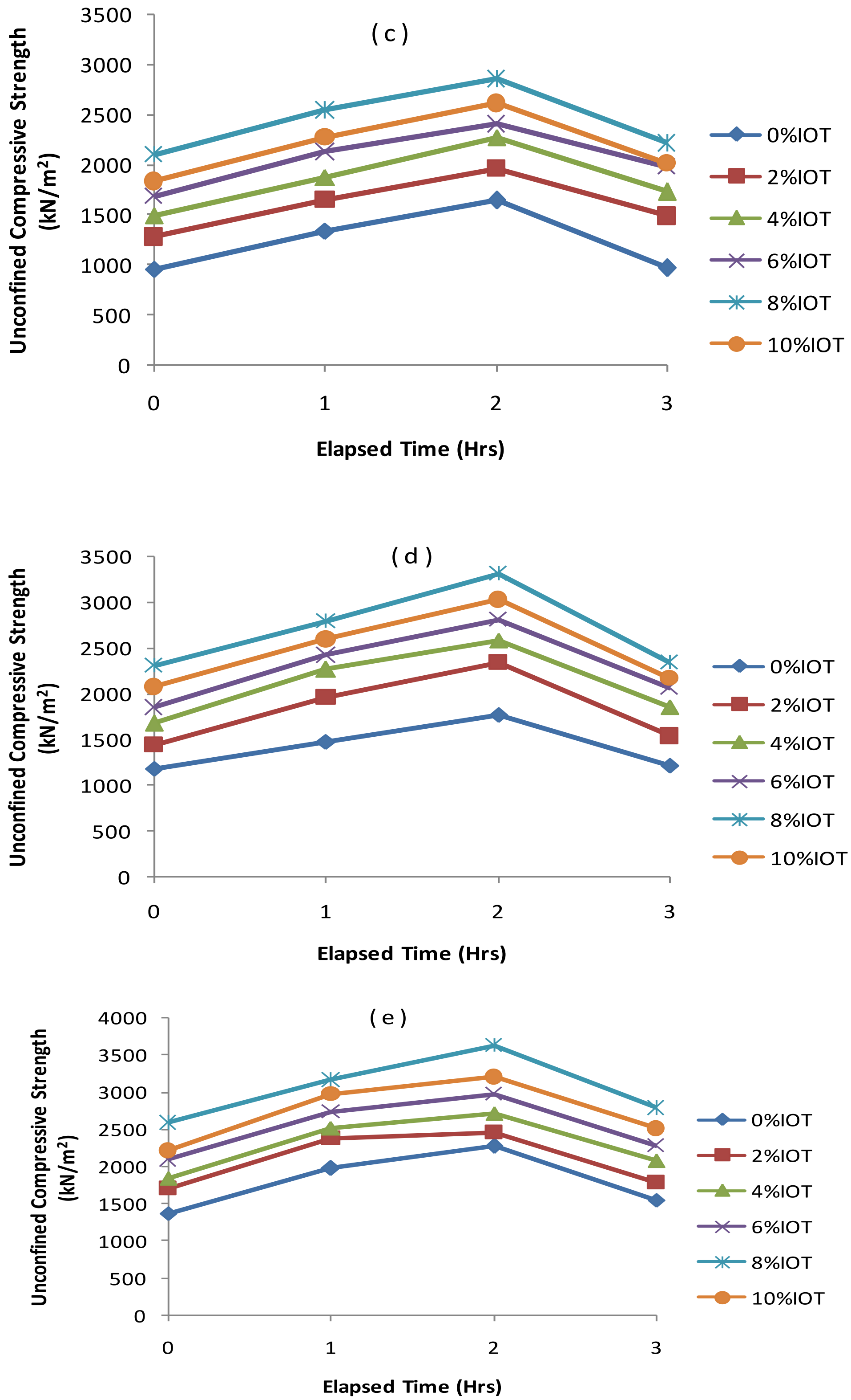
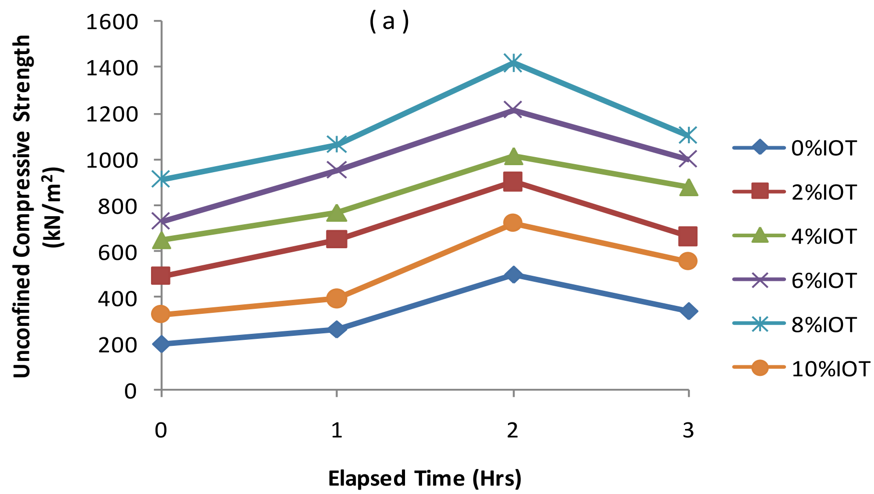
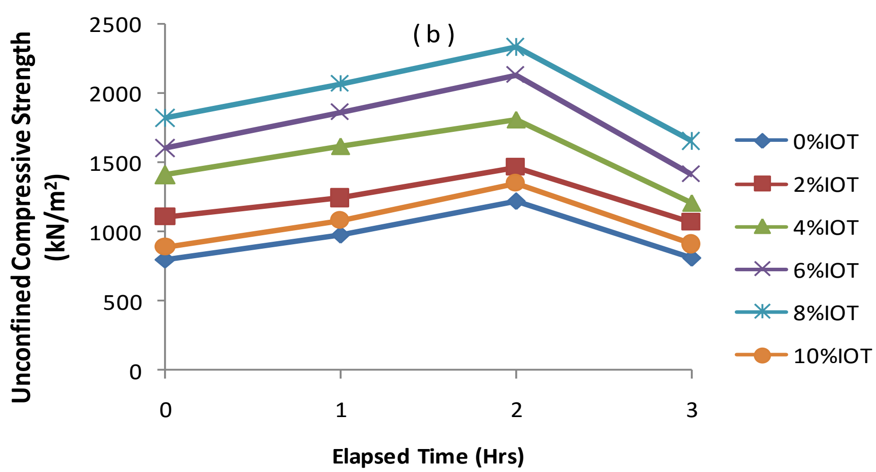
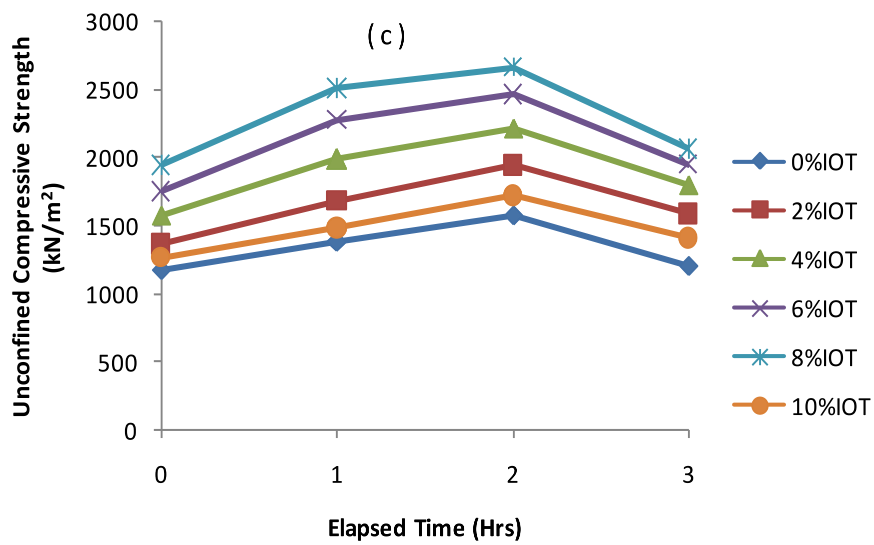
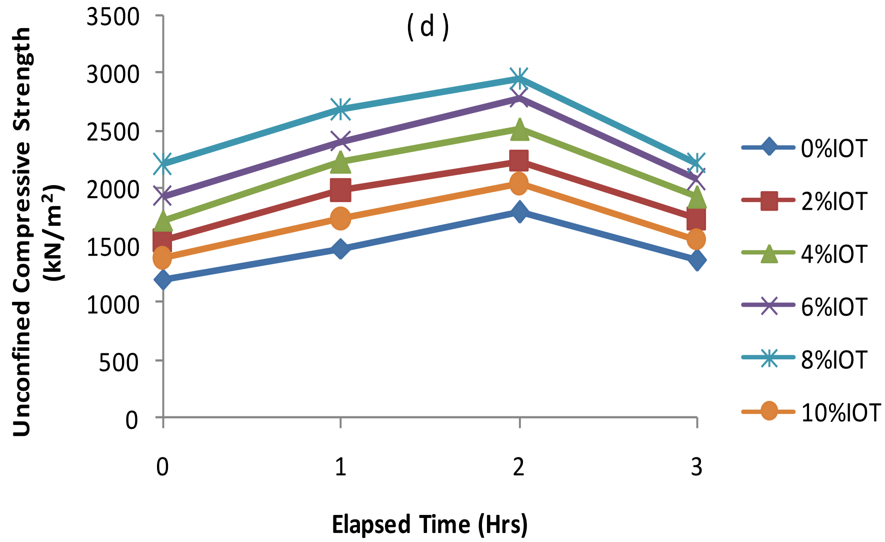


Fig. 4.30: Variation of unconfined compressive strength (28 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (WAScompaction)


(a)
Unconfined Compressive Strength (kN/m²)
1600
1400
1200
1000
800
600
400
200
0
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(b)
Unconfined Compressive Strength (kN/m²)
2500
2000
1500
1000
500
0
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT


(c)
Unconfined Compressive Strength (kN/m²)
3000
2500
2000
1500
1000
500
0
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT



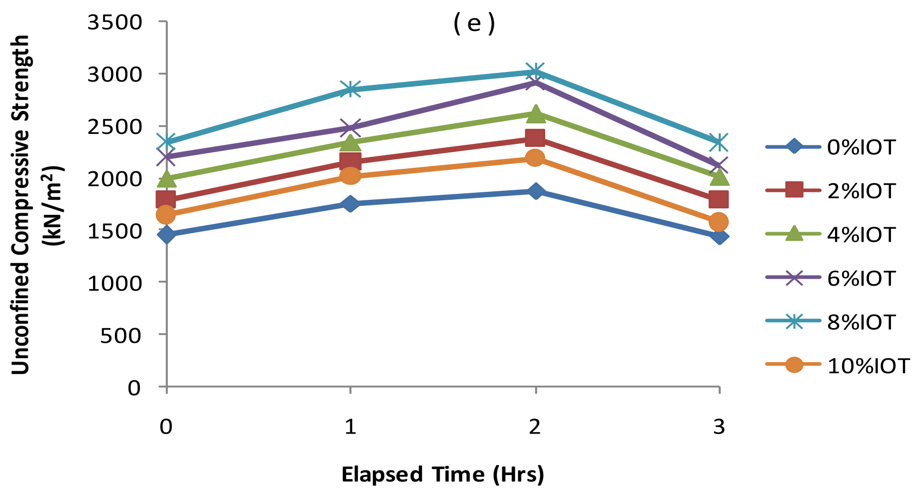
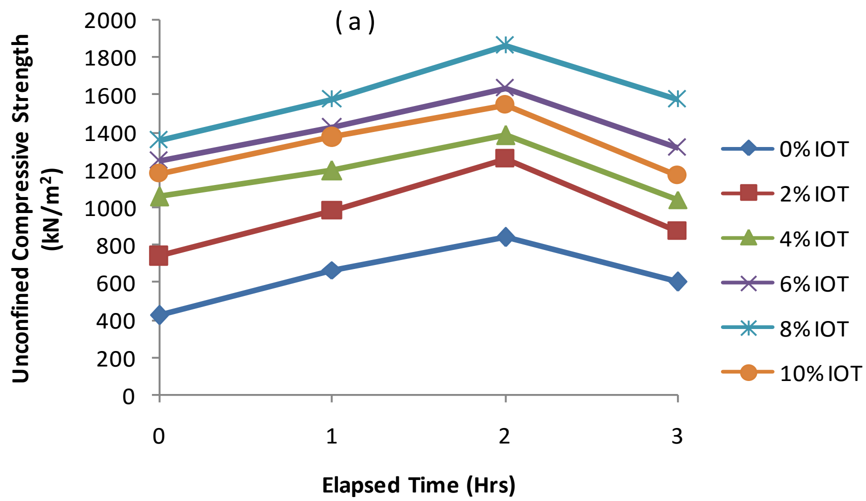
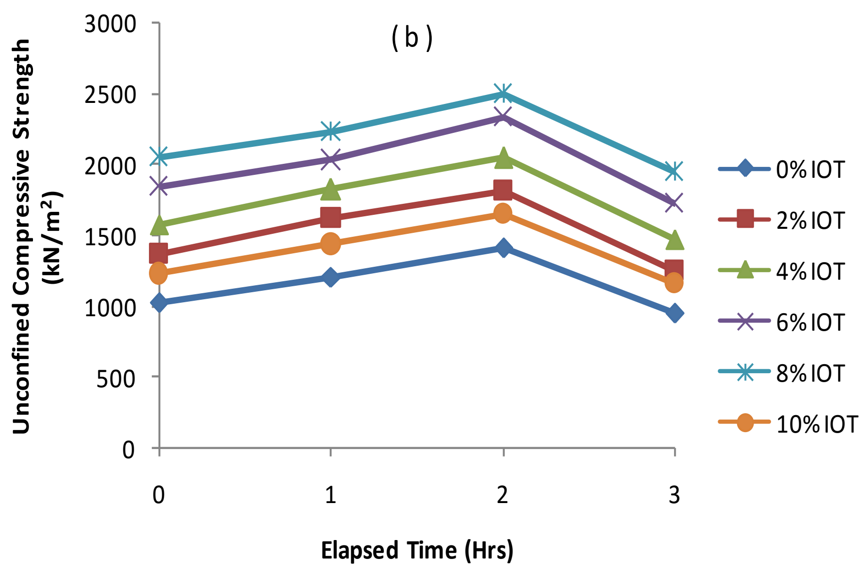


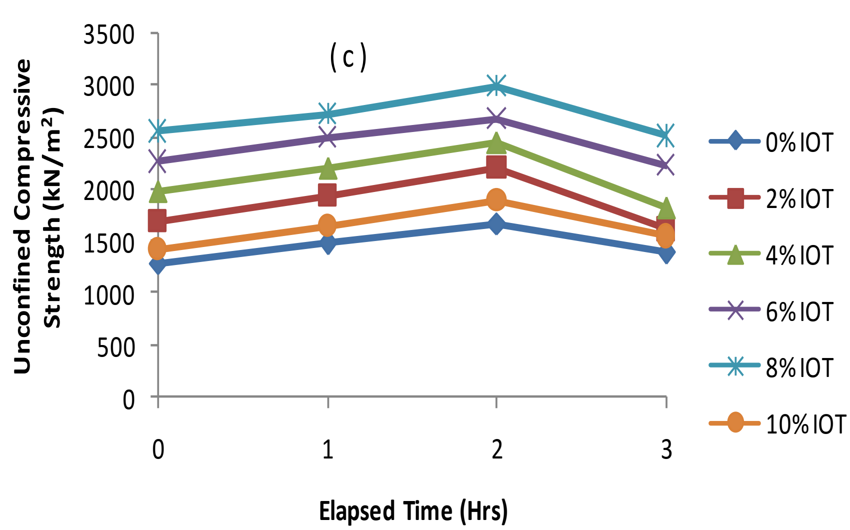
Fig. 4.31: Variation of unconfined compressive strength (7 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSHcompaction)



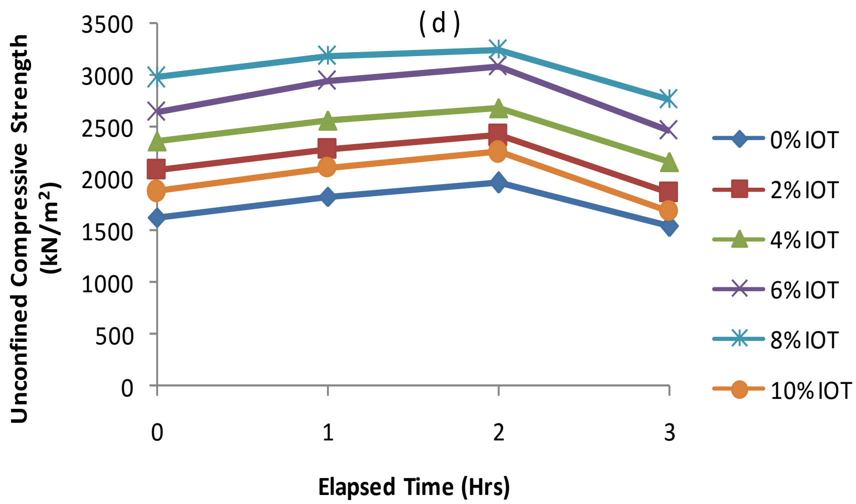
(a)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT



(b)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT



(c)
Unconfined Compressive Strength (kN/m²)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT



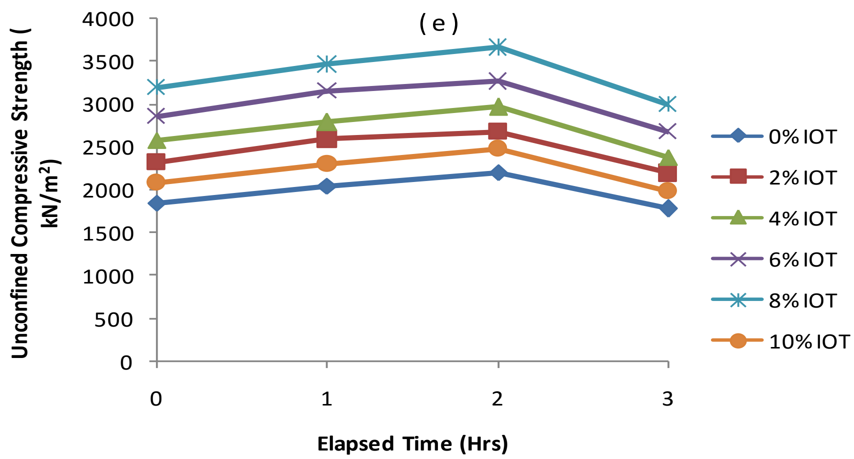
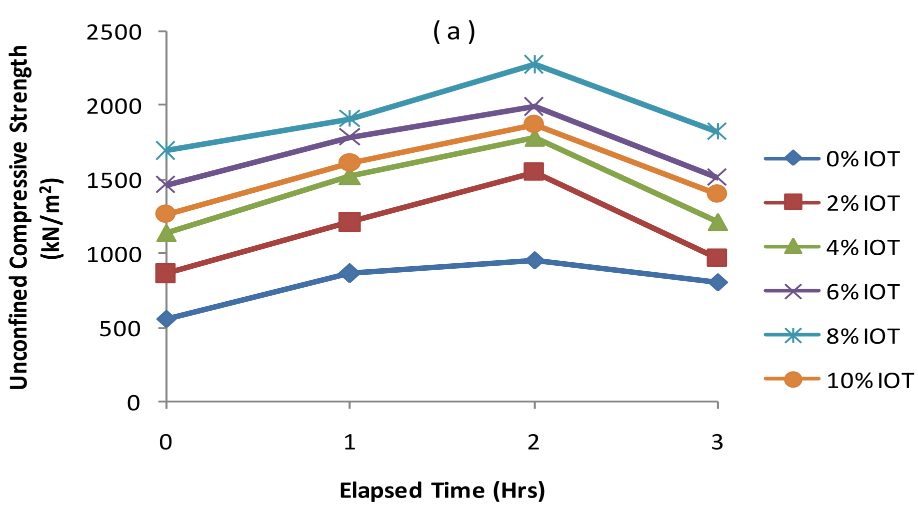
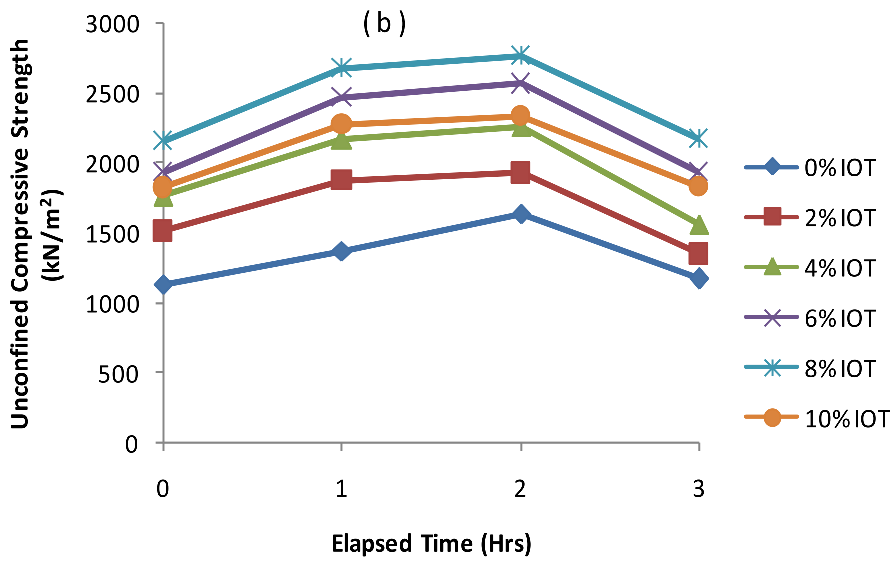
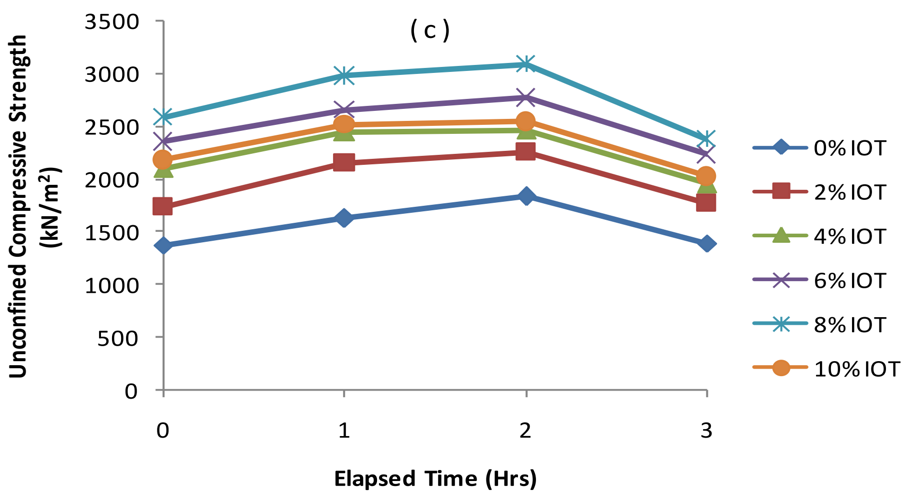
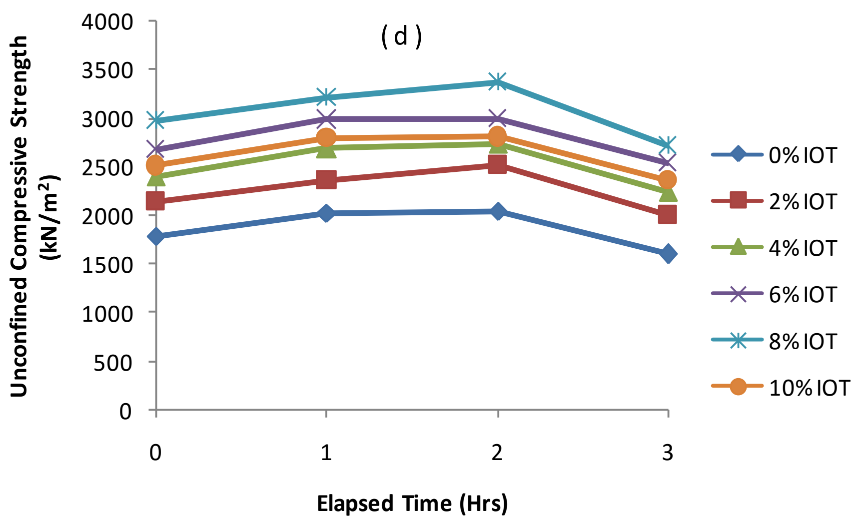


Fig. 4.32: Variation of unconfined compressive strength (14 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSHcompaction)




(b)
Unconfined Compressive Strength (kN/m²)
3000
2500
2000
1500
1000
500
0
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(c)
Unconfined Compressive Strength (kN/m²)
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(d)
Unconfined Compressive Strength (kN/m²)
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT

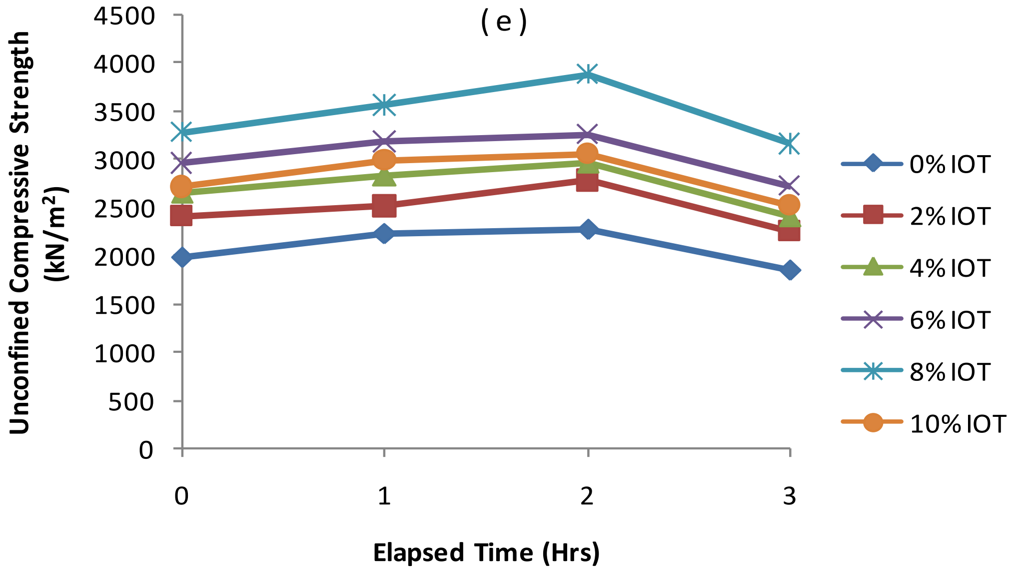


Fig. 4.33:Variation of unconfined compressive strength (28 days curing period)of black cotton soil - iron ore tailings with elapsed time after mixing for varying limecontent:(a) 0% (b) 2% (c) 4% (d) 6% (e) 8% (BSHcompaction)

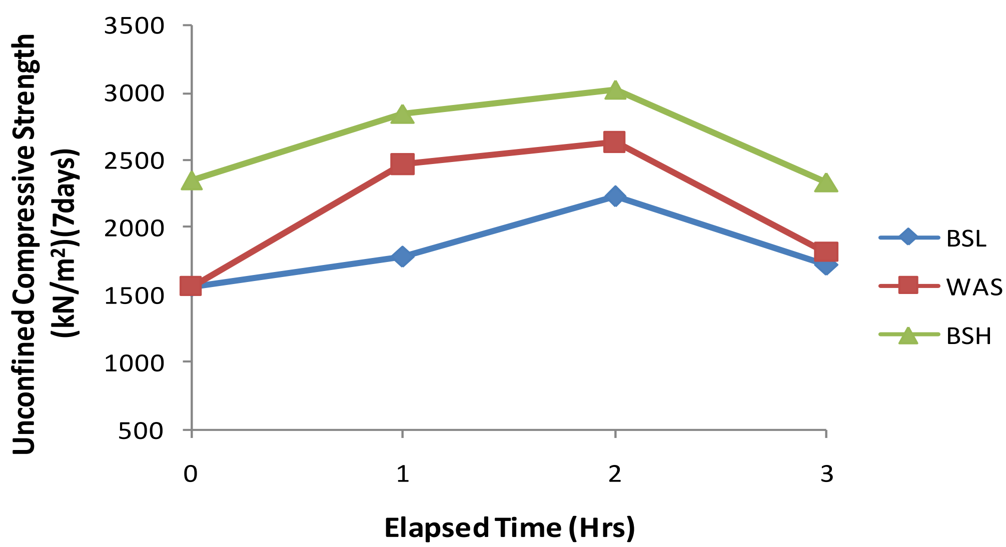


Fig. 4.34:Variation in peak values of unconfined compressive strength (7 days curing period)of black cotton soil – lime – iron ore tailings mixtures with elapsed time after mixing.

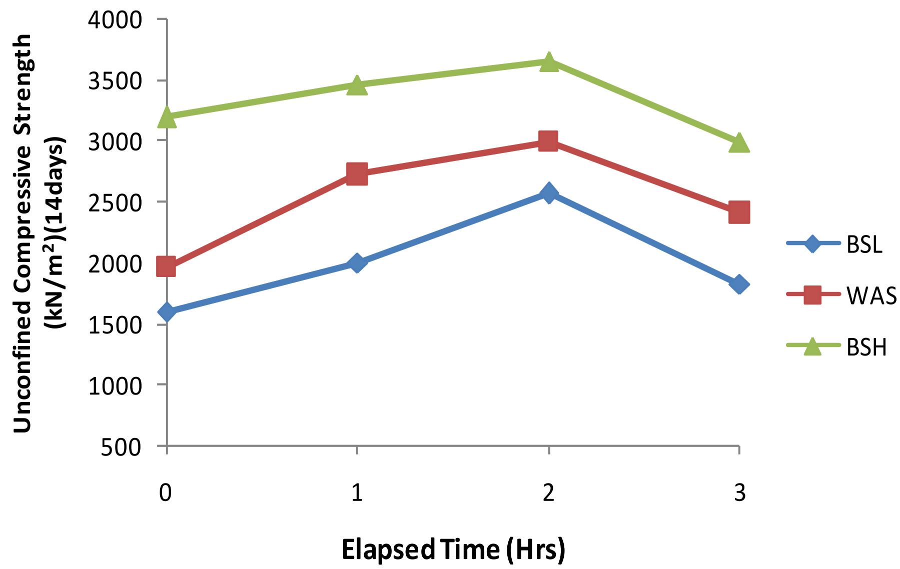


Fig. 4.35: Variation in peak values of unconfined compressive strength (14 days curing period)of black cotton soil – lime – iron ore tailings mixtures with elapsed time after mixing.

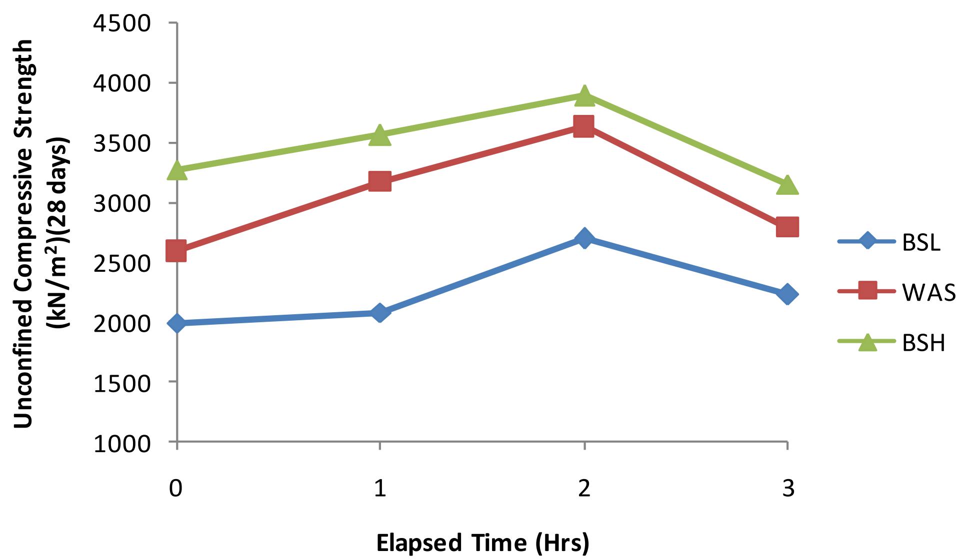


Fig. 4.36: Variation in peak values of unconfined compressive strength (28days curing period)of black cotton soil – lime – iron ore tailings mixtures with elapsed time after mixing.

The effect of elapsed time on specimens compacted with BSL; WAS and BSH energy levels showed increase in the UCS for the first two hours and reduction at the third hour for all the compactive efforts and lime treatment. The decrease in unconfined compressive strength may be due to destruction of the cementitious bond formed during soil – lime- IOT reaction over the period between mixing and compaction. The destruction of this matrix during compaction result in decrease in strength of the compacted soil. Ochepo,(2008) and Nwadiogbu (2012) reported also improvement in the unconfined compressive strength and reduction in UCS at a higher admixture/additives content.

The percentage increase in the UCS values relative to the natural soil isshown in Fig. 4.37 – 4.39. The graph showed higher percentage increase for the BSL compactive effort irrespective of the curing period and the elapsed time after mixing.

The percentage increase in the UCS values increased up to 2 hours elapsed time after mixing before dropping to 3 hours. Hence the curing period and the compactive efforts has effect on the percentage increase in the UCS. The high increase in the UCS values might be as a result of flocculation and agglomeration of the clay particles from the addition of the additives – iron ore tailings and lime.

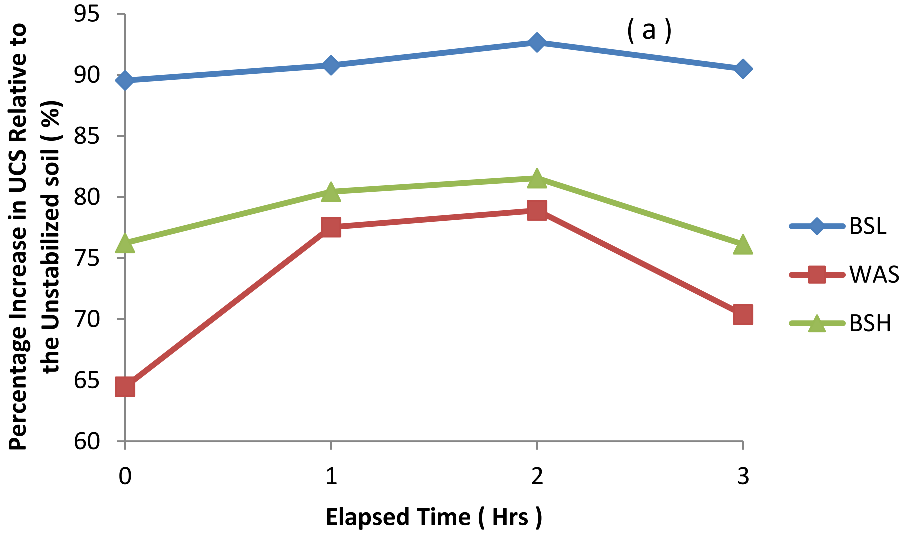


Fig. 4.37:Variation in percentage increase in peak values of unconfined compressive strength (7 days curing period)of black cotton soil – lime – iron ore tailings mixtures relative to unstabilized soil with elapsed time after mixing.

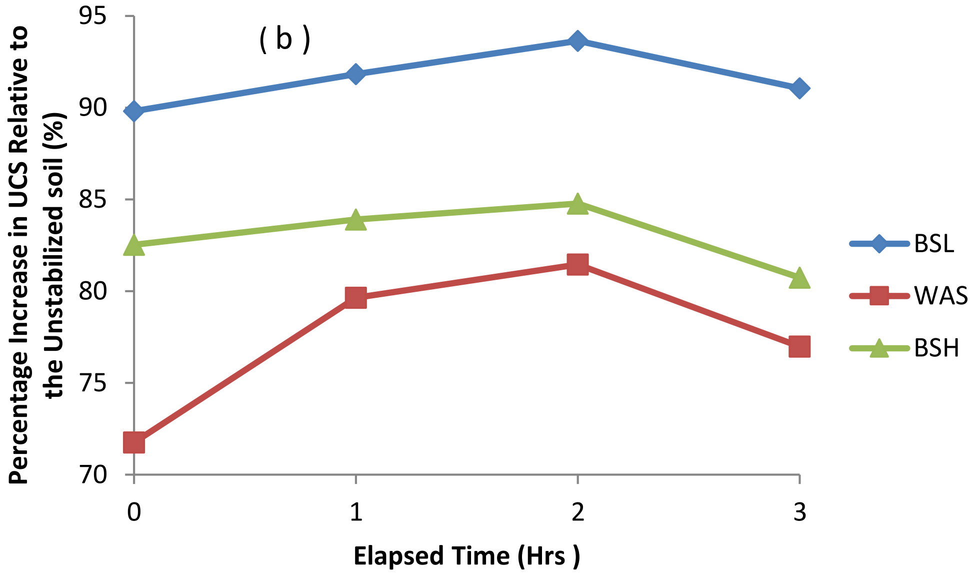


Fig. 4.38: Variation in percentage increase in peak values of unconfined compressive strength (14 days curing period)of black cotton soil – lime – iron ore tailings mixtures relative to unstabilized soil with elapsed time after mixing.

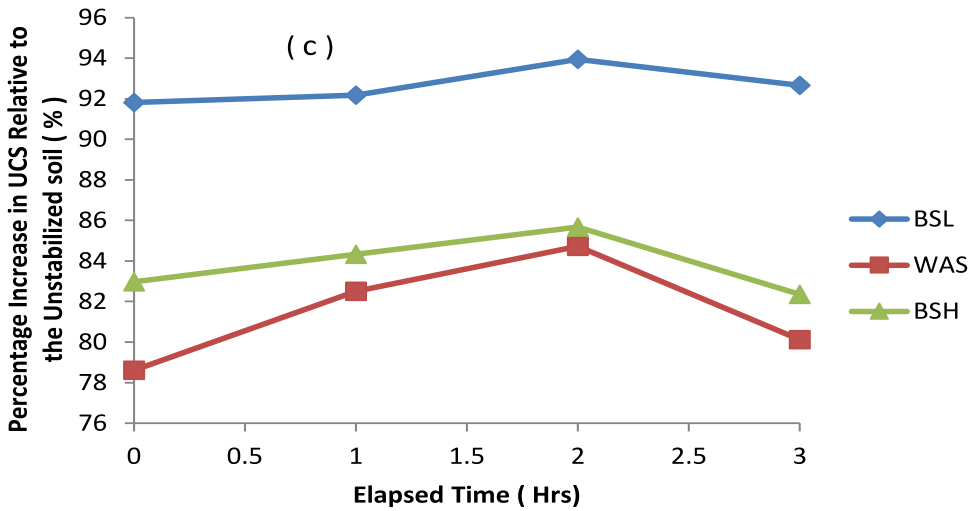


Fig. 4.39: Variation in percentage increase in peak values of unconfined compressive strength (28 days curing period)of black cotton soil – lime – iron ore tailings mixtures relative to unstabilized soil with elapsed time after mixing.

The two-way analysis of variance (ANOVA) carried out on tests results showed that the effect of lime and IOT and elapsed time on the UCS test for black cotton soil treated for the threecompactive efforts and curing period were statistically significant. (See Appendix Tables.F9; F25; F41; F57; F73; F89; F105; F121 and F137 in Appendix F). A typical ANOVA result for BSH compaction energy is shown in Table 4.7.

For BSL- 7days, 14days and 28days: lime (F_{CAL}=67.976; 66.422 and 60.760>F_{CRIT}= 2.8661) and IOT (F_{CAL}=22.325; 26.543 and 23.302 >F_{CRIT}= 2.7109) For WAS -7days, 14days and 28days:- Lime (F_{CAL}=175.063; 258.491 and 328.154 >F_{CRIT}= 2.8661) and IOT(F_{CAL}=78.441;131.704 and 236.426>F_{CRIT} = 2.7109). BSH:- Lime (F_{CAL} = 526.764; 114.860 and 284.695>F_{CRIT} = 2.8661) and IOT (F_{CAL}=197.807; 59.006 and 157.370> F_{CRIT}= 2.7109)

For the elapsed time, (See Appendix Table F16; F32; F48; F64; F80; F96; F112; F128 and F144); the effects of time and IOT on the UCS were statistically significant .

BSL (7days, 14days and 28days); Time (FCAL= 46.211; 47.763 and 26.415 > F_{CRIT}= 3.2874) and IOT (F_{CAL} = 101.663; 151.721 and 113.633 > F_{CRIT}= 2.9013).

WAS (7days, 14days and 28days);Time (F_{CAL}= 153.879; 488.225 and 270.100 >F_{CRIT}= 3.2874) and IOT (F_{CAL}= 73.787; 202.2565 and 212.5399 > F_{CRIT}= 2.9013).

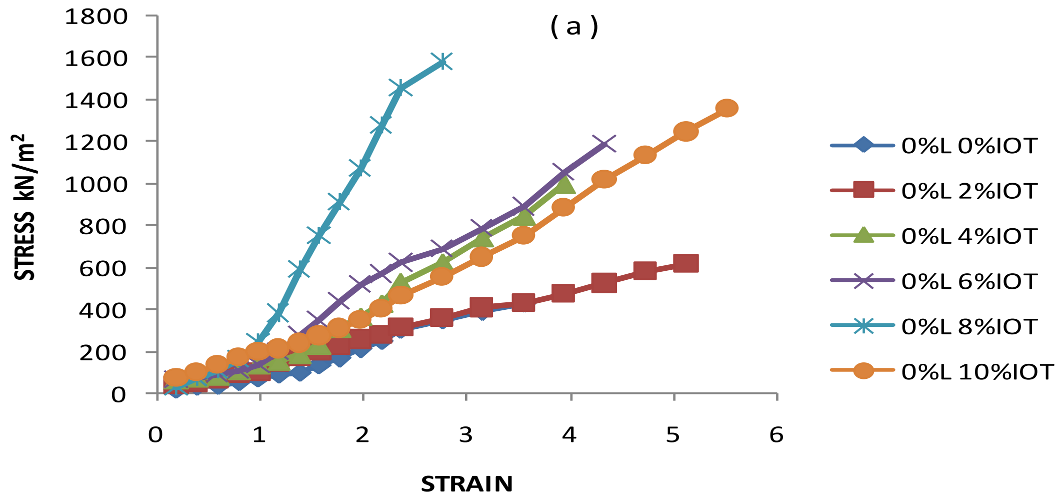
BSH (7days, 14days and 28days); Time (F_{CAL}= 128.7663; 190.6122 and 86.2890 > F_{CRIT}= 3.2874) and IOT (F_{CAL}= 132.7381; 543.6353 and 216 295 > F_{CRIT}= 2.9013).

Table 4.7: Two–way analysis of variance (ANOVA) results for the effect of elapsed time after mixing on the unconfined compressive strength of black cotton soil – lime - iron ore tailings mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	p-Value	F_{CRIT}	Remark
UCS: BSH-28days	0	Time	3	70.2885	4.62E-09	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	119.9428	1.51E-11	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	2	Time	3	100.7452	3.65E-10	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	125.9005	1.06E-11	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	4	Time	3	102.7994	3.16E-10	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	179.6197	7.87E-13	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	6	Time	3	203.9369	2.23E-12	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	447.4899	9.14E-16	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	8	Time	3	86.2890	1.09E-09	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	216.295	2E-13	2.9013	F_{CAL}>F_{CRIT}, Significant Effect

4.5 Stress – strain relationships for stabilized soil

The stress and strain from the UCS results are plotted for WAS compaction to get the stress- strain relationship. WAS compactive effort was considered because it is the energy prescribed by the Nigerian General Specification (1997). The variation in stress with strain for different soil – lime – IOT mixtures at varying elapsed time are shown in Figs. 4.40 - 4.43. The stress values increased from 0 hour up to2 hours before decreasing at 3 hours elapsed time after mixing for the various lime – IOT treatments considered. The Young Modulus (E) which is the ratio of stress to the strain was computed for each of the plots. The E values increased from 422.42 kN/m^2 at 0 hour to peak value of 6, 94.09 kN/m^2 at 2 hours before decreasing to261.11 kN/m^2 at 3 hours elapsed time after mixing for 8% IOT and 2% lime. At the peak value, the treated soil became more stiffened and required higher stress to cause deformation.



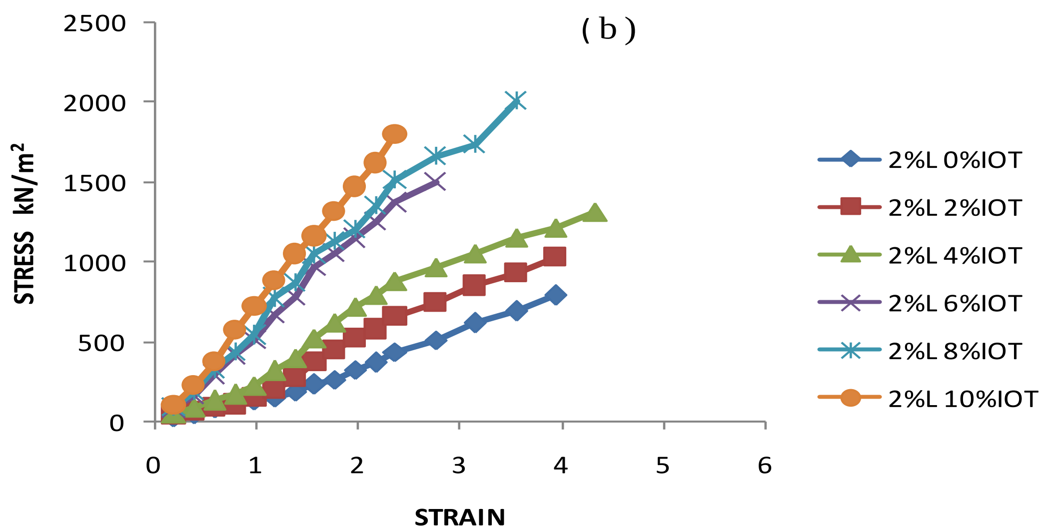


Fig.4.40: Variation of stress with strain for black cotton soil – lime – iron ore tailings mixtures(28days curing period) for varying lime content at 3 hours elapsed time after mixing:(a) 0% (b) 2% (WAS compaction)

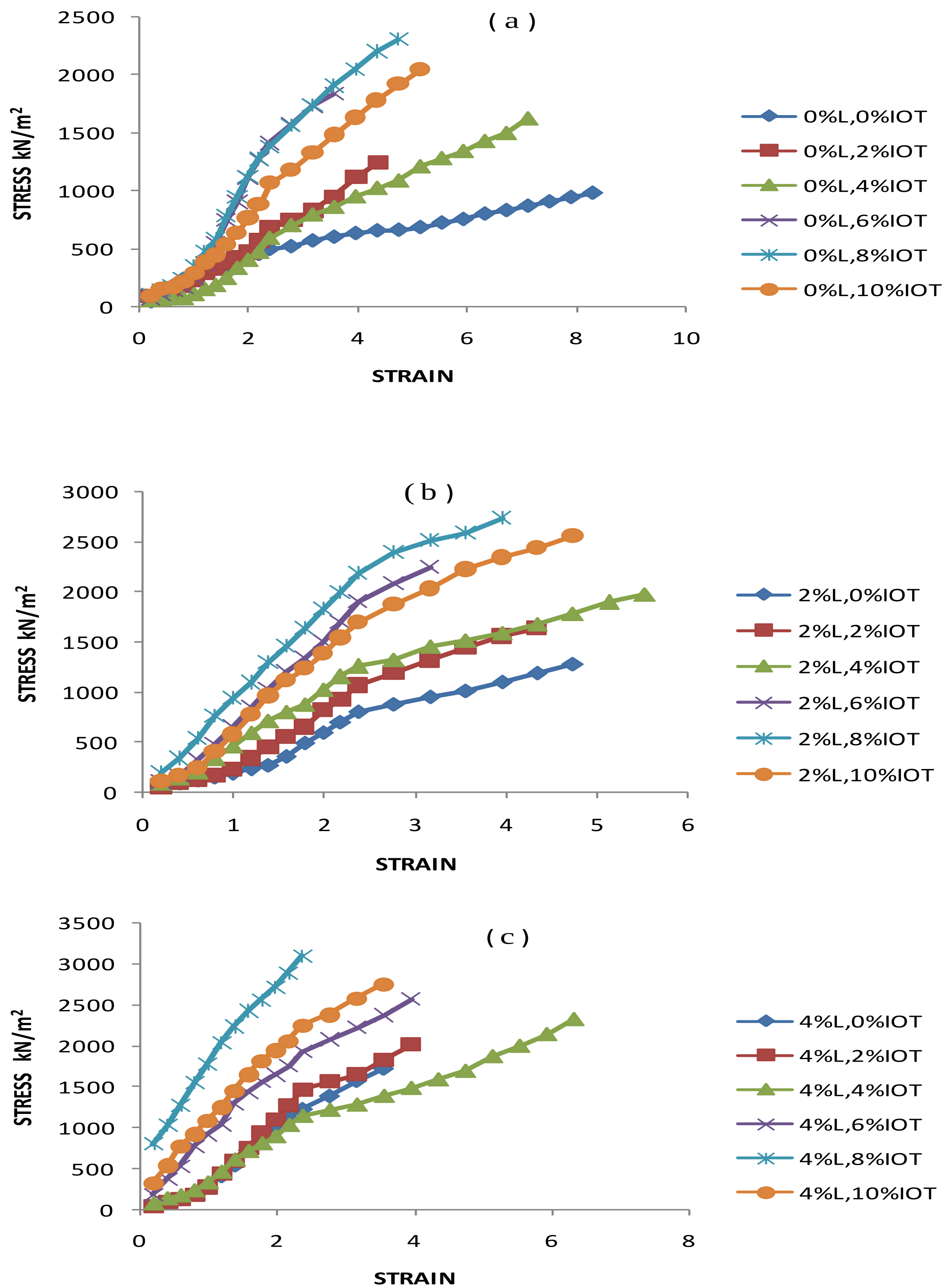
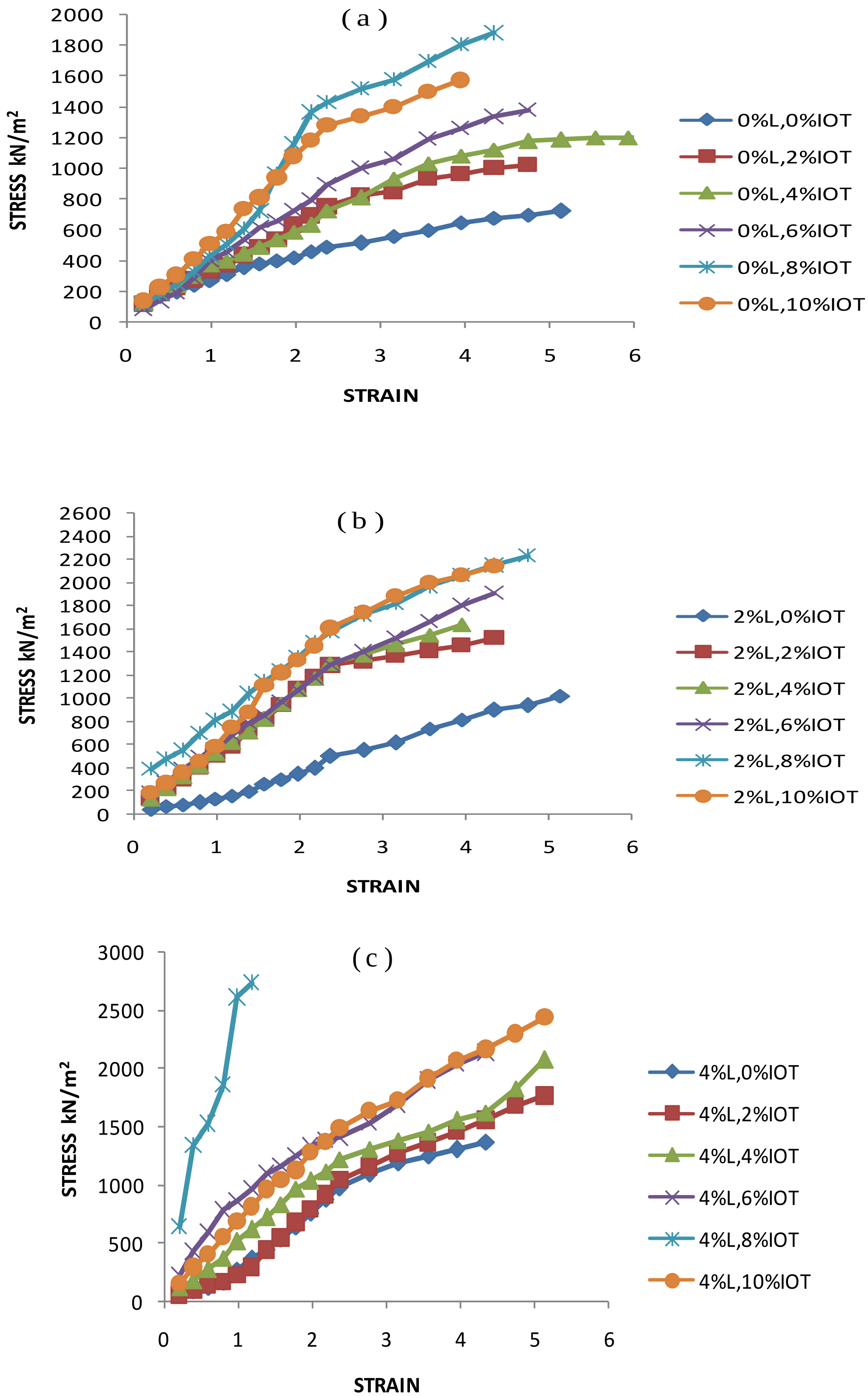


Fig.4.41: Variation of stress with strain for black cotton soil – lime – iron ore tailings mixtures (28 days curing period) for varying lime content at 2 hours elapsed time aftermixing: (a) 0 % (b) 2 % (c) 4 % (WAS compaction)


(a)
STRESS kN/m²
STRAIN
0%L,0%IOT
0%L,2%IOT
0%L,4%IOT
0%L,6%IOT
0%L,8%IOT
0%L,10%IOT
(b)
STRESS kN/m²
STRAIN
2%L,0%IOT
2%L,2%IOT
2%L,4%IOT
2%L,6%IOT
2%L,8%IOT
2%L,10%IOT
(c)
STRESS kN/m²
STRAIN
4%L,0%IOT
4%L,2%IOT
4%L,4%IOT
4%L,6%IOT
4%L,8%IOT
4%L,10%IOT

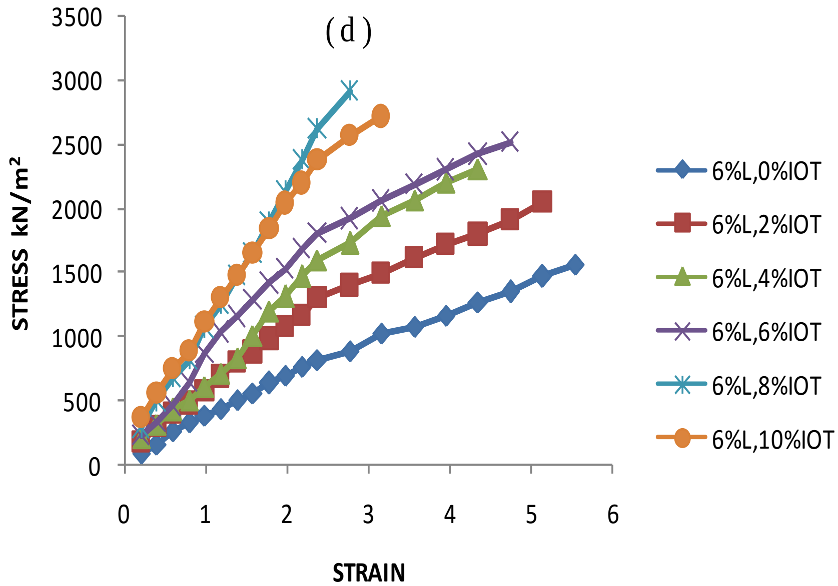
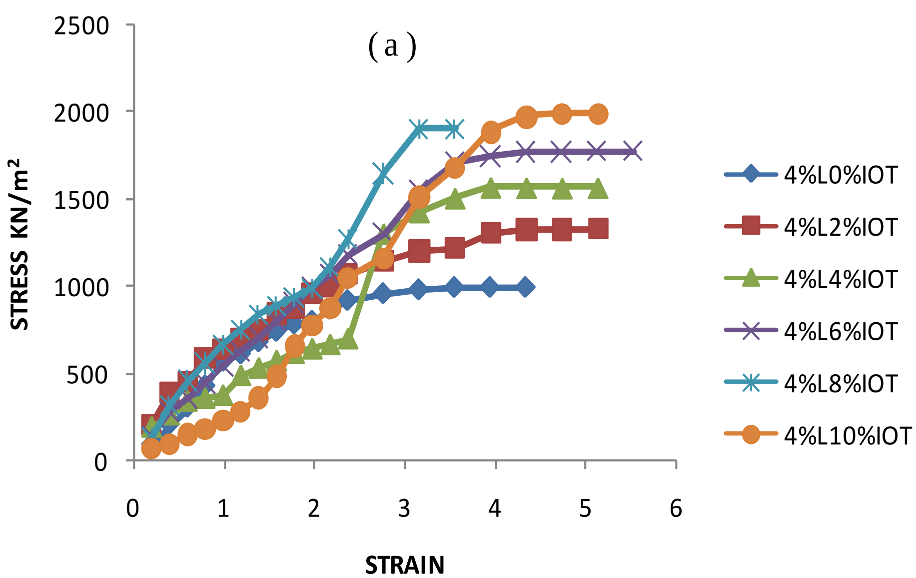


Fig.4.42:Variation of stress with strain for black cotton soil – lime – iron ore tailings mixtures (28days curing period) for varying lime content at 1 hour elapsed time after mixing: (a) 0% (b) 2% (c) 4% (d) 6% (WAS compaction)



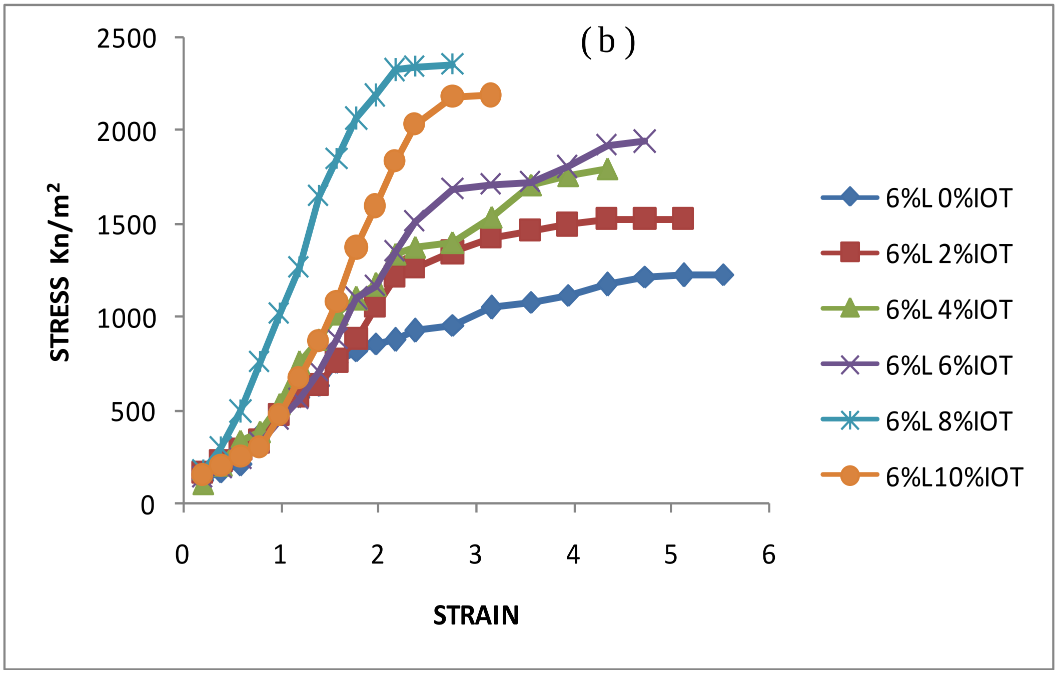


Fig.4.43: Variation of stress with strain for black cotton soil – lime – iron ore tailings mixtures (28days curing period) for varying lime content at 0 hour elapsed time after mixing: (a) 4% (b) 6% (WAS compaction)

4.6 California Bearing Ratio (CBR)

The California bearing ratio is a penetration test for evaluation of mechanical strength of road sub-grades and base courses. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. It is an important parameter used to indicate the strength and bearing capacity for base and sub-base in pavement structure.

4.6.1 California bearing ratio (soaked and unsoaked conditions)

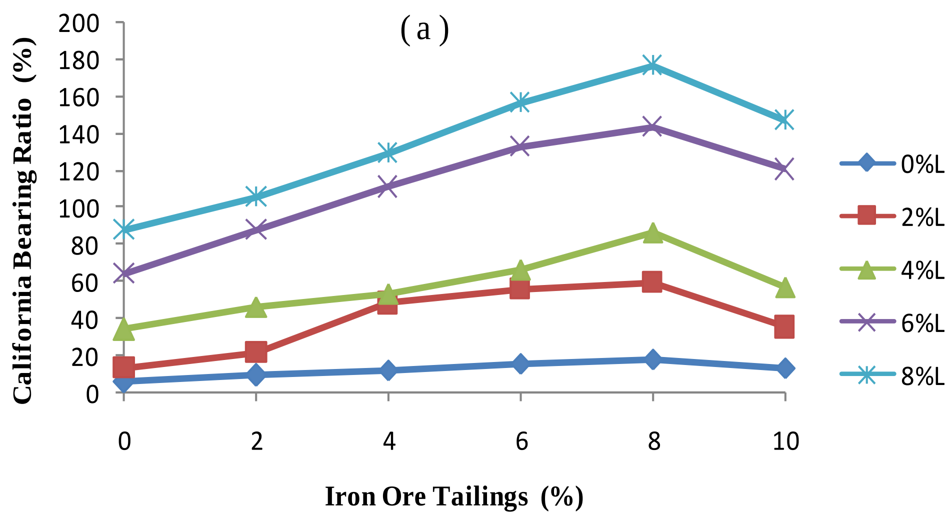
The CBR (unsoaked and soaked conditions) values of black cotton soil – lime - Iron ore tailings mixture varied for the three energy levels considered as shown in Figs. 4.44 - 4.49. The CBR improved with increase in lime / IOT contents. Generally, peak CBR values were recorded for the three energy levels considered at 8 % lime / 8 % IOT treatment before decreasing at 10 % IOT for the lime content considered.

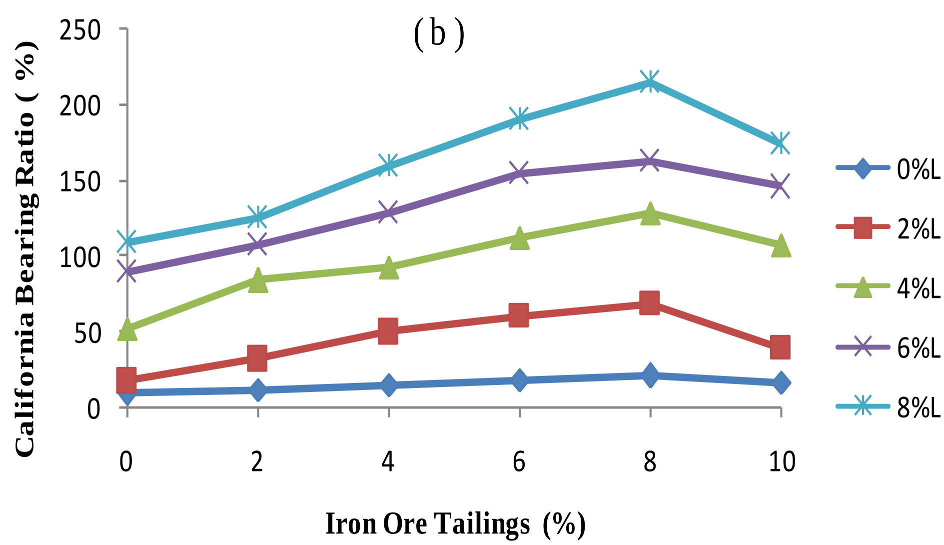
For BSL compaction energy level, the peak CBR values for 0-3 hrs elapsed time are: 100; 130; 150 and 140 %. For WAS compaction energy levels; the peak CBR values are 130; 150; 170 and 160 %, respectively, for 0 – 3 hrs elapsed time range considered. While for BSH energy CBR values of 180; 220; 230 and 220 %, respectively were recorded. The peak CBR values for BSL, WAS and BSH are 150; 170 and 230 % respectively, were recorded at 2 hours elapsed time after mixing.

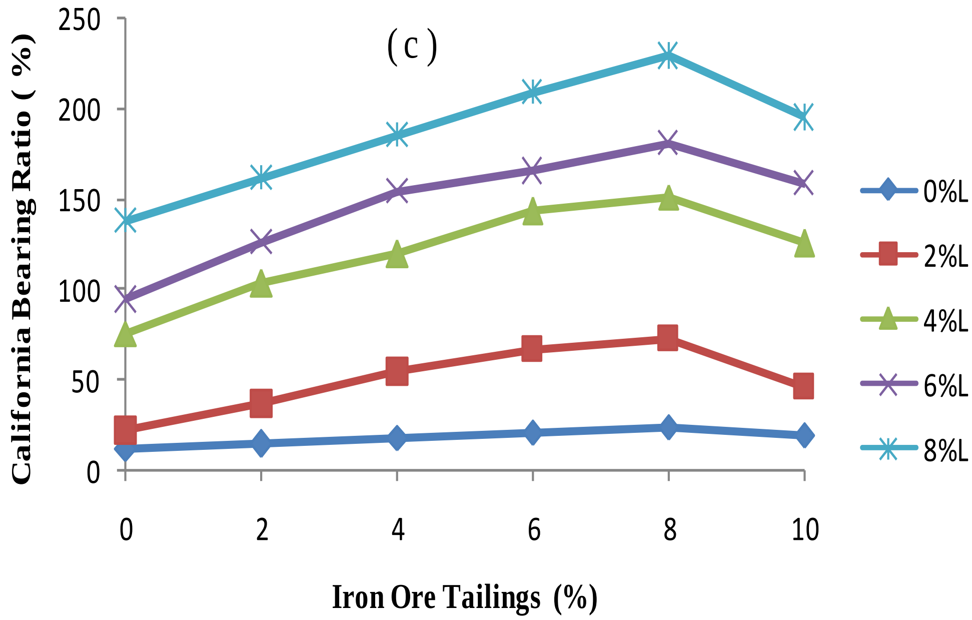
The lower values recorded for the soaked condition in comparison to the unsoaked condition were due to ingress of water into the specimen that decreased their strength. The CBR (soaked condition) values of 65, 95 and 180 % were recorded for specimens optimally treated with 8 % lime / 8 % IOT for BSL, WAS and BSH compaction respectively.

Black cotton soil treated with 8 % lime / 8 % IOT blend and compacted using the three energy levels considered met the 80 % requirement for base materials for both unsoaked and soaked conditions exception of BSL compaction for the soaked condition. The observed increase in CBR value was due to the development of cementitious substances like calcium silicate hydrates (CSH), calcium aluminates hydrates (CAH) and hydrated lime due to the hydration of lime. The first two hydrates developed cementations linkages between these hydration products and soil particles regardless of the type of soil (Ola, 1983). The hydrated lime released however, reacted with pozzolanic iron ore tailing to form secondary cementitious material.

The trend of increase in CBR with higher compactive efforts is consistent with the findings reported by Osinubi (2000a), Mustapha (2006), Yisa (2014), Yohanna*et al*, (2014) as well as Etim*et al.* (2014). The reason for this trend is the increase in dry density with higher compaction energy levels.







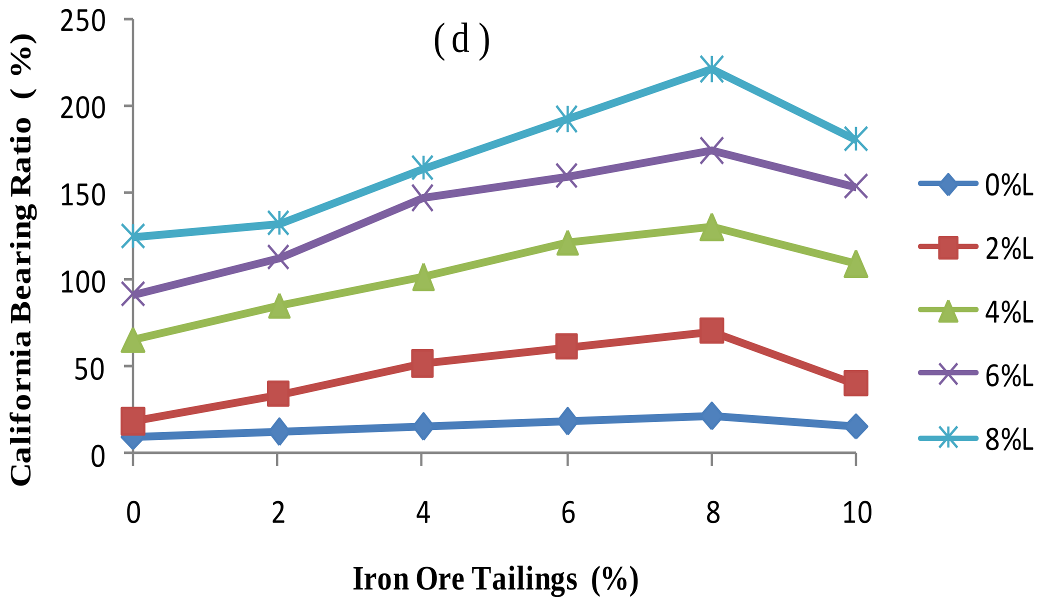
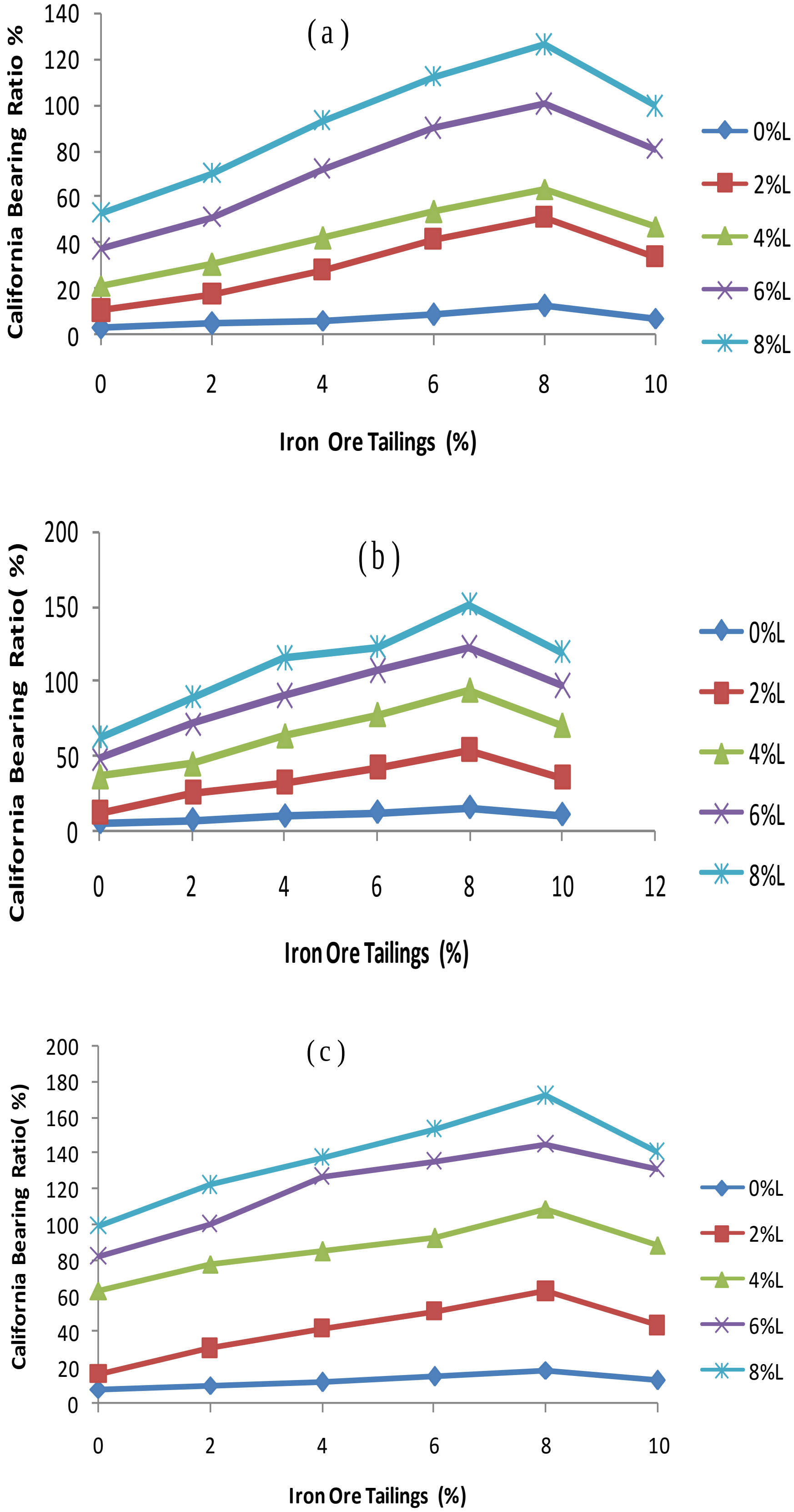


Fig. 4.44: Variation of California bearing ratio (unsoaked condition) of black cotton soil – lime mixtures with iron ore tailings content at varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours (BSH compaction).



(a)
California Bearing Ratio %
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Iron Ore Tailings (%)
0%L
2%L
4%L
6%L
8%L
(b)
California Bearing Ratio(%)
200
150
100
50
0
0
2
4
6
8
10
12
Iron Ore Tailings (%)
0%L
2%L
4%L
6%L
8%L
(c)
California Bearing Ratio(%)
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Iron Ore Tailings (%)
0%L
2%L
4%L
6%L
8%L

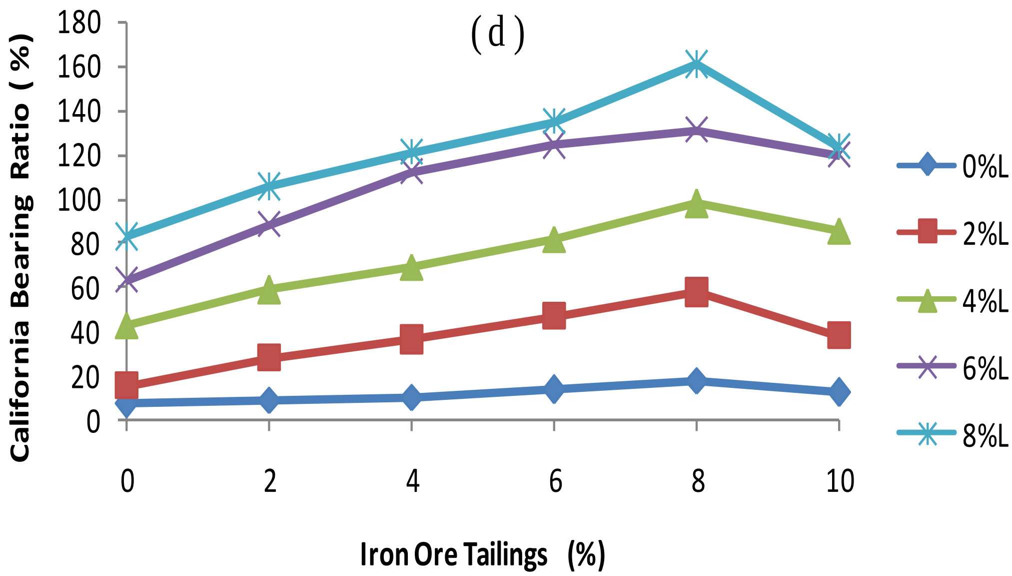
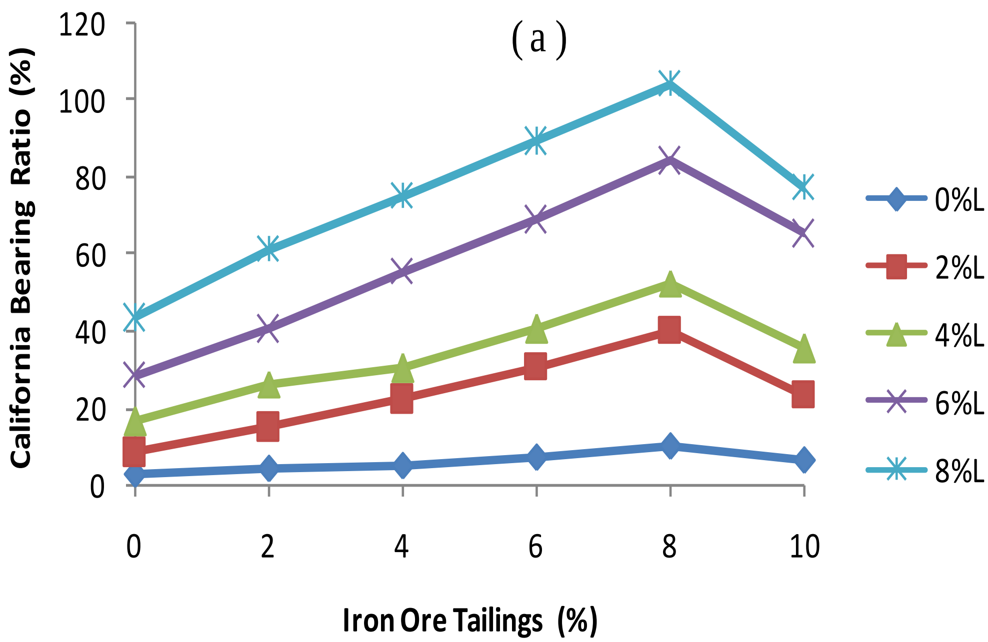
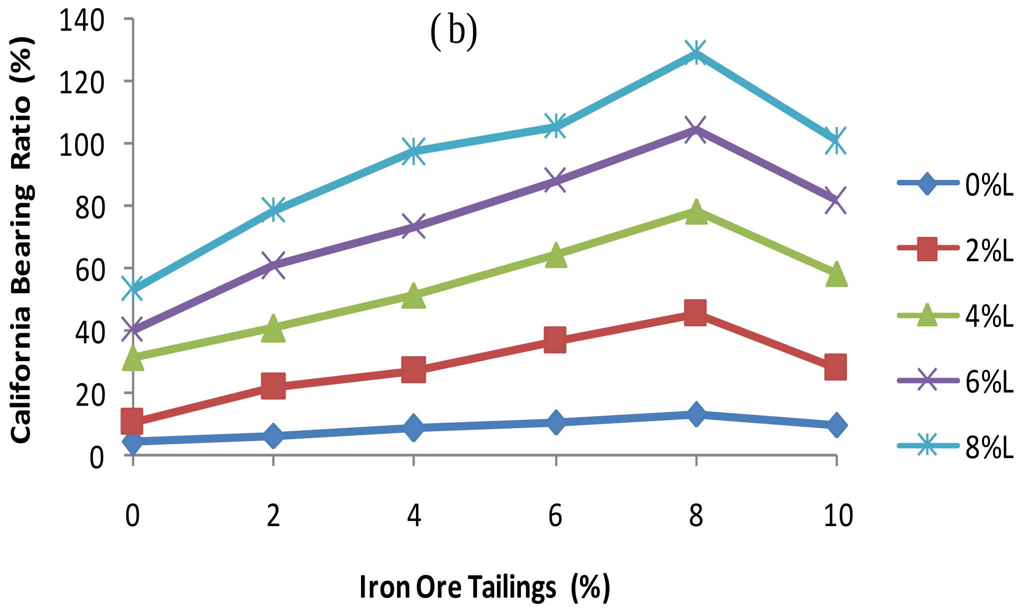
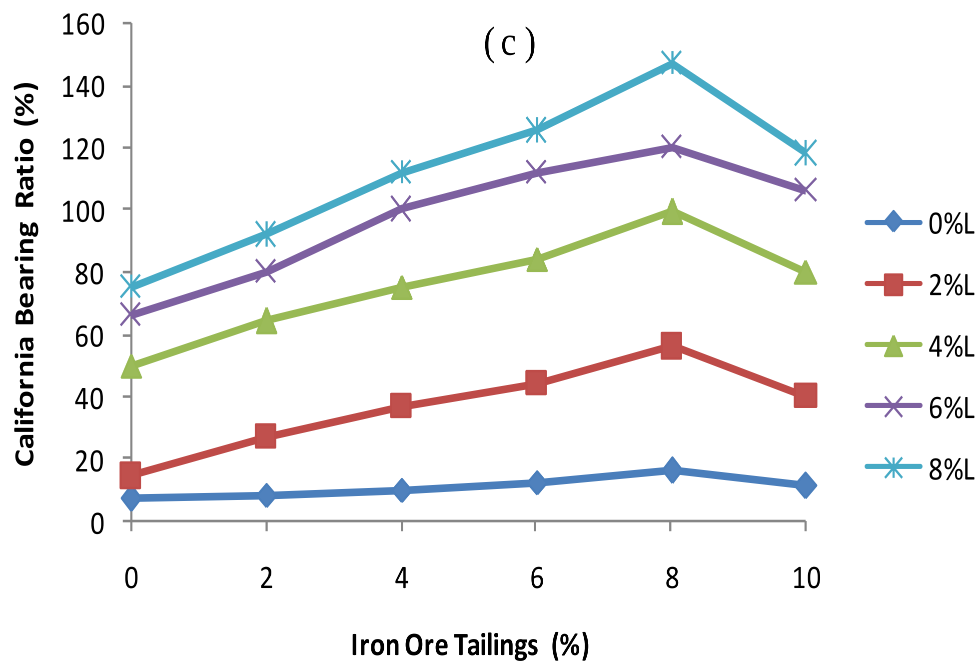


Fig. 4.45: Variation of California bearing ratio (unsoaked condition) of black cotton soil – lime mixtures with iron ore tailings content at varying elapsed time after mixing: (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours (WAS compaction).




(b)
California Bearing Ratio (%)
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Iron Ore Tailings (%)
0%L
2%L
4%L
6%L
8%L


(c)
California Bearing Ratio (%)
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Iron Ore Tailings (%)
0%L
2%L
4%L
6%L
8%L

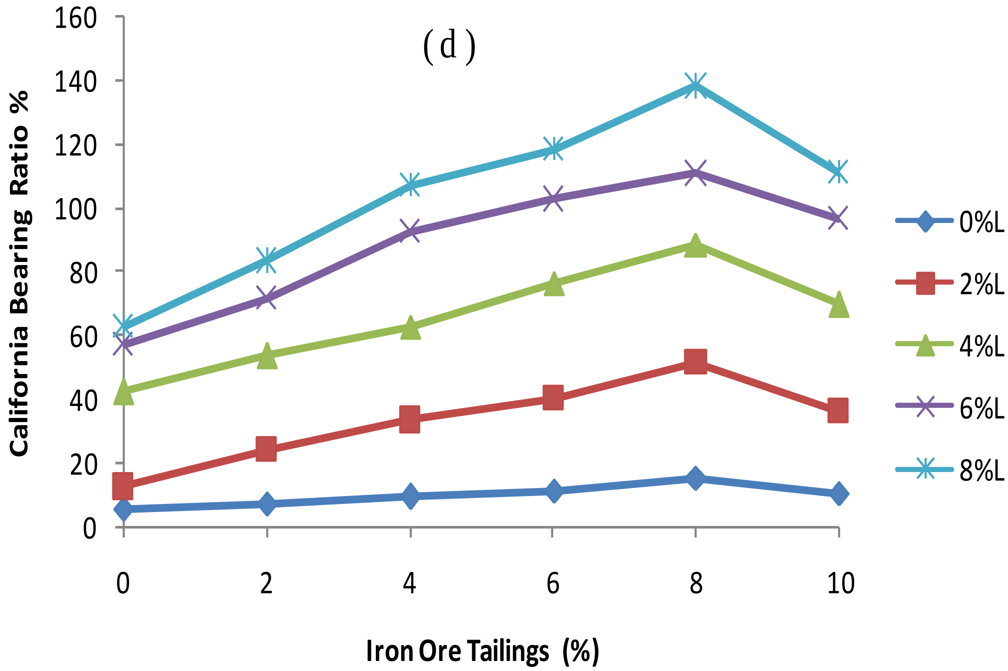
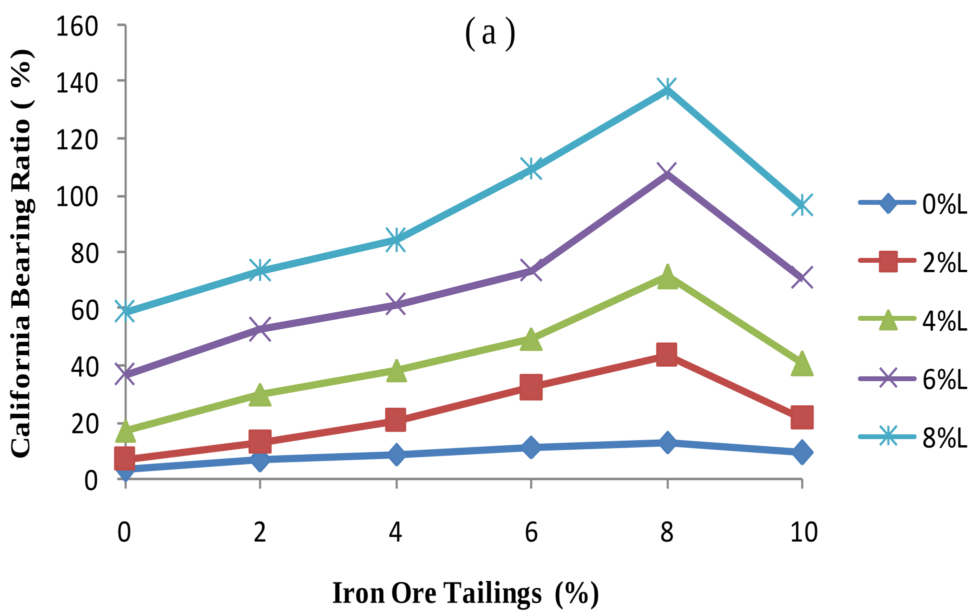


Fig. 4.46: Variation of California bearing ratio (unsoaked condition) of black cotton soil – lime mixtures with iron ore tailings content at varying elapsed time after mixing:(a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours (BSL compaction).



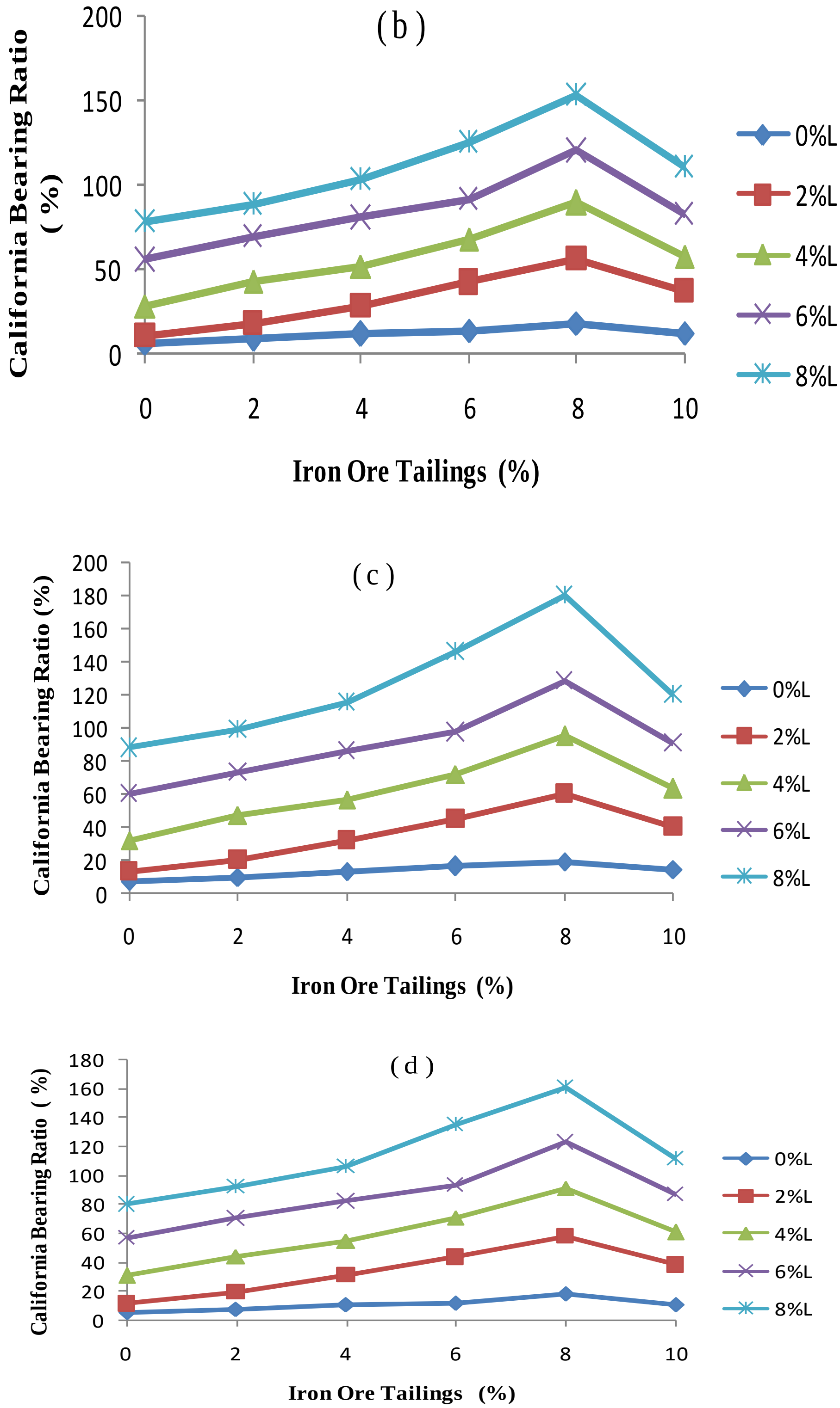
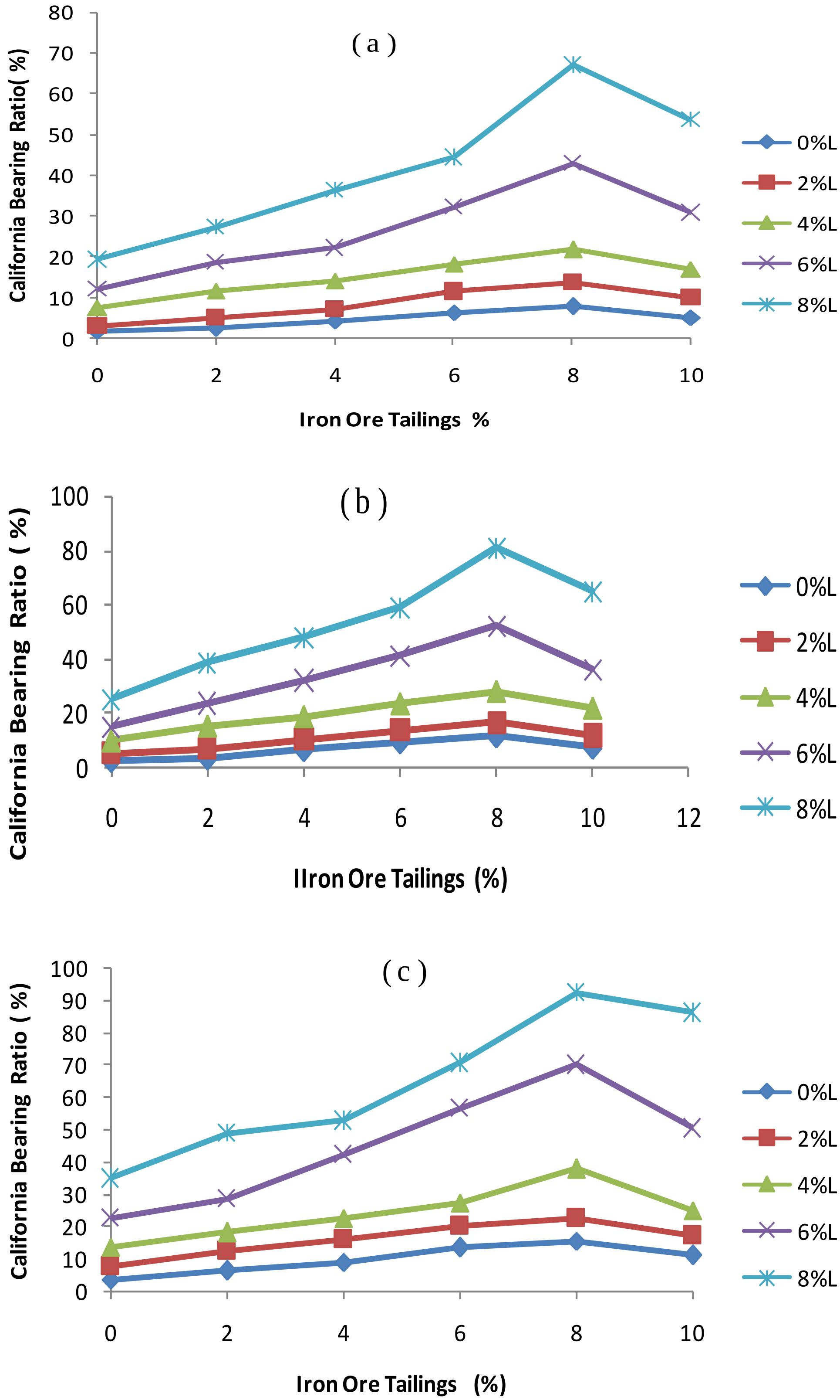


Fig. 4.47: Variation of California bearing ratio (soaked condition) of black cotton soil – lime mixtures with iron ore tailings content at (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours elapsed time after mixing (BSH compaction)


(a)
California Bearing Ratio(%)
Iron Ore Tailings %
0%L
2%L
4%L
6%L
8%L
(b)
California Bearing Ratio (%)
IIron Ore Tailings (%)
0%L
2%L
4%L
6%L
8%L
(c)
California Bearing Ratio (%)
Iron Ore Tailings (%)
0%L
2%L
4%L
6%L
8%L

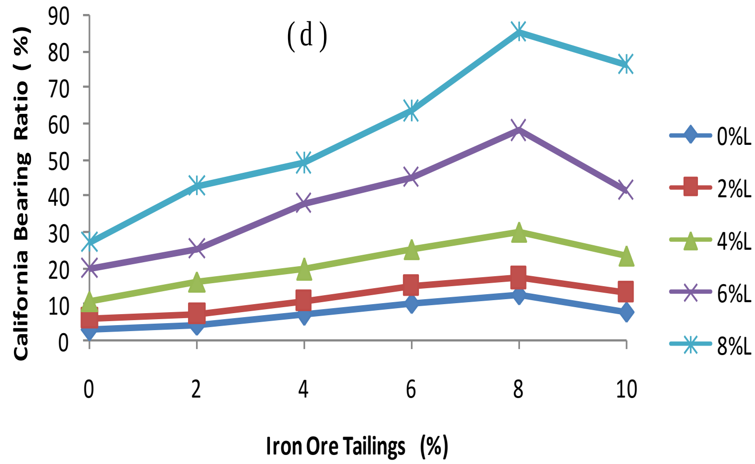
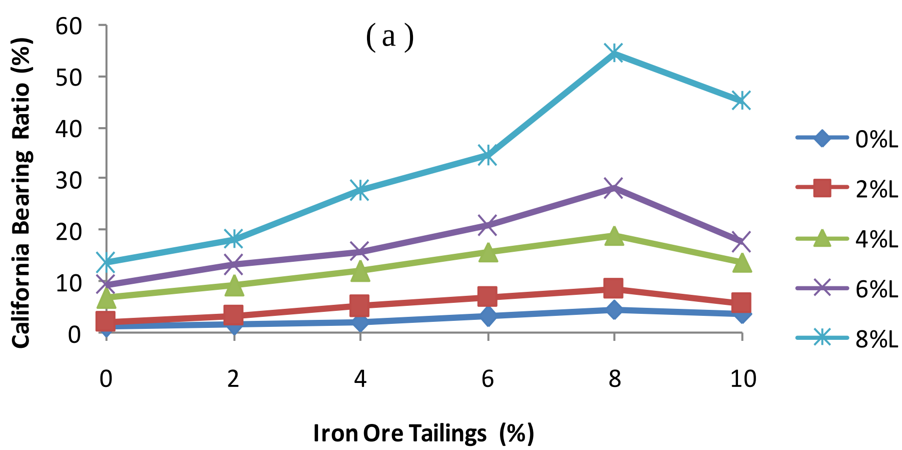
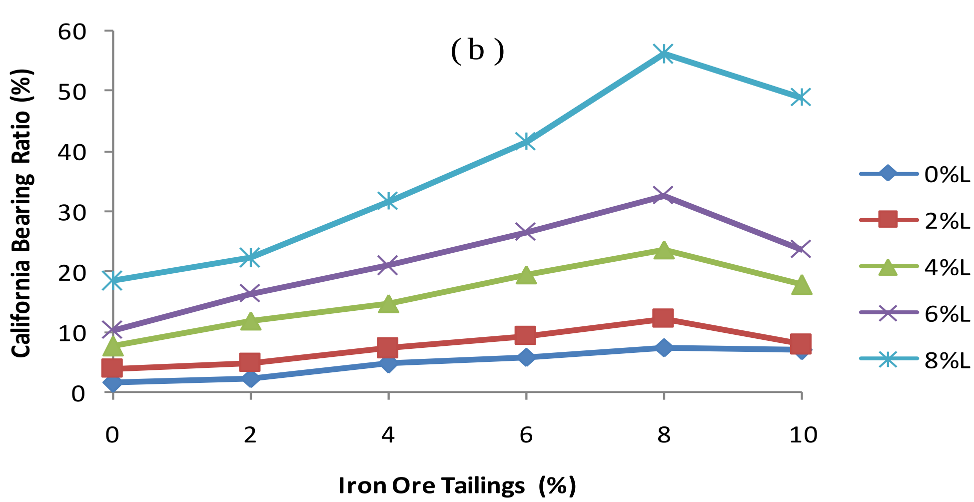
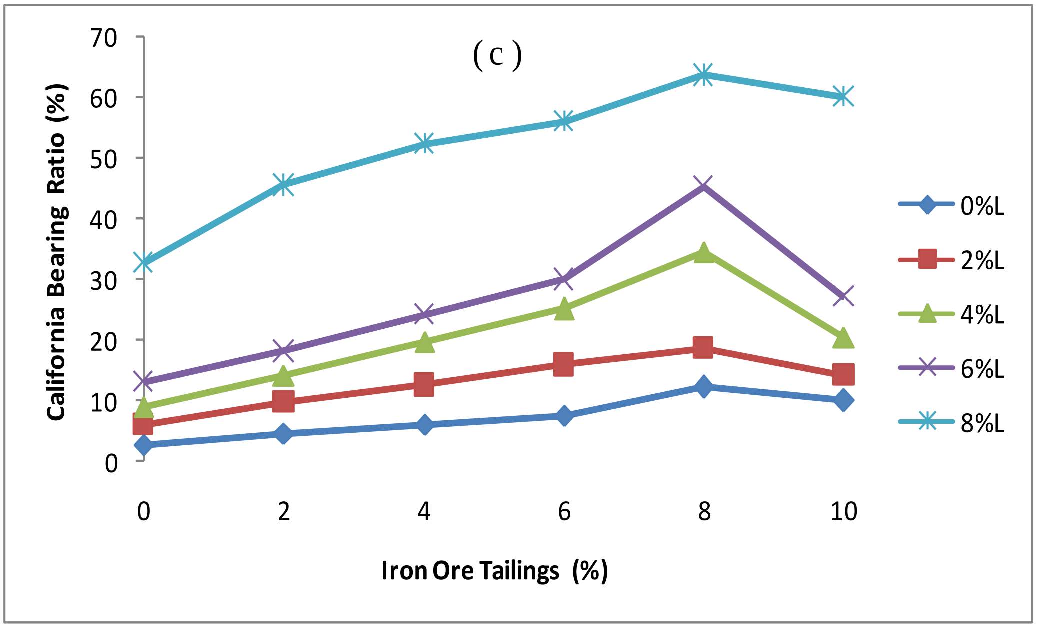


Fig. 4.48: Variation of California bearing ratio (soaked condition) of black cotton soil – lime mixtures with iron ore tailings content at (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours elapsed time after mixing (WAS compaction)







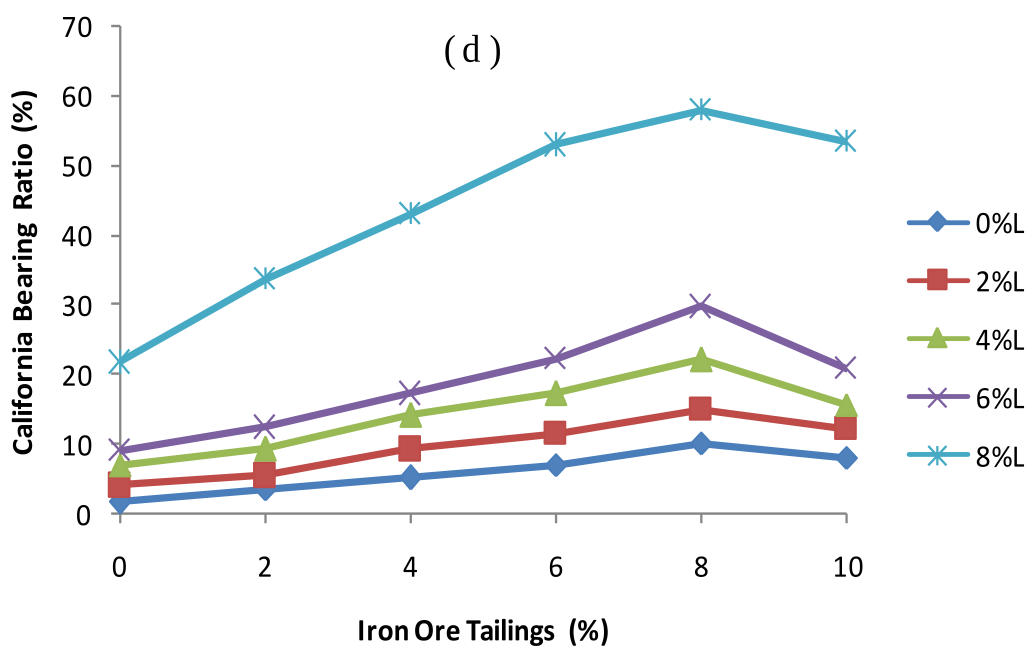
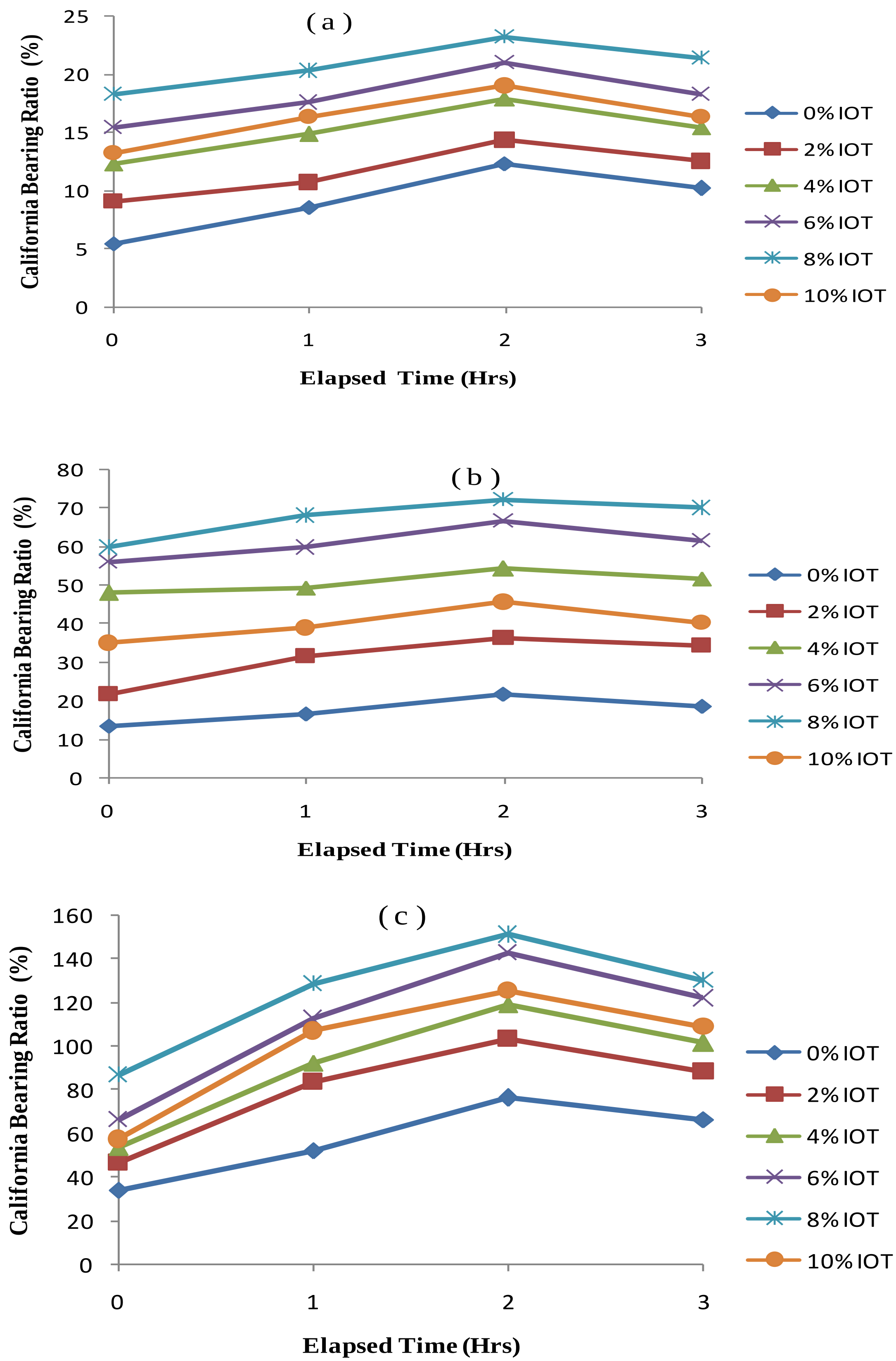


Fig. 4.49: Variation of California bearing ratio (soaked condition) of black cotton soil – lime mixtures with iron ore tailings content at (a) 0 hour (b) 1 hour (c) 2 hours (d) 3 hours elapsed time after mixing (BSL compaction)

The two – way analysis of variance (ANOVA) test on the un-soaked CBR result for BSL, WAS and BSH compaction (see Tables G19, G44, and G70 in Appendix) showed that the effects of lime (F_{CAL} = 149.858, 202.394, 190.477> F_{CRIT} = 2.87) and IOT (F_{CAL} = 17.975, 16.869, 17.088> F_{CRIT} = 2.71) on black cotton soil were statistically significant.The two – way analysis of variance (ANOVA) test on the soaked CBR result for BSL, WAS and BSH compaction (see Table G6, G32 and G57 inAppendix G) showed that the effects of lime (F_{CAL} = 102.015, 41.463, 96.039> F_{CRIT} = 2.8661) and IOT (F_{CAL} = 16.620, 8.881, 16.202> F_{CRIT} = 2.71)on the black cotton soil were statistically significant.

4.6.2 Effect of elapsed time after mixing on CBR behaviour

The variation in California bearing ratio with elapsed time after mixing for the various lime and IOT treatment using the three compactive efforts for soaked and un-soaked condition are shown in Figs. 4.50 –4.55. The variation of California bearing ratio with the elapsed time for the three energy levels considered and for both soaked and un-soaked conditions is shown in Fig. 4.56. The CBR values generally increased with elapsed time up to 2 hours, before decreasing at 3 hours elapsed time irrespective of lime and IOT treatment as well as the compactive effort applied. The reduction in the CBR values was probably due to the disruption of the hydration products in the process of compaction. The hydration product bound the soil particles however; the processes of compaction after delay disrupted this aggregation thereby resulting in lower densities and consequently lower strength (Ochepo *et al*., 2013). Detailed test results are given in Appendix G.


(a)
(b)
(c)
California Bearing Ratio (%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT

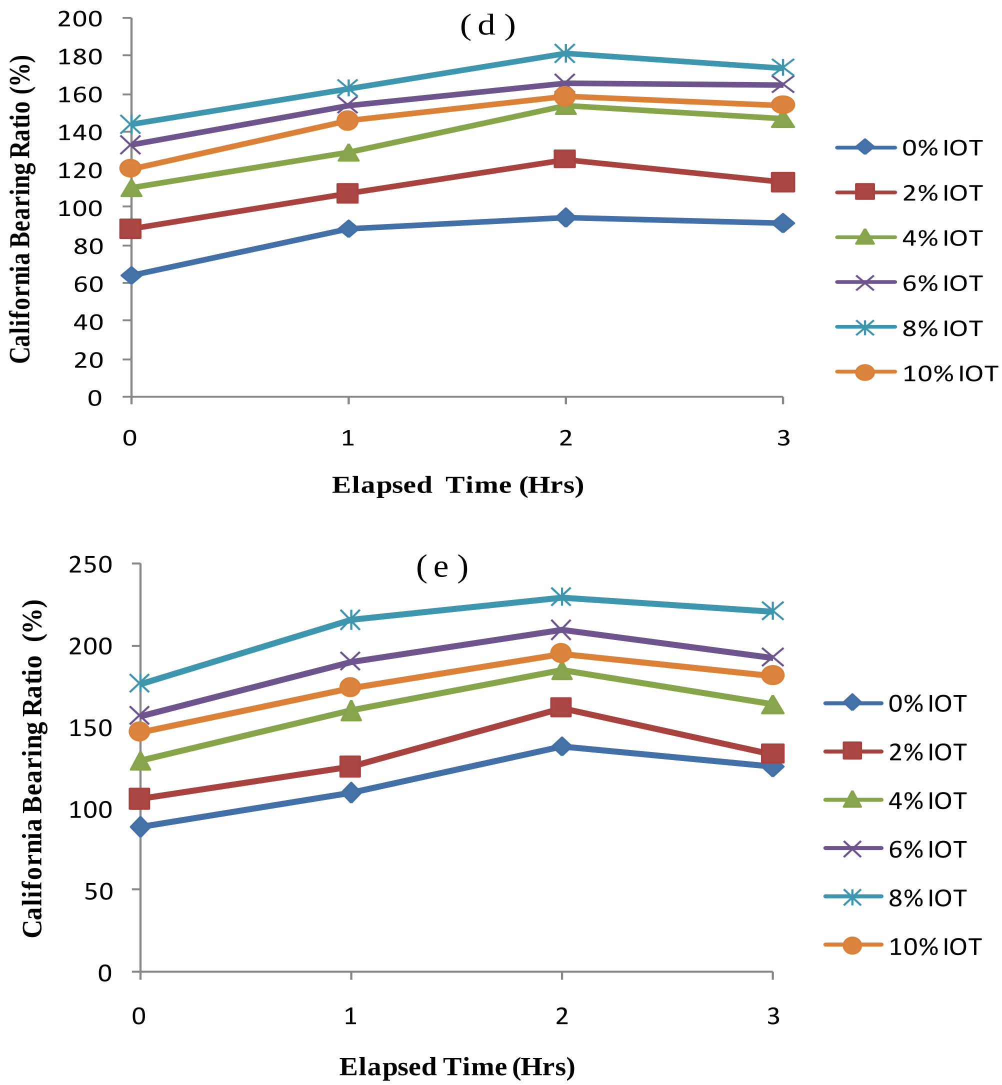
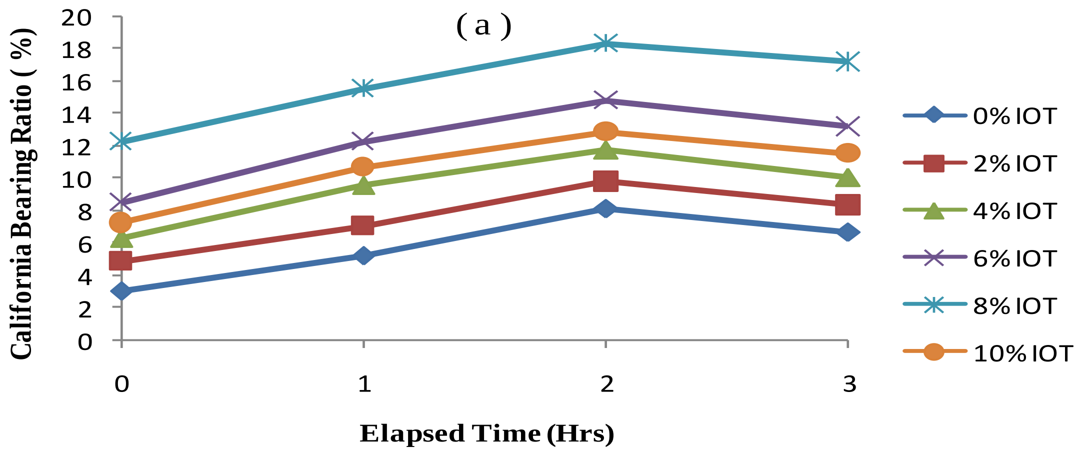
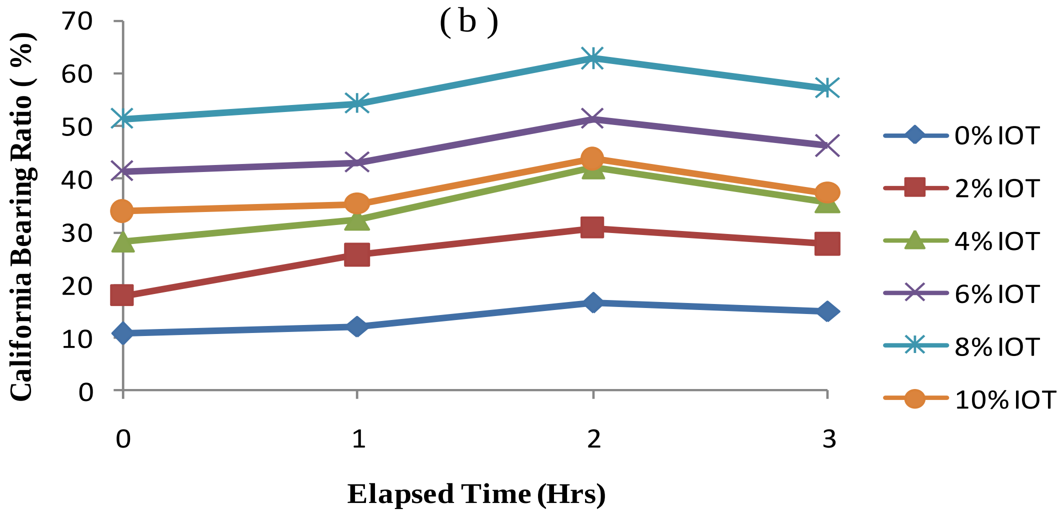
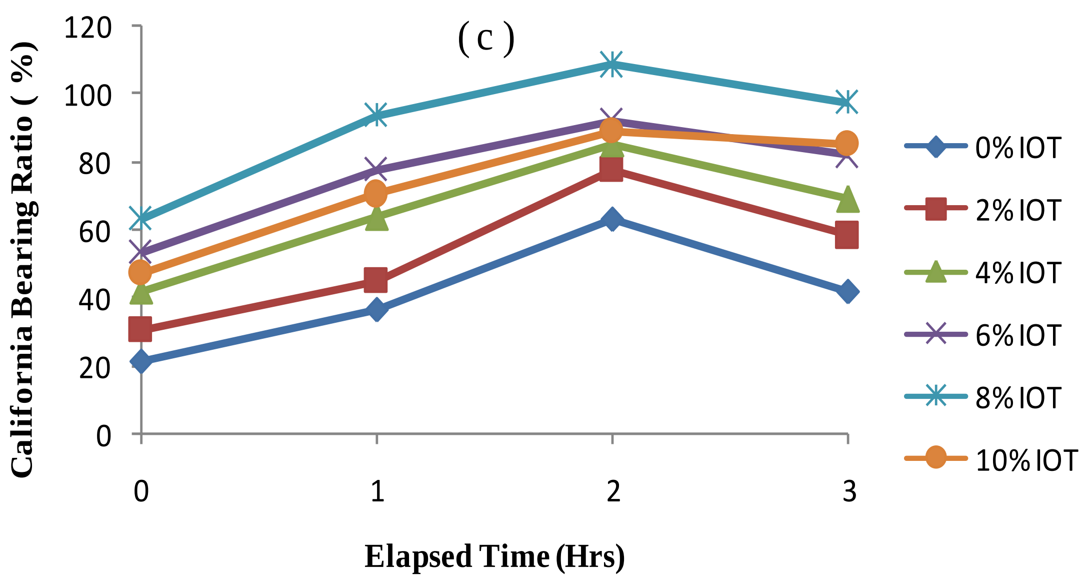
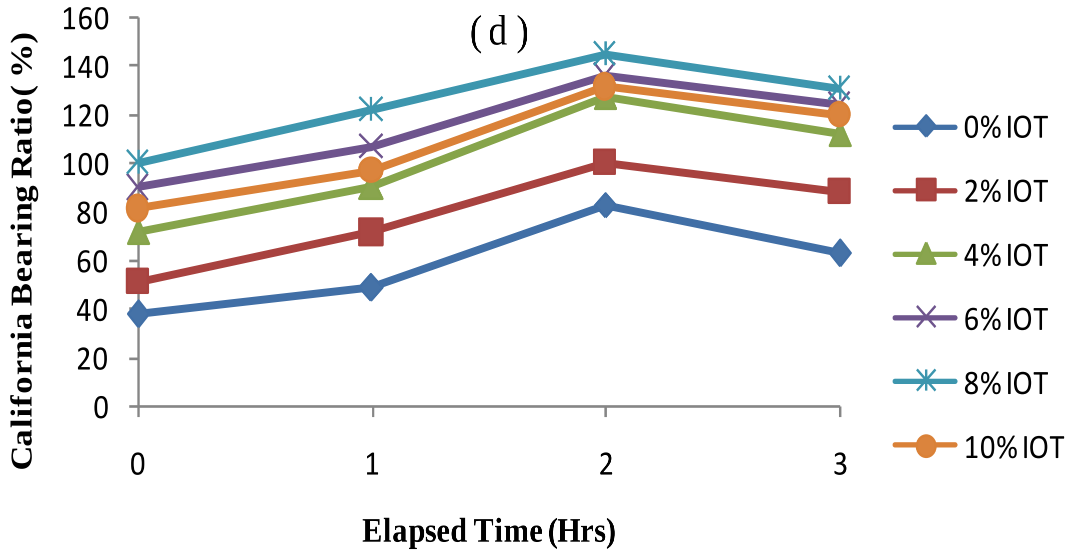


Fig. 4.50:Variation of California bearing ratio (un-soaked condition) of black cotton soil–iron ore tailings mixtures with elapse time after mixing for varyinglime content: (a) 0 % (b) 2% (c) 4% (d) 6% (e) 8% (BSH compaction)


(a)
California Bearing Ratio (%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(b)
California Bearing Ratio (%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(c)
California Bearing Ratio (%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT



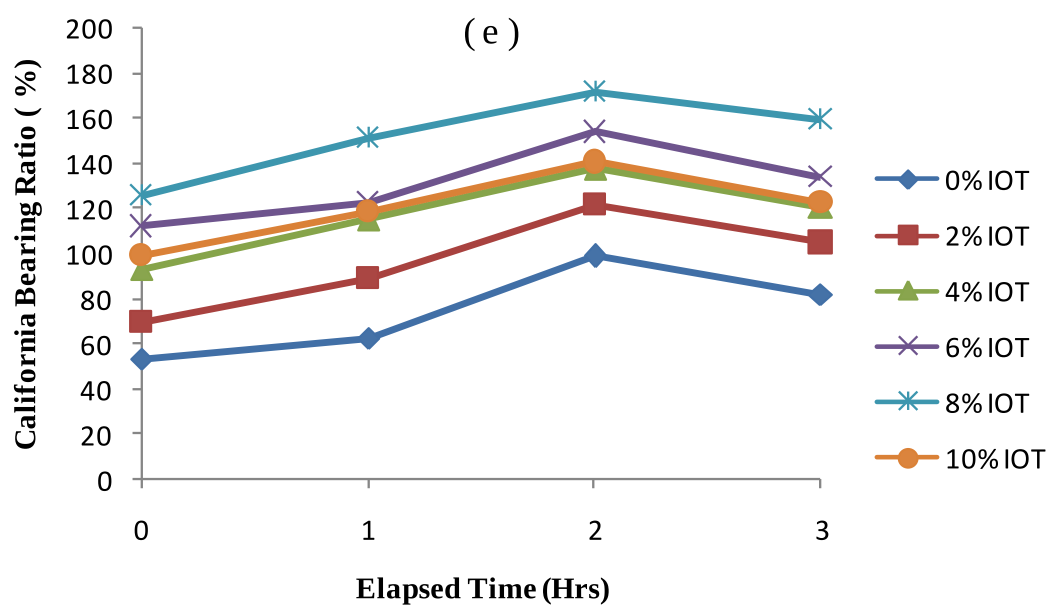
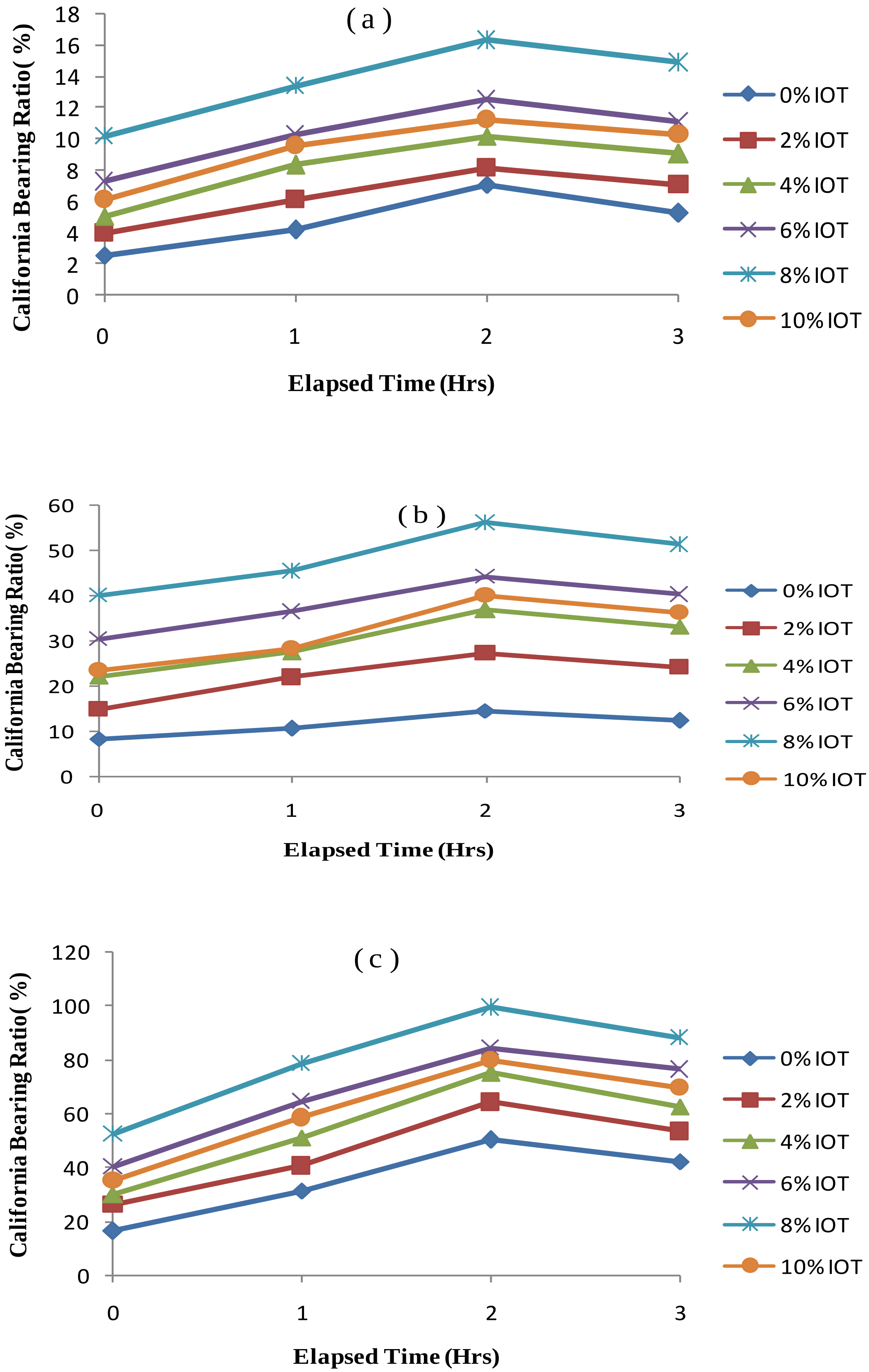
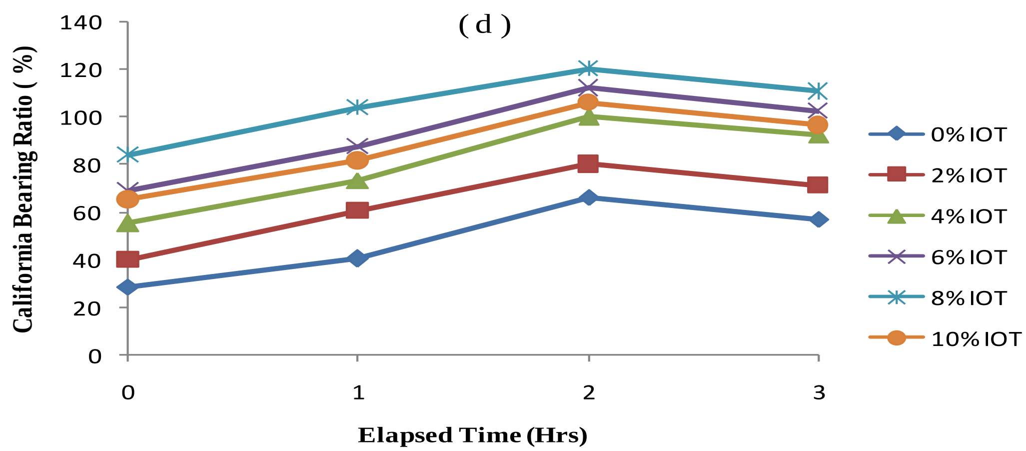


Fig. 4.51: Variation of California bearing ratio (un-soaked condition) of black cotton soil–iron ore tailings mixtures with elapse time after mixing for varyinglime content: (a) 0 % (b) 2% (c) 4% (d) 6% (e) 8% (WAScompaction)


(a)
California Bearing Ratio(%)
18
16
14
12
10
8
6
4
2
0
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT
(b)
California Bearing Ratio(%)
60
50
40
30
20
10
0
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT
(c)
California Bearing Ratio(%)
120
100
80
60
40
20
0
0
1
2
3
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT



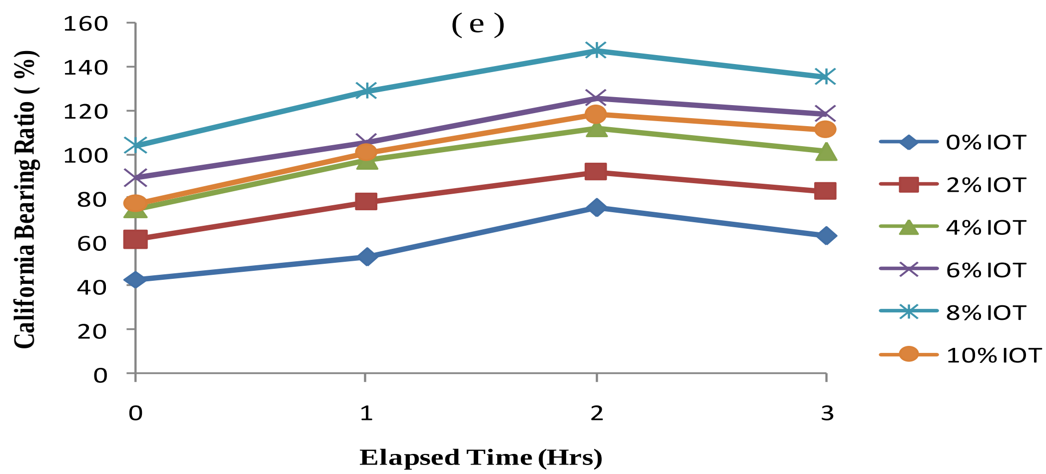
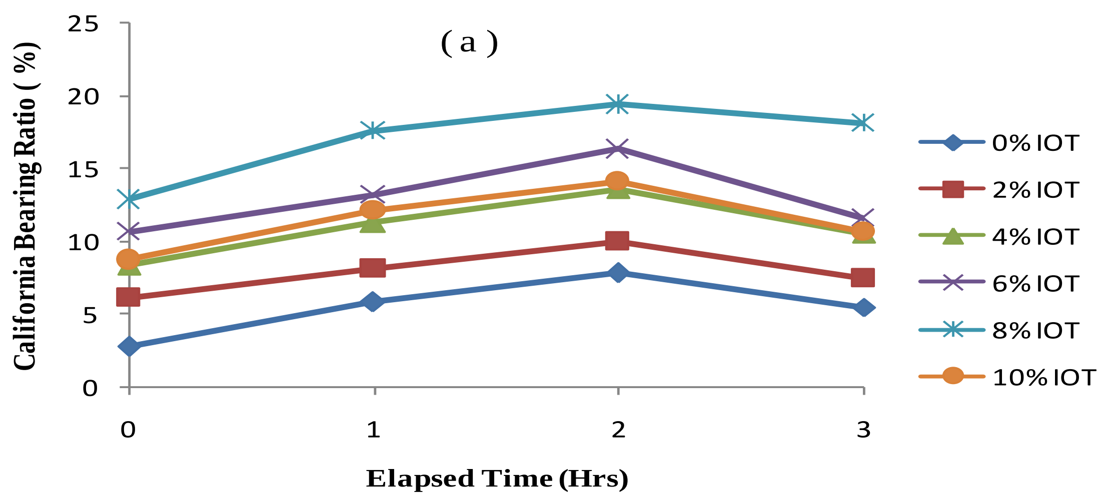
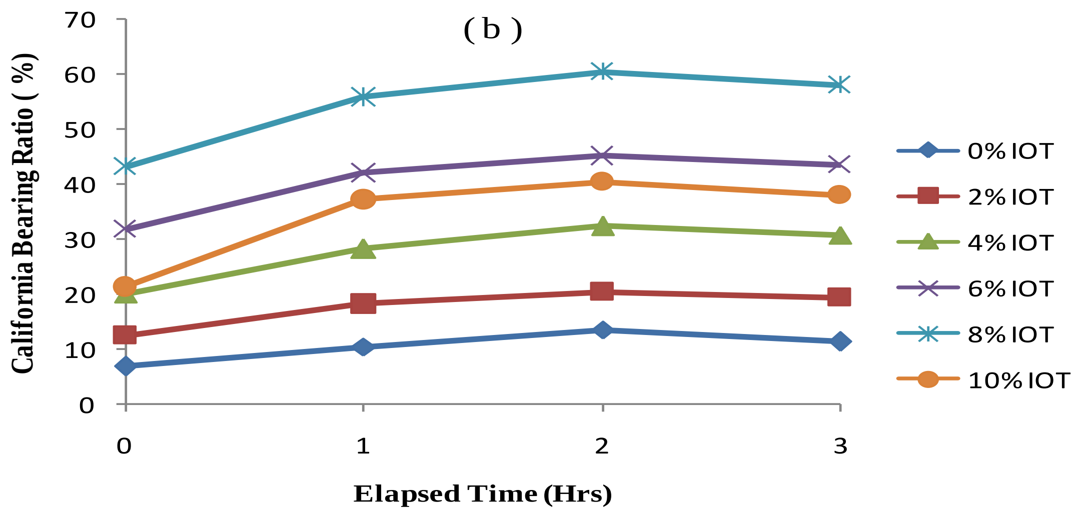
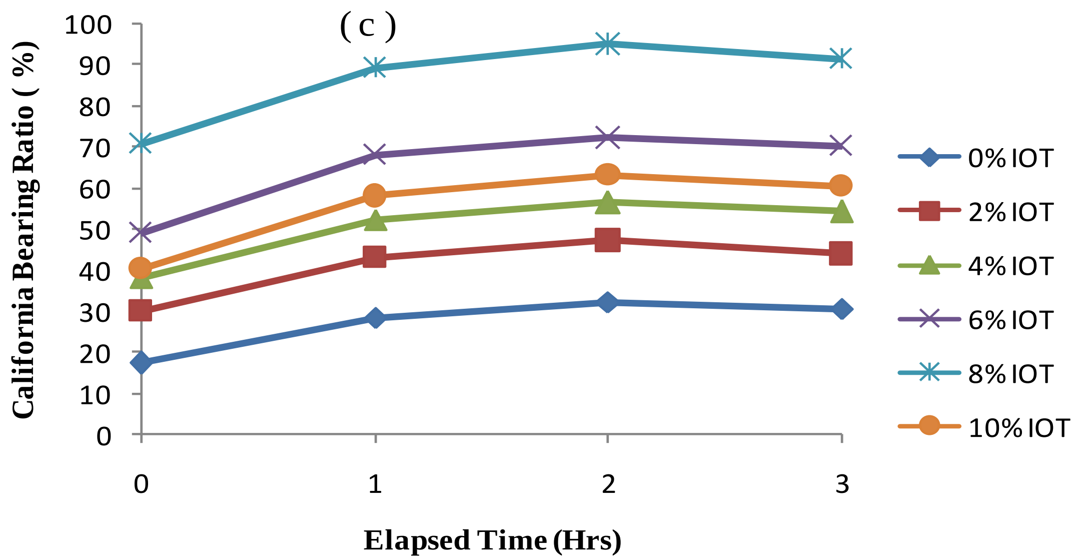
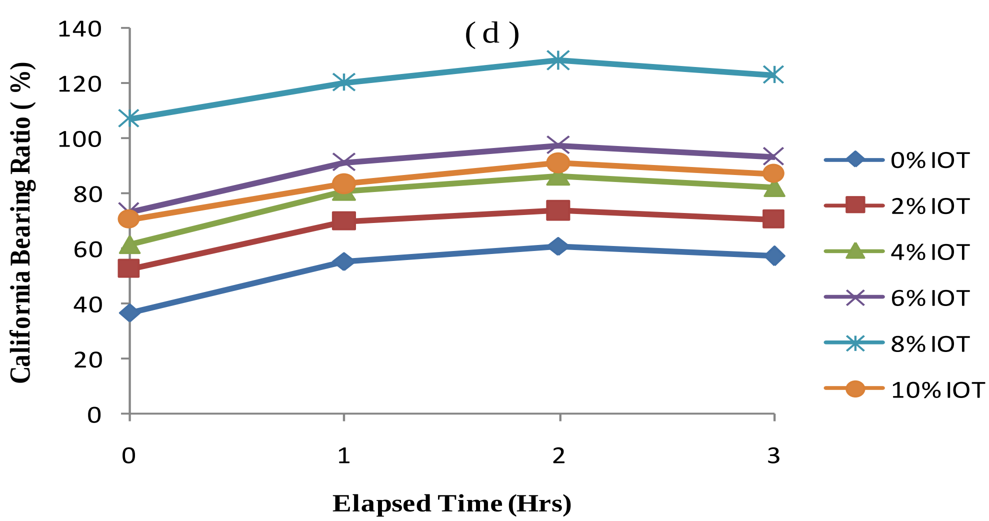


Fig. 4.52: Variation of California bearing ratio (un-soaked condition) of black cotton soil–iron ore tailings mixtures with elapse time after mixing for varyinglime content: (a) 0 % (b) 2% (c) 4% (d) 6% (e) 8% (BSLcompaction)




(b)
California Bearing Ratio (%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(c)
California Bearing Ratio (%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(d)
California Bearing Ratio (%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT

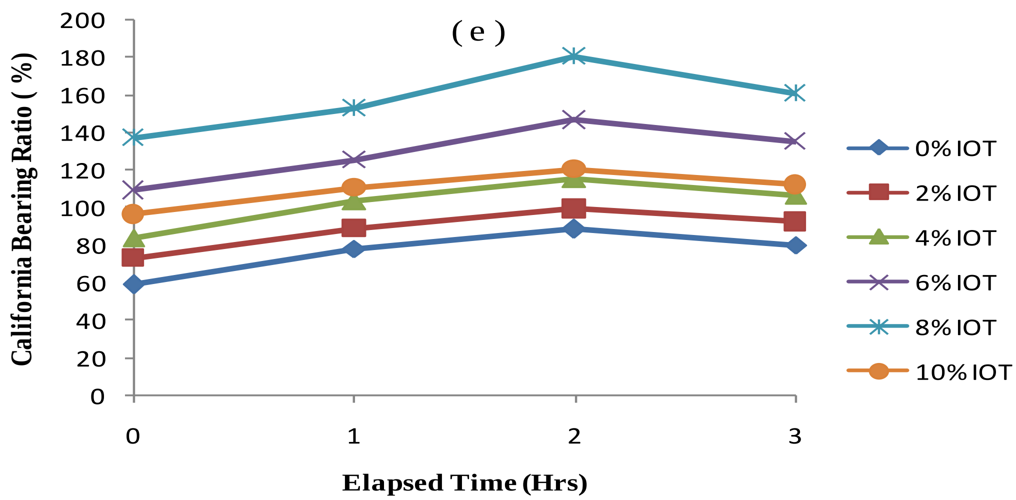
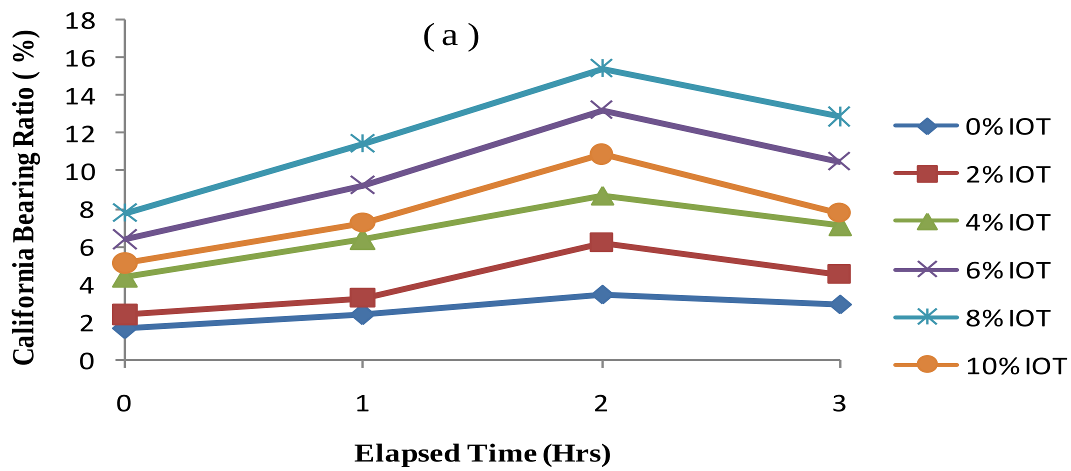
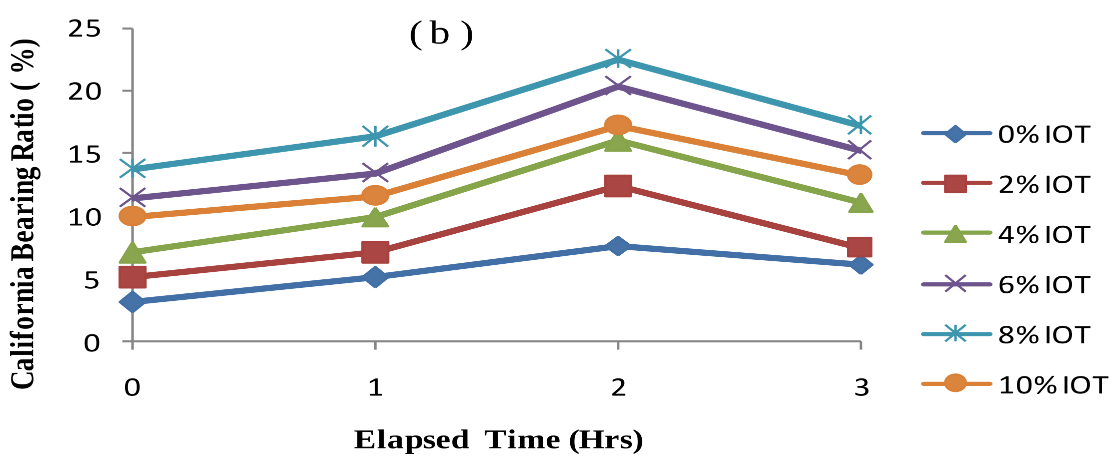


Fig. 4.53:Variation of California bearing ratio (soaked condition) of black cotton soil–iron ore tailings mixtures with elapse time after mixing for varying lime content: (a) 0 % (b) 2% (c) 4% (d) 6% (e) 8% (BSH compaction)





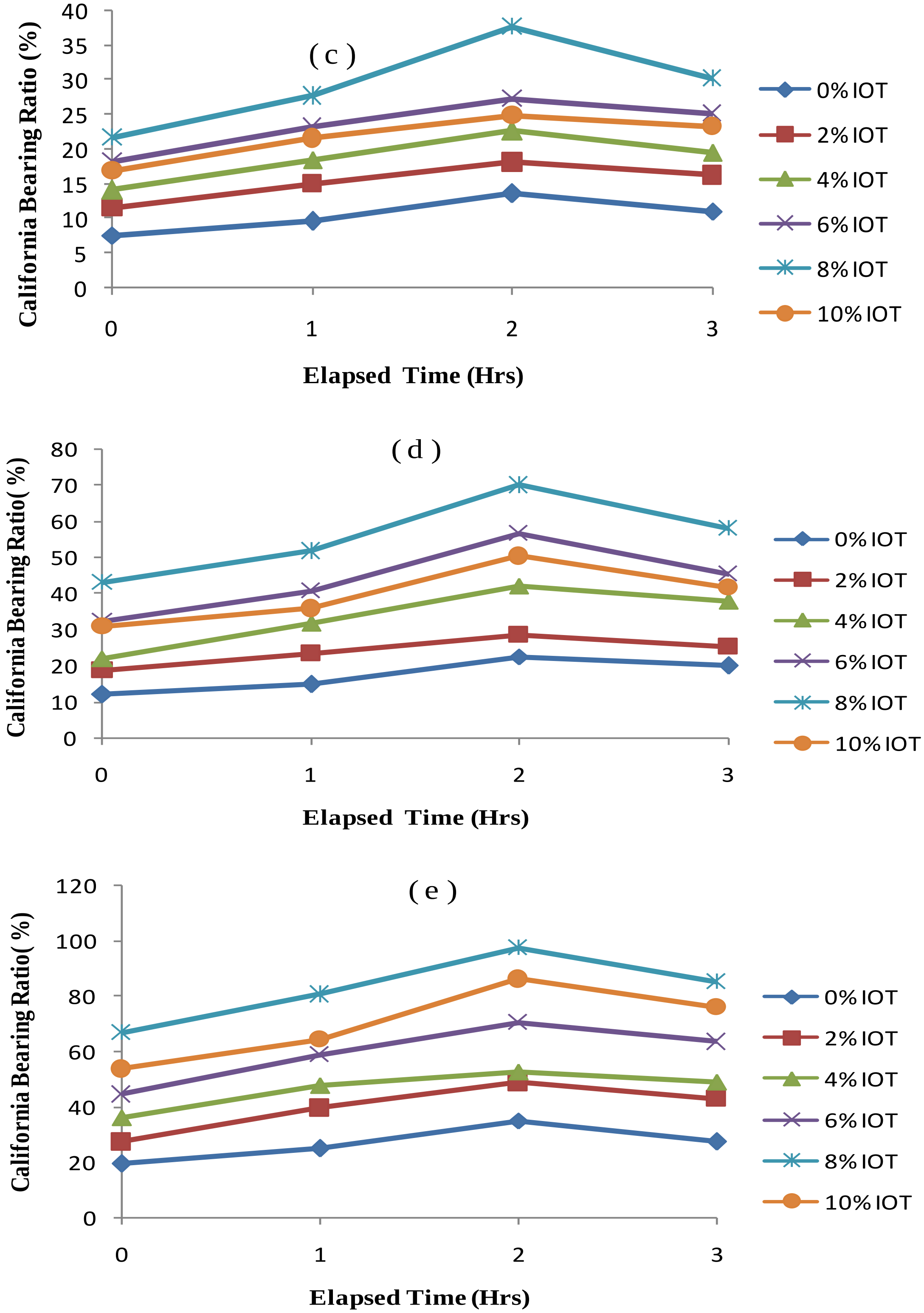
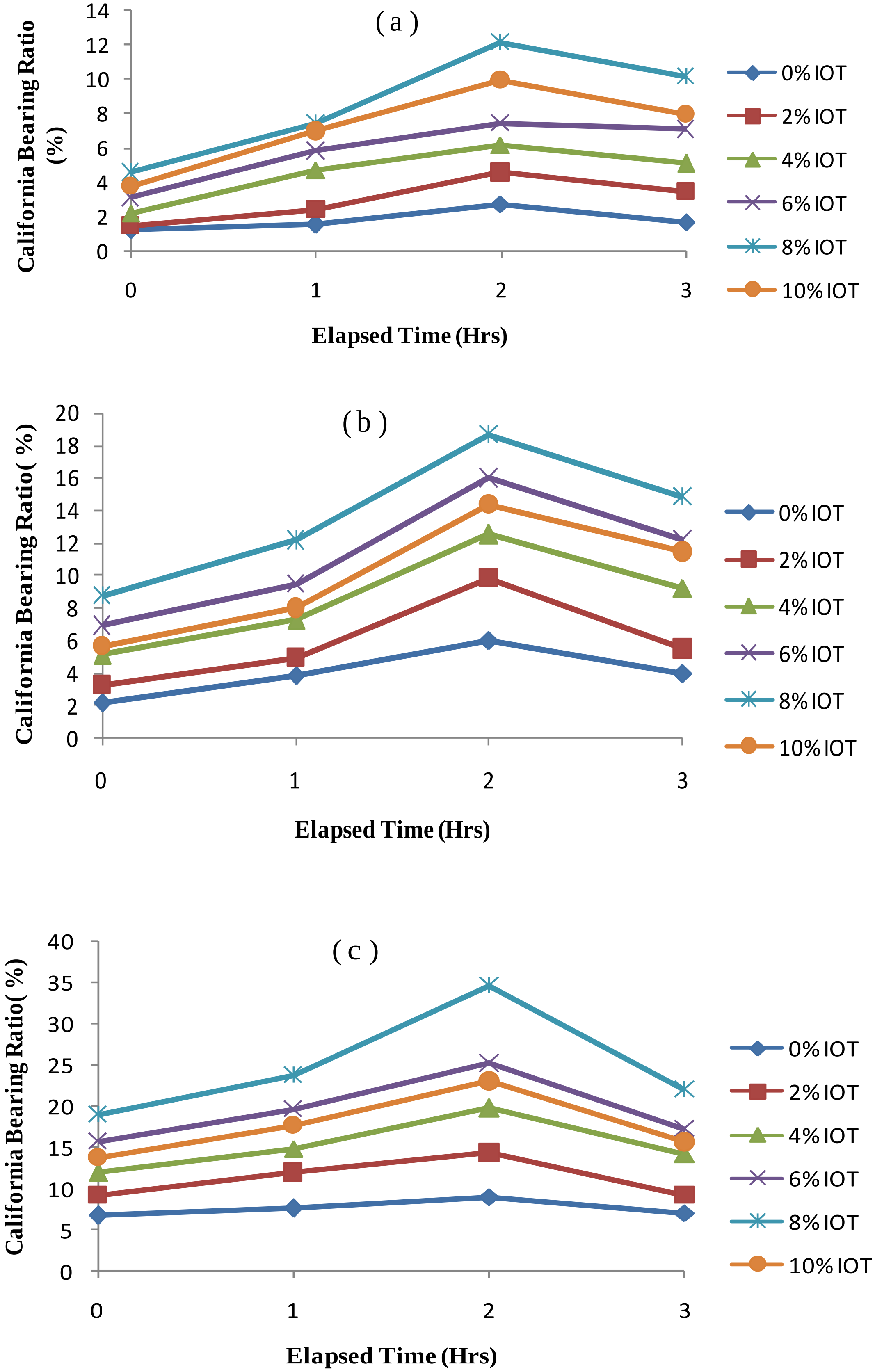


Fig. 4.54: Variation of California bearing ratio (soaked condition) of black cotton soil–iron ore tailings mixtures with elapse time after mixing for varyinglime content: (a) 0 % (b) 2% (c) 4% (d) 6% (e) 8% (WAScompaction)



(a)
California Bearing Ratio (%)
Elapsed Time (Hrs)
(b)
California Bearing Ratio(%)
Elapsed Time (Hrs)
(c)
California Bearing Ratio(%)
Elapsed Time (Hrs)
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT

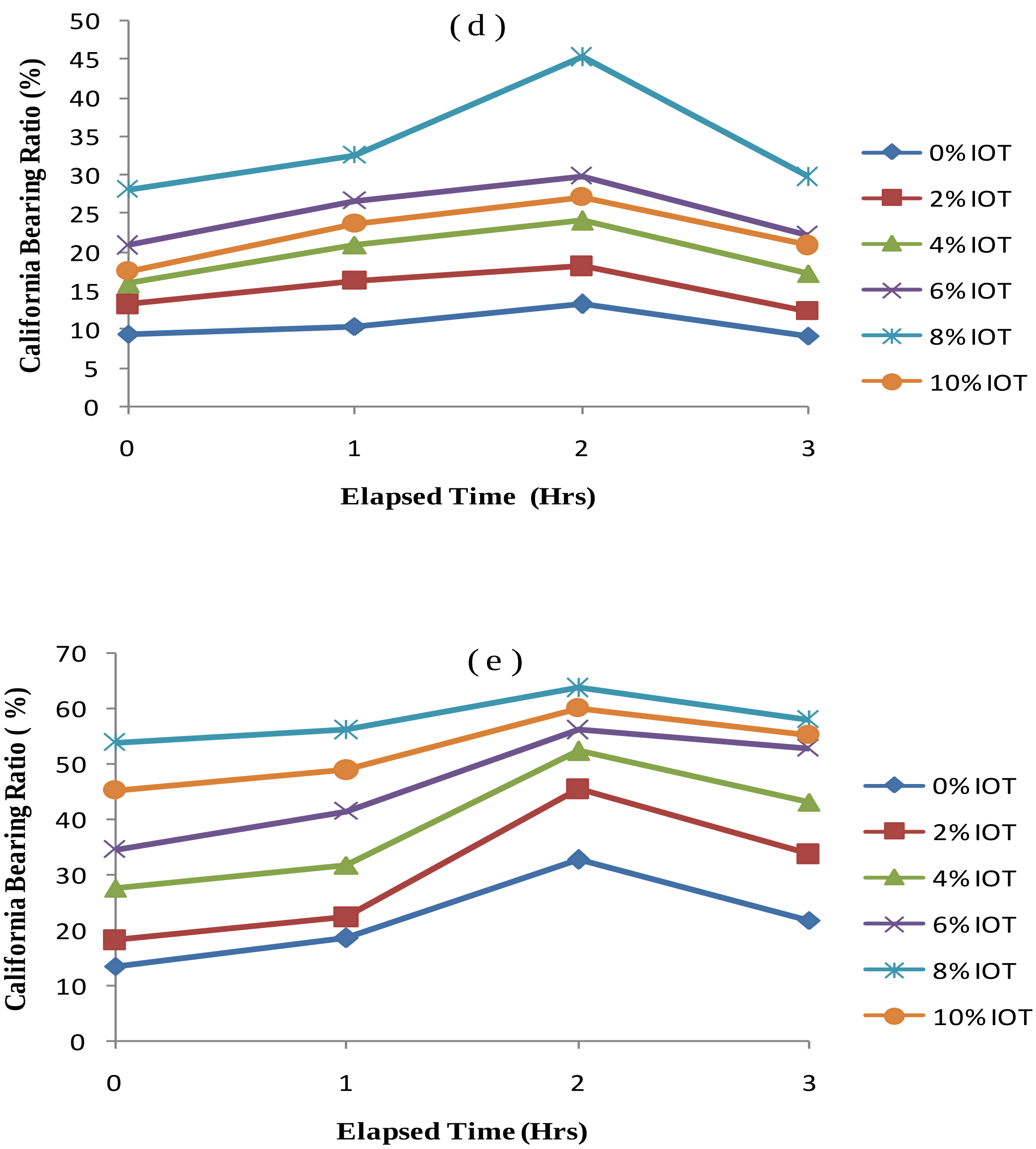


Fig. 4.55: Variation of California bearing ratio (soaked condition) of black cotton soil - iron ore tailingsmixtures with elapse time after mixing for varyinglimecontent: (a) 0 % (b) 2% (c) 4% (d) 6% (e) 8% (BSLcompaction)

Nigerian General Specifications (1997) recommends a CBR value of 180% for adequate cement stabilization in the laboratory. However when compacted at 100 % West African Standard energy with optimum moisture content, an un-soaked CBR value of 80 % is desired for bases and soaked value of 30 % for sub-bases (Gidigasu and Dogbey 1980; Osinubi, 2000a, 2006; Sani *et al*., 2018).

Based on the above criterion, the soil optimally treated with 8 % lime / 8 % iron ore tailings compacted with BSL, WAS and BSH energy recorded CBR values of 150, 170 and 230 % respectively, met the requirement for base course material. The variation of peak CBR (soaked and un-soaked) with elapsed time for the three energy levels is as shown in Fig.4.56. However, the least conventional CBR values for lime treated soils of 40, 80 and 100% (BSL) for sub grade; sub base and base are used in assessing the strength of soil-lime specimen.

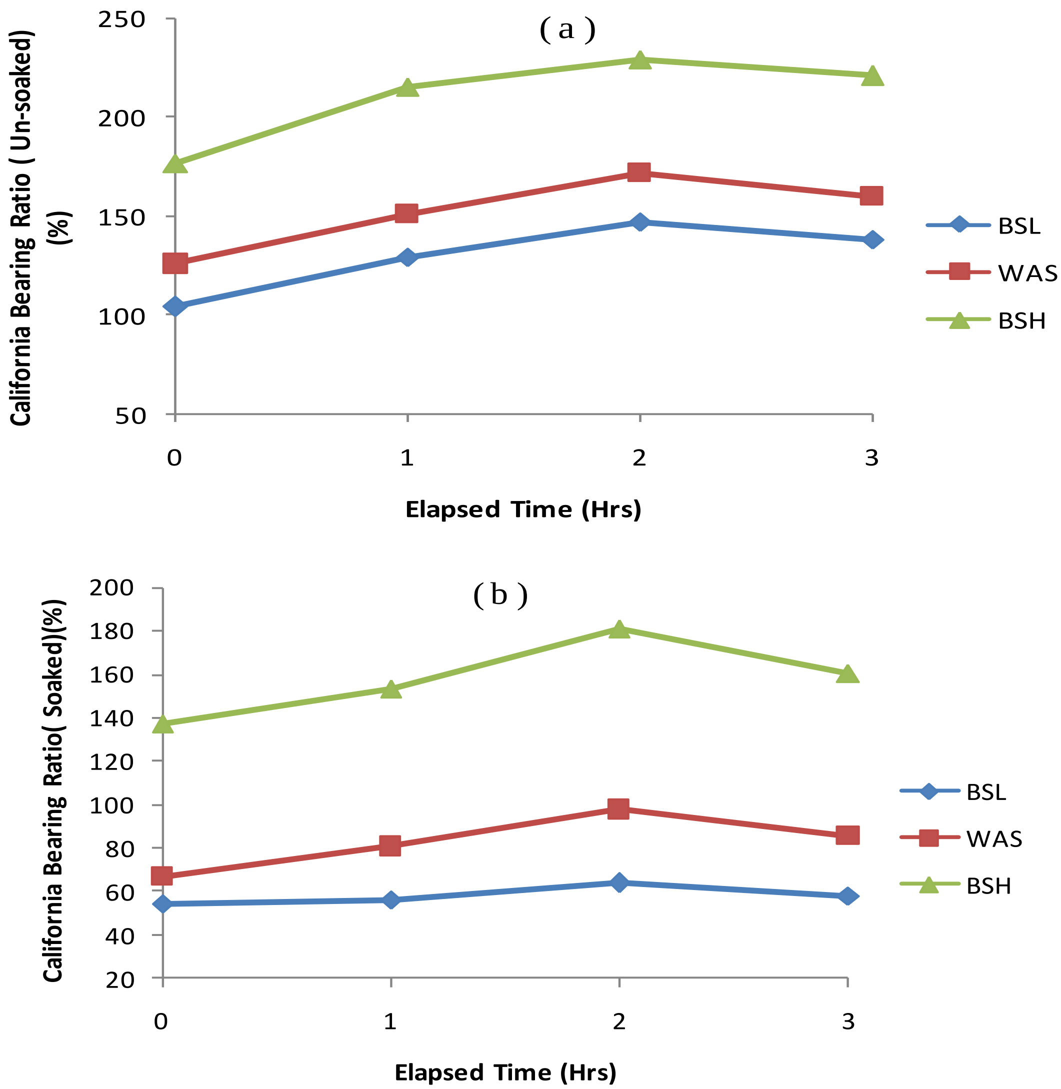


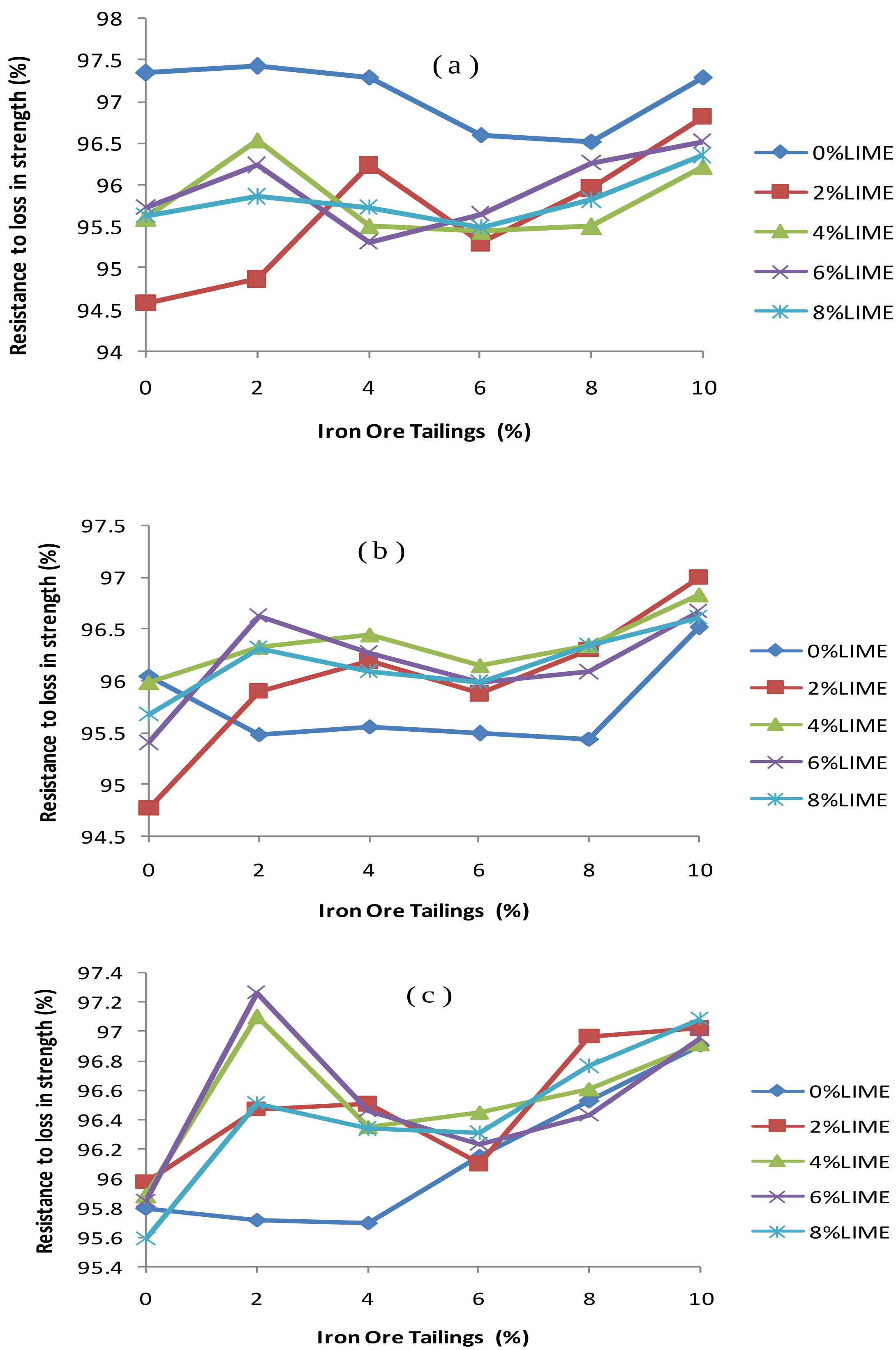
Fig. 4.56: Variation of peak California bearing ratio for the 3 energy levels with elapse time after mixing for different conditions: (a) Un-soaked (b) Soaked.

The two – way analysis of variance (ANOVA) test on the effect of elapsed time on soaked and un-soaked CBR for BSL; WAS and BSH compaction (see Tables G13; G26; G38; G51; G64; and G77 in Appendix G.) showed that forthe un-soaked conditions, the effects of elapsed time (F_{CAL} = 151.4503, 152.2944, 151.7386> F_{CRIT} = 3.2874) and IOT (F_{CAL} = 249.4357, 206.4693, 264.685> F_{CRIT} = 2.9013)onblack cotton soil were statistically significant. Also,for the soaked conditions the effects of elapsed time (F_{CAL} = 38.244, 8888848.877, 86.289> F_{CRIT} = 2.8661)and IOT (F_{CAL} = 65.373, 139.611, 216.295> F_{CRIT} = 2.71)on black cotton soil were statistically significant.

4.7 Durability

Durability assessment was carried out by immersion in water to establish the resistance to loss in strength of soil specimen (Ola, 1974). Conventionally, an allowable 20 % loss in strength is recommended for a specimen cured for 7 days and immersed in water for days (Ola, 1974; Osinubi, 1998; 1999; Osinubi *et al*., 2009; Ikeagwuani and Nwonu, 2019).

For the three compactive efforts considered, the resistance to loss in strength decreased to 94.58, 94.76 and 93.87 % at 2 % lime 0 % IOT, 2 % lime 6 % IOT and 4 % lime 10 % IOT, respectively, as shown in Fig. 4.57 – 4.59. The peak resistance to loss in strength values fell within the limit 80 % earlier mentioned for all the energy levels considered. Ochepo (2008); Samadou (2014) and Etim (2015) reported increase in the resistance to loss in strength. Detailed test results are given in Table H1 – 24 in Appendix H.


(a)
(b)
(c)
Resistance to loss in strength (%)
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME

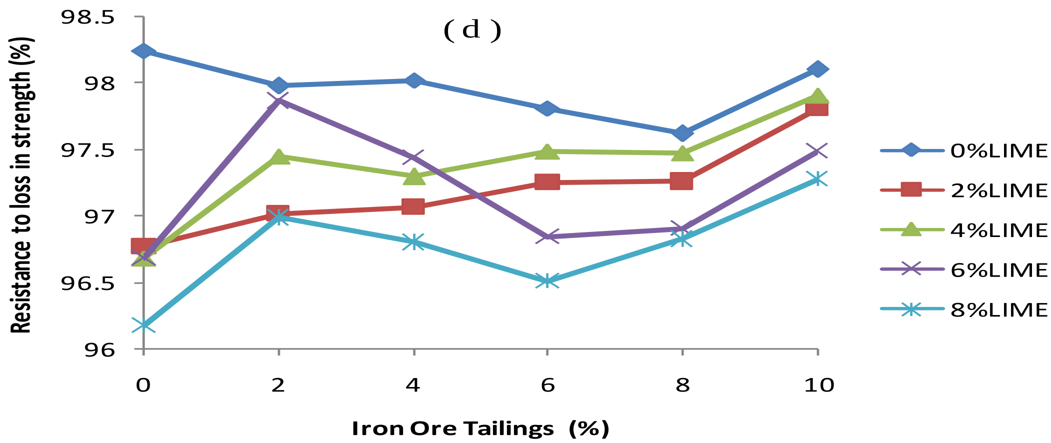
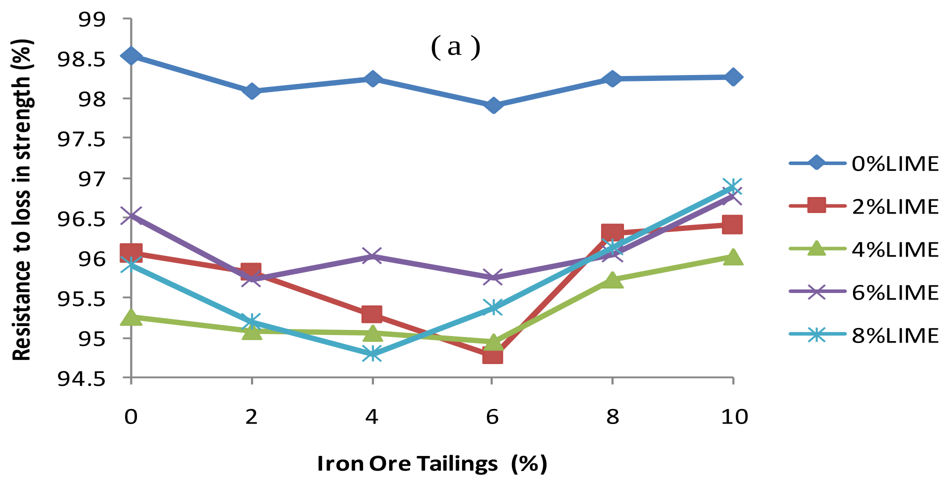
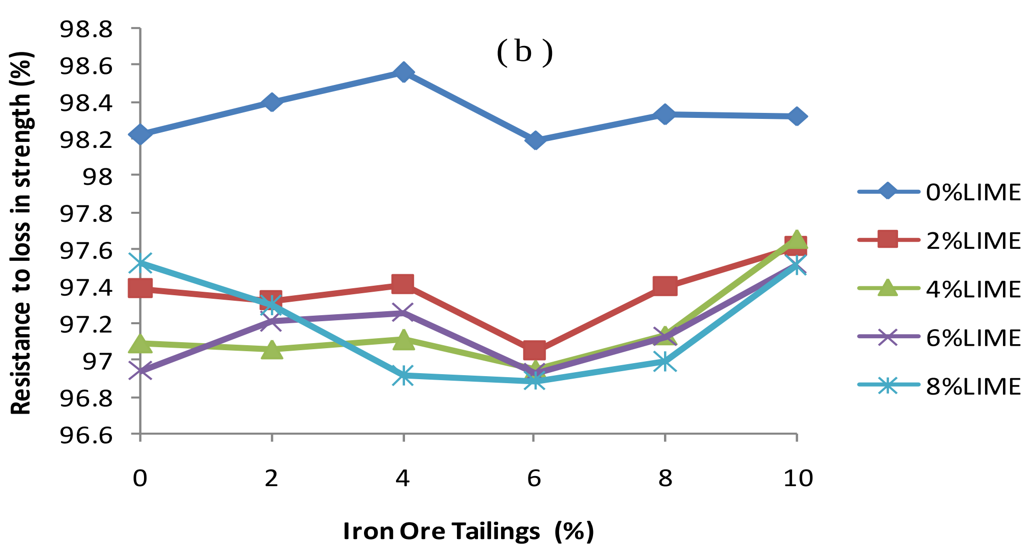
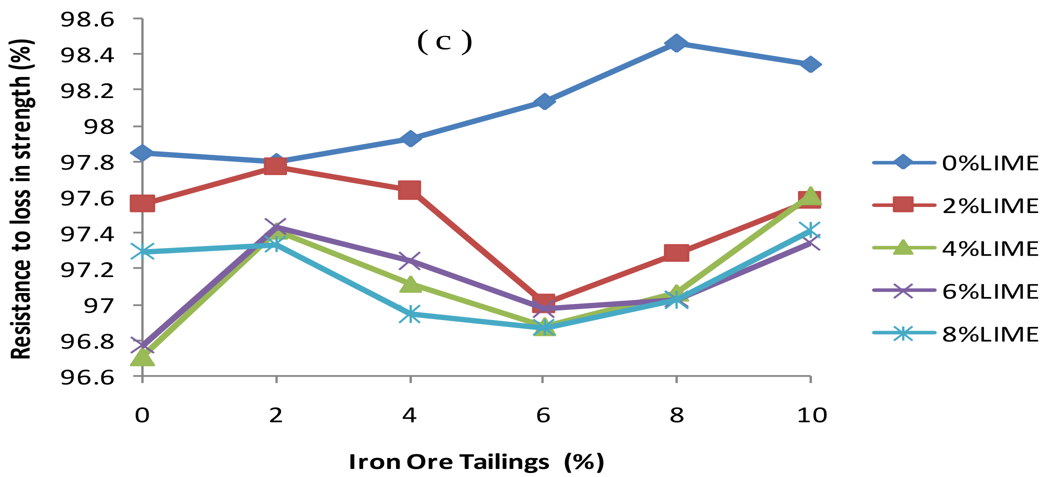


Fig. 4.57: Variation of resistance to loss in strength of black cotton soil –lime mixtures with iron ore tailings content for varying elapsed time after mixing:(a) 0 hour (b) 1 hour (c) 2 hours(d) 3 hours.(BSL compaction)







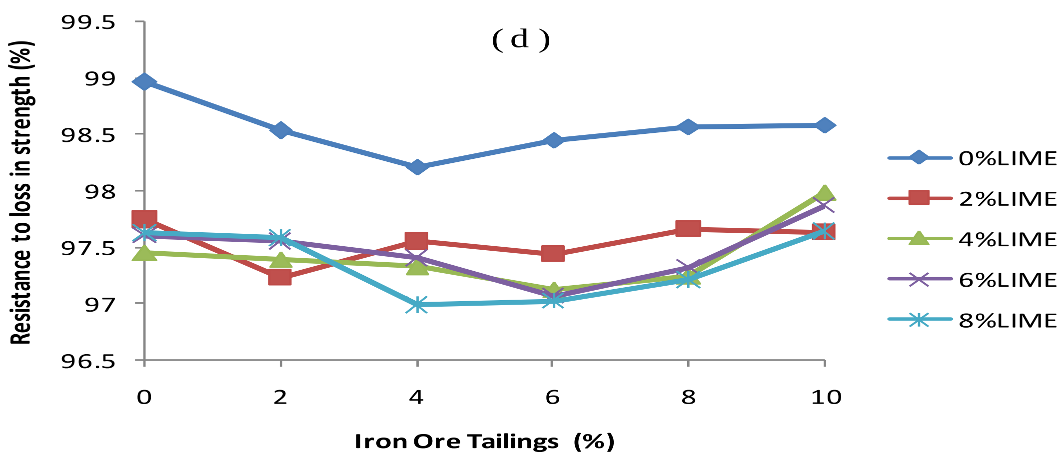
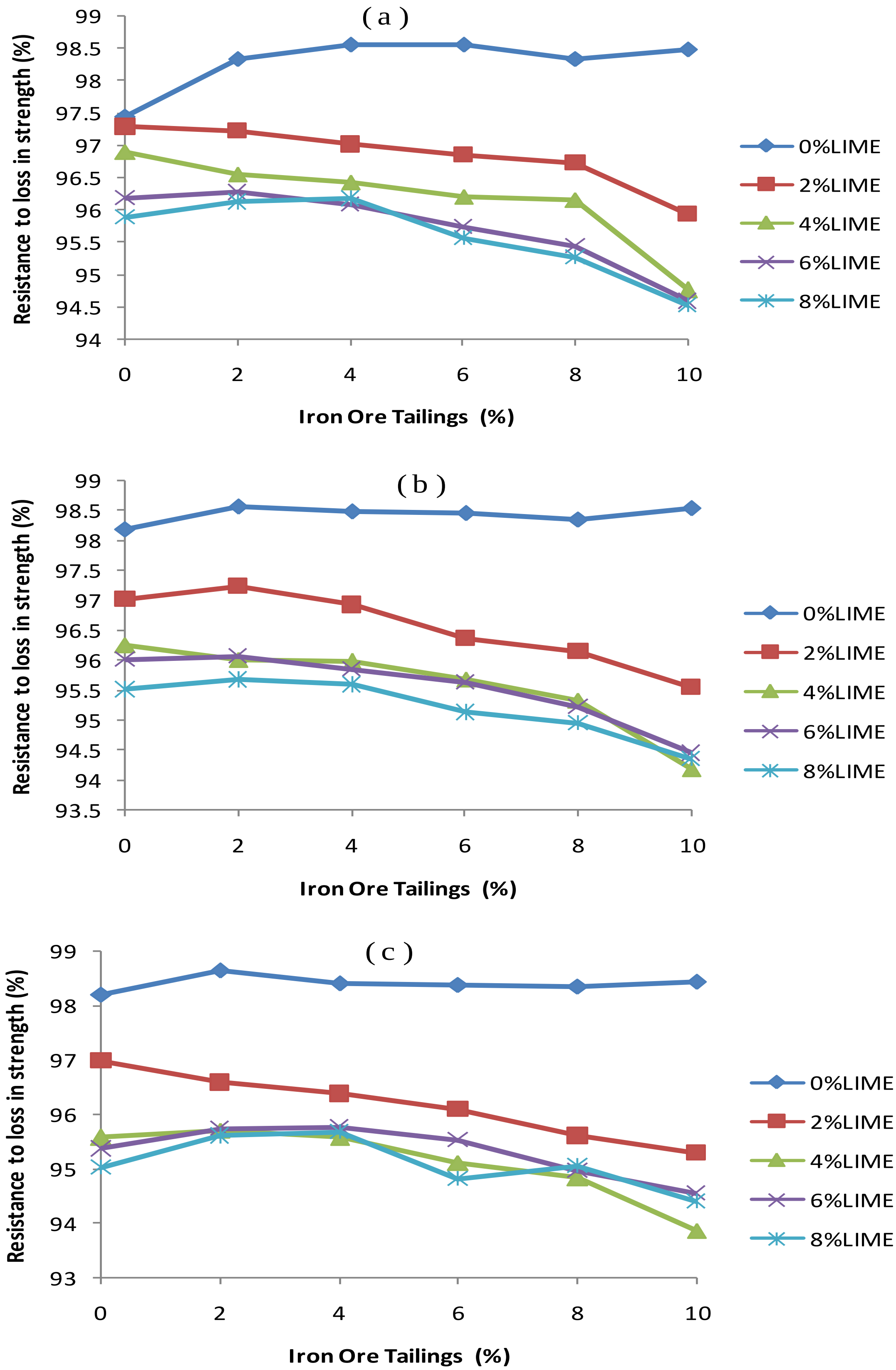


Fig. 4.58: Variation of resistance to loss in strength of black cotton soil –lime mixtures with iron ore tailings content for varying elapsed time after mixing:(a) 0 hour (b) 1 hour (c) 2 hours(d) 3 hours.(WAS compaction)


(a)
(b)
(c)
Resistance to loss in strength (%)
Iron Ore Tailings (%)
0%LIME
2%LIME
4%LIME
6%LIME
8%LIME

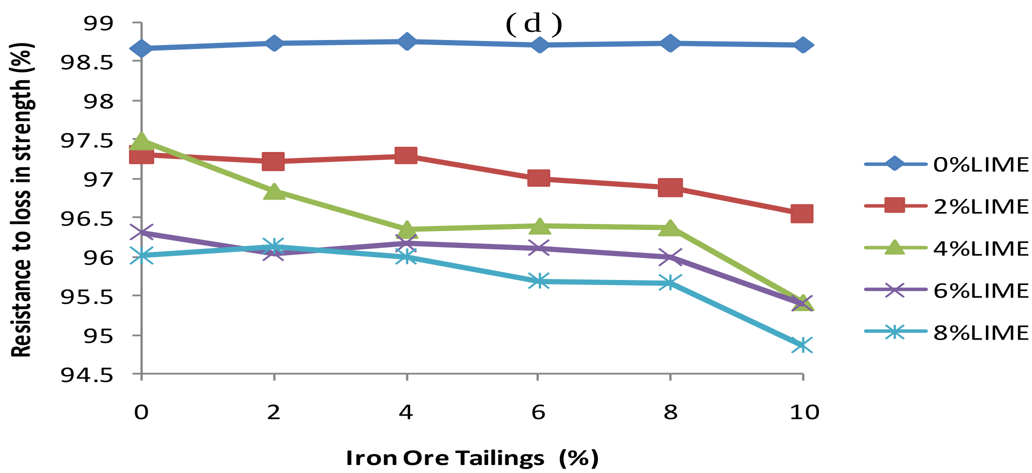
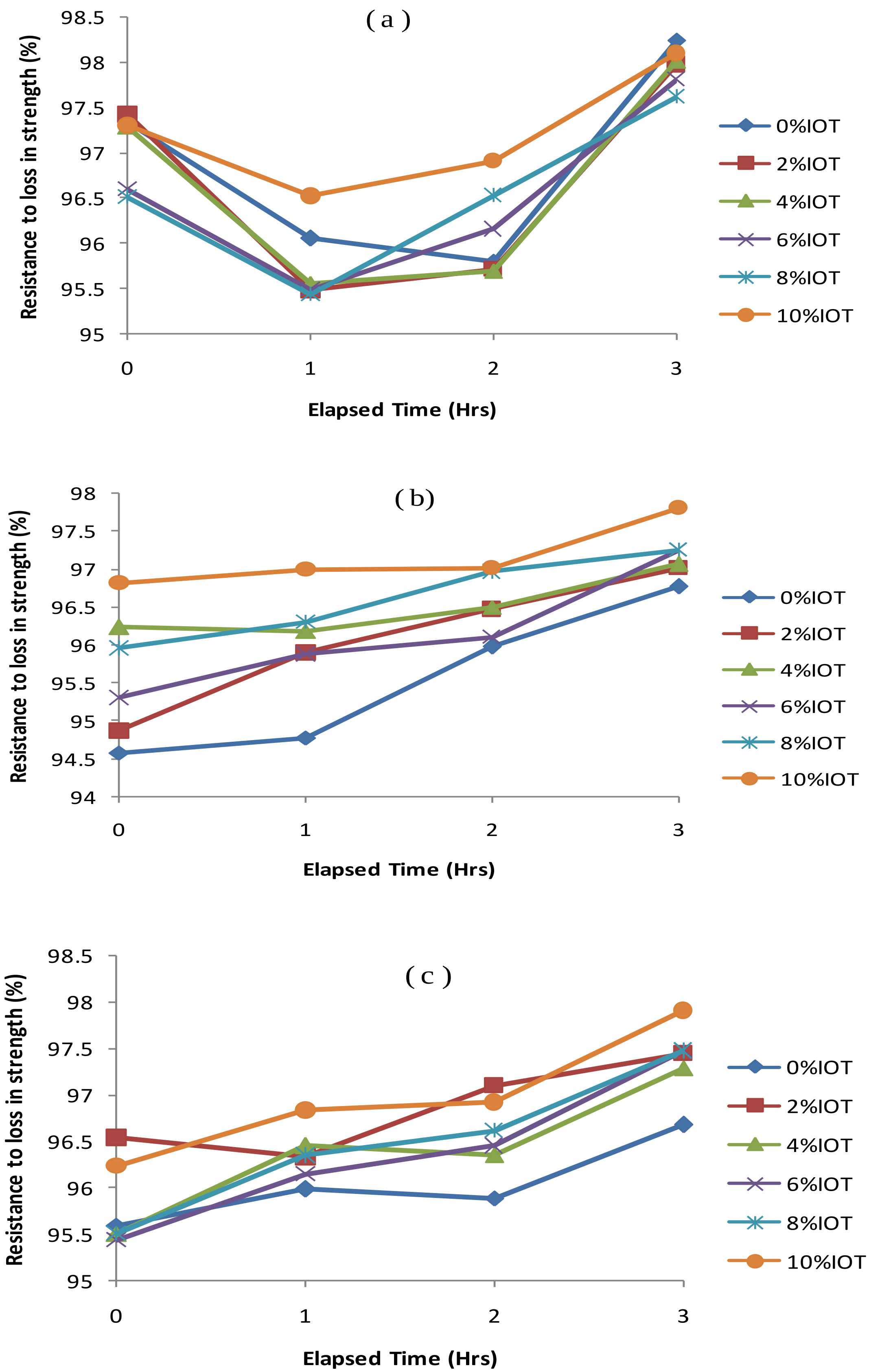
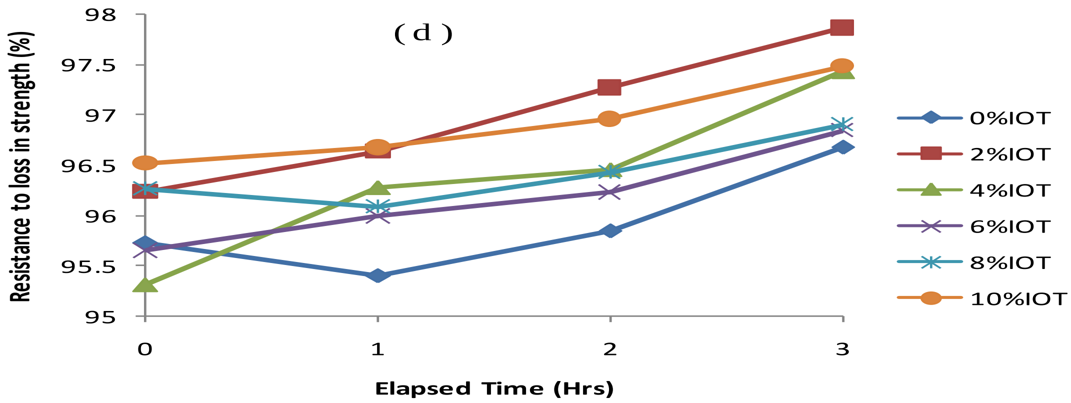


Fig. 4.59: Variation of resistance to loss in strength of black cotton soil –lime mixtures with iron ore tailings content for varying elapsed time after mixing:(a) 0 hour (b) 1 hour (c) 2 hours(d) 3 hours.(BSH compaction)

4.7.1. Effects of elapsed timeon resistance to loss in strength

The variation of resistance to loss in strength of black cotton soil – lime – iron ore tailings mixture with elapsed time for different IOT content are shown in Figs. 4.61- 4.60. Generally, for BSL compaction the resistance to loss in strength slightly increased up to 1 hour elapsed time after mixing and thereafter sharply increased up to 3 hours. The same trend was observed for the WAS compactive effort but the rate of the increase up to 1 hour was higher than that recorded for BSL compaction with a reduction at 2 hours. The BSH compactive effort recorded a decrease in the resistance to loss in strength with elapsed time after mixing from 0 – 2 hours and thereafter increased up to 3 hours for each soil – lime - IOT mixture considered.


(a)
Resistance to loss in strength (%)
98.5
98
97.5
97
96.5
96
95.5
95
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT
(b)
Resistance to loss in strength (%)
98
97.5
97
96.5
96
95.5
95
94.5
94
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT
(c)
Resistance to loss in strength (%)
98.5
98
97.5
97
96.5
96
95.5
95
0
1
2
3
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT



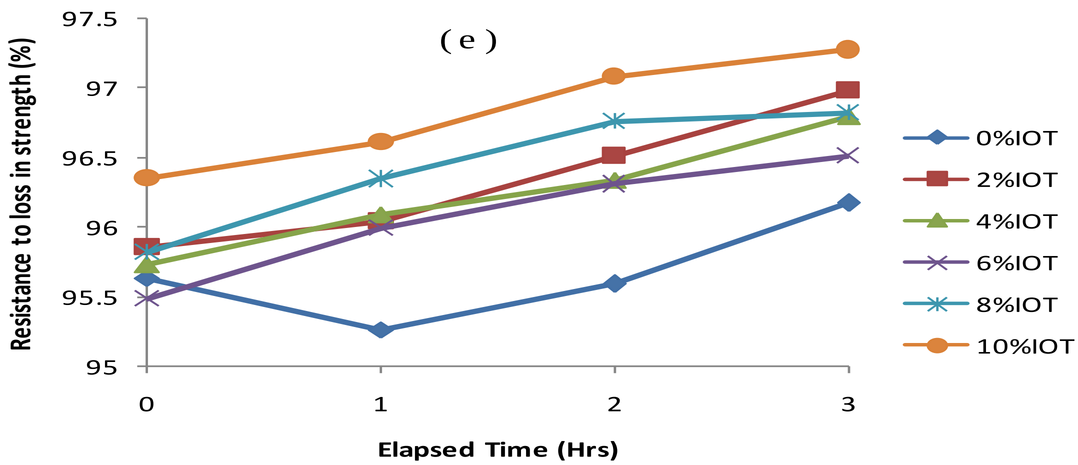
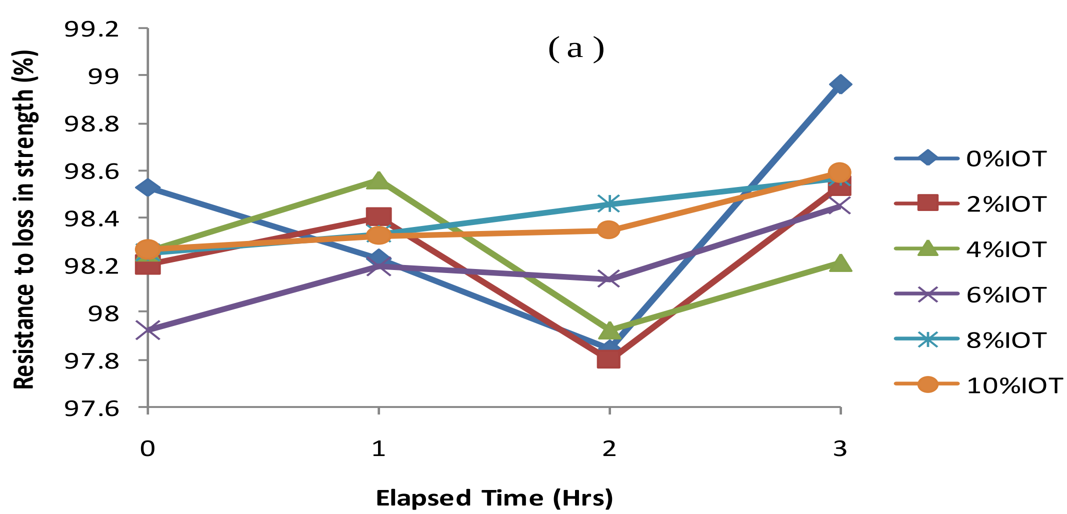
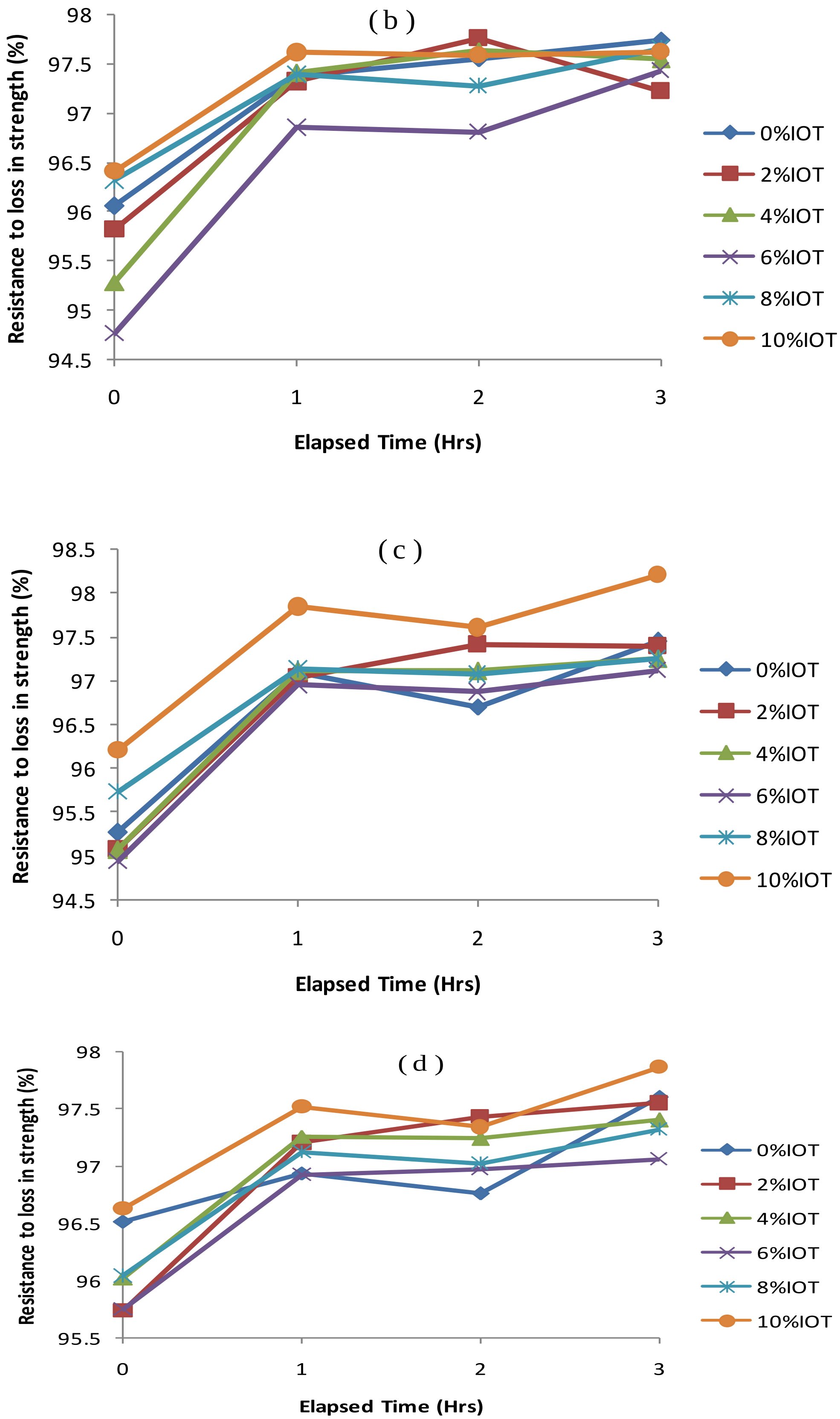


Fig: 4.60: Variation of resistance to loss in strength of black cotton soil – iron ore tailings with elapsed time after mixing for varying lime content at (a) 0 % (b) 2 % (c) 4% (d) 6% and 8% (BSL compaction).





(b)
98
97.5
97
96.5
96
95.5
95
94.5
0
1
2
3
Resistance to loss in strength (%)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT
(c)
98.5
98
97.5
97
96.5
96
95.5
95
94.5
0
1
2
3
Resistance to loss in strength (%)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT
(d)
98
97.5
97
96.5
96
95.5
0
1
2
3
Resistance to loss in strength (%)
Elapsed Time (Hrs)
0%IOT
2%IOT
4%IOT
6%IOT
8%IOT
10%IOT

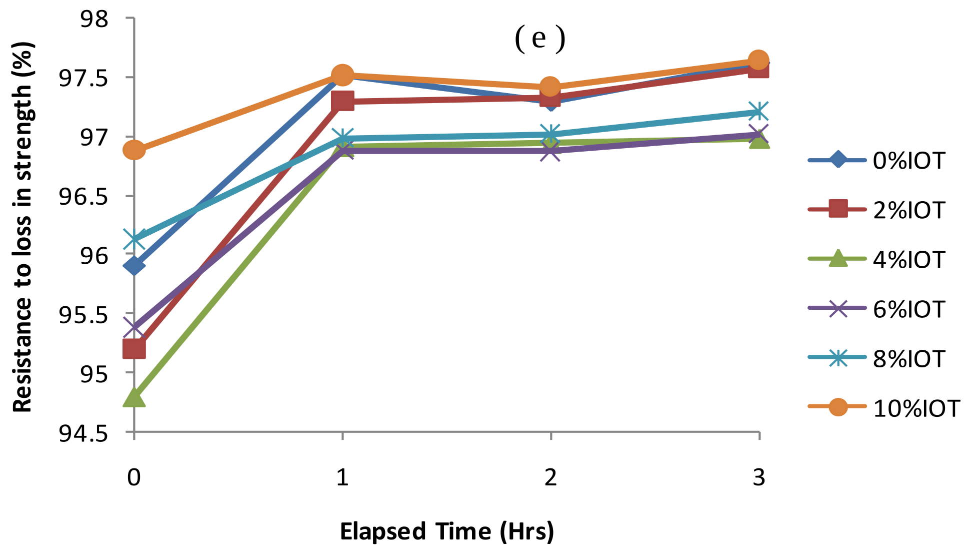
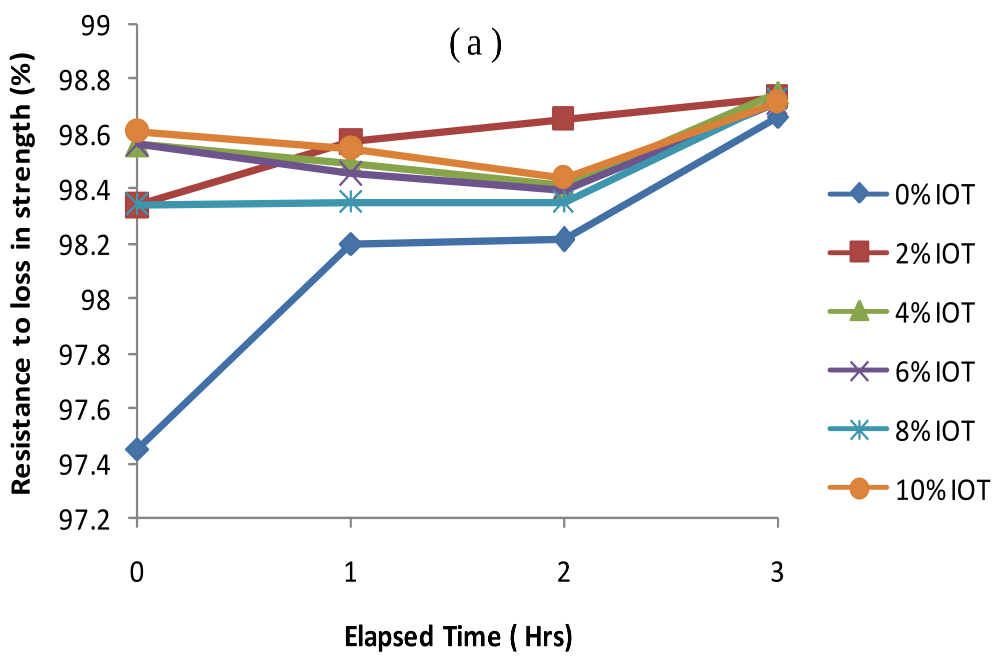
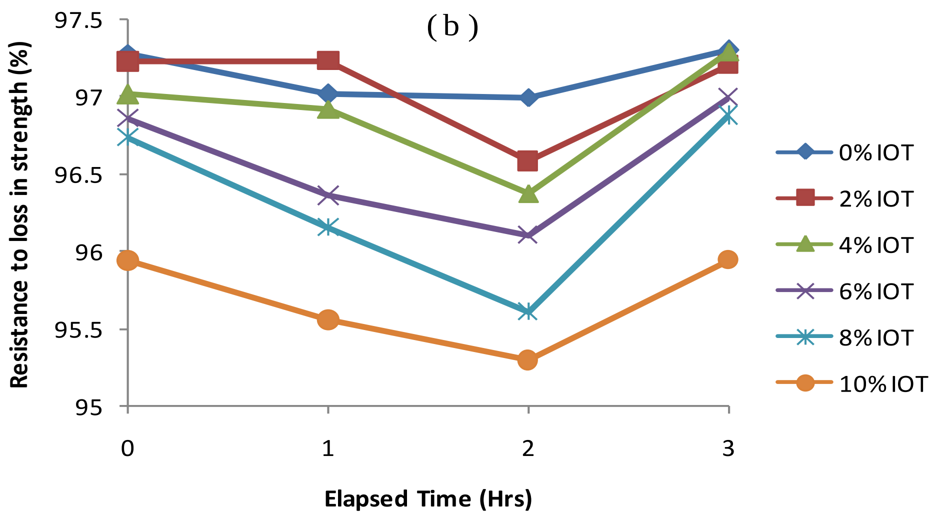
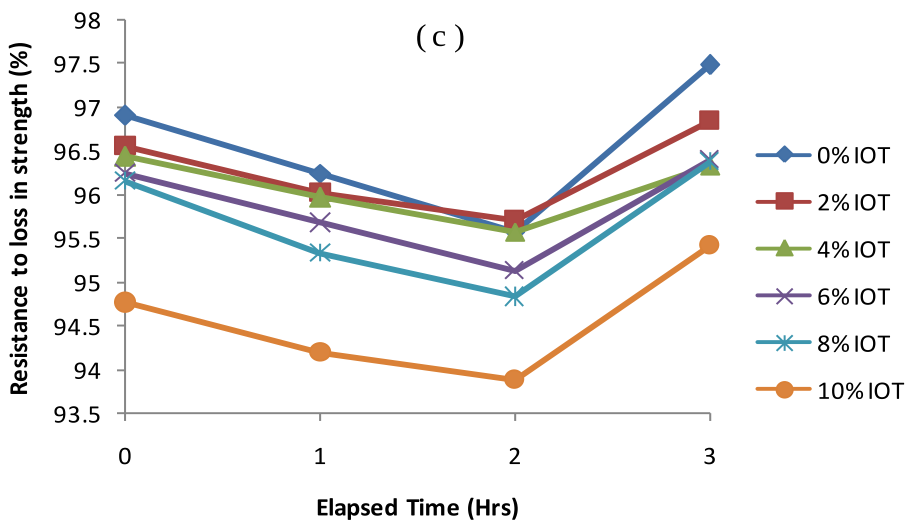
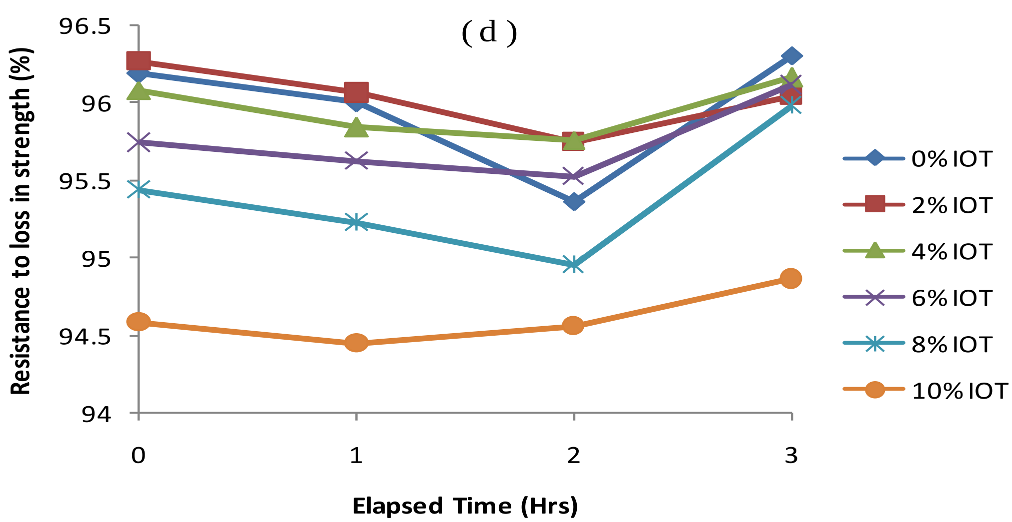


Fig. 4.61: Variation of resistance to loss in strength of black cotton soil – iron ore tailings with elapsed time after mixing for varying lime content at (a) 0 % (b) 2 % (c) 4% (d) 6% and 8% (WAS compaction).




(b)
Resistance to loss in strength (%)
Elapsed Time (Hrs)
97.5
97
96.5
96
95.5
95
0
1
2
3
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(c)
Resistance to loss in strength (%)
Elapsed Time (Hrs)
98
97.5
97
96.5
96
95.5
95
94.5
94
93.5
0
1
2
3
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT


(d)
Resistance to loss in strength (%)
Elapsed Time (Hrs)
96.5
96
95.5
95
94.5
94
0
1
2
3
0% IOT
2% IOT
4% IOT
6% IOT
8% IOT
10% IOT

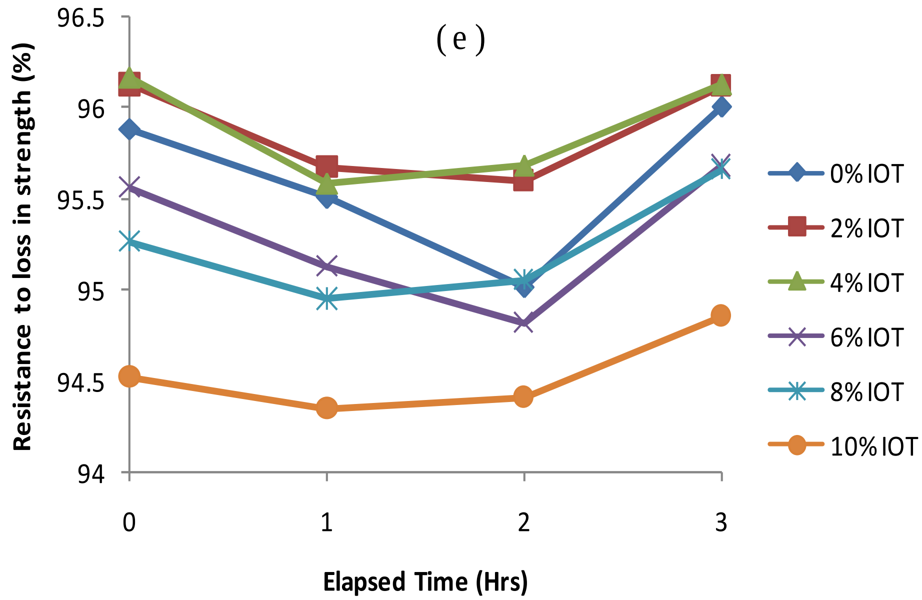


Fig. 4.62:Variation of resistance to loss in strength of black cotton soil – iron ore tailings with elapsed time after mixing for varying lime content at (a) 0 % (b) 2 % (c) 4% (d) 6% and 8% (BSH compaction).

The two - way analysis of variance (ANOVA) test on the durability assessment results for BSL compaction (see Table 4.8)showed that lime and IOT were not statistically significant at 0 hour, 1 hour, and 2 hours. For WAS and BSH compaction; it showed that the effects of lime, IOT and elapsed time on black cotton soil were statistically significant.Detailed test results are given in Tables H 1 – 24 in Appendix H.

Table 4.8: Two–way analysis of variance (ANOVA) resultsfor resistance to loss in strength of black cotton soil – lime – iron ore tailings mixtures (BSL compaction).

Property	Time	S. O.V	D.F	F_{CAL}	p-Value	F_{CRIT}	Remark
DUR:BSL	0	Lime	4	9.7449	0.000153	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	2.7341	.04860	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	1	Lime	4	2.7919	0.05426	2.8661	$F_{CAL}<F_{CRIT}$,NotSignificant Effect
		IOT	5	6.6189	0.000871	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Lime	4	2.2803	0.09647	2.8661	$F_{CAL}<F_{CRIT}$,NotSignificant Effect
		IOT	5	10.4365	4.9E-05	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	3	Lime	4	14.3185	1.13E-05	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	4.6970	0.005342	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect

4.8 Microanalysis of Specimens

4.8.1 Scanning electron microscopy

Clayey soils consist of colloidal particles which has made it difficult to observe the mode of deposition of their particles and determine the pore structure by means of any direct visual technique. Scanning Electron Microscopy (SEM) uses micro structural studies in analysing the different soils particles arrangements, distribution, assemblies, pores, and connectivity (Collins and McGowan, 1974; Delage and Lefebvre, 1984; Delage *et al.*, 1996; Al-Rawas and McGown, 1999; Mitchell and Soga, 2005; Osinubi et al., 2015).

4.8.1.1 Micrograph of specimens for 7 days curing period

Scanning electron microscope (SEM) equipment was employed to investigate the morphology of the stabilized soil. Plate 4.1 and 4.2shows the SEM micrographs of the natural and optimally treated black cotton soil-lime mixtures with iron ore tailings after 7 days curing time.

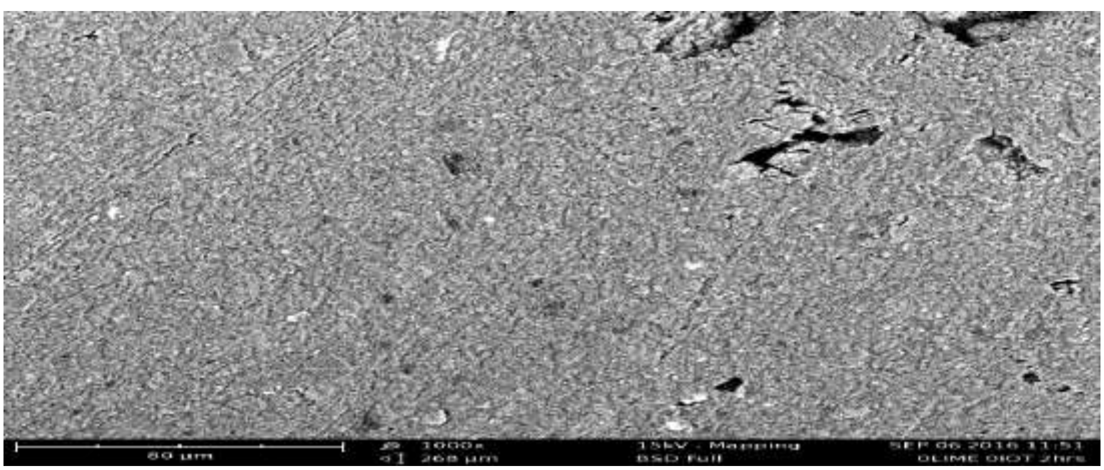


Plate 4.1: Micrograph of natural black cotton soil after 7 days curing period at 1000x magnification and 80µm scale.

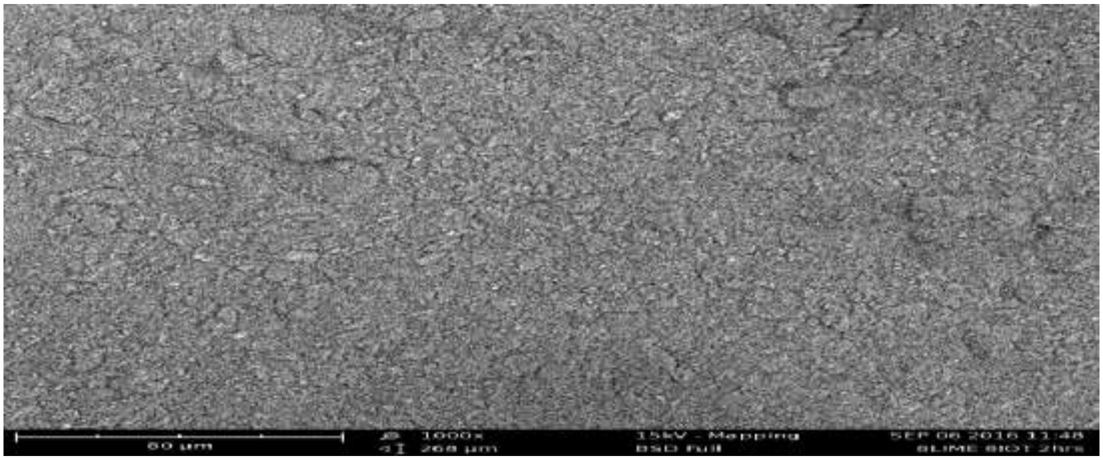


Plate 4.2: Micrograph of black cotton soil optimally stabilized with 8 % lime - 8 % iron ore tailings blend after 7 days curing at 1000x magnification and 80μm scale.

From the image of the optimally treated black cotton soil, after 7 days of curing period, samples were aggregated. Moreover, new compounds were formed. The aggregation of the soil particle may be due to cation exchange, flocculation-agglomeration, pozzolanic reaction, and carbonation that took place during the curing period. The micrograph shows the development of cementitious products of calcium silicates hydrates, calcium aluminate hydrates and calcium aluminosilicate hydrates covering the soil grains and filling the inter-aggregate pores. These compounds were responsible for the strength gain. Similar results were reported by Lambe and Martin (1954), Mallela *et al*. (2004) and Deneele *et al*. (2010; Sharma and Sahoo, 2012; Osinubi *et al*., 2015).

4.8.1.2 Micrograph of specimens cured for 28 days

The micrographs of specimen of the natural and stabilized black cotton soil cured for 28 days are shown in Plate 4.3 and 4.4. The image for the untreated soil show changes in the micro-structural particle orientations which appeared to be different from those of specimens cured for 7 days. This could be attributed to the insignificant inter-surface activity/reaction within the untreated sample during curing. However, the orientation changes indicate that flocculation of clay probably occurred through simple electrostatic attraction between positively charged particles edges and negative particle surface.

The micrograph of stabilized black cotton soil after 28 days curing period shows a more aggregated structure. This shows that the clay particles and the flocs, were grown within the pore. The stabilization reaction in the soil -lime - iron ore tailing mixture might have taken place with complete flocculation and agglomeration, cation exchange and gain in strength that contributed to the inter-particle bonding of the mixture. Also, the curing period enhanced the formation of cementitious compounds that precipitated in the soil matrix because of the high pH of the medium caused by lime and iron ore tailing (see Plate 4.5 -4.8).This finding is consistent with those reported by Okonkwo (2009); Negi *et al.* (2013); Osinubi *et al*. (2015); Murmu*et al*. (2020).

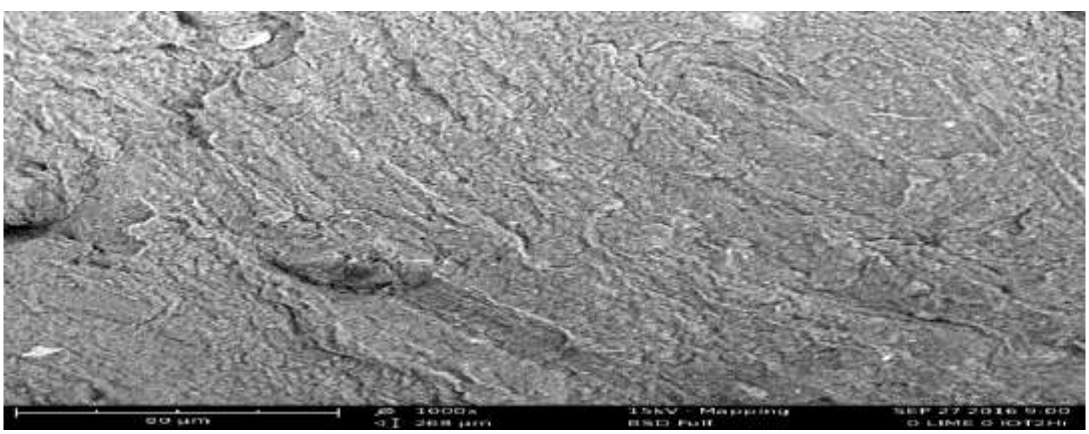


Plate 4.3: Micrograph of natural black cotton soil after 28 days curing at 80µm scale and 1000x magnification

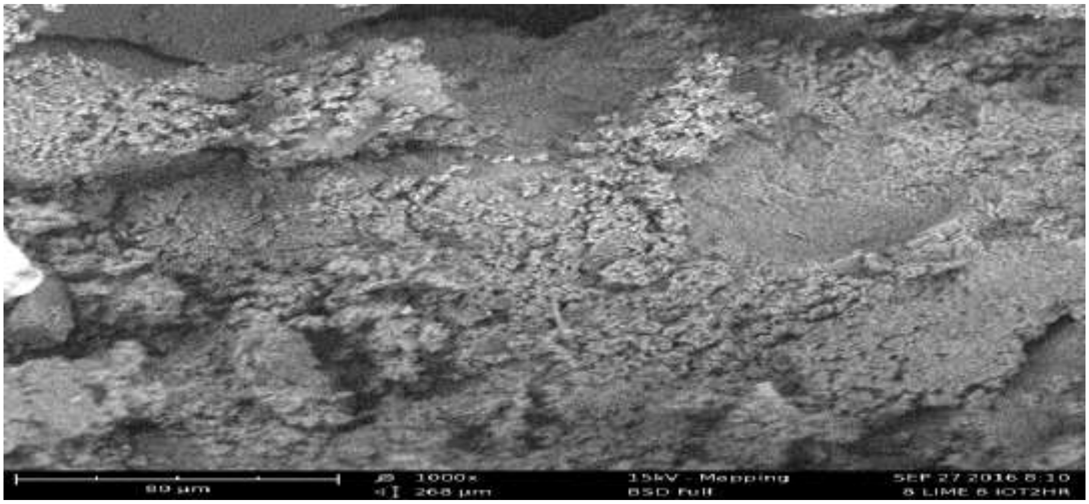


Plate 4.4: Micrograph of stabilized black cotton soil optimally blend at 8 % lime 8% iron ore tailing after 28 days curing at 80µm scale and 1000x magnification.

4.8.2 Fibremetric analysis

The fibremetric application is a statistical package incorporated in SEM that generates all the statistical data needed for analysis. It automatically analyses hundreds of data points that provide solid statistical analysis. This data is displayed in various formats like an interactive fibre and pore size distribution histogram. The fibre metric application can be used on fibres ranging from 40 µm to 100 nm. It can be used for a wide range of applications, like investigation of filtration materials, diaper paddings, fibre research, and fibre and filter production control. This technique could be used to make qualitative and quantitative inferences about unsaturated behaviour of soils such as water retention and water permeability properties, evolution of pore size density functions along different hydro-mechanical paths, macroscopic volume change behaviour, micro and macro scale interactions, and so on (Romero and Simms, 2008; Osinubi *et al*. 2015).

The desktop screen shot obtained from fibre and pore image measurement (fibremetric analysis) of the natural and optimally treated black cotton soil is shown in Plates 4.5 – 4.8. The red patches/spots indicate data points from which the fibremetric analysis was achieved.

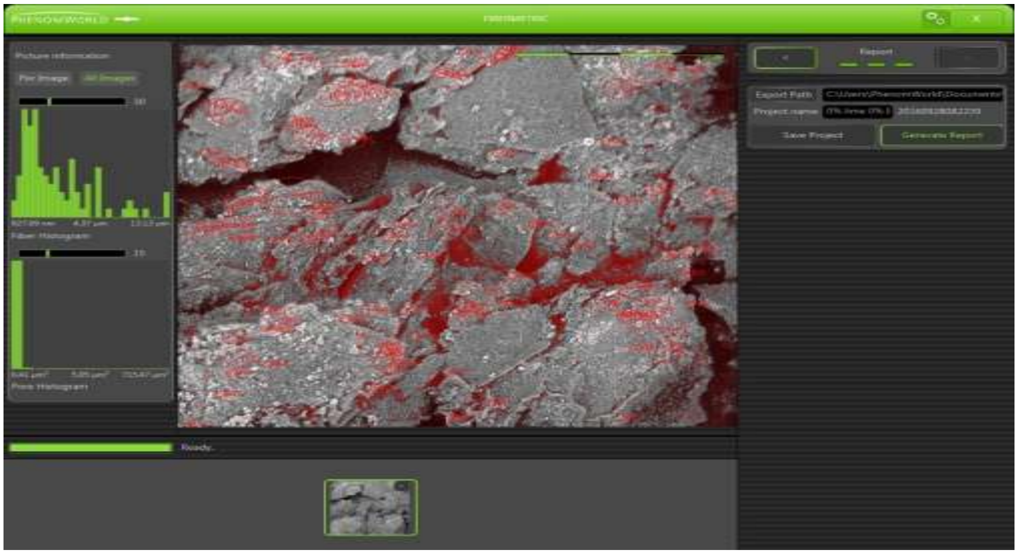


Plate 4.5: Fiber and pore image measurements of natural black cotton soil cured for 7 days

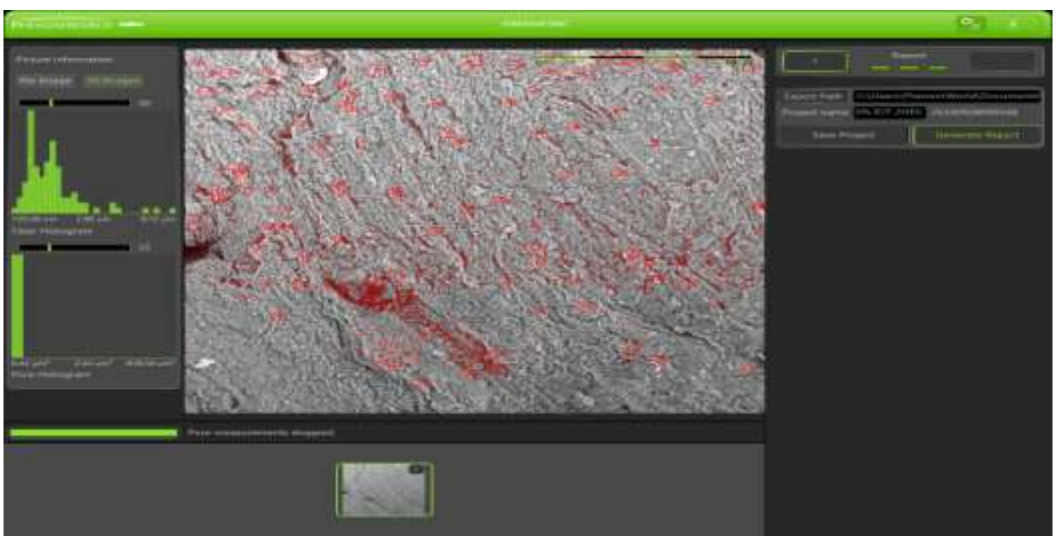


Plate 4.6: Fiber and pore image measurements of optimally stabilized black cotton soil treated with 8 % lime 8 % iron ore tailings blend after 7 days curing period

Plate 4.7: Fiber and pore image measurements of natural black cotton soil cured for 28 days

Plate 4.8: Fiber and pore image measurements of black cotton soil optimally stabilized with 8 % lime / 8 % iron ore tailings blend after 28 days curing period

4.8.2.1 Fiber histogram of specimens cured for 7 days

The histograms of fabrics of the untreated natural BCS soil and the stabilized black cotton soil optimally treated with 8 % lime / 8 % IOT blend and cured for 7 days was determined using SEM are shown on Plates 4.9-4.10. It was observed that the length of soil fiber/sizes decreased from 13.13 μm for the natural soil to 720.36 nm for the stabilized soil. The decrease in length of soil fiber could be due to the flocculent nature of IOT and also as a result of cation ion exchange reaction that resulted in the formation of calcium silicate.

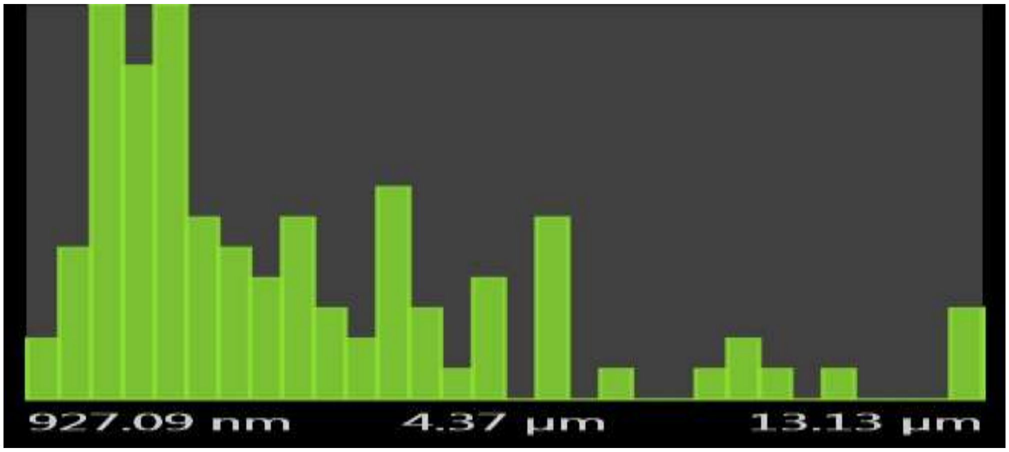


Plate 4.9: Fibre histogram of natural black cotton soil after 7 days curing period

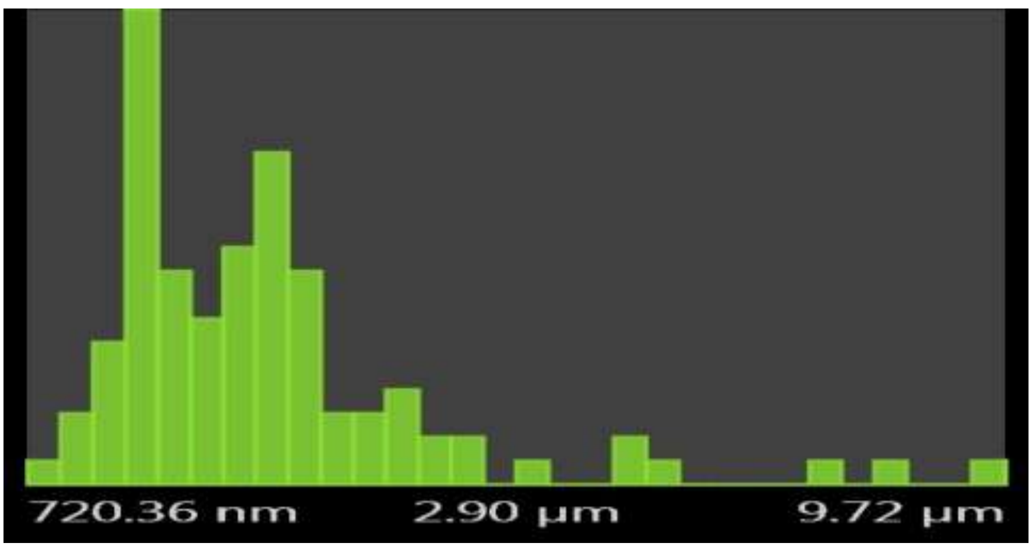


Plate 4.10: Fibre histogram of black cotton soil optimally stabilized with 8 % lime / 8 % iron ore tailing blend after 7 days curing period

4.8.2.2 Fiber histogram of specimens cured for 28 days

Fiber analysis for specimens cured for 28 days is similar to those of specimens cured for 7 days (see Plate 4.11-4.12).

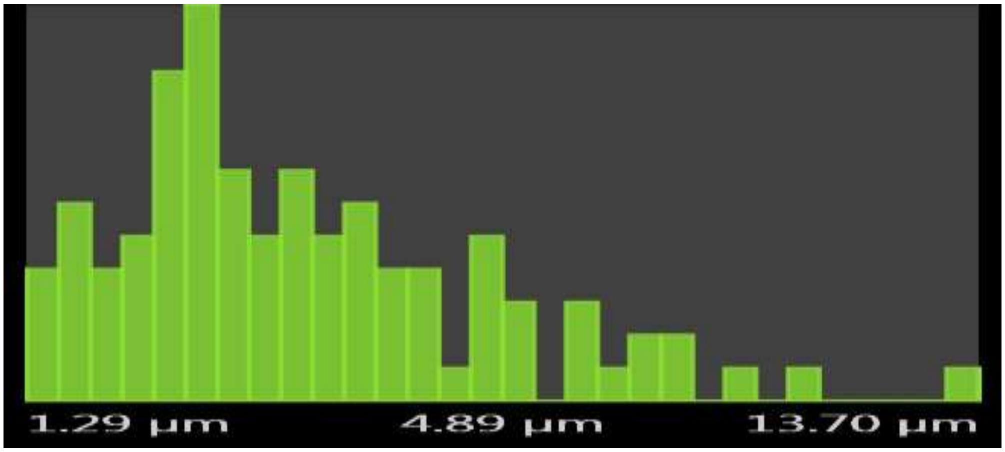


Plate 4.11: Fiber histogram of natural black cotton soil after 28 days curing period

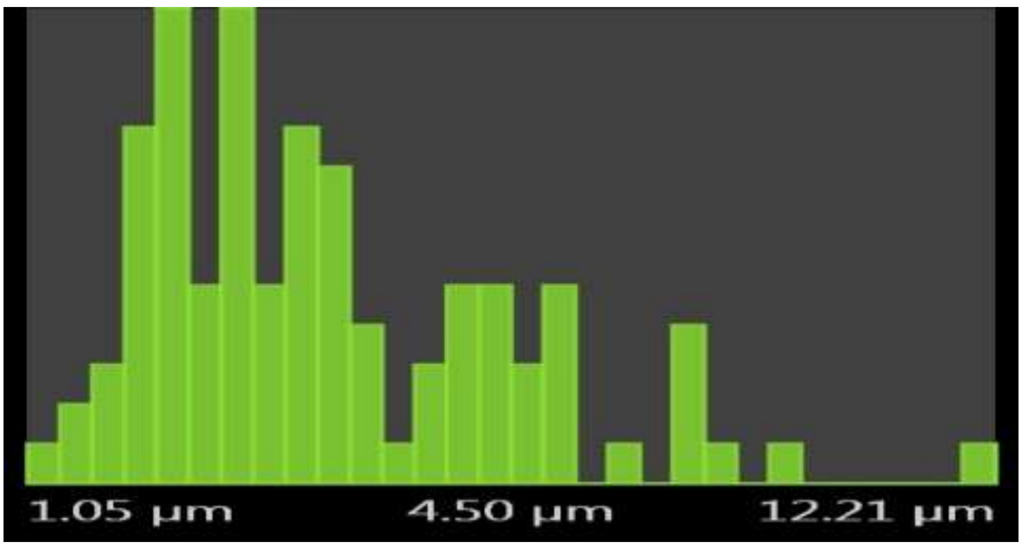


Plate 4.12: Fibre histogram of black cotton soil optimally stabilized with 8 % lime / 8 % iron ore tailing after 28 days curing period

4.8.2.3 Pore histogram of specimens cured for 7 days

The variation of surface area of pores of the natural black cotton soil and black cotton soil optimally stabilized with 8 % lime / 8 % iron ore tailing after 7 days curing period is shown in Plate 4.13a-b. It was observed that the surface area of pores within soil-lime-IOT mixtures considered decreased from the value of 715.47 μm^2 for the natural soil to a value of 838.54 μm^2 for the optimally stabilized soil. The decrease in pores spaces was due to the formed calcium silicates hydrates that covered the soil grains and filling the inter-aggregate porosity similar to the findings reported by Deneele *et al*. (2010). From the micro-structural point of view, the lime-IOT treatment reduced the proportion of the bigger pores, while the cementation products stabilized the surface state of the soil grains. In addition, this techniques gives further information on the relationship between the dominant pore sizes observed directly with SEM and the pore size distribution (PSD) measured as shown on the histogram. The decrease in pores was due to the re-arrangement and distribution of particles, particle assemblies and pores and their contacts and connectivity in different soils. Similar behaviour was observed by Collins and McGowan (1974), Delage and Lefebvre (1984); Delage *et al*. (1996), Al-Rawas and McGown (1999), Mitchell and Soga (2005), Osinubi *et al*, (2015) and Murmu *et al*. (2020).

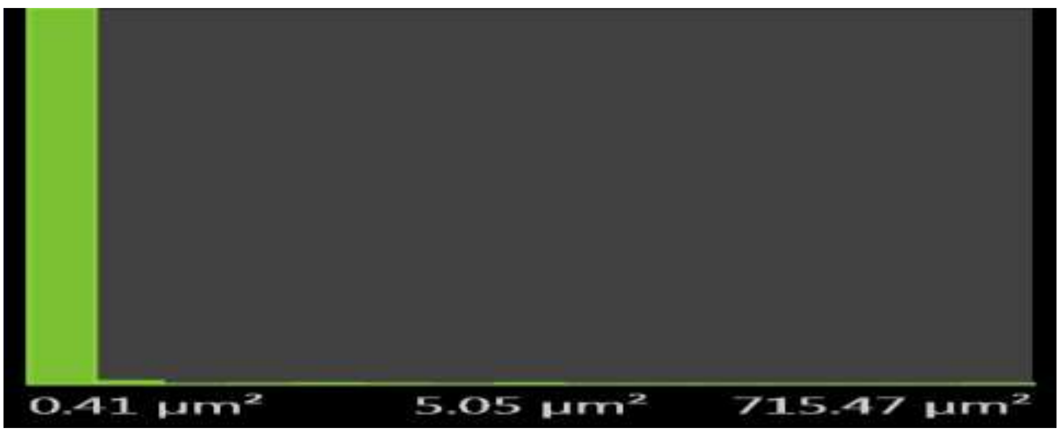


Plate 4.13a: Pore histogram of natural black cotton soil after 7 days curing period

Plate 4.13b: Pore histogram of black cotton soil optimally stabilized with 8 % lime / 8 % iron ore tailings after 7 days curing period

4.8.2.4 Pore histogram of specimens cured for 28 days

Pore analysis of specimens after 28 days curing period also follows similar trend like that of seven days curing period (See Plate 4.14a-b). However, there was no significant difference between the pore sizes of the untreated and optimally treated black cotton soil which could be as a result of complete dryness caused by hydration and pozzolanic reaction.

Plate 4.14a: Pore histogram of natural black cotton soil after 28 days curing period

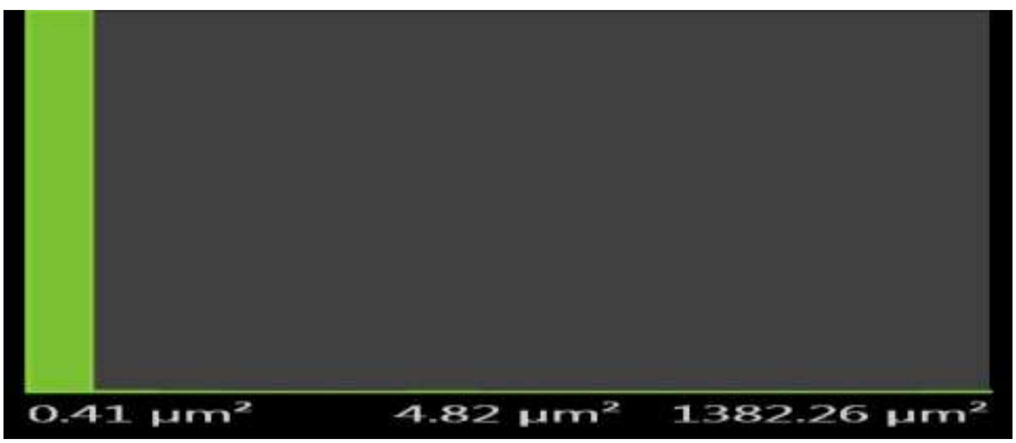


Plate 4.14b: Pore histogram of black cotton soil optimally stabilized with 8 % lime / 8 % iron ore tailing after 28 days curing period

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The study considered the consequence of elapsed time after mixing on the properties of black cotton soil stabilized with lime in the range 0, 2, 4, 6 and 8 % and IOT in the range 0, 2, 4, 6, 8, and 10 %, respectively, by dry weight of soil. Preliminary investigation on the physical properties of the soil revealed a soft soil with a natural moisture content of 11.9%. The Unified Soil Classification System (USCS) put the soil in the CH group and A-7-6(19) soil group according to the AASHTO soil classification system. The soil is greyish black in colour. From the tests carried out the following conclusions can be made:

1. The Atterberg limits of the treated soil improved. The liquid limit of the natural black cotton soil decreased from 61.3 % to a minimum value of 39.9 % when treated with 8 % lime/ 10 % IOT blend at 3 hrs elapsed time after mixing. The plastic limit decreased from 32.6 % for the natural soil to a minimum value of 19.1 % at 2 hours and 16.4 % at 0 hour elapsed time after mixing at 8 % lime/10 % IOT treatment. The plasticity index (PI) decreased from 27.8 % for the natural soil to 16.3 % at 8% lime /0%IOT treatment but increased with higher IOT content. The PI value decreased with higher elapsed time after mixing.

2. The compaction characteristics, (MDD and OMC) decreased with higher elapsed time after mixing. MDD increased from 1.47, 1.55 and 1.63 Mg/m^3 for the natural soil to the peak values of 1.60, 1.68 and 1.79 Mg/m^{3}at 2 % lime / 8 % IOT, 4 % lime / 8 % IOT

and 6 % lime 10%IOT treatment for BSI, WAS and BSH compaction, respectively. On the other hand, (OMC) values decreased from 25.6, 20.3 and 19.0% for the natural soil to 15.2, 15.8 and 16.8 % at 4 and 8 % lime/ 10 % IOT treatment for BSL, WAS and BSH compaction, respectively.With respect to elapsed time after mixing, MDD increased up to 2 hours but thereafter decreased at 3 hours after mixing. For BSL and WAS compaction, peak MDD values were recorded at 2 hours elapsed time after mixing for all lime considered at 8%IOT content, while for BSH compaction, the MDD increased up to1 hour and thereafter decreased up to 3 hours after mixing.

3. Based on the Nigerian General Specification requirement of maximum 12 % value for plasticity index (PI) and 35 % value for liquid limit (LL) for sub-base materials; the plasticity index (PI) and liquid limit (LL) of the treated black cotton soil – lime – IOT mixtures generally for 2 hours elapsed time after mixing met the specification.

4. The Unconfined Compressive Strength (UCS) values for specimens compacted with BSL, WAS and BSH energy and cured for 7, 14 and 28 days recorded peak values of 2,223.83, 2,564.81 and 2,696.51 kN/m^2 ; 2,627.61, 2,990.19 and 3,628.88 kN/m^2 ; as well as 3,021.93, 3,661.18 and 3,888.93 kN/m^2 , respectively. All the three energy levels considered recorded increase in the UCS values from 0 hour to peak at 2 hours, and dropped to 3 hours at 8% IOT content. The UCS (7 days) met the 1034.25kN/m^2 for adequate lime stabilization.

5. The results of stress-strain relationship for WAS compaction recorded peak value of 694.09kN/m^2 at 2 % lime / 8 % IOT and at 2 hours elapsed time after mixing. The Young Modulus (E) increased from 0 hour to 2 hours and dropped at 3 hours for the black cotton soil – lime – iron ore tailings mixtures considered.

6. Peak CBR (Un-soaked condition) values for specimens optimally treated with 8 % lime / 8 % IOT for BSL, WAS and BSH compaction are 150, 170 and 230 %, respectively. On the other hand, specimens soaked for 24 hours recorded peak values of 65, 90 and 180 % respectively. With reference to the effect of elapsed time after mixing, peak CBR values for both un-soaked and soaked conditions were recorded at 2 hours elapsed time after mixing. The BSL compaction value of 150 % for the un-soaked condition met the minimum conventional CBR values for lime treated soils of 40, 80 and 100% for sub grade, sub base and base. Also both the CBR value for soaked and un-soaked WAS compaction met the minimum CBR value of 60-80% for bases and 20-30% for sub base.

7. The resistance to loss in strength of the soil recorded peak values of 95.44, 94.94 and 93.87 % for specimen compacted using BSL, WAS and BSH energy respectively when treated with 8 % Lime / 8 % IOT blend. With the elapsed time, the resistance to loss in strength generally increased from 0 hour to 2 hours after which it dropped at 3 hours for all the three compaction efforts considered.

8. The two – way analysis of variance (ANOVA) on the tests results showed that lime and IOT had significant effects on black cotton soil optimally treated with 8 % lime / 8 % IOT. The ANOVA carried out showed that elapsed time after mixing and IOT were significant with 2 hours being the maximum allowable elapse time.

9. The micrograph of stabilized soil cured for 7 days and 28 days curing periodusing microanalysis showeda more aggregated structure which may be due to cation exchange, flocculation and agglomeration resulting in strength gain. Fibre histogram of fabrics of 8 % lime/ 8 % IOT optimally treated soil showed a decrease in

length of soil fibre. It was observed that the surface area of pores within soil – lime –IOT mixture considered decreased from the value of 715.42 μ for the natural soil to a value of 838.5 μ for the optimally stabilized soil cured for 7 days and no significant difference for 28 days cured specimen..

5.2 Recommendation:

Based on tests results obtained, it is recommended that:

1. Black cotton soil be treated with 8 % lime / 8 % IOT blend compacted with WAS and BSH energy not more than 2 hours after mixing can be used for the construction of low – volume roads.

5.3 Contributions to Knowledge

The study established:

1. Black cotton soil treated with 8% lime/8% iron ore tailing, when compacted with at least WAS energy can be used as base course of low-volume roads.
2. A maximum elapsed time after mixing of not more than 2 hours can be adopted during construction work.
3. The study has proffered a waste management solution to IOT waste by reusing as soil stabilizer, thereby preventing/reducing environmental pollution.

REFERENCES

AASHTO (1986). Standard specification for transport materials and method sampling and testing 14th Edition.American Association of State Highway and Transport Officials (AASHTO). Washington DC.

Abdullahi, M. M., (2011) “The effect of elapsed ime after mixing on the properties of cement- locust bean waste ash modified lateritic soil” an unpublished Msc Thesis submitted to the Department of Civil Engineering Ahmadu Bello University Zaria.

Adedayo, S.M. and Onitiri, M.A., (2012). “Tensile properties of Iron ore tailings filled epoxy composites” *The West Indian Journal of Engineering, Vol.35, No. 1, pp. 51-59*

Adepoju, S. O. and Olaleye, B. M. (2001).‘Gravity concentration of silica sand from Itakpe iron-ore tailings by tabling operation’. *Nigerian Journal of Engineering Management. Vol. 2, No. 2, 51-55.*

Adewuyi, A. and Moatsha, S. (2019). “Laboratory investigation of black cotton soils sampled from Gaborone – Boatle road site in Botswana” *Journal of Multidisciplinary Engineering Science Studies (JMESS) Vol. 5,* issue 12.

Afrin, H(2017). A Review on Different Types Soil Stabilization Techniques. *International Journal of Transportation Engineering and Technology*. Vol. 3, No. 2, , pp. 19-2

Ajaka E.O. (2004). “Recovering fine iron minerals from Itakpe iron ore process tailing”. *ARPN Journal of Engineering and Applied Sciences*, 4, (9), 17 – 27.

Ajaka, E. O.(2009). “Recovering fine iron minerals from Itakpe iron ore process tailing”. *ARPN Journal of Engineering and Applied Sciences.Akure, Nigeria*, v. 4, n.9, p. 17- 28.

Akawwi, E. and Al-Kharabsheh, A. (2002). “Lime stabilization Effects on Geotechnical properties of Expansive soils in Amman, Jordan”. *Electronic Journal of Geotechnical Engineering.*www.ejge.com/2000 ppr0020.

Alhassan, M. (2006). ‘Effect of Bagasse Ash on Modified Laterite.UnpublishedM.Sc Thesis Civil Engineering Department, Ahmadu Bello University, Zaria.

Alhassan, M., and Mustapha, A.M. (2007).‘Effect of Rice Husk Ash on Cement Stabilized Laterites’. *Leonardo Electronic Journal of Practice and Technology, 6(11): 47-58.*

Alhassan M. (2008a).‘Potentials of Rice Husk Ash for Soil Stabilization’. *Assumption University Journal of Technology, 11(4): 246-250.*

Alhassan, M. (2008b). ‘Permeability of Lateritic Soil Treated With Lime and Rice Husk Ash’. *Assumption University Journal of Technology, 12(2): 115-120.*

Ali, M S and Koranne S S (2011). “Performance Analysis of Expansive Soil Treated with Granite dust and Fly ash”, *EJGE, Vol. 16, Bund. I, pp. 973-982*.

Al-Rawas, A. A and McGowan, A. (1999) “Microstructure of Omani Expansive Soils”. *Canadian Geotechnical Journal vol. 36, pp 272 – 290*.

Al-Rawas, A.A., Taha, R., Nelson, J.D., Beit Al-Shab, T. and Al-Siyabi, H. (2002). A Comparative Evaluation of Various Additives Used in the Stabilization of ExpansiveSoils, *Geotechnical Testing Journal*, GTJODJ, ASTM; 25 (2):199-209.

Al- Refeai,T. O. and AL – Karni, A. A.(1999). Experimental study on the utilization of Cement kiln dust for ground modification. *King Saud Univ. Sci. 11 (2)*, 217 – 232.

Al-Swaidani, A., Hammoud, I., and Meziab, A. (2016). “Effect of adding natural pozzolana on geotechnical properties oflime-stabilized clayey soil.” *Journal of Rock Mechanicsand Geotechnical Engineering*, **8**, 714-725.

Amadi, A.A, (2010). Evaluation of changes in index properties of lateritic soil stabilized withFly ash. *Leonard Electro J. Pract. Technol. (LEJPT)* 9 (17), 69 – 78.

Amadi, A.A (2014). Enhancing durability of quarry fines modified black cotton soil subgradewith cement kiln dust stabilization. *Transp. Geotech 1:* 55–61.

Amadi, A. A. and Osu,A. S. (2016) "Effect of curing time on strength development in black cotton soil - Quarry fines composite stabilized with cement kiln dust (CKD)," *Journalof King Saud University - Engineering Sciences,*.

Amadi, A.A. and Okeiyi, A. (2017). “Use of quick and hydrated lime in stabilization of lateritic soil: Comparative analysis of laboratory data.” *International Journal of GeoEngineering*, TGS, **8**(3), 1-13. http://dx.doi.org/10.1186/s40703-017-0041-3

Amruta, A. Badge., Lobhesh, N. Muley. And Kunal, R.Raul. (2015). “Quality Assessment for Stabilization of Black cotton Soil by Using Lime” *International Journal of Innovations in Engineering and Technology (IJIET)* Vol. 5 Issue 2.

ASTM (1992).Annual Book of standards vol. 04.08, American Society of Testing and Materials, Philadelphia.

ASTM C618-12a. (2013) Specification for Fly Ash and Raw or Calcined Natural Pozzolanas for Use as a Mineral Admixture in Portland cements Concrete. Philadelphia: American Society for Testing and Materials;.

Ayininuola, G. M. and Balogun, L. O. (2018). "Investigation of glass fiber potential in soil stabilization," *Int. J. Eng. Adv . Technol., vol. 7,* no. 5, pp. 113 – 117.

Balogun, L. A. (1991). "Effect of sand and salt additives on some geotechnical properties of lime stabilized black cotton soil." *The Nigeria Engineer, Vol.* 26 No., pp. 15 – 24.

Bell, F.G (1988a). Stabilization and treatment of clay soils with lime part I -Basic principles, Ground Engineering, Vol. 21, No.1, pp. 10 -15.

Bell, F.G (1988b). Stabilization and treatment of clay soils with lime part 2 –Some Applications, Ground Engineering, Vol. 21, No. 2, pp. 25 -29.

Bell, F.G.(1996). Lime Stabilization of Clay Minerals and Soils, *Engineering Geology;* 42: 223-237.

Bessaim, M.M.; Bessuim, A.; Missoum, H and Bendani, K (2018). Effect of quick lime on physicochemical properties of clay soil. MATEC Web. Of Conferences 149

Broms B (1984). Lime – clay mineral reaction product, Ontario Ministry of Transportation and research report RR 243.

BS 1924 (1990). "Methods of tests for stabilized soils." British Standard Institute, London, Great Britain.

BS 1377 (1990) Methods of Testing Soils for Civil Engineering Purposes. British Standard Institution, London.

Buhnski, J. and Sergiel, L. (2014). Effect of moisture content on soil density-compaction relationship during soil compaction in the soil bin. *Annals of Warsaw University, Life Sciences – SGGW Agriculture no. 64.*

Butches, F. and Sailie, E. L. (1984). "Swelling behaviuor of tropical black clays." *Proceeding of the 8th Regional Conference for Africa on soil mechanics and Foundation Engineering, Harare. 81 – 86.*

Carrasco, E. V. M,,Manlilla, J. N. R., Espósito, T and Moreira, L. E. (2013) "Compression performance of walls of interlocking bricks made of iron ore by-products and cement". *International Journal of Civil and Environmental Engineering, 13, (3), 56 -62.*

Clare, K. E and Cruchley, A. E. (1957).Laboratory Experiments on the Stabilization of Clays with Hydrated Lime. Geotechnique, 7: 97 – 100.

Cokca E (2001). “Use of class C fly ashes for the stabilization- of an expansive soil”, *Journal of Geotechnical and Geo-environmental Engineering, ASCE Vol. 127,* No.7, pp. 568-573.

Collins, K and McGowan, A. (1974). The Form and Function of Microfabric Features in a Variety of natural soils. *Ge' oechnique vol. 24* (2) pp 223 – 254

Crowder, J.J., Grabinsky, M.W.F. and Landriault, D.A., (2000).Consolidation testing and S.E.Mimages of tailings pastesfor surface disposal. *Proc., 53 Can. Geotech. Conf., Can. Geotech.Society, Montreal, Canada,* pp. 625-632.

Dalal S.P., Patel R. and Dalal P. D. (2017). Effect on engineering properties of black cotton soil treated with agricultural and industrial waste. *Materials Today Proceeding, 4,(9) pp*. 9640 – 9644.

Delage, P. and Lefebvire, G. (1984). Study of the Structure of a sensitive Champlain clay and of its Evolution during consolidation. *Canadian Geotechnical Journal vol.* 21, pp 21 – 35

Delage, P., Audiguier, M., Cui, Y.J., Howat, M.D., (1996). Microstructure of a compacted silt.*Canadian Geotechnical Journal 33 (1)*, 150–158.

DeneeleD.,Cuisinier O. and Hallaire V.(2010).Micostructural evolution and physico-chemical behavior of compacted clayey soil submitted to an alkaline plume. *Journal of Rock Mechanics Geotechnical Engineering, 2, 169–177.*

Demers, B., and Haile, G., (2003), Management of tailings stabilized by lime and cement at Canadian electrolytic zinc,Valleyfield, Quebec, *Proc. Sudbury 2003 Mining and theEnvironment, May 25-28, Sudbury, Ontario.*

Diamond, S.andKinter, E.B (1965). “Mechanisms of Lime Stabilization”, Highway Research Record, 92, p.83.

Dinesh, A.,Gokilavani, S.and Ramya, G. (2017). Stabilization of soil by using solid waste – A Review , *International Journal of Engineering Development and Research (IJEDR) Vol. 5, Issue 3.*

Eades, J.L., and Grim, R.E. (1960).“The reaction of hydrated lime with pure clay minerals in Soil Stabilization” U.S. Highway Research Board Buletin, Vol 262, pp 51 – 63.

Eades, J. L.,andGrim R. E.(1966). A quick test to determine lime requirements of lime stabilization. *Highway Research Record*, 139: 61–72.

Eberemu, A. O., Abdullahi, M.M and Osinubi, K. J. (2015). Influence of Delay after mixing on Compaction Characteristics of cement – locust – Bean waste ash modified lateritic soil. *Journal of Applied Science, Engineering and Technology. Vol. 15, Issue 1: 1 - 7*

Elinwa A. U and Maichibi J. E. (2014) “Evaluation of the Iron Ore Tailings from Itakpe in Nigeria as Concrete Material”. *Advances in Materials.* Vol. 3, No. 4, pp. 27-32. doi: 10.11648/j.am.20140304.12

Etim, R. K., Eberemu, A. O. and Osinubi, K. J.(2014).Effect of lime - iron ore tailing blend on the expansive behavior of black cotton soil. *Proceedings 2014 Nigerian Engineering Conference*, Theme: Engineering and Technology for Economic Transformation, Ahmadu Bello University Zaria. 15th - 18th Sept. 2014, Zaria, Kaduna State. CD ROM of Presentation. Section 6, Pg. 864 – 872.

Etim, R. K. (2015).Stabilization of black cotton soil with lime- iron ore tailings blend.Unpublished M.Sc. Thesis Civil Engineering Department, Ahmadu Bello University, Zaria.

Etim, R. K., Eberemu, A. O. and Osinubi, K. J. (2017). "Stabilization of black cotton soil with Lime and iron ore tailings admixture," *Transportation GeotechnicsElsevier*, vol. 10, pp.85-95.

Feng, Tao-Wei.(2002). Effect of Small Cement Content on Consolidation Behavior of a LacustrineClay.*ASTM Geotechnical Testing Journal*, GTJODJ, 25 (1): 53-60.

Firoozi, A. A.; Olgun, C. G.; Firoozi, A. A. and Baghiin, S. M. (2017). Fundamentals of Soil Stabilization” *International Journal of Geo – Engineering 8, 26*. https// doi.org/10.1186/540703 – 017 – 0064-9.

Garand, P., Vezina, S., and Bocking, K. (2000). Effects of flocculent on deposition of tailings sludge for upstream raise of impoundment dykes, *Proc., 53 Can. Geotech. Conf., Can. Geotech. Society, Montreal, Canada*, pp. 633-640.

Ghose, M.K. (1997). “Environmental Management for the Disposal of Spoils and Tailings from Mines”. Environment and Ecology, 15(1): 206 - 210.

Ghose, M.K. and Sen, P.K. (1999). “Recovery of Usable Ore Fines from Iron - Ore Tailings and their Environmental management – A case study”. Land Contamination and Reclamation, 7 (2)

Gidigasu, M.D. and Dogbey, J.L.K. (1980). “Geotechnical characterization of laterized Decomposed rocks for pavement construction in dry sub-humid environment”. *6th South East Asian Conferenceon Soil Engineering, Taipei*, 1: 493-506.

Hadi, A.A., Lawal S.,Mahmoud, H. A. and Zawami, D (2017). Novel admixture for Improvement of foundation on tropical expansive soils. *International Journal of Integrated Engineering, vol. 9 No.* 1 p. 44-49.

Haile, G., O'Callaghan, W.B., Hartney, T.F., and Cameron, W., (2000). Experience with thickened red mud tailings (paste) stacking tropical and temperate climates and applicability of the technology to other tailings, *Proc., 53 Can. Geotech.Conf., Can. Geotech.Society, Montreal, Canada.*

Harish G. R., (2017)." Studies on stabilization of black cotton soil using lime", *International Research Journal of Engineering and Technology (IRJET). Vol. 04 Issue*. 06 pp. 0072.

Hitt, G.H. and Davidson, D.T. (1960)."Lime fixation in clayey soils". Highway Research Board, Bulletin 262, pp. 20 – 32.

Ikeagwuani, C. C. (2016) "Compressibility characteristics of black cotton soil with saw dust and lime". *Nigerian Journal of Technology, 35 (4*) pp.718 – 725.

Ikeagwuani, C. C. and Nwonu, D. C. (2019) "Emerging trends In expansive soil stabilization: Areview" *Journal of Rock Mechanics and Geotechnical Engineering. Vol. II. Issue 2, pg. 423-440.*

Ingles, O.G. and Metcalf, J. B. (1972)."Soil Stabilization Principles and Practice", Butterworths, Sydney, Australia.

Ishola, K. (2014). "Modification of Lateritic Soil with Iron Ore Tailing". Unpublished M.Sc. Thesis, Civil Engineering Department, Ahmadu Bello University, Zaria.

Jayashree, J. and Roja, S. Y. (2019). "Stabilization of Expansive Soil using Rice Husk Ash and Lime" *International Journal of Recent Technology and Engineering (IJRTE) Vol. 8, issue 3*

Jiang X., Huang Z., Ma F., Luo X. (2019). Analysis of Strength Development and Soil–Water Characteristics of Rice Husk Ash–Lime Stabilized Soft Soil. Materials.;12

Jones, D.E. and Holtz, W.G. (1973). "Expansive Soils - the hidden disaster". CivilEngineering – ASCE. Vol. 43, No. 8, pp.49-51.

Kamon M and Katsumi T (1994)."Potential Utilization of Waste Rock Powder".*Proc of the First International Congress on Environmental Geotechnics",biTech, Vancouver, British Columbia,* pp. 287-292.

Kanalli, S. A., Naagesh,S and Ganesh, K.(2015)."A Review of Utilization of mine waste on black cotton soil". *International Journal of Research in Engineering and Technology*, vol. 04. Issue 07.

Katti, R.K., and Kulakarni, K.R and Radhakrishna, N. (1966). "Research on Black Cotton Soils with and without Inorganic Activities", *The Indian Road Congress, Road Research Bulletin,No. 10, New Delhi, pp. 1-97*

Katti, R.K., and Kulakarni, K.R.(1996). "Research on Black Cotton Soils with and without Inorganic Activities", *The Indian Road Congress, Road, Research Bulletin,No. 10, New Delhi, pp. 1-81.*

Kedzi, A. (1979)."Stabilized Earth Roads". Elsevier, Amsterdam, pp. 327.

Kiran, R. G. and Kiran, L. (2013) "Analysis of Strength Characteristics of Black Cotton Soil Using Bagasse Ash and Additives as Stabilizer" *International Journal of Engineering Research & Technology, Vol.2Issue 7,* pp 2240 – 2246.

Kiran, K. S., Gopinatha, N., and Vipul, V. (2014). "Effect of red mud and iron ore tailings on the strength of self-compacting concrete". *European Scientific Journal, 10, (21),* 168 – 176.

Kumar, S., and Prasanna, M. (2012). "Silica and Calcium Effect on Geo-technical Properties of Expansive Soil Extracted from Rice Husk Ash" IPCBEE", Vol. 32.

Kumar, S. (2012). "A Study on Some Geotechnical Properties of Stabilized Expansive Soil –Quarry Dust Mixes", No. 2, Vol. 1.1.

Kumar, B.N.S., Suhas, R.R., Shet, S.U and Srishaila, J. M. (2014). "Utilization of iron ore tailings as replacement to fine aggregates in cement concrete pavements". *International Journal of Research in Engineering and Technology, 3, (7), 369 – 376*

Kuppusamy, J. and Krishnamurthy, M.(2020). Effect of polymeric resins on geotechnical properties of black cotton soil.*International Journal of Recent Technology and Engineering (IJRTE)* Vol. 8, issue 5

Lambe T. W and Martin R. T. (1954) Composition and engineering properties of soil (II)Proc. Highw. Res.Bd, vol. 33, 515- 532.

Lawton, E.C. 1996. Soil Improvement and Stabilization: Section 5A: Nongrouting Techniques. *Part 5 of the Practical Foundation Engineering Handbook*. Edited by Robert Wade Brown:Editor in Chief. McGraw Hill, 5.3-5.276.

Locat, Y., Bembe, M. A. and Choquette, M. (1990). Laboratory investigation on the lime stabilization of sensitive clays; shear strength development. *Canadian Geotechnical Journal, Vol. 27, pp. 294 - 304.*

Locat J, Tremblay H, and Leroueil S (1996) Mechanical and hydraulic behaviour of a soft inorganic clay treated with lime. *Can Geotech J 33:654–669*

Mallela, J., Quintus, P.E., and Smith, K.L.(2004). Consideration of lime-stabilized layers in mechanistic-empirical pavement design. Retrieved from http://www.training.ce (accessed on 24.01.2006

Maneli A., Kupolati W. K., Abiola O. S. and Ndambuki J. M. (2015): Influence of fly ash, ground-granulated blast furnace slag and lime on unconfined compressive strength of black cotton soil, Road Materials and Pavement Design.

Matawal, D. S. and Tomarin, O. I. (1996). "Response of some tropical laterite to cement stabilization." *College of Engineering Conference Series, Kaduna Polytechnic, Vol. 3 pp* 90-95.

Medjo, E and Riskowiski, G. (2004). "A procedure for processing mixtures of soil, cement, and sugar cane bagasse".Agricultural Engineering International. *The Journal of Scientific* Res*earch and Development*. Manuscript BC 990. Vo. III. 1-5.TC

Meshida, E.A., Oyekanmi, G. L. and Ogundalu, A. O. (2013). Effect of steel mill dust on the strength characteristics of Black cotton clay soils. *International Journal of Scientificand Engineering Research.* Vol.4. No. 5 p.2242 - 2246.

Mitchell, J. K. and Hooper, D. R. (1961). Influence of time between mixing and compaction on properties of lime stabilized expansive clay. Highway Res. Board Bull. 14 – 31.

Mitchell, J.K. and Soga, K. (2005) *Fundamentals of Soil Behavior*, 3rd Edition, John Wiley andSons, May 2005, 592pp.

Mittal, H., and Morgenstern, N.R. (1975). Parameters for the design of tailings dams, *Can. Geotech. J., 12: 235-261*.

Mohammedbhai, G.T.G. and Baguant, B.K. (1990). "Possibility of using bagassae ash and other furnace residue as partial substitute for cement in Maurice". Vol. 64, .No. 3 Sept-Dec.

Mohammed H., Kundiri, A. M. and Suleiman A. Y. (2017). "Effect of Compaction effort on Strength Characteristics of Black cotton soil Admixed with Eggshell Powder – Gum Arabic" *International Research Journal of Engineering and Technology (IRJET) Vol. 4 Issue. 07.*

Morin, W.J. (1971). "Properties of African Tropical Black Clay Soils."*5th Reg. Conf. for African on Soil Mech.And Foundation Engrg. Luanda, Vol. 1, pp. 51*-59.

Mosa, A. M; Banyhussan, Q. S; and Yousif, R.A. (2017) "Improvementof expansive soil properties used in earthworks of highways and railroads using cement kilndust" *Journal of Advanced Civil Engineering Practice and Research, 4:13-24.*

Moses, G., Saminu, A., and Oriola, F.O.P. (2012). "Influence of compactive effort on Compactedfoundry sand treated with cement kiln dust." *Civil and Environmental Research,***2**(5), 11-24.

Moses, G., Etim, R.K., Sani, J.E., and Nwude, M.(2018) "Desiccation effect of compacted tropical black clay treated withconcrete waste." *Leonardo Electronic Journal of Practices and Technologies, Engineering, Environment,* **33**, 69-88.

Moses, G. (2006). *Stabilization of Black Cotton Soil with Cement and BaggasseAsh.*Unpublished M.Sc. Thesis Civil Engineering Department Ahmadu Bello University Zaria

Moses, G. (2008). Stabilization of black cotton soil with Ordinary Portland Cement Using Bagasse ash as admixture. *IRJI Journal of Research in Engrg . Vol. 5 No. 3, pp. 107 – 115*

Moses, G., Saminu, A., and Oriola, F. O.P (2012). "Influence of Compactive Efforts on compacted Foundry Sand Treated with Cement Kiln Dust". *Civil and Environmental Research vol. 2, No.5, pp 11 – 24.*

Moses, G and Osinubi, K. J (2013). "Influence of Compactive Efforts on Cement-Bagasse Ash Treatment of Expansive Black Cotton Soil" *World Academy of Science, Engineering and Technology. Vol: 7 2013-07-28*

Murmu, A. L, Dhole, N and Patel, A. (2020). Stabilization of black cotton soil for sub-grade application using fly ash geopolymer. *Road Materials and Pavement Design. Vol. 21 issue 3 pp 867 -885.*

Mustapha, A. M. (2006). Effect of Bagasse Ash on cement Stabilized Laterite. Unpublished M. SC. Thesis Ahmadu Bello University, Zaria, Nigeria.

Nadgouda, K. A. and Hegde, R. A (2010)."The effect of lime stabilization on properties of black cotton soil," in *Indian Geotechnical Conference, Mumbai C*hapter & IIT Bombay.

National Lime Association, (2001).200N Glebe Road, Suite 800 Arlington, Virginia 222033728.: Fact Sheet on Using lime for soil Stabilization and Modification.

Negi, S.S., Gupta, M. K., Sharma, S. D. (2013). Sequestered organic carbon pool in the forestSoils of Uttarakh and State, India. *Inter. J. Sci. Environ. Tech., 2(3): 510 – 520.*

Nelson, J.D. and Miller, D.J. (1992). Expansive soils, problems and practice in foundation and pavement engineering. Wiley,New York.

Nigerian General Specification, (1997). Roads and Bridges. Federal Ministry of Works, Abuja.Nigeria.

Nwadiogbu, C. P., (2012). "The Effect of Elapsed Time on Lateritic soil Modified with lime and Locust Bean Ash" an unpublished Msc Thesis submitted to the Department of Civil Engineering Ahmadu Bello University Zaria.

Obeahon, S. O. (1992). "Effect of elapsed time after mixing on the properties of modified Laterite. M.Sc. thesis submitted to the Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

Ochepo, J. (2008). "Effect of elapsed time on the Geotechnical Properties of lime – bagasse ash stabilized black cotton soil. Unpublished M.Sc.Thesis.Civil Engineering Department, Ahmadu Bello University, Zaria, Nigeria.

Ochepo, J., Osinubi, K. J and Sadeeq, J. A (2013). Statistical evaluation of the effect of elapsed time on the strength properties of lime-bagasse ash treated black cotton soil. *International Journal of Engineering Research and Technology. IJERT. Vol.02, issue 01*

Office of Geotechnical Engineering, (2008). Design Procedures for soil modification or stabilization, Production Division, 120 South Short Ridge Road Indianapolis, Indiana 46219

O'Flaherty, C.A. (1988). Highway Engineering vol. 2, Edward Arnold, London

O'Flaherty, C.A. (2002). Highway: The Location, Design, Construction and Maintenance of Pavement. 4th Ed., Butterworth Heinemann. pp. 175 – 182

Okonkwo, U. N., (2009). "Effect of Compaction Delay on the Properties of Cement-Bond Lateritic Soils", *Nigerian Journal of Technology, Vol. 28, No 2*.

Ola, S. A. (1974). "Need for estimated cement requirement for stabilizing lateritic soil, *Journal of Transportation Division, ASCE, 17 (8): 379 -388*.

Ola, S. A. (1978). "The geology and geotechnical properties of the black cotton soils of north eastern Nigeria", Engineering Geology. Vol. 12, pp. 375-391.

Ola, S. A. (1983). "The geotechnical properties of black cotton soils of North Eastern Nigeria." In: S. A. Ola (Editor). *Tropical Soils of Nigeria in Engineering Practice*, A. A. Balkema, the Netherlands, Rotterdam, pp155 – 171. soil." *The Nigeria Engineer, Vol. 26 No., pp. 15 – 24*.

Olubambi, P. A. and Potgieter, J. H., (2005). "Effectiveness of gravity concentration for the beneficiation of Itakpe (Nigeria) iron ore achieved through jigging operation", *Journal of Mineral and Materials Characterisation and Engineering*, Vol.4, No.1, pp. 21-30.

Oluyemi-Ayibiowu, B.D. and Ola, S. A. (2015). Stabilization of black cotton soil from North-Eastern Nigeria with sodium silicate. *International Journal Of Scientific Research and Innovative Technology. Vol. 2*, No. 6

Onyelowe, K. C. (2012). “Cement Stabilized Akwuete Lateritic Soil and the Use of Bagasse Ash as Admixture” *International Journal of Science and Engineering Investigations, vol. 1, issue 2, pp16 -2*0.

Onyelowe, K.C. and Duc, B.V. (2018a).“Durability of nanostructured biomasses ash (NBA) stabilized expansivesoils for pavement foundation.” *International Journal of Geotechnical Engineering*, 1-10.
http://dx.doi.org/10.1080/19386362.2017.1422909

Onyelowe, K.C. and Duc, B.V. (2018b). “Predicting subgrade stiffness of nano structured Palm bunch ash stabilizedlateritic soil for Transport geotechnics purposes.” *Journal of GeoEngineering*,TGS, **13**(1), 167-175.
http://dx.doi.org/10.6310/jog.2018.13(1).3

Oriola, F. and Moses, G. (2010), “Groundnut Shell Ash Stabilization of Black Cotton Soil*”, Electronic Journal of Geotechnical Engineering.*15:415-428, Bund, E.

Osinubi, K. J. (1995). “Lime modification of black cotton soils.” *Spectrum Journal, 2 (1, 2), 112 -122.*

Osinubi, K. J. (1998a). “Influence of compactive efforts and compaction delays on lime-treated soil.” *Journal of Transportation Engineering. ASCE, Vol. 124, No. 2, pp. 149 – 155.*

Osinubi, K. J. (1998b). “Permeability of lime – treated lateritic soil.”*Journal of Transportation Engineering. ASCE, Vol. 124, No. 5, pp. 465 – 469.*

Osinubi, K.J.(1998c). “Laboratory investigation of Engineering use of phosphatic waste” *Journal of Engineering Research, University of Lagos, vol. JER – 6, No.2; pp 47 – 60*

Osinubi, K. J. 1999. “Evaluation of Admixture Stabilization of Nigerian Black Cotton Soil.”*Nigerian Society of Engineers Technical Transactions 34(3): 88–96.*

Osinubi, K.J. (2000a). Laboratory trial of soil stabilization using pulverized coal bottom ash. *NSE Technical Transactions*, Vol. 35, No. 4, pp. 1–13.

Osinubi, K.J. (2000b). “Laboratory trial of soil stabilization of Nigerian black cotton soils.” *Nigerian Society of Engineers Technical Transaction,vol. 35, No. 4. Pp 13 – 21*

Osinubi, K.J. (2006). Influence of compactive efforts on lime – slag treated tropical black clay. *Journal of Materials in Civil Engineering*. ASCE, Vol.18*, No. 2. pp 175–181.*

Osinubi, K. J. and Alhassan, M (2008). "Use of Lime and Baggasse ash in modification of Laterite." *Nigeria Journal of Engineering* Vol. 14, No 1, pp 70-80.

Osinubi K. J. and Eberemu, A. O. (2005). "The use of blast furnace slag treated laterite in attenuation of ground contaminants." *Proc. Of The Nigeria Material Congress 2005 (NIMACON). Nov. 17th – 19th 2005*. Zaria, Nigeria. pp. 28-35.

Osinubi, K. J. and Eberemu, A. O. (2009a).''Desiccation induced Shrinkage of Compacted Lateritic Soil treated with bagasse ash." *The Twenty-Fourth International Conference on Solid Waste Technology and Management* CD-ROM, 15-18 March, Philidelphia, PA, U.S.A. Session 5C: Bioreactors and Innovative Landfills, pp.856-867.

Osinubi, K.J. and Katte V. Y.(1997). "Effect of elapse time after mixing on grain size plasticity Characteristics of Soil- Cement mixes.*NSE Technical Transaction, 34(3), 38-46.*

Osinubi K.J. and Medubi A.B. (1997a)."Evaluation of cement and phosphatic waste admixture on tropical black clay road foundation.*"Proceedings of the 4th Conference in Structural Engineering Analysis and Modelling (SEAM), Vol. 2.* pp. 297 – 307.

Osinubi K.J. and Medubi A.B. (1997b)."Effect of lime and phosphatic waste admixture on tropical black clay.*"Proceedings of the 4th Conference on Geotechnical Engineering GEOTROPIKA'97 Johor Bahru 11- 12 Nov., Malaysia, pp. 257 – 272.*

Osinubi, K.J. and Stephen, T.A. (2006).'Effect of bagasse ash content on particle size distribution and plasticity characteristics of black cotton soil.' *Proceedings of the 5th Nigerian Materials Congress "NIMACON 2006"* , Abuja, Nigeria, 15-18 November, pp. 214 - 220.

Osinubi K.J. and Toro, A. (1997)."Evaluation of admixture stabilization of black cotton soils." *Proceedings of the 4th Conference on Geotechnical Engineering GEOTROPIKA'97 Johor Bahru 11- 12 November, Malaysia, pp. 273 – 289.*

Osinubi, K. J, Didden, R., Ijimdiaya, T. S., Eberemu, O.A. (2012). Effect of elapsed time after mixing on the strength properties of black cotton soil - cement - blast furnace slag mixtures. *Journal of Engineering Research (JER). JER 17 (*4) 63 – 75.

Osinubi, K. J., Eberemu, A.O. and Aliu, O.S. (2007a) "Stabilization of laterite with cementand bagasse ash admixture." *Proc. of the first Inter. Conf. on*

Environ.Res.,echn. And Policy "ERTEP 2007" under the auspices of International Society of Environmental Geotechnology, Accra, Ghana, 16 – 19 July, Category B: Mining and Environment, PP. 1.

Osinubi, K. J., Eberemu, A. O. and Simon, K. L. (2007b). "Influence of Bagasse ash contentcuring period on the permeability of lateritic soil compacted at reduced Proctor effort.", *Proc. of Bi-Monthly Meetings /Workshops organized by the Zaria Chapter of Materials Society of Nigeria,* pp.17 -25.

Osinubi,K. J.,Eberemu,A. Yohanna,O. P. and Etim,R. K.(2016). "Reliability Estimate of the Compaction Characteristics of Iron Ore Tailings Treated Tropical Black Clay as Road Pavement Sub-Base Material," in Geo-Chicago

Osinubi, K. J., Ijimdiya, T. S. and Nmadu, I. (2009). 'Lime stabilization of black cotton soil using bagasse ash as admixture.' *Advanced Materials Research,* Vols. 62 – 64, pp. 3 - 10.In: Advances in Materials Systems Technologies II Online http://www.scientific.net Trans Tech Publications, Switzerland.

Osinubi, K. J., Oyelakin, M. A.andEberemu, A. O. (2011). "Improvement of Black cotton soil with ordinary Portland cement – Locust Bean Waste ash blends" *Electronic Journal of Geotechnical Engineering. Vol. 16, pp. 619 – 627*

Osinubi, K. J., Soni, E. J. and Ijimdiya, T. S. (2010) "Lime and slag admixture improvement of tropical black clay road foundation" *Transportation Research Board (TRB) 89th Annual Meeting* CD-ROM, January 10 - 14 Washington, D. C., U.S.A. Subject: Recycled Materials in Transportation Infrastructure, Session AFP40 – Physico-chemical and Biological Processes in Soils Committee, Paper # .10-0585, pp. 1 -18.

Osinubi, K.J., Yohanna, P., and Eberemu, A.O. (2015). "Cement modification of tropical black clay using iron ore tailing as admixture."*Journal of Transportation Geotechnics,* **5**,35-49. http://dx.doi.org/10.1016/j.trgeo.2015.10.001

Ovuarume, U. B. (2011). "Effect of locust bean waste ash on lime modified black cotton soil. Unpublished M.Sc. Thesis Civil Engineering Department, Ahmadu Bello University, Zaria, Nigeria.

Oyekan, G. L., Meshida,E. A and Ogundalu, A. O. (2013).Effect of Ground Polyvinyl Waste on the Strength Characteristics of Black Cotton Clay Soil. *Journal of Engineering and Manufacturing Technology,* Volume 1, pp. 1–10.

Pardakhe, P and Ban, P. (2019). "Soil stabilization by using Waste Material – Brick Dust"*International Research Journal of Engineering and Technology (IRJET). Vol.06. Issue: 09 pg 56 – 72.*

Pastor, J. L.; Tomas R.; Cano, M.; Riquelmi, A. and Gutierrez, E. (2019). “Evaluation of the Improvement Effect of limestone Powder Waste in the Stabilization of Swelling Clayey Soil” *Mdpi.com/Sustainability. 11, 679*.

Patil A, Lakhadive, K; Surawashe, A; Kale, R and Pawar, S (2019). Soil stabilization using shredded rubber and design of flexible pavement. *International Research Journal of Engineering and Technology (IRJET). Vol 06 issue 04 pg : 56* - 72.

Pebble Project (2005). “Tailings and Tailings Managements”, Northern Dynasty Mines Inc, pp 1-4.

Pedarla, A., Chittoori, S. and Puppala, A.(2011). Influence of mineralogy and plasticity index On stabilization effectiveness of expansive clays. *J. Transp. Res. Board* 2212, 91–99.

Pei X, Zhang F, Wu W, and Liang S (2015) Physicochemical and index properties of loess stabilized with lime and fly ash piles. *Appl Clay Sci 114:77–84*

Phani Kumar S. R. and Sharma R. S. (2004).“Effect of fly ash on engineering properties of expansive soils.” *J. Geotech. Geoenviron. Eng., 130(7), 764–767*

Plait, R.M. (1953).“Determination of swelling pressures of black cotton soil – A method.”*Proc. of the Third International Conference on Soil Mech. and Foundation.Engrg. Vol*.1 pp 170-172.

Portelinha, F.H., Lima, D.C., Fontes, M.P., and Carvalho, C.A., (2012), "Modification of aLateritic Soil with Lime and Cement: An Economical Alternative for Flexible Pavement Layers", *Soils and Rocks, São Paulo, Vol.35, No.1, p*p.51-63.

Prahallada, M. C and Shanthappa, B. C. (2014).“Use of copper tailings – as an excellent pozzolana in the preparation of concrete”. *International Journal of Advanced Research in Engineering and Applied Sciences,* 3, (3), 1 – 10.

Pravin, P and Mahiyar H. K. (2014).“A Experimental study of black cotton soil stabilized with Rice Husk Ash, Fly ash and Lime”. *International Journal of Engineering Research and Technology (IJERT), Issn: 2278 -0181 vol.3. Issue 11*.

Qian, G.; Huang, T. and Bai, S. (2011).“Use of cement-stabilized granite mill tailings as pavement subbase”, *Journal of Materials in Civil Engineering, pp. 1575- 1578.*

Qiu, Y., and Sego, D.C., (2001), Laboratory properties of mine tailings, *Can. Geotech. J., 38:183-190*

Ramesh, H.N, Krishnaiah, A.J,and Shilpa S.S., (2013). “Effect of lime on the index Properties of Black cotton soil and mine tailing mixtures”, *IQSR Journal of Engineering (IQSRJEN)*. Vol. 3, issue 4, pp 01- 07.

Ravi, E., Udhayasakthi. R. and Vadivel, T. S. (2016). "Enhancing the clay soil characteristics using copper slag stabilization". *Journal of Advances in Chemistry.* Vol. 12, Issue No. 26.

Ravi, K. C. M., Anil, K., Prashanth, M. H., and Venkat, D. R., (2012). "Experimental studies on iron-ore tailing based interlocking paver blocks". *International Journal of Earth Sciences and Engineering,* 5, (3), 501 – 504.

Rezende, L. R. and Carvalho, J. C. (2003). "The use of quarry waste in pavement construction. Resources", Conservation &recycling, Vol. 39, pp. 91-105.

Romero, E. and Simms, P. H., (2008). Investigation in Unsaturated soils: A Review with special attention to contribution of Mercury Intrusion Porosity and Environmental Scanning Electron Microscopy. *Journal of Geotechnical and Geological Engineering*. vol. 8, pp 1 – 23.

Sabat,V.Shaikh,M. Kanap,M. Chaudhari,M. Suryawanshi, S. and Knadgouda,K. (2015) "Use of iron ore tailings as a construction material", *Int. J. of Conceptions on Mechanical and Civil Engineering,* 3(2)

Salahudeen, A.B., Eberemu, A.O., and Osinubi, K.J. (2014). "Assessment of cement kiln dust-treated expansive soil forthe construction of flexible pavements." *Journal of Geotechnical and Geological Engineering*, **32**(4), 923-931. https://doi.org/10.1007/s10706-018-00760-6

Samadou, J. (2015). "Stabilization of Black Cotton Soil with Iron-ore Tailing". Unpublished M.Sc Thesis submitted to the Department of Civil Engineering, Ahmadu Bello University, Zaria.

Sani, R. O., Eberemu, A. O. and Osinubi, K. J. (2014).The effect of elapsed time after mixing on the compaction characteristics of bagasse ash modified black cotton soil.*Proceedings 2014 Nigerian Engineering Conference, Ahmadu Bello University* Zaria.15th – 18th Sept. 2014, Zaria, Kaduna State. pp. 234 – 240.

Sani, J.E., Etim, R.K., and Joseph, A. (2018) "Compaction Behaviour of Lateritic Soil-CalciumChloride Mixtures." *Geotechnical and Geological Engineering,* Springer. https://doi.org/10.1007/s10706-018-00760-6

Sefene, S.S. (2020). Determination of effective wood ash proportion for black cotton soil improvement. *Geotechnical and Geological Engineering, Springer*.39,617 – 625.

Sen, P. K. and Ghose, M. K. (1997). Sitting of Tailings Pond for Safe Disposal of Tailings from Iron - Ore Beneficiation plants - A case Study. Mine Technology, 18: No.1 and 2, pp. 63- 67.

Shaia, H., Aodah, H. H. and Al- Hameidawi, H. B (2016). Improvement of Subgrade soil usingNatural jute Fiber sheet at various Layers. *Journal University of Kerbala, vol. 14, no.3*.

Shailendra, S. and Hemant, B. V.(2015). Stabilization of black cotton soil using lime. *International Journal of Science and Research* (IJSR), vol. 4, Issue. 5.

Sharma, N. and Sahoo,U.(2012). Stabilization of a clayed soil with fly ash and lime: a micro level investigation. *Journal of Geotechnic and Geological Engineering*.

Sherwood P. T. (1993). *Soil stabilization with cement and lime*, London:HMSO.

Shivam T, Anubhav R. and Bajpai Y. K. (2017). "Effect of Iron ore Tailings on the Flexural Strength of Concrete" *International Journal for Research in Applied Science and Engineering Technology (IJRASET). Vol. 5 Issue xii*.

Shivapullaiah, P.V., Prashanth,J.P., and Sridharan,A.,(1996), Effect of fly ash on the index properties of black cotton soil, Soils and Foundations, vol.36, pp.97-104.

Singh, G. (1991). Highway Engineering, 3rd edition, Standard publisher Distributors, pp 599 - 619.

Singh, G (2018). A Simple Introduction to ANOVA (with applications in Excel). Analytics Vidhya Data Scientist

Sivrikaya,O,,Koray, R. K., and Zeki,K. (2013). "Recycling waste from natural stone processing plants to stabilize clayey soil", Environmental *Earth Sciences, Springer Pub.,* October.

Soframine.(1987). Evaluation of the National Iron Ore Mining Project, Itakpe. National Steel Development Agency (NSDA) - Personal communication.

Sowers, G.F., Vesic, A. and Grandolfi, M.(1959). "Penetration tests for liquid limit", *Procedings of a Symposium on Atterberg Limits., ASTM No. STP 254, PP.216-224*

Sridharan, A and Jayadeva, M. S.(1982). "Double layer theory and compressibility of clays", *Geotechnique, Vol. 32, pp.133-144*.,

Sridharan,A. Rao, S.M., and Murthy, N.S. (1986) "Liquid limit of Montmorillonite Soils", *ASTM Geotechnical Testing Journal, Vol.9, No.3 pp.156-159.,*

Surendra R. and Sanjeev, K. B. (2017).Role of geotechnical properties of soil on civil engineering structures. *Resources and Environment. Vol. 7, No. 4 pp103 - 109*

Syed, M., GuhaRay, A., Avinash, G.S.S and Kar, A. (2020). Geopolmerization of expansive black cotton soils with Alkali-activated binders. Problematic Soils and Geoenvironmental concerns. Pp. 503-516.

Tamer Y. E.(2016)" Theeffect of curing conditions on the unconfined compression strength of Lime treated expansive soils" *Journal Road Materials and pavement Design. Vol 17, issue 1. P 52 – 69*

Thomson, M.R.,(1977). "Final Report Sub-gradeStability" -Civil Engineering Studies, TransportationEngineering Series No. 18, IllinoisCooperativeHighway AndTransportation Series No. 169, University of Illinois at Urbana – Champaign.

Toland, G. (1977). Case history of failure and reconstruction of Mike Horse tailings dam near Lincoln, Montana. *Proceedings of 15th American Engineering Geology and Soil Engineering Symposium, Idaho State University.*

Tomlinson, M.J. (1999). Foundation Design and Construction. 6th edition, Longman, Harlow,Essex.

Trindade, T.P.(2005). "Chemical Stabilization of Road Subgrade: Influence of Elapsed Time between Mixture and Compaction on Mechanical Strength of Soil –RBI Grade81 mixtures."*Rev Arvore , Vol 9, N.3,* pp.413. ISSN 0100-6762.http; //dx.doi.org/10.1590/s0100-67622005000300008.

Ugama,T.I.,Ejeh S.P. and Amartey,D.Y. (2014). Effect of iron ore tailings on the properties of concrete, *Civil and Environmental Research* vol 6. No. 10. www.iiste.org.

Umar, SY and Elinwa, AU. (2005). "Effects of IOT and limeon engineering properties of laterite. *Journal of Raw Materials Research, 25, (4), 7.*

Umar, S.Y., Elinwa, A.U., and Matawal, D.S. (2015). "Hydraulic conductivity of Compactedlateritic soil partially replaced with metakaolin." *Journal of Environment and Earth Science,* **5**(4), 53-64.

Vaibhav, R. D., and Shrikant M. H. (2017). "Effects of IOT and lime on engineering properties of laterite .*Journal of Raw Materials Research, 25, (4), 7.*

Wei, W. (2010). Analysis of soil microstructure parameters based on image mosaic technology. *Xiao-Yuan He Conference publication,*1:286-289.

Yin C., Zhang W., Jiang X., and Huang Z. (2018). Effects of initial water content onmicrostructure and mechanical properties of lean clay soil stabilized by compound calcium-based stabilizer. Materials.;11(10):1933. https://doi.org/10.3390/ma11101933

Yisa, G. L. (2014). Stabilization of Lateritic Soil with Iron-ore Tailing. Unpublished M.Sc Thesis submitted to the Department of Civil Engineering, Ahmadu Bello University, Zaria.

Yoder, E. J. and Witczak, M. W. (1975).Principles of Pavement Design.John Wiley and Sons. Inc, New York, pp 300–321.

Yohanna, P., Eberemu, A. O. and Osinubi, K. J. (2014).Effect of cement – iron ore tailing blend on the gradation and compaction characteristics of black cotton soil. *Proceedings 2014 Nigerian Engineering Conference, Theme: Engineering and Technology for Economic Transformation*. Ahmadu Bello University Zaria.15th – 18th Sept. 2014, Zaria, Kaduna State.CD ROM of Presentation.Section 3. Pg. 521 – 531.

Yorimichi, K and Kazuhiko, N (1999). “Experimental studies on cement stabilization of soft clay utilizing waste rock powder as a supplement material”, *Proc. Jpn. Soc. Civil Engg.,* PP. 1-12, in Japanese.

Zar, J. H. (1999) Biostatistical Analysis, 4th ed. Upper Saddle River, NJ. Prentice-Hall. In © Agilent Technologies, 2005 genespring_support@agilent.com Phone (866) 744-7638.

APPENDIX A: SPECIFIC GRAVITY

Table A1: Specific Gravity Raw Data

0% LIME						
Bottle No. 8	0% 0%	0% 2%	0% 4%	0% 6%	0% 8%	0% 10%
Wt. of bottle + water full (W4)	87.2	50.4	87.2	50.4	87.2	50.4
Wt. of bottle + soil + water (W3)	91.1	54.6	95.2	54.9	93.5	54.8
Wt. of bottle + soil (W2)	44.6	32.8	51.5	33.6	48.4	33.4
Wt. of bottle (W1)	37.6	25.7	37.6	25.7	37.6	25.7
Wt. of full water (W4 - W1)	49.6	24.7	49.6	24.7	49.6	24.7
Wt. of water added to soil (W3- W2)	46.5	21.8	43.7	21.3	45.1	21.4
Wt. of soil (W2 - W1)	7	7.1	13.9	7.9	10.8	7.7
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	3.1	2.9	5.9	3.4	4.5	3.3
Spec. gravity of soil particles(W2 - W1)/W	2.258065	2.448276	2.355932	2.323529	2.4	2.333333
Bottle No. 8						
Wt. of bottle + water full (W4)	93.5	45.5	93.5	45.5	93.5	45.5
Wt. of bottle + soil + water (W3)	96.4	49.7	99.8	50.7	100.1	49.8
Wt. of bottle + soil (W2)	49.1	28	54.8	29.7	55.4	28.2
Wt. of bottle (W1)	43.8	20.7	43.8	20.7	43.8	20.7
Wt. of full water (W4 - W1)	49.7	24.8	49.7	24.8	49.7	24.8
Wt. of water added to soil (W3- W2)	47.3	21.7	45	21	44.7	21.6
Wt. of soil (W2 - W1)	5.3	7.3	11	9	11.6	7.5
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	2.4	3.1	4.7	3.8	5	3.2
Spec. gravity of soil particles(W2 - W1)/W	2.208333	2.354839	2.340426	2.368421	2.32	2.34375
Bottle No. 8						
Wt. of bottle + water full (W4)	86.7	47.9	86.7	47.9	86.7	47.9
Wt. of bottle + soil + water (W3)	92	50.7	92.9	54.4	96.3	54
Wt. of bottle + soil (W2)	46.3	28.2	47.8	34.5	53.7	33.8
Wt. of bottle (W1)	37.2	23.1	37.3	23.1	37.2	23.1
Wt. of full water (W4 - W1)	49.5	24.8	49.4	24.8	49.5	24.8
Wt. of water added to soil (W3- W2)	45.7	22.5	45.1	19.9	42.6	20.2
Wt. of soil (W2 - W1)	9.1	5.1	10.5	11.4	16.5	10.7
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	3.8	2.3	4.3	4.9	6.9	4.6
Spec. gravity of soil particles(W2 - W1)/W	2.394737	2.217391	2.44186	2.326531	2.391304	2.326087
AVERAGE SPEC. Gravity	2.287045	2.340169	2.379406	2.339494	2.370435	2.33439

Table A2: Specific Gravity Raw Data 2%

2% lime						
Bottle No. 8	2% 0%	2% 2%	2% 4%	2% 6%	2% 8%	2% 10%
Wt. of bottle + water full (W4)	87.2	50.4	87.2	50.4	87.2	50.4
Wt. of bottle + soil + water (W3)	93.2	56.2	93.2	55.3	93.6	54.6
Wt. of bottle + soil (W2)	48	35.9	48.1	34.4	48.6	32.8
Wt. of bottle (W1)	37.6	25.7	37.6	25.7	37.6	25.7
Wt. of full water (W4 - W1)	49.6	24.7	49.6	24.7	49.6	24.7
Wt. of water added to soil (W3- W2)	45.2	20.3	45.1	20.9	45	21.8
Wt. of soil (W2 - W1)	10.4	10.2	10.5	8.7	11	7.1
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	4.4	4.4	4.5	3.8	4.6	2.9
Spec. gravity of soil particles(W2 - W1)/W	2.363636	2.318182	2.333333	2.289474	2.391304	2.448276
Bottle No. 8						
Wt. of bottle + water full (W4)	93.5	45.5	93.5	45.5	93.5	45.5
Wt. of bottle + soil + water (W3)	99	50.8	99.1	51.8	100.4	51.7
Wt. of bottle + soil (W2)	53.5	30	53.7	31.6	55.7	31.4
Wt. of bottle (W1)	43.8	20.7	43.8	20.7	43.8	20.7
Wt. of full water (W4 - W1)	49.7	24.8	49.7	24.8	49.7	24.8
Wt. of water added to soil (W3- W2)	45.5	20.8	45.4	20.2	44.7	20.3
Wt. of soil (W2 - W1)	9.7	9.3	9.9	10.9	11.9	10.7
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	4.2	4	4.3	4.6	5	4.5
Spec. gravity of soil particles(W2 - W1)/W	2.309524	2.325	2.302326	2.369565	2.38	2.377778
Bottle No. 8						
Wt. of bottle + water full (W4)	86.7	47.9	86.7	47.9	86.7	47.9
Wt. of bottle + soil + water (W3)	94.1	53.8	93.4	52.7	94.7	53
Wt. of bottle + soil (W2)	50	33.8	48.7	31.8	50.9	32
Wt. of bottle (W1)	37.2	23.1	37.2	23.1	37.2	23.1
Wt. of full water (W4 - W1)	49.5	24.8	49.5	24.8	49.5	24.8
Wt. of water added to soil (W3- W2)	44.1	20	44.7	20.9	43.8	21
Wt. of soil (W2 - W1)	12.8	10.7	11.5	8.7	13.7	8.9
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5.4	4.8	4.8	3.9	5.7	3.8
Spec. gravity of soil particles(W2 - W1)/W	2.37037	2.229167	2.395833	2.230769	2.403509	2.342105
AVERAGE SPEC. Gravity	2.347844	2.290783	2.343831	2.296603	2.391604	2.389386

TableA3: Specific Gravity Raw Data 4%

4% LIME						
Bottle No. 8	4% 0%	4% 2%	4% 4%	4% 6%	4% 8%	4% 10%
Wt. of bottle + water full (W4)	87.2	50.4	87.2	50.4	87.2	50.4
Wt. of bottle + soil + water (W3)	93.2	56.1	94.9	56.3	95.6	56.8
Wt. of bottle + soil (W2)	48.1	35.8	51	36.1	51.8	36.6
Wt. of bottle (W1)	37.6	25.7	37.6	25.7	37.6	25.7
Wt. of full water (W4 - W1)	49.6	24.7	49.6	24.7	49.6	24.7
Wt. of water added to soil (W3- W2)	45.1	20.3	43.9	20.2	43.8	20.2
Wt. of soil (W2 - W1)	10.5	10.1	13.4	10.4	14.2	10.9
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	4.5	4.4	5.7	4.5	5.8	4.5
Spec. gravity of soil particles(W2 - W1)/W	2.333333	2.295455	2.350877	2.311111	2.448276	2.422222
Bottle No. 8						
Wt. of bottle + water full (W4)	93.5	45.5	93.5	45.5	93.5	45.5
Wt. of bottle + soil + water (W3)	100	52.9	101.3	51.4	100.8	52.8
Wt. of bottle + soil (W2)	55.4	33.7	57.5	31.1	56.4	33.3
Wt. of bottle (W1)	43.8	20.7	43.8	20.7	43.8	20.7
Wt. of full water (W4 - W1)	49.7	24.8	49.7	24.8	49.7	24.8
Wt. of water added to soil (W3- W2)	44.6	19.2	43.8	20.3	44.4	19.5
Wt. of soil (W2 - W1)	11.6	13	13.7	10.4	12.6	12.6
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5.1	5.6	5.9	4.5	5.3	5.3
Spec. gravity of soil particles(W2 - W1)/W	2.27451	2.321429	2.322034	2.311111	2.377358	2.377358
Bottle No. 8						
Wt. of bottle + water full (W4)	86.7	47.9	86.7	47.9	86.7	47.9
Wt. of bottle + soil + water (W3)	94.1	53.5	94.7	53	94.3	53.4
Wt. of bottle + soil (W2)	49.9	32.9	51	32.2	50.2	32.8
Wt. of bottle (W1)	37.2	23.1	37.2	23.1	37.2	23.1
Wt. of full water (W4 - W1)	49.5	24.8	49.5	24.8	49.5	24.8
Wt. of water added to soil (W3- W2)	44.2	20.6	43.7	20.8	44.1	20.6
Wt. of soil (W2 - W1)	12.7	9.8	13.8	9.1	13	9.7
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5.3	4.2	5.8	4	5.4	4.2
Spec. gravity of soil particles(W2 - W1)/W	2.396226	2.333333	2.37931	2.275	2.407407	2.309524
AVERAGE SPEC. Gravity	2.33469	2.316739	2.35074	2.299074	2.411014	2.369702

Table A4: Specific Gravity Raw Data 6%

6% LIME						
Bottle No. 8	6% 0%	6% 2%	6% 4%	6% 6%	6% 8%	6% 10%
Wt. of bottle + water full (W4)	87.2	50.4	87.2	50.4	87.2	50.4
Wt. of bottle + soil + water (W3)	94.5	56.7	95.9	56.6	94.7	58.2
Wt. of bottle + soil (W2)	50.2	36.7	52.6	36.3	50.1	38.7
Wt. of bottle (W1)	37.6	25.7	37.6	25.7	37.6	25.7
Wt. of full water (W4 - W1)	49.6	24.7	49.6	24.7	49.6	24.7
Wt. of water added to soil (W3- W2)	44.3	20	43.3	20.3	44.6	19.5
Wt. of soil (W2 - W1)	12.6	11	15	10.6	12.5	13
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5.3	4.7	6.3	4.4	5	5.2
Spec. gravity of soil particles(W2 - W1)/W	2.377358	2.340426	2.380952	2.409091	2.5	2.5
Bottle No. 8						
Wt. of bottle + water full (W4)	93.5	45.5	93.5	45.5	93.5	45.5
Wt. of bottle + soil + water (W3)	100.9	51.4	100.8	53.4	101.2	52
Wt. of bottle + soil (W2)	56.7	30.9	56.5	34.4	56.8	31.5
Wt. of bottle (W1)	43.8	20.7	43.8	20.7	43.8	20.7
Wt. of full water (W4 - W1)	49.7	24.8	49.7	24.8	49.7	24.8
Wt. of water added to soil (W3- W2)	44.2	20.5	44.3	19	44.4	20.5
Wt. of soil (W2 - W1)	12.9	10.2	12.7	13.7	13	10.8
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5.5	4.3	5.4	5.8	5.3	4.3
Spec. gravity of soil particles(W2 - W1)/W	2.345455	2.372093	2.351852	2.362069	2.45283	2.511628
Bottle No. 8						
Wt. of bottle + water full (W4)	86.7	47.9	86.7	47.9	86.7	47.9
Wt. of bottle + soil + water (W3)	93.9	55	97.5	53.2	96.2	53.4
Wt. of bottle + soil (W2)	49.4	35.5	55.5	32.3	53.2	32.5
Wt. of bottle (W1)	37.2	23.1	37.2	23.1	37.2	23.1
Wt. of full water (W4 - W1)	49.5	24.8	49.5	24.8	49.5	24.8
Wt. of water added to soil (W3- W2)	44.5	19.5	42	20.9	43	20.9
Wt. of soil (W2 - W1)	12.2	12.4	18.3	9.2	16	9.4
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5	5.3	7.5	3.9	6.5	3.9
Spec. gravity of soil particles(W2 - W1)/W	2.44	2.339623	2.44	2.358974	2.461538	2.410256
AVERAGE SPEC. Gravity	2.387604	2.350714	2.390935	2.376711	2.471456	2.473961

TableA5: Specific Gravity Raw Data 8%

8% LIME						
Bottle No. 8	8% 0%	8% 2%	8% 4%	8% 6%	8% 8%	8% 10%
Wt. of bottle + water full (W4)	87.2	50.4	87.2	50.4	87.2	50.4
Wt. of bottle + soil + water (W3)	93.9	58.4	96.7	56.9	96.1	59.3
Wt. of bottle + soil (W2)	49.3	39.5	53.8	36.8	52.7	40.7
Wt. of bottle (W1)	37.6	25.7	37.6	25.7	37.6	25.7
Wt. of full water (W4 - W1)	49.6	24.7	49.6	24.7	49.6	24.7
Wt. of water added to soil (W3- W2)	44.6	18.9	42.9	20.1	43.4	18.6
Wt. of soil (W2 - W1)	11.7	13.8	16.2	11.1	15.1	15
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5	5.8	6.7	4.6	6.2	6.1
Spec. gravity of soil particles(W2 - W1)/W	2.34	2.37931	2.41791	2.413043	2.435484	2.459016
Bottle No. 8						
Wt. of bottle + water full (W4)	93.5	45.5	93.5	45.5	93.5	45.5
Wt. of bottle + soil + water (W3)	102.1	51.8	100.5	51.6	103.3	54.5
Wt. of bottle + soil (W2)	58.6	31.8	55.9	30.9	60.7	36
Wt. of bottle (W1)	43.8	20.7	43.8	20.7	43.8	20.7
Wt. of full water (W4 - W1)	49.7	24.8	49.7	24.8	49.7	24.8
Wt. of water added to soil (W3- W2)	43.5	20	44.6	20.7	42.6	18.5
Wt. of soil (W2 - W1)	14.8	11.1	12.1	10.2	16.9	15.3
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	6.2	4.8	5.1	4.1	7.1	6.3
Spec. gravity of soil particles(W2 - W1)/W	2.387097	2.3125	2.372549	2.487805	2.380282	2.428571
Bottle No. 8						
Wt. of bottle + water full (W4)	86.7	47.9	86.7	47.9	86.7	47.9
Wt. of bottle + soil + water (W3)	95	55.1	97.1	54.4	94.9	54.8
Wt. of bottle + soil (W2)	51.2	35.7	55.1	34.4	51	34.8
Wt. of bottle (W1)	37.2	23.1	37.2	23.1	37.2	23.1
Wt. of full water (W4 - W1)	49.5	24.8	49.5	24.8	49.5	24.8
Wt. of water added to soil (W3- W2)	43.8	19.4	42	20	43.9	20
Wt. of soil (W2 - W1)	14	12.6	17.9	11.3	13.8	11.7
Wt.of water displaced by soil						
(W4 - W1) - (W3 - W2) = W	5.7	5.4	7.5	4.8	5.6	4.8
Spec. gravity of soil particles(W2 - W1)/W	2.45614	2.333333	2.386667	2.354167	2.464286	2.4375
AVERAGE SPEC. Gravity	2.394412	2.341715	2.392375	2.418338	2.426684	2.441696

Table A6: Variation of Specific Gravity with IOT

IOT %	0% Lime	2% Lime	4% Lime	6%Lime	8%Lime
0	2.29	2.33	2.35	2.37	2.39
2	2.32	2.34	2.36	2.38	2.41
4	2.34	2.35	2.37	2.39	2.44
6	2.37	2.38	2.39	2.42	2.45
8	2.37	2.39	2.42	2.47	2.49
10	2.38	2.39	2.43	2.47	2.49

Table A7: Variation of Specific Gravity with IOT

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	11.73	2.346	0.00148
Row 2	5	11.81	2.362	0.00122
Row 3	5	11.89	2.378	0.00157
Row 4	5	12.01	2.402	0.00107
Row 5	5	12.14	2.428	0.00262
Row 6	5	12.16	2.432	0.00232
Column 1	6	14.07	2.345	0.00123
Column 2	6	14.18	2.363333	0.000707
Column 3	6	14.32	2.386667	0.001067
Column 4	6	14.5	2.416667	0.001987
Column 5	6	14.67	2.445	0.00167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.031027	5	0.006205	54.59238	5.67E-11	2.71089
Columns	0.038847	4	0.009712	85.43988	2.79E-12	2.866081
Error	0.002273	20	0.000114			
Total	0.072147	29				

APPENDIX B: LIQUID LIMIT

Table B1: Variation of Liquid Limit of Black Cotton Soil -Lime Mixture with IOTContent

0HR					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	60.39	57.29	54.03	52.02	50.29
2	58.73	55.48	52.73	50.09	48.33
4	57.34	54.91	51.66	48.68	46.64
6	56.22	53.84	51.16	47.63	45.1
8	54.89	51.62	49.14	45.98	43.94
10	52.72	49.14	47.12	43.86	42.14
1HR					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	61.29	58.84	56.76	55.09	53.62
2	60.2	57.45	55.75	53.62	51.48
4	58.38	56.52	53.59	51.63	49.22
6	56.67	54.07	52.12	50.07	47.82
8	55.79	52.6	50.71	49	46.12
10	53.63	51.25	48.75	47.24	44.97
2HRs					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	61.86	59.24	56.18	51.27	49.67
2	60.79	56.64	53.71	49.88	48.74
4	58.88	55.18	50.18	48.61	46.35
6	57.35	53.84	49.23	47.86	45.5
8	56.5	52.99	48.77	46.28	44.82
10	55.77	51.79	47.32	45.69	42.95
3HRs					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	61.2	56.33	54.15	52.01	49.59
2	60.47	55.65	53.1	50.32	48.44
4	59.67	53.41	50.42	47.81	46.02
6	57.17	51.31	48.06	45.14	42.76
8	55.58	49.64	46.53	43.3	40.91
10	52.73	48.41	44.89	42.73	39.97

Table B2: Variation of Liquid Limit of Black Cotton Soil -Lime Mixture with IOT Content (ANOVA) 0hr

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	274.02	54.804	16.52738
Row 2	5	265.36	53.072	17.32682
Row 3	5	259.23	51.846	19.18318
Row 4	5	253.95	50.79	20.3215
Row 5	5	245.57	49.114	19.05878
Row 6	5	234.98	46.996	17.69788
Column 1	6	340.29	56.715	7.49843
Column 2	6	322.28	53.71333	8.531827
Column 3	6	305.84	50.97333	6.228947
Column 4	6	288.26	48.04333	8.467307
Column 5	6	276.44	46.07333	8.832707

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	195.2397	5	39.04795	305.4981	3.62E-18	2.71089
Columns	437.9058	4	109.4765	856.5071	4.74E-22	2.866081
Error	2.556347	20	0.127817			
Total	635.7019	29				

Table B3: Variation of Liquid Limit of Black Cotton Soil -Lime Mixture with IOT Content (1hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	285.6	57.12	9.21195
Row 2	5	278.5	55.7	11.36245
Row 3	5	269.34	53.868	13.52027
Row 4	5	260.75	52.15	11.79825
Row 5	5	254.22	50.844	13.32023
Row 6	5	245.84	49.168	11.43982
Column 1	6	345.96	57.66	8.17296
Column 2	6	330.73	55.12167	8.731417
Column 3	6	317.68	52.94667	9.222427
Column 4	6	306.65	51.10833	8.584297
Column 5	6	293.23	48.87167	10.67442

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	224.7623	5	44.95247	415.218	1.75E-19	2.71089
Columns	280.4466	4	70.11166	647.609	7.61E-21	2.866081
Error	2.165247	20	0.108262			
Total	507.3742	29				

Table B4: Variation of Liquid Limit of Black Cotton Soil -Lime Mixture with IOT Content (2hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	278.22	55.644	26.66943
Row 2	5	269.76	53.952	24.44707
Row 3	5	259.2	51.84	26.01145
Row 4	5	253.78	50.756	22.83323
Row 5	5	249.36	49.872	23.32297
Row 6	5	243.52	48.704	25.88998
Column 1	6	351.15	58.525	5.88995
Column 2	6	329.68	54.94667	7.274467
Column 3	6	305.39	50.89833	11.28702
Column 4	6	289.59	48.265	4.49843
Column 5	6	278.03	46.33833	6.271417

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	169.006	5	33.80121	95.20966	3.04E-13	2.71089
Columns	589.5961	4	147.399	415.1867	6.19E-19	2.866081
Error	7.100373	20	0.355019			
Total	765.7025	29				

Table B5: Variation of Liquid Limit of Black Cotton Soil -Lime Mixture with IOT Content (3hrs)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	273.28	54.656	19.63698
Row 2	5	267.98	53.596	22.25833
Row 3	5	257.33	51.466	28.80103
Row 4	5	244.44	48.888	31.68577
Row 5	5	235.96	47.192	32.85017
Row 6	5	228.73	45.746	24.76608
Column 1	6	346.82	57.80333	10.64319
Column 2	6	314.75	52.45833	10.34658
Column 3	6	297.15	49.525	13.51435
Column 4	6	281.31	46.885	14.41635
Column 5	6	267.69	44.615	16.01987

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	317.8965	5	63.57931	186.8573	4.51E-16	2.71089
Columns	633.1883	4	158.2971	465.2294	2.01E-19	2.866081
Error	6.80512	20	0.340256			
Total	957.89	29				

Table B6: Effect of Elapsed Time on Liquid Limit of Black Cotton Soil –Lime - IOT Mixture.

0 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	60.39	58.73	57.34	56.22	54.89	52.72
1	61.29	60.2	58.38	56.67	55.79	53.63
2	61.86	60.79	58.88	57.35	56.5	55.77
3	61.2	60.47	59.67	57.17	55.58	52.73
2 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	57.29	55.48	54.91	53.84	51.62	49.14
1	58.84	57.45	56.52	54.07	52.6	51.25
2	59.24	56.64	55.18	53.34	52.99	51.79
3	56.33	55.65	53.41	51.31	49.64	48.41
4 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	54.03	52.73	51.66	51.16	49.14	47.12
1	56.76	55.75	53.59	52.12	50.71	48.75
2	56.18	53.71	50.18	49.23	48.77	47.32
3	54.15	53.1	50.42	48.06	46.53	44.89
6 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	52.02	50.09	48.68	47.63	45.98	43.86
1	55.09	53.62	51.63	50.07	49	47.24
2	51.27	49.88	48.61	47.86	46.28	45.69
3	52.01	50.32	47.81	45.14	43.3	42.73
8 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	50.29	48.33	46.64	45.1	43.94	42.14
1	53.62	51.48	49.22	47.82	46.12	44.97
2	49.67	48.74	46.35	45.5	44.82	42.95
3	49.59	48.44	46.02	42.76	40.91	39.97

TableB7: Effect of Elapsed Time on Liquid Limit of Black Cotton Soil –Lime - IOT Mixture. (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	340.29	56.715	7.49843
Row 2	6	345.96	57.66	8.17296
Row 3	6	351.15	58.525	5.88995
Row 4	6	346.82	57.80333	10.64319
Column 1	4	244.74	61.185	0.3663
Column 2	4	240.19	60.0475	0.829625
Column 3	4	234.27	58.5675	0.951692
Column 4	4	227.41	56.8525	0.260558
Column 5	4	222.76	55.69	0.4394
Column 6	4	214.85	53.7125	2.063492

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	9.96475	3	3.321583	10.44863	0.00058	3.287382
Columns	156.2542	5	31.25084	98.30502	6.42E-11	2.901295
Error	4.76845	15	0.317897			
Total	170.9874	23				

TableB8: Effect of Elapsed Time on Liquid Limit of Black Cotton Soil –Lime - IOT Mixture. (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	322.28	53.71333	8.531827
Row 2	6	330.73	55.12167	8.731417
Row 3	6	329.18	54.86333	7.537467
Row 4	6	314.75	52.45833	10.34658
Column 1	4	231.7	57.925	1.8379
Column 2	4	225.22	56.305	0.8443
Column 3	4	220.02	55.005	1.6263
Column 4	4	212.56	53.14	1.581267
Column 5	4	206.85	51.7125	2.241158
Column 6	4	200.59	50.1475	2.649092

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	26.73755	3	8.912517	23.86216	5.81E-06	3.287382
Columns	170.1339	5	34.02679	91.10251	1.11E-10	2.901295
Error	5.6025	15	0.3735			
Total	202.474	23				

TableB9: Effect of Elapsed Time on Liquid Limit of Black Cotton Soil –Lime - IOT Mixture. (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	305.84	50.97333	6.228947
Row 2	6	317.68	52.94667	9.222427
Row 3	6	305.39	50.89833	11.28702
Row 4	6	297.15	49.525	13.51435
Column 1	4	221.12	55.28	1.9466
Column 2	4	215.29	53.8225	1.814492
Column 3	4	205.85	51.4625	2.432292
Column 4	4	200.57	50.1425	3.371758
Column 5	4	195.15	48.7875	2.972292
Column 6	4	188.08	47.02	2.543267

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	35.68028	3	11.89343	18.65769	2.53E-05	3.287382
Columns	191.7019	5	38.34038	60.14607	2.17E-09	2.901295
Error	9.561817	15	0.637454			
Total	236.944	23				

Table B10: Effect of Elapsed Time on Liquid Limit of Black Cotton Soil –Lime - IOT Mixture. (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	288.26	48.04333	8.467307
Row 2	6	306.65	51.10833	8.584297
Row 3	6	289.59	48.265	4.49843
Row 4	6	281.31	46.885	14.41635
Column 1	4	210.39	52.5975	2.884492
Column 2	4	203.91	50.9775	3.135758
Column 3	4	196.73	49.1825	2.818092
Column 4	4	190.7	47.675	4.066167
Column 5	4	184.56	46.14	5.430133
Column 6	4	179.52	44.88	3.962867

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	57.91588	3	19.30529	32.2592	8.74E-07	3.287382
Columns	170.8553	5	34.17105	57.09993	3.14E-09	2.901295
Error	8.976646	15	0.598443			
Total	237.7478	23				

Table B11: Effect of Elapsed Time on Liquid Limit of Black Cotton Soil –Lime - IOT Mixture. (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	276.44	46.07333	8.832707
Row 2	6	293.23	48.87167	10.67442
Row 3	6	278.03	46.33833	6.271417
Row 4	6	267.69	44.615	16.01987
Column 1	4	203.17	50.7925	3.651092
Column 2	4	196.99	49.2475	2.245158
Column 3	4	188.23	47.0575	2.142558
Column 4	4	181.18	45.295	4.293967
Column 5	4	175.79	43.9475	4.902492
Column 6	4	170.03	42.5075	4.277892

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	56.30175	3	18.76725	34.1731	6.02E-07	3.287382
Columns	200.7543	5	40.15086	73.11031	5.41E-10	2.901295
Error	8.237729	15	0.549182			
Total	265.2938	23				

APPENDIX C: PLASTIC LIMT

Table C1: Variation of Plastic Limit of Black Cotton Soil -Lime Mixture with IOT Content

0HR					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	32.62	31.31	29.29	28.26	26.72
2	30.53	28.17	26.67	25.39	24.33
4	27.78	26.78	24.69	23.28	22.22
6	26.19	24.6	23.4	21.73	20.29
8	24.44	22.19	20.51	19.87	18.68
10	22.7	19.18	17.21	16.9	16.4
1HR					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	37.95	37.04	36.18	35.35	34.19
2	35.56	34.29	33.28	32.22	31.05
4	32.32	31.73	30.42	29.27	28.18
6	29.73	28.11	27.41	26.19	24.85
8	27.68	25.55	25.28	24.36	21.77
10	24.63	23.41	22.69	21.36	19.93
2HRS					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	37.78	37.04	34.81	31.07	29.64
2	36.15	33.33	31.57	28.33	27.78
4	32.91	31.33	27.08	26.11	24.65
6	31.31	28.36	25.27	24.63	23.58
8	29.01	26.85	24.29	22.68	21.82
10	26.48	24.74	21.88	21.67	19.13
3HRS					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	38.62	37.34	36.65	35.3	33.33
2	37.27	35.84	34.55	32.5	31.52
4	35.76	32.76	31.29	29.33	28.33
6	32.61	29.83	27.59	25.89	23.87
8	30.45	27.42	25.59	22.92	21.73
10	26.41	25.76	23.1	21.36	20.24

Table C2: Variation of Plastic Limit of Black Cotton Soil -Lime Mixture with IOT Content (ANOVA) (0hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	148.2	29.64	5.55565
Row 2	5	135.09	27.018	5.91452
Row 3	5	124.75	24.95	5.4168
Row 4	5	116.21	23.242	5.39007
Row 5	5	105.69	21.138	5.01347
Row 6	5	92.39	18.478	6.68352
Column 1	6	164.26	27.37667	13.90043
Column 2	6	152.23	25.37167	18.82662
Column 3	6	141.77	23.62833	18.6809
Column 4	6	135.43	22.57167	16.19542
Column 5	6	128.64	21.44	14.23612

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	405.2116	5	81.04232	406.6586	2.15E-19	2.71089
Columns	131.9104	4	32.97759	165.4768	5.04E-15	2.866081
Error	3.985767	20	0.199288			
Total	541.1077	29				

Table C3: Variation of Plastic Limit of Black Cotton Soil -Lime Mixture with IOT Content (ANOVA) (1hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	180.71	36.142	2.12857
Row 2	5	166.4	33.28	3.07875
Row 3	5	151.92	30.384	2.91493
Row 4	5	136.29	27.258	3.44972
Row 5	5	124.64	24.928	4.59497
Row 6	5	112.02	22.404	3.31488
Column 1	6	187.87	31.31167	24.69358
Column 2	6	180.13	30.02167	27.5517
Column 3	6	175.26	29.21	25.56104
Column 4	6	168.75	28.125	26.79307
Column 5	6	159.97	26.66167	30.1529

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	671.6942	5	134.3388	1299.743	2.09E-24	2.71089
Columns	75.86012	4	18.96503	183.4887	1.85E-15	2.866081
Error	2.06716	20	0.103358			
Total	749.6215	29				

Table C4: Variation of Plastic Limit of Black Cotton Soil -Lime Mixture with IOT Content (ANOVA) (2hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	170.34	34.068	12.93937
Row 2	5	157.16	31.432	12.21012
Row 3	5	142.08	28.416	12.49318
Row 4	5	133.15	26.63	10.01185
Row 5	5	124.65	24.93	8.86925
Row 6	5	113.9	22.78	8.22405
Column 1	6	193.64	32.27333	18.17947
Column 2	6	181.65	30.275	20.44907
Column 3	6	164.9	27.48333	23.40743
Column 4	6	154.49	25.74833	12.48282
Column 5	6	146.6	24.43333	14.80791

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	436.5579	5	87.31158	173.3142	9.39E-16	2.71089
Columns	248.9158	4	62.22894	123.5249	8.43E-14	2.866081
Error	10.07553	20	0.503776			
Total	695.5492	29				

Table C5: Variation of Plastic Limit of Black Cotton Soil -Lime Mixture with IOT Content (ANOVA) (3hrs)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	181.24	36.248	4.09847
Row 2	5	171.68	34.336	5.55423
Row 3	5	157.47	31.494	8.63423
Row 4	5	139.79	27.958	11.56732
Row 5	5	128.11	25.622	12.24797
Row 6	5	116.87	23.374	7.21588
Column 1	6	201.12	33.52	21.17904
Column 2	6	188.95	31.49167	21.38226
Column 3	6	178.77	29.795	27.84063
Column 4	6	167.3	27.88333	29.91507
Column 5	6	159.02	26.50333	28.81111

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	635.7739	5	127.1548	257.7492	1.93E-17	2.71089
Columns	187.4058	4	46.85146	94.97027	1.03E-12	2.866081
Error	9.866553	20	0.493328			
Total	833.0463	29				

Table C6: Effect of Elapsed Time on Plastic Limit of Black Cotton Soil –Lime-IOT Mixtures.

0 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	32.62	30.53	27.78	26.19	24.44	22.7
1	37.95	35.56	32.32	29.73	27.68	24.63
2	37.78	36.15	32.91	31.31	29.01	26.48
3	38.62	37.27	35.76	32.61	30.45	26.41
2 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	31.31	28.17	26.78	24.6	22.19	19.18
1	37.04	34.29	31.73	28.11	25.55	23.41
2	37.04	33.33	31.33	28.36	26.85	24.74
3	37.34	35.84	32.76	29.83	27.42	25.76
4 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	29.29	26.67	24.69	23.4	20.51	17.21
1	36.18	33.28	30.42	27.41	25.28	22.69
2	34.81	31.57	27.08	25.27	24.29	21.88
3	36.65	34.55	31.29	27.59	25.59	23.1
6 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	28.26	25.39	23.28	21.73	19.87	16.9
1	35.35	32.22	29.27	26.19	24.36	21.36
2	31.07	28.33	26.11	24.63	22.68	21.67
3	35.3	32.5	29.33	25.89	22.92	21.36
8 %LIME						
HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	26.72	24.33	22.32	20.29	18.68	16.4
1	34.19	31.05	28.18	24.85	21.77	19.93
2	29.64	27.78	24.65	23.58	21.82	19.13
3	33.33	31.52	28.33	23.87	21.73	20.24

Table C7: Effect of Elapsed Time on Plastic Limit of Black Cotton Soil –Lime-IOT Mixtures(ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	164.26	27.37667	13.90043
Row 2	6	187.87	31.31167	24.69358
Row 3	6	193.64	32.27333	18.17947
Row 4	6	201.12	33.52	21.17904
Column 1	4	146.97	36.7425	7.684825
Column 2	4	139.51	34.8775	8.903292
Column 3	4	128.77	32.1925	10.90943
Column 4	4	119.84	29.96	7.7036
Column 5	4	111.58	27.895	6.584833
Column 6	4	100.22	25.055	3.197767

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	126.8367	3	42.27892	78.15458	2.2E-09	3.287382
Columns	381.6481	5	76.32961	141.0989	4.63E-12	2.901295
Error	8.114479	15	0.540965			
Total	516.5993	23				

Appendix C8: Effect of Elapsed Time on Plastic Limit of Black Cotton Soil –Lime-IOT Mixtures (ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	152.23	25.37167	18.82662
Row 2	6	180.13	30.02167	27.5517
Row 3	6	181.65	30.275	20.44907
Row 4	6	188.95	31.49167	21.38226
Column 1	4	142.73	35.6825	8.517225
Column 2	4	131.63	32.9075	11.04443
Column 3	4	122.6	30.65	7.019267
Column 4	4	110.9	27.725	4.916033
Column 5	4	102.01	25.5025	5.489158
Column 6	4	93.09	23.2725	8.369558

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	130.2374	3	43.41247	111.7035	1.74E-10	3.287382
Columns	435.2186	5	87.04372	223.97	1.55E-13	2.901295
Error	5.8296	15	0.38864			
Total	571.2856	23				

Table C9: Effect of Elapsed Time on Plastic Limit of Black Cotton Soil –Lime-IOT Mixtures (ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	141.77	23.62833	18.6809
Row 2	6	175.26	29.21	25.56104
Row 3	6	164.9	27.48333	23.40743
Row 4	6	178.77	29.795	27.84063
Column 1	4	136.93	34.2325	11.46629
Column 2	4	126.07	31.5175	11.93449
Column 3	4	113.48	28.37	9.3118
Column 4	4	103.67	25.9175	3.927292
Column 5	4	95.67	23.9175	5.467825
Column 6	4	84.88	21.22	7.403667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	139.0668	3	46.35561	73.446	3.4E-09	3.287382
Columns	467.9827	5	93.59654	148.2947	3.21E-12	2.901295
Error	9.467283	15	0.631152			
Total	616.5168	23				

Table C10: Effect of Elapsed Time on Plastic Limit of Black Cotton Soil –Lime-IOT Mixtures (ANOVA) (6%lime)

Table C11: Effect of Elapsed Time on Plastic Limit of Black Cotton Soil –Lime-IOT Mixtures (ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	128.74	21.45667	14.26899
Row 2	6	159.97	26.66167	30.1529
Row 3	6	146.6	24.43333	14.80791
Row 4	6	159.02	26.50333	28.81111
Column 1	4	123.88	30.97	11.92313
Column 2	4	114.68	28.67	11.1382
Column 3	4	103.48	25.87	8.492867
Column 4	4	92.59	23.1475	3.924292
Column 5	4	84	21	2.393533
Column 6	4	75.7	18.925	3.0523

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	106.0453	3	35.34843	31.69752	9.78E-07	3.287382
Columns	423.4768	5	84.69536	75.94772	4.12E-10	2.901295
Error	16.7277	15	1.11518			
Total	546.2498	23				

APPENDIX D: PLASTICITY INDEX

Table D1: Variation of Plasticity Index of Black Cotton Soil -Lime Mixture with IOT Content

0HR					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	27.77	25.98	24.74	23.76	23.57
2	28.2	27.31	26.06	24.7	24
4	29.56	28.13	26.97	25.4	24.42
6	30.03	29.24	27.76	25.9	24.81
8	30.45	29.43	28.63	26.11	25.26
10	30.02	29.49	28.89	26.96	25.74
1HR					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	23.34	21.8	20.58	19.74	19.43
2	24.64	23.16	22.47	21.4	20.43
4	26.06	24.79	23.17	22.36	21.04
6	26.94	25.96	24.71	23.88	22.97
8	28.11	27.05	25.43	24.64	24.35
10	29	27.84	26.06	25.88	25.04
2HRS					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	24.08	22.2	21.37	20.2	20.03
2	24.64	23.31	22.14	21.55	20.96
4	25.97	23.85	23.1	22.5	21.7
6	26.04	24.98	23.96	23.23	21.92
8	27.49	26.14	24.48	23.6	23
10	29.29	27.05	25.44	24.02	23.82
3HRS					
IOT%	0%lime	2%lime	4%lime	6%lime	8%lime
0	22.58	18.99	17.5	16.71	16.26
2	23.2	19.81	18.55	17.82	16.92
4	23.91	20.65	19.13	18.48	17.69
6	24.56	21.48	20.47	19.25	18.89
8	25.13	22.22	20.94	20.38	19.18
10	26.32	22.65	21.79	21.37	19.73

Table D2: Variation of Plasticity Index of Black Cotton Soil -Lime Mixture with IOT Content (0hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	125.82	25.164	3.03723
Row 2	5	130.27	26.054	3.05878
Row 3	5	134.48	26.896	4.24843
Row 4	5	137.74	27.548	4.82017
Row 5	5	139.88	27.976	4.88028
Row 6	5	141.1	28.22	3.25995
Column 1	6	176.03	29.33833	1.196697
Column 2	6	169.58	28.26333	1.991987
Column 3	6	163.05	27.175	2.52299
Column 4	6	152.83	25.47167	1.267297
Column 5	6	147.8	24.63333	0.645187

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	35.07274	5	7.014547	46.02651	2.71E-10	2.71089
Columns	90.17131	4	22.54283	147.9166	1.49E-14	2.866081
Error	3.048047	20	0.152402			
Total	128.2921	29				

TableD3: Variation of Plasticity Index of Black Cotton Soil -Lime Mixture with IOT Content (1hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	104.89	20.978	2.58552
Row 2	5	112.1	22.42	2.61975
Row 3	5	117.42	23.484	3.91913
Row 4	5	124.46	24.892	2.52157
Row 5	5	129.58	25.916	2.60408
Row 6	5	133.82	26.764	2.60168
Column 1	6	158.09	26.34833	4.507297
Column 2	6	150.6	25.1	5.35988
Column 3	6	142.42	23.73667	4.220547
Column 4	6	137.9	22.98333	5.070787
Column 5	6	133.26	22.21	5.08636

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	119.836	5	23.9672	345.2658	1.08E-18	2.71089
Columns	66.01859	4	16.50465	237.762	1.48E-16	2.866081
Error	1.388333	20	0.069417			
Total	187.2429	29				

Table D3: Variation of Plasticity Index of Black Cotton Soil -Lime Mixture with IOT Content (2hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	107.88	21.576	2.74633
Row 2	5	112.6	22.52	2.15935
Row 3	5	117.12	23.424	2.64863
Row 4	5	120.13	24.026	2.50988
Row 5	5	124.71	24.942	3.42832
Row 6	5	129.62	25.924	5.22103
Column 1	6	157.51	26.25167	3.640537
Column 2	6	147.53	24.58833	3.300857
Column 3	6	140.49	23.415	2.28775
Column 4	6	135.1	22.51667	2.048827
Column 5	6	131.43	21.905	1.86343

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	62.83739	5	12.56748	87.59004	6.74E-13	2.71089
Columns	71.98455	4	17.99614	125.4255	7.28E-14	2.866081
Error	2.869613	20	0.143481			
Total	137.6915	29				

Table D5: Variation of Plasticity Index of Black Cotton Soil -Lime Mixture with IOT Content (3hr)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	92.04	18.408	6.51647
Row 2	5	96.3	19.26	5.96985
Row 3	5	99.86	19.972	6.02752
Row 4	5	104.65	20.93	5.16875
Row 5	5	107.85	21.57	5.1553
Row 6	5	111.86	22.372	5.99672
Column 1	6	145.7	24.28333	1.831147
Column 2	6	125.8	20.96667	2.002667
Column 3	6	118.38	19.73	2.59612
Column 4	6	114.01	19.00167	2.898137
Column 5	6	108.67	18.11167	1.878537

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	54.93671	5	10.98734	200.4392	2.27E-16	2.71089
Columns	138.2421	4	34.56053	630.4787	9.93E-21	2.866081
Error	1.096327	20	0.054816			
Total	194.2751	29				

Table D6: Effect of Elapsed Time on Plasticity Index of Black Cotton Soil –Lime - IOT Mixtures.

0% LIME						
Hrs	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	27.72	28.19	29.53	30.1	30.32	30.63
1	23.46	25.1	25.75	26.87	28.33	28.89
2	24.1	24.67	25.28	26.04	27.49	29.32
3	22.88	23.33	23.89	24.3	25.11	26.64
2% LIME						
Hrs	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	25.92	27.22	28.18	29.04	29.44	29.94
1	21.66	23.31	24.25	25.76	27.35	27.94
2	22.11	23.11	23.79	24.93	26.23	27.09
3	19.01	19.81	20.71	21.74	22.2	22.8
4% LIME						
Hrs	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	24.93	25.97	26.95	27.75	28.5	29.84
1	20.48	22.61	23.58	24.78	25.54	26.31
2	21.43	22.01	23.07	23.94	24.61	25.43
3	17.92	18.56	19.15	20.39	20.89	21.75
6% LIME						
Hrs	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	24.01	24.77	25.34	25.79	26.03	26.96
1	19.99	21.43	22.58	23.75	24.82	26
2	20.21	21.54	22.48	23.11	23.65	24.04
3	17	17.84	18.41	19.22	20.48	21.33
8% LIME						
Hrs	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	23.5	24.12	24.5	24.78	25.21	25.78
1	19.57	20.41	21.22	22.9	24.42	25.03
2	20.03	20.89	21.48	22.05	22.87	23.76
3	16.25	16.88	17.71	18.82	19.17	19.81

Table D7: Effect of Elapsed Time on Plasticity Index of Black Cotton Soil –Lime - IOT Mixtures. (ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	176.49	29.415	1.43027
Row 2	6	158.4	26.4	4.1804
Row 3	6	156.9	26.15	3.80128
Row 4	6	146.15	24.35833	1.847337
Column 1	4	98.16	24.54	4.742667
Column 2	4	101.29	25.3225	4.222625
Column 3	4	104.45	26.1125	5.814425
Column 4	4	107.31	26.8275	5.906492
Column 5	4	111.25	27.8125	4.654292
Column 6	4	115.48	28.87	2.7578

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	79.14195	3	26.38065	76.79286	2.49E-09	3.287382
Columns	51.14348	5	10.2287	29.77526	2.79E-07	2.901295
Error	5.15295	15	0.34353			
Total	135.4384	23				

Table D8: Effect of Elapsed Time on Plasticity Index of Black Cotton Soil –Lime - IOT Mixtures. (ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	169.74	28.29	2.27628
Row 2	6	150.27	25.045	5.86115
Row 3	6	147.26	24.54333	3.604587
Row 4	6	126.27	21.045	2.13515
Column 1	4	88.7	22.175	8.1039
Column 2	4	93.45	23.3625	9.189025
Column 3	4	96.93	24.2325	9.395625
Column 4	4	101.47	25.3675	8.997158
Column 5	4	105.22	26.305	9.258967
Column 6	4	107.77	26.9425	9.054025

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	158.3214	3	52.77378	215.4179	1.49E-12	3.287382
Columns	65.71108	5	13.14222	53.64535	4.87E-09	2.901295
Error	3.67475	15	0.244983			
Total	227.7072	23				

Table D9: Effect of Elapsed Time on Plasticity Index of Black Cotton Soil –Lime - IOT Mixtures. (ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	163.94	27.32333	3.119827
Row 2	6	143.3	23.88333	4.546667
Row 3	6	140.49	23.415	2.35943
Row 4	6	118.66	19.77667	2.165987
Column 1	4	84.76	21.19	8.414067
Column 2	4	89.15	22.2875	9.212025
Column 3	4	92.75	23.1875	10.20856
Column 4	4	96.86	24.215	9.1739
Column 5	4	99.54	24.885	9.8443
Column 6	4	103.33	25.8325	11.03896

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	171.5735	3	57.19118	408.1432	1.35E-14	3.287382
Columns	58.85767	5	11.77153	84.00721	2E-10	2.901295
Error	2.101879	15	0.140125			
Total	232.5331	23				

Table D10: Effect of Elapsed Time on Plasticity Index of Black Cotton Soil –Lime - IOT Mixtures. (ANOVA) (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	152.9	25.48333	1.054707
Row 2	6	138.57	23.095	4.90443
Row 3	6	135.03	22.505	2.04643
Row 4	6	114.28	19.04667	2.669667
Column 1	4	81.21	20.3025	8.252758
Column 2	4	85.58	21.395	8.016967
Column 3	4	88.81	22.2025	8.148825
Column 4	4	91.87	22.9675	7.547625
Column 5	4	94.98	23.745	5.682033
Column 6	4	98.33	24.5825	6.178292

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	127.0537	3	42.35123	143.537	2.87E-11	3.287382
Columns	48.95035	5	9.79007	33.18055	1.35E-07	2.901295
Error	4.425817	15	0.295054			
Total	180.4299	23				

Table D11: Effect of Elapsed Time on Plasticity Index of Black Cotton Soil –Lime - IOT Mixtures.(ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	147.89	24.64833	0.646657
Row 2	6	133.55	22.25833	4.897657
Row 3	6	131.08	21.84667	1.819867
Row 4	6	108.64	18.10667	1.930027
Column 1	4	79.35	19.8375	8.797558
Column 2	4	82.3	20.575	8.782167
Column 3	4	84.91	21.2275	7.715292
Column 4	4	88.55	22.1375	6.192558
Column 5	4	91.67	22.9175	7.186358
Column 6	4	94.38	23.595	7.0623

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	131.6224	3	43.87412	117.8075	1.19E-10	3.287382
Columns	40.8847	5	8.17694	21.9561	2.07E-06	2.901295
Error	5.586333	15	0.372422			
Total	178.0934	23				

APPENDIX E: COMPACTION-MDD& OMC

Table E1: Variation of Maximum Dry Density (MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)

0 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.47	1.5	1.49	1.48	1.44
2%	1.47	1.52	1.5	1.49	1.45
4%	1.48	1.53	1.51	1.49	1.46
6%	1.48	1.54	1.52	1.5	1.47
8%	1.5	1.55	1.52	1.51	1.48
10%	1.48	1.54	1.51	1.5	1.47
1 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.53	1.55	1.51	1.5	1.48
2%	1.54	1.57	1.52	1.51	1.49
4%	1.55	1.57	1.54	1.53	1.5
6%	1.57	1.58	1.55	1.54	1.52
8%	1.58	1.59	1.56	1.55	1.53
10%	1.56	1.58	1.54	1.53	1.52
2 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.54	1.55	1.53	1.52	1.5
2%	1.56	1.58	1.54	1.53	1.51
4%	1.57	1.58	1.55	1.54	1.52
6%	1.58	1.6	1.56	1.55	1.54
8%	1.59	1.6	1.58	1.57	1.55
10%	1.56	1.58	1.55	1.54	1.53
3 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.52	1.54	1.51	1.49	1.48
2%	1.54	1.56	1.53	1.51	1.5
4%	1.55	1.57	1.54	1.53	1.51
6%	1.56	1.58	1.55	1.54	1.52
8%	1.57	1.59	1.56	1.54	1.53
10%	1.56	1.58	1.54	1.53	1.52

Table E.6:- Two –Way Analysis of variance (ANOVA) on the MDD

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
BSL	0	Lime	4	168.8356	4.15E-15	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	33.1233	5.13E-09	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	204.4828	6.46E-16	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	79.6207	1.66E-12	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	135.1563	3.55E-14	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	70.375	5.33E-12	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	406.25	7.68E-19	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	201.4167	2.16E-16	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table E7: Variation of Optimum Moisture Content (OMC) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)

0 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	25.62	23.44	26.21	24.72	21.7
2%	24.65	23.11	25.82	24.31	21.24
4%	24.35	22.87	25.42	23.91	20.87
6%	24	22.41	25.03	23.67	20.1
8%	23.75	21.89	24.86	22.83	19.86
10%	22.63	21.11	24.34	21.55	18.05
1 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	25.1	23.26	25.72	23.94	20.04
2%	24.12	22.1	25.68	23.56	19.85
4%	23.78	21.78	25.17	23.35	19.13
6%	23.2	21.22	24.71	22.77	18.6
8%	22.01	20.78	24.13	21.54	18.02
10%	21.58	20.17	22.13	20.63	17.79
2 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	23.62	21.07	22.33	23.83	19.96
2%	22.42	20.75	21.93	23.22	19.23
4%	22.1	20.53	21.24	22.57	19.1
6%	21.62	20.03	21.01	21.99	18.74
8%	20.85	19.52	20.24	21.51	18.43
10%	20.54	19.09	20.02	21.01	17.65
3 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	21.83	19.45	20.09	23.71	17.26
2%	21.42	19.11	19.8	23.01	17.03
4%	20.87	18.33	19.51	22.03	16.76
6%	20.51	17.73	19.11	21.51	16.05
8%	19.75	17.19	18.93	20.27	15.51
10%	18.46	16.2	17.93	20.01	15.2

Table E13: Effect of Elapsed Time on Maximum Dry Density(MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)

0% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.47	1.48	1.49	1.51	1.52	1.5
1	1.53	1.54	1.55	1.57	1.58	1.56
2	1.54	1.55	1.56	1.58	1.59	1.57
3	1.51	1.52	1.54	1.57	1.58	1.55
2% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.5	1.51	1.52	1.54	1.55	1.53
1	1.54	1.55	1.56	1.58	1.59	1.57
2	1.55	1.56	1.57	1.59	1.6	1.58
3	1.54	1.55	1.56	1.58	1.59	1.57
4% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.49	1.5	1.51	1.53	1.54	1.52
1	1.51	1.52	1.53	1.55	1.56	1.54
2	1.53	1.54	1.55	1.57	1.58	1.56
3	1.52	1.53	1.54	1.56	1.57	1.55
6% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.48	1.49	1.5	1.53	1.55	1.52
1	1.5	1.51	1.52	1.54	1.56	1.53
2	1.51	1.52	1.53	1.55	1.57	1.54
3	1.49	1.51	1.52	1.54	1.56	1.53
8% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.44	1.45	1.46	1.48	1.49	1.47
1	1.48	1.49	1.5	1.52	1.53	1.51
2	1.5	1.51	1.52	1.54	1.55	1.53
3	1.48	1.5	1.51	1.53	1.54	1.52

Table E14: Effect of Elapsed Time on Maximum Dry Density(MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)(ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	8.97	1.495	0.00035
Row 2	6	9.33	1.555	0.00035
Row 3	6	9.39	1.565	0.00035
Row 4	6	9.27	1.545	0.00075
Column 1	4	6.05	1.5125	0.000958
Column 2	4	6.09	1.5225	0.000958
Column 3	4	6.14	1.535	0.000967
Column 4	4	6.23	1.5575	0.001025
Column 5	4	6.27	1.5675	0.001025
Column 6	4	6.18	1.545	0.000967

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0174	3	0.0058	290	1.68E-13	3.287382
Columns	0.0087	5	0.00174	87	1.55E-10	2.901295
Error	0.0003	15	2E-05			
Total	0.0264	23				

Table E15: Effect of Elapsed Time on Maximum Dry Density(MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)(ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.15	1.525	0.00035
Row 2	6	9.39	1.565	0.00035
Row 3	6	9.45	1.575	0.00035
Row 4	6	9.39	1.565	0.00035
Column 1	4	6.13	1.5325	0.000492
Column 2	4	6.17	1.5425	0.000492
Column 3	4	6.21	1.5525	0.000492
Column 4	4	6.29	1.5725	0.000492
Column 5	4	6.33	1.5825	0.000492
Column 6	4	6.25	1.5625	0.000492

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.00885	3	0.00295	65535	#DIV/0!	3.287382
Columns	0.007	5	0.0014	65535	#DIV/0!	2.901295
Error	0	15	0			
Total	0.01585	23				

Table E16: Effect of Elapsed Time on Maximum Dry Density(MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)(ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.09	1.515	0.00035
Row 2	6	9.21	1.535	0.00035
Row 3	6	9.33	1.555	0.00035
Row 4	6	9.27	1.545	0.00035
Column 1	4	6.05	1.5125	0.000292
Column 2	4	6.09	1.5225	0.000292
Column 3	4	6.13	1.5325	0.000292
Column 4	4	6.21	1.5525	0.000292
Column 5	4	6.25	1.5625	0.000292
Column 6	4	6.17	1.5425	0.000292

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.00525	3	0.00175	7.57E+15	4.6E-114	3.287382
Columns	0.007	5	0.0014	6.05E+15	3.2E-114	2.901295
Error	3.47E-18	15	2.31E-19			
Total	0.01225	23				

Table E17: Effect of Elapsed Time on Maximum Dry Density(MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)(ANOVA) (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.07	1.511667	0.000697
Row 2	6	9.16	1.526667	0.000467
Row 3	6	9.22	1.536667	0.000467
Row 4	6	9.15	1.525	0.00059
Column 1	4	5.98	1.495	0.000167
Column 2	4	6.03	1.5075	0.000158
Column 3	4	6.07	1.5175	0.000158
Column 4	4	6.16	1.54	6.67E-05
Column 5	4	6.24	1.56	6.67E-05
Column 6	4	6.12	1.53	6.67E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0019	3	0.000633	63.33333	9.52E-09	3.287382
Columns	0.01095	5	0.00219	219	1.83E-13	2.901295
Error	0.00015	15	1E-05			
Total	0.013	23				

Table E18: Effect of Elapsed Time on Maximum Dry Density(MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSL)(ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	8.79	1.465	0.00035
Row 2	6	9.03	1.505	0.00035
Row 3	6	9.15	1.525	0.00035
Row 4	6	9.08	1.513333	0.000467
Column 1	4	5.9	1.475	0.000633
Column 2	4	5.95	1.4875	0.000692
Column 3	4	5.99	1.4975	0.000692
Column 4	4	6.07	1.5175	0.000692
Column 5	4	6.11	1.5275	0.000692
Column 6	4	6.03	1.5075	0.000692

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.012213	3	0.004071	977	2.05E-17	3.287382
Columns	0.007521	5	0.001504	361	4.51E-15	2.901295
Error	6.25E-05	15	4.17E-06			
Total	0.019796	23				

Table E.19: Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the MDD of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
BSL	0	Time	3	290.0	1.68E-13	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	87.0	1.55E-10	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	2	Time	3	215.4179	1.49E-12	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	53.6454	4.87E-09	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	4	Time	3	408.1432	1.35E-14	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	84.0072	2E-10	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	6	Time	3	63.3333	9.52E-09	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	219.0	1.83E-13	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	8	Time	3	977.0	2.05E-17	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	361.0	4.51E-15	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect

Table E20: Effect of Elapsed Time on Optimum Moisture Content (OMC) on Black Cotton Soil -Lime – Mixtures. (BSL)

0% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	25.62	24.65	24.35	24	23.75	22.63
1	25.1	24.12	23.78	23.2	22.01	21.58
2	23.62	22.42	22.1	21.62	20.85	20.54
3	21.83	21.42	20.87	20.51	19.75	18.46
2% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	23.44	23.11	22.87	22.41	22.24	21.84
1	23.26	22.1	21.78	21.22	20.78	20.17
2	22.62	21.46	21.01	20.24	19.92	19.09
3	20.06	19.38	18.33	17.73	17.19	16.2
4% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	26.21	25.82	25.42	25.03	24.86	24.34
1	25.72	25.68	25.17	24.71	24.13	22.13
2	22.33	21.93	21.24	21.01	20.24	20.02
3	20.09	19.8	19.51	19.11	18.93	17.93
6% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	24.72	24.43	24.16	23.67	22.83	21.55
1	23.94	23.56	23.35	22.77	21.54	20.63
2	23.83	23.22	22.57	21.99	21.51	21.01
3	23.71	23.01	22.03	21.51	20.27	20.01
8% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	21.7	21.24	20.87	20.1	19.86	18.05
1	20.04	19.85	19.13	18.6	18.02	17.79
2	18.64	18.11	17.78	17.12	16.92	16.32
3	17.26	17.03	16.76	16.05	15.51	15.2

Table E21: Effect of Elapsed Time on Optimum Moisture Content (OMC) on Black Cotton Soil -Lime – Mixtures. (BSL)(ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	8.97	1.495	0.00035
Row 2	6	9.33	1.555	0.00035
Row 3	6	9.39	1.565	0.00035
Row 4	6	9.27	1.545	0.00075
Column 1	4	6.05	1.5125	0.000958
Column 2	4	6.09	1.5225	0.000958
Column 3	4	6.14	1.535	0.000967
Column 4	4	6.23	1.5575	0.001025
Column 5	4	6.27	1.5675	0.001025
Column 6	4	6.18	1.545	0.000967

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0174	3	0.0058	290	1.68E-13	3.287382
Columns	0.0087	5	0.00174	87	1.55E-10	2.901295
Error	0.0003	15	2E-05			
Total	0.0264	23				

Table E22: Effect of Elapsed Time on Optimum Moisture Content (OMC) on Black Cotton Soil -Lime – Mixtures.(BSL)(ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.15	1.525	0.00035
Row 2	6	9.39	1.565	0.00035
Row 3	6	9.45	1.575	0.00035
Row 4	6	9.39	1.565	0.00035
Column 1	4	6.13	1.5325	0.000492
Column 2	4	6.17	1.5425	0.000492
Column 3	4	6.21	1.5525	0.000492
Column 4	4	6.29	1.5725	0.000492
Column 5	4	6.33	1.5825	0.000492
Column 6	4	6.25	1.5625	0.000492

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.00885	3	0.00295	65535	#DIV/0!	3.287382
Columns	0.007	5	0.0014	65535	#DIV/0!	2.901295
Error	0	15	0			
Total	0.01585	23				

Table E23: Effect of Elapsed Time on Optimum Moisture Content (OMC) on Black Cotton Soil -Lime – Mixtures. (BSL)(ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.09	1.515	0.00035
Row 2	6	9.21	1.535	0.00035
Row 3	6	9.33	1.555	0.00035
Row 4	6	9.27	1.545	0.00035
Column 1	4	6.05	1.5125	0.000292
Column 2	4	6.09	1.5225	0.000292
Column 3	4	6.13	1.5325	0.000292
Column 4	4	6.21	1.5525	0.000292
Column 5	4	6.25	1.5625	0.000292
Column 6	4	6.17	1.5425	0.000292

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.00525	3	0.00175	7.57E+15	4.6E-114	3.287382
Columns	0.007	5	0.0014	6.05E+15	3.2E-114	2.901295
Error	3.47E-18	15	2.31E-19			
Total	0.01225	23				

Table E24: Effect of Elapsed Time on Optimum Moisture Content (OMC) on Black Cotton Soil -Lime – Mixtures.(BSL)(ANOVA) (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.07	1.511667	0.000697
Row 2	6	9.16	1.526667	0.000467
Row 3	6	9.22	1.536667	0.000467
Row 4	6	9.15	1.525	0.00059
Column 1	4	5.98	1.495	0.000167
Column 2	4	6.03	1.5075	0.000158
Column 3	4	6.07	1.5175	0.000158
Column 4	4	6.16	1.54	6.67E-05
Column 5	4	6.24	1.56	6.67E-05
Column 6	4	6.12	1.53	6.67E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0019	3	0.000633	63.33333	9.52E-09	3.287382
Columns	0.01095	5	0.00219	219	1.83E-13	2.901295
Error	0.00015	15	1E-05			
Total	0.013	23				

Table E25: Effect of Elapsed Time on Optimum Moisture Content (OMC) on Black Cotton Soil -Lime – Mixtures.(BSL)(ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	8.79	1.465	0.00035
Row 2	6	9.03	1.505	0.00035
Row 3	6	9.15	1.525	0.00035
Row 4	6	9.08	1.513333	0.000467
Column 1	4	5.9	1.475	0.000633
Column 2	4	5.95	1.4875	0.000692
Column 3	4	5.99	1.4975	0.000692
Column 4	4	6.07	1.5175	0.000692
Column 5	4	6.11	1.5275	0.000692
Column 6	4	6.03	1.5075	0.000692

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.012213	3	0.004071	977	2.05E-17	3.287382
Columns	0.007521	5	0.001504	361	4.51E-15	2.901295
Error	6.25E-05	15	4.17E-06			
Total	0.019796	23				

Table E.26a: Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the OMC of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
BSL	0	Time	3	222.7794	1.17E-12	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	74.2553	4.84E-10	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	157.203	1.48E-11	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	33.3739	1.29E-07	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	352.50	3.99E-14	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	23.3573	1.39E-06	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	34.7490	5.4E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	62.2535	1.7E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	202.8372	2.32E-12	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	41.9173	2.72E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table E27: Variation of Maximum Dry Density (MDD) on Black Cotton Soil -Lime Mixture with IOT Content (WAS)

0 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.55	1.58	1.56	1.57	1.53
2%	1.57	1.6	1.59	1.6	1.56
4%	1.59	1.62	1.6	1.61	1.58
6%	1.6	1.63	1.61	1.62	1.59
8%	1.61	1.65	1.62	1.63	1.6
10%	1.6	1.64	1.61	1.62	1.59
1 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.58	1.6	1.59	1.57	1.59
2%	1.6	1.61	1.61	1.59	1.6
4%	1.61	1.63	1.62	1.6	1.62
6%	1.62	1.66	1.64	1.61	1.63
8%	1.63	1.66	1.65	1.62	1.64
10%	1.62	1.65	1.64	1.61	1.63
2 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.58	1.62	1.61	1.59	1.6
2%	1.6	1.64	1.63	1.61	1.62
4%	1.62	1.65	1.64	1.63	1.63
6%	1.62	1.66	1.65	1.63	1.64
8%	1.63	1.67	1.66	1.64	1.65
10%	1.62	1.66	1.65	1.63	1.64
3 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.56	1.63	1.65	1.59	1.62
2%	1.59	1.64	1.66	1.6	1.62
4%	1.59	1.65	1.67	1.61	1.63
6%	1.6	1.65	1.67	1.62	1.64
8%	1.62	1.65	1.68	1.63	1.64
10%	1.61	1.64	1.66	1.62	1.63

Table E.32:- Two –Way Analysis of variance (ANOVA) on the MDD

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
WAS	0	Lime	4	136.9512	3.13E-14	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	198.6829	2.47E-16	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	48.7313	4.9E-10	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	94.3582	3.32E-13	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	271.0	4.12E-17	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	322.6667	2.11E-18	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	84.8089	2.99E-12	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	13.2612	8.89E-06	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table E33: Variation of Optimum Moisture Content(OMC) on Black Cotton Soil -Lime Mixture with IOT Content (WAS)

0 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	20.32	20.95	23.55	21.47	24.25
2%	19.21	19.87	22.49	21	23.47
4%	19.27	19.79	22.01	20.6	22.26
6%	19.1	19.63	21.88	20.41	22.14
8%	18.89	19.42	21.58	20.13	21.96
10%	18.51	19.18	20.01	19.2	20.49
1 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	20.17	20.51	22.08	21.22	23.31
2%	19.29	19.81	21.71	20.65	22.34
4%	19.09	19.75	21.04	20.44	21.82
6%	18.89	19.32	20.74	19.95	21.14
8%	18.33	18.7	20.07	19.43	20.34
10%	18.15	18.5	19.77	19.11	20.03
2 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	19.33	19.67	20.13	18.89	20.65
2%	19.24	19.52	19.82	18.62	20.32
4%	18.72	19.12	19.51	18.21	19.81
6%	18.23	18.55	19.12	17.74	19.42
8%	17.71	18.4	18.75	17.38	18.92
10%	17.1	18.07	18.36	16.88	18.65
3 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	18.51	19.1	18.72	18.1	17.67
2%	18.23	18.86	18.54	17.67	17.31
4%	17.93	18.46	18.23	17.42	17.04
6%	17.5	18.3	17.75	17.1	16.87
8%	17.05	18.01	17.43	16.68	16.32
10%	16.22	17.53	16.69	16.03	15.75

Table E39: Effect of Elapsed Time on Maximum Dry Density (MDD) of black cotton soil – lime – IOT Mixtures. (WAS)

0% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.55	1.57	1.58	1.6	1.61	1.59
1	1.58	1.59	1.6	1.62	1.63	1.61
2	1.59	1.6	1.62	1.64	1.65	1.63
3	1.56	1.59	1.6	1.62	1.63	1.61
2% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.58	1.6	1.62	1.64	1.65	1.63
1	1.6	1.61	1.63	1.65	1.66	1.64
2	1.62	1.63	1.64	1.66	1.67	1.65
3	1.61	1.62	1.63	1.65	1.66	1.64
4% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.56	1.59	1.6	1.62	1.63	1.61
1	1.59	1.6	1.61	1.63	1.64	1.62
2	1.6	1.61	1.62	1.64	1.65	1.63
3	1.62	1.63	1.64	1.66	1.67	1.65
6% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.57	1.59	1.61	1.62	1.63	1.6
1	1.59	1.6	1.62	1.63	1.64	1.61
2	1.6	1.61	1.63	1.64	1.65	1.62
3	1.59	1.6	1.62	1.63	1.64	1.61
8% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.53	1.55	1.57	1.59	1.6	1.58
1	1.59	1.6	1.62	1.64	1.65	1.63
2	1.6	1.61	1.63	1.65	1.66	1.64
3	1.62	1.63	1.64	1.66	1.67	1.65

Table E40: Effect of Elapsed Time on Maximum Dry Density (MDD) of black cotton soil – lime – IOT Mixtures.(WAS)(ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.5	1.583333	0.000467
Row 2	6	9.63	1.605	0.00035
Row 3	6	9.73	1.621667	0.000537
Row 4	6	9.61	1.601667	0.000617
Column 1	4	6.28	1.57	0.000333
Column 2	4	6.35	1.5875	0.000158
Column 3	4	6.4	1.6	0.000267
Column 4	4	6.48	1.62	0.000267
Column 5	4	6.52	1.63	0.000267
Column 6	4	6.44	1.61	0.000267

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.004446	3	0.001482	97	4.77E-10	3.287382
Columns	0.009621	5	0.001924	125.9455	1.06E-11	2.901295
Error	0.000229	15	1.53E-05			
Total	0.014296	23				

Table E41: Effect of Elapsed Time on Maximum Dry Density (MDD) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.72	1.62	0.00068
Row 2	6	9.79	1.631667	0.000537
Row 3	6	9.87	1.645	0.00035
Row 4	6	9.81	1.635	0.00035
Column 1	4	6.41	1.6025	0.000292
Column 2	4	6.46	1.615	0.000167
Column 3	4	6.52	1.63	6.67E-05
Column 4	4	6.6	1.65	6.67E-05
Column 5	4	6.64	1.66	6.67E-05
Column 6	4	6.56	1.64	6.67E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001912	3	0.000637	36.42857	3.97E-07	3.287382
Columns	0.009321	5	0.001864	106.5238	3.59E-11	2.901295
Error	0.000263	15	1.75E-05			
Total	0.011496	23				

Table E42: Effect of Elapsed Time on Maximum Dry Density (MDD) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.61	1.601667	0.000617
Row 2	6	9.69	1.615	0.00035
Row 3	6	9.75	1.625	0.00035
Row 4	6	9.87	1.645	0.00035
Column 1	4	6.37	1.5925	0.000625
Column 2	4	6.43	1.6075	0.000292
Column 3	4	6.47	1.6175	0.000292
Column 4	4	6.55	1.6375	0.000292
Column 5	4	6.59	1.6475	0.000292
Column 6	4	6.51	1.6275	0.000292

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.006	3	0.002	120	1.04E-10	3.287382
Columns	0.008083	5	0.001617	97	7.08E-11	2.901295
Error	0.00025	15	1.67E-05			
Total	0.014333	23				

Table E43: Effect of Elapsed Time on Maximum Dry Density (MDD) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.62	1.603333	0.000467
Row 2	6	9.69	1.615	0.00035
Row 3	6	9.75	1.625	0.00035
Row 4	6	9.69	1.615	0.00035
Column 1	4	6.35	1.5875	0.000158
Column 2	4	6.4	1.6	6.67E-05
Column 3	4	6.48	1.62	6.67E-05
Column 4	4	6.52	1.63	6.67E-05
Column 5	4	6.56	1.64	6.67E-05
Column 6	4	6.44	1.61	6.67E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001412	3	0.000471	113	1.61E-10	3.287382
Columns	0.007521	5	0.001504	361	4.51E-15	2.901295
Error	6.25E-05	15	4.17E-06			
Total	0.008996	23				

Table E44: Effect of Elapsed Time on Maximum Dry Density (MDD) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.42	1.57	0.00068
Row 2	6	9.73	1.621667	0.000537
Row 3	6	9.79	1.631667	0.000537
Row 4	6	9.87	1.645	0.00035
Column 1	4	6.34	1.585	0.0015
Column 2	4	6.39	1.5975	0.001158
Column 3	4	6.46	1.615	0.000967
Column 4	4	6.54	1.635	0.000967
Column 5	4	6.58	1.645	0.000967
Column 6	4	6.5	1.625	0.000967

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.019379	3	0.00646	494.7872	3.24E-15	3.287382
Columns	0.010321	5	0.002064	158.1064	2.01E-12	2.901295
Error	0.000196	15	1.31E-05			
Total	0.029896	23				

Table E.45- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the MDD of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
WAS	0	Time	3	97.0	4.77E-10	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	125.9455	1.06E-11	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	36.1286	3.97E-07	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	106.5238	3.59E-11	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	120.0	1.04E-10	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	97.0	7.08E-11	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	113.0	1.61E-10	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	361.0	4.51E-15	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	494.7872	3.24E-15	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	158.1064	2.01E-12	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

Table E46: Effect of Elapsed Time on Optimum Moisture Content (OMC) of black cotton soil – lime – IOT Mixtures. (WAS)

0% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	20.32	19.35	19.27	19.1	18.89	18.51
1	20.17	19.29	19.09	18.89	18.33	18.15
2	19.33	19.24	18.72	18.23	17.71	17.1
3	18.51	18.23	17.93	17.5	17.05	16.22
2% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	20.95	19.87	19.79	19.63	19.42	19.18
1	20.51	19.81	19.75	19.32	18.7	18.5
2	19.67	19.52	19.12	18.55	18.4	18.07
3	19.1	18.86	18.46	18.3	18.01	17.53
4% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	23.55	22.49	22.01	21.88	21.58	20.01
1	22.08	21.71	21.04	20.74	20.02	19.77
2	20.13	19.82	19.51	19.12	18.75	18.36
3	18.72	18.54	18.23	17.75	17.43	16.69
6% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	21.47	21	20.6	20.41	20.13	19.2
1	21.22	20.65	20.44	19.95	19.43	19.11
2	18.89	18.62	18.21	17.74	17.38	16.88
3	18.1	17.67	17.42	17.1	16.68	16.03
8% LIME						
Hr	0%IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	24.25	23.47	22.26	22.14	21.96	20.49
1	23.31	22.34	21.82	21.14	20.34	20.03
2	20.65	20.32	19.81	19.42	18.92	18.65
3	17.67	17.31	17.04	16.87	16.32	15.75

Table E47: Effect of Elapsed Time on Optimum Moisture Content (OMC) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	115.44	19.24	0.37088
Row 2	6	113.92	18.98667	0.528707
Row 3	6	110.33	18.38833	0.773417
Row 4	6	105.44	17.57333	0.709307
Column 1	4	78.33	19.5825	0.701025
Column 2	4	76.11	19.0275	0.284692
Column 3	4	75.01	18.7525	0.353092
Column 4	4	73.72	18.43	0.5218
Column 5	4	71.98	17.995	0.629167
Column 6	4	69.98	17.495	1.0803

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	9.880546	3	3.293515	59.54438	1.46E-08	3.287382
Columns	11.08187	5	2.216374	40.07044	3.71E-08	2.901295
Error	0.829679	15	0.055312			
Total	21.7921	23				

Table E48: Effect of Elapsed Time on Optimum Moisture Content (OMC) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	118.84	19.80667	0.376987
Row 2	6	116.59	19.43167	0.564617
Row 3	6	113.33	18.88833	0.417257
Row 4	6	110.26	18.37667	0.324187
Column 1	4	80.23	20.0575	0.689425
Column 2	4	78.06	19.515	0.214033
Column 3	4	77.12	19.28	0.393
Column 4	4	75.8	18.95	0.393933
Column 5	4	74.53	18.6325	0.355425
Column 6	4	73.28	18.32	0.4862

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	7.04835	3	2.34945	64.34499	8.53E-09	3.287382
Columns	7.867533	5	1.573507	43.09403	2.25E-08	2.901295
Error	0.5477	15	0.036513			
Total	15.46358	23				

Table E49: Effect of Elapsed Time on Optimum Moisture Content (OMC) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	131.52	21.92	1.35104
Row 2	6	125.36	20.89333	0.828947
Row 3	6	115.69	19.28167	0.443977
Row 4	6	107.36	17.89333	0.579627
Column 1	4	84.48	21.12	4.5222
Column 2	4	82.56	20.64	3.2166
Column 3	4	80.79	20.1975	2.779558
Column 4	4	79.49	19.8725	3.284625
Column 5	4	77.78	19.445	3.144033
Column 6	4	74.83	18.7075	2.338825

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	56.63075	3	18.87692	230.8107	9.01E-13	3.287382
Columns	14.79117	5	2.958234	36.17074	7.49E-08	2.901295
Error	1.226779	15	0.081785			
Total	72.6487	23				

Table E50: Effect of Elapsed Time on Optimum Moisture Content (OMC) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	122.81	20.46833	0.605977
Row 2	6	120.8	20.13333	0.623467
Row 3	6	107.72	17.95333	0.582787
Row 4	6	103	17.16667	0.544387
Column 1	4	79.68	19.92	2.821933
Column 2	4	77.94	19.485	2.564967
Column 3	4	76.67	19.1675	2.547292
Column 4	4	75.2	18.8	2.642733
Column 5	4	73.62	18.405	2.684167
Column 6	4	71.22	17.805	2.551767

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	47.26621	3	15.7554	1371.128	1.63E-18	3.287382
Columns	11.61072	5	2.322144	202.0867	3.31E-13	2.901295
Error	0.172363	15	0.011491			
Total	59.0493	23				

Table E51: Effect of Elapsed Time on Optimum Moisture Content (OMC) of black cotton soil – lime – IOT Mixtures. (WAS) (ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	134.57	22.42833	1.698297
Row 2	6	128.98	21.49667	1.544027
Row 3	6	117.77	19.62833	0.611497
Row 4	6	100.96	16.82667	0.481627
Column 1	4	85.88	21.47	8.742133
Column 2	4	83.44	20.86	7.298867
Column 3	4	80.93	20.2325	5.667158
Column 4	4	79.57	19.8925	5.322092
Column 5	4	77.54	19.385	5.7177
Column 6	4	74.92	18.73	4.558133

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	109.8534	3	36.61779	266.0038	3.18E-13	3.287382
Columns	19.61235	5	3.92247	28.49413	3.74E-07	2.901295
Error	2.064883	15	0.137659			
Total	131.5306	23				

Table E.52:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the OMC of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
WAS	0	Time	3	59.5444	1.46E-08	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	40.0704	3.71E-08	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	2	Time	3	64.3450	8.53E-09	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	43.0940	2.25E-08	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	4	Time	3	230.8107	9.01E-13	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	36.1707	7.49E-08	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	6	Time	3	371.128	1.63E-18	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	202.0867	3.31E-13	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	8	Time	3	266.0038	3.18E-13	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	28.4941	3.74E-07	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect

Table E53: Variation of Maximum Dry Density (MDD) on Black Cotton Soil -Lime Mixture with IOT Content (BSH)

IOT	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.63	1.61	1.56	1.64	1.57
2%	1.66	1.64	1.58	1.67	1.6
4%	1.69	1.67	1.65	1.72	1.66
6%	1.74	1.71	1.67	1.75	1.68
8%	1.74	1.73	1.68	1.76	1.7
10%	1.76	1.74	1.68	1.75	1.7
1 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.64	1.67	1.62	1.68	1.66
2%	1.66	1.69	1.65	1.7	1.68
4%	1.68	1.7	1.67	1.73	1.7
6%	1.71	1.72	1.7	1.75	1.73
8%	1.73	1.74	1.72	1.76	1.75
10%	1.76	1.77	1.74	1.79	1.78
2 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.64	1.65	1.63	1.68	1.62
2%	1.66	1.67	1.65	1.7	1.64
4%	1.67	1.69	1.66	1.71	1.65
6%	1.69	1.7	1.68	1.73	1.67
8%	1.7	1.73	1.69	1.74	1.67
10%	1.72	1.74	1.68	1.74	1.67
3 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	1.59	1.59	1.63	1.6	1.65
2%	1.63	1.62	1.65	1.64	1.67
4%	1.66	1.65	1.69	1.67	1.7
6%	1.69	1.68	1.72	1.71	1.73
8%	1.72	1.71	1.73	1.72	1.74
10%	1.71	1.7	1.75	1.74	1.76

Table E.58:- Two –Way Analysis of variance (ANOVA) on the MDD

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
BSH	0	Lime	4	101.4467	5.51E-13	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	203.2081	1.99E-16	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	74.8947	9.56E-12	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	280.8421	8.3E-18	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	62.5824	5.04E-11	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	54.5165	5.74E-11	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	48.2258	5.38E-10	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	220.7097	8.84E-17	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table E59: Variation of Optimum Moisture Content (OMC) on Black Cotton Soil -Lime Mixture with IOT Content (BSH)

BSH 0 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	19	19.25	20.45	19.99	21.96
2%	18.51	19.01	19.91	19.21	20.81
4%	18	18.25	19	18.54	19.44
6%	17.79	18.02	18.64	18.3	18.98
8%	17.5	17.65	18.27	17.95	18.65
10%	16.87	17.35	17.86	17.5	17.95
BSH 1 Hr					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	21.76	20.76	21.65	20.3	19.96
2%	21	19.71	20.5	20.08	19.78
4%	20.25	19.14	20	19.58	19.5
6%	20.01	18.71	19.5	19.22	18.95
8%	19.51	18.16	19.25	19.01	18.5
10%	19	17.33	18.5	18.11	17.87
BSH 2 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	21.55	21.62	21.66	20.38	20.66
2%	21.18	20.84	21.01	20.22	19.98
4%	21.02	20.5	20.85	20.1	19.27
6%	20.83	20	20.35	19.57	18.69
8%	20.45	19.2	19.8	18.78	18.35
10%	20	19.03	19.05	18.49	18.06
BSH 3 Hrs					
IOT %	0% lime	2% lime	4% lime	6% lime	8% lime
0%	22.29	20.58	19.5	19.84	21.47
2%	21.15	20.04	19	19.38	21
4%	20.62	19.75	18.51	18.97	20.25
6%	20.16	19.39	17.74	18.28	19.8
8%	19.55	18.78	17.22	17.89	19.25
10%	19.03	18.26	16.83	17.12	18.5

Table E65: Effect of Elapsed Time on Maximum Dry Density (MDD) of Black cotton soil–lime – IOT Mixtures.(BSH)

0% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.63	1.66	1.69	1.74	1.75	1.76
1	1.64	1.66	1.68	1.71	1.73	1.76
2	1.64	1.66	1.67	1.68	1.7	1.72
3	1.59	1.63	1.66	1.69	1.72	1.73
2% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.61	1.64	1.67	1.71	1.73	1.74
1	1.67	1.69	1.7	1.72	1.74	1.77
2	1.65	1.67	1.69	1.7	1.73	1.74
3	1.59	1.62	1.65	1.68	1.72	1.73
4% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.56	1.58	1.65	1.67	1.68	1.69
1	1.62	1.65	1.67	1.7	1.72	1.74
2	1.63	1.65	1.66	1.68	1.69	1.7
3	1.63	1.65	1.69	1.72	1.73	1.75
6% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.64	1.67	1.72	1.75	1.76	1.77
1	1.68	1.7	1.73	1.75	1.76	1.79
2	1.68	1.7	1.71	1.73	1.74	1.75
3	1.6	1.64	1.67	1.71	1.72	1.74
8% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1.57	1.6	1.66	1.68	1.7	1.72
1	1.66	1.68	1.7	1.73	1.75	1.78
2	1.62	1.64	1.65	1.67	1.7	1.72
3	1.65	1.67	1.7	1.73	1.74	1.76

Table E66: Effect of Elapsed Time on Maximum Dry Density (MDD) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	10.23	1.705	0.00283
Row 2	6	10.18	1.696667	0.002027
Row 3	6	10.07	1.678333	0.000817
Row 4	6	10.02	1.67	0.00292
Column 1	4	6.5	1.625	0.000567
Column 2	4	6.61	1.6525	0.000225
Column 3	4	6.7	1.675	0.000167
Column 4	4	6.82	1.705	0.0007
Column 5	4	6.9	1.725	0.000433
Column 6	4	6.97	1.7425	0.000425

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.004683	3	0.001561	8.168605	0.001852	3.287382
Columns	0.0401	5	0.00802	41.96512	2.7E-08	2.901295
Error	0.002867	15	0.000191			
Total	0.04765	23				

Table E67: Effect of Elapsed Time on Maximum Dry Density (MDD) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	10.1	1.683333	0.002707
Row 2	6	10.29	1.715	0.00131
Row 3	6	10.18	1.696667	0.001187
Row 4	6	9.99	1.665	0.00307
Column 1	4	6.52	1.63	0.001333
Column 2	4	6.62	1.655	0.000967
Column 3	4	6.71	1.6775	0.000492
Column 4	4	6.81	1.7025	0.000292
Column 5	4	6.92	1.73	6.67E-05
Column 6	4	6.98	1.745	0.0003

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.008033	3	0.002678	17.33813	3.87E-05	3.287382
Columns	0.03905	5	0.00781	50.56835	7.37E-09	2.901295
Error	0.002317	15	0.000154			
Total	0.0494	23				

Table E68: Effect of Elapsed Time on Maximum Dry Density (MDD) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.83	1.638333	0.003017
Row 2	6	10.1	1.683333	0.002027
Row 3	6	10.01	1.668333	0.000697
Row 4	6	10.17	1.695	0.00223
Column 1	4	6.44	1.61	0.001133
Column 2	4	6.53	1.6325	0.001225
Column 3	4	6.67	1.6675	0.000292
Column 4	4	6.77	1.6925	0.000492
Column 5	4	6.82	1.705	0.000567
Column 6	4	6.88	1.72	0.000867

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.010813	3	0.003604	18.56223	2.61E-05	3.287382
Columns	0.036938	5	0.007388	38.04721	5.3E-08	2.901295
Error	0.002913	15	0.000194			
Total	0.050663	23				

Table E69: Effect of Elapsed Time on Maximum Dry Density (MDD) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	10.31	1.718333	0.002777
Row 2	6	10.41	1.735	0.00163
Row 3	6	10.31	1.718333	0.000697
Row 4	6	10.08	1.68	0.00284
Column 1	4	6.6	1.65	0.001467
Column 2	4	6.71	1.6775	0.000825
Column 3	4	6.83	1.7075	0.000692
Column 4	4	6.94	1.735	0.000367
Column 5	4	6.98	1.745	0.000367
Column 6	4	7.05	1.7625	0.000492

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.009779	3	0.00326	17.18155	4.07E-05	3.287382
Columns	0.036871	5	0.007374	38.86823	4.58E-08	2.901295
Error	0.002846	15	0.00019			
Total	0.049496	23				

Table E70: Effect of Elapsed Time on Maximum Dry Density (MDD) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	9.93	1.655	0.00343
Row 2	6	10.3	1.716667	0.002027
Row 3	6	10	1.666667	0.001427
Row 4	6	10.25	1.708333	0.001817
Column 1	4	6.5	1.625	0.001633
Column 2	4	6.59	1.6475	0.001292
Column 3	4	6.71	1.6775	0.000692
Column 4	4	6.81	1.7025	0.001025
Column 5	4	6.89	1.7225	0.000692
Column 6	4	6.98	1.745	0.0009

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.016633	3	0.005544	40.24194	2.06E-07	3.287382
Columns	0.041433	5	0.008287	60.14516	2.17E-09	2.901295
Error	0.002067	15	0.000138			
Total	0.060133	23				

Table E.71:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the MDD of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
BSH	0	Time	3	8.1686	0.00185	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	41.9651	2.7E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	17.3381	3.87E-05	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	50.5684	7.37E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	18.5622	2.61E-05	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	38.0472	5.3E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	17.1816	4.07E-05	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	38.8682	4.58E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	40.2419	2.06E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	60.1452	2.17E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table E72: Effect of Elapsed Time on Optimum Moisture Content (OMC) of Black cotton soil –lime – IOT Mixtures.(BSH)

0% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	19	18.51	18	17.79	17.5	16.87
1	21.76	21	20.25	20.01	19.51	19
2	21.55	21.18	21.02	20.83	20.45	20
3	22.29	21.15	20.62	20.16	19.56	19.03
2% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	19.25	19.01	18.51	18.02	17.65	17.35
1	20.76	19.71	19.14	18.71	18.16	17.33
2	21.62	20.84	20.5	20	19.2	19.03
3	20.58	20.04	19.75	19.39	18.78	18.26
4% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	20.45	19.91	19	18.64	18.27	17.86
1	21.65	20.5	20	19.5	19.25	18.5
2	21.66	21.01	20.85	20.35	19.8	19.05
3	19.5	19	18.51	17.74	17.22	16.83
6% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	19.99	19.21	18.54	18.3	17.95	17.5
1	20.3	20.08	19.58	19.22	19.01	18.11
2	20.38	20.22	20.1	19.57	18.78	18.49
3	19.84	19.38	18.97	18.28	17.89	17.12
8% LIME						
Hr	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	21.96	20.81	19.64	18.98	18.65	17.95
1	19.96	19.78	19.5	18.78	18.5	17.87
2	20.66	19.98	19.27	18.69	18.35	18.06
3	21.47	21	20.25	19.8	19.25	18.5

Table E73: Effect of Elapsed Time on Optimum Moisture Content (OMC) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (0%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	107.67	17.945	0.56259
Row 2	6	121.53	20.255	1.00203
Row 3	6	125.03	20.83833	0.301977
Row 4	6	122.81	20.46833	1.359017
Column 1	4	84.6	21.15	2.1514
Column 2	4	81.84	20.46	1.6962
Column 3	4	79.89	19.9725	1.828092
Column 4	4	78.79	19.6975	1.744225
Column 5	4	77.02	19.255	1.555367
Column 6	4	74.9	18.725	1.7451

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	30.89607	3	10.29869	122.1108	9.2E-11	3.287382
Columns	14.86298	5	2.972597	35.24586	8.94E-08	2.901295
Error	1.265083	15	0.084339			
Total	47.02413	23				

Table E74: Effect of Elapsed Time on Optimum Moisture Content (OMC) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (2%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	109.79	18.29833	0.570817
Row 2	6	113.81	18.96833	1.438777
Row 3	6	121.19	20.19833	0.984977
Row 4	6	116.8	19.46667	0.716387
Column 1	4	82.21	20.5525	0.959958
Column 2	4	79.6	19.9	0.577133
Column 3	4	77.9	19.475	0.723233
Column 4	4	76.12	19.03	0.731
Column 5	4	73.79	18.4475	0.465158
Column 6	4	71.97	17.9925	0.666558

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	11.58071	3	3.860238	73.44323	3.4E-09	3.287382
Columns	17.76637	5	3.553274	67.60308	9.47E-10	2.901295
Error	0.788413	15	0.052561			
Total	30.1355	23				

Table E75: Effect of Elapsed Time on Optimum Moisture Content (OMC) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (4%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	114.13	19.02167	0.977977
Row 2	6	119.4	19.9	1.195
Row 3	6	122.72	20.45333	0.866027
Row 4	6	108.8	18.13333	1.089667
Column 1	4	83.26	20.815	1.091233
Column 2	4	80.42	20.105	0.7447
Column 3	4	78.36	19.59	1.090067
Column 4	4	76.23	19.0575	1.258825
Column 5	4	74.54	18.635	1.2903
Column 6	4	72.24	18.06	0.908867

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	18.62995	3	6.209982	178.4378	5.91E-12	3.287382
Columns	20.12132	5	4.024264	115.6333	1.98E-11	2.901295
Error	0.522029	15	0.034802			
Total	39.2733	23				

Table E76: Effect of Elapsed Time on Optimum Moisture Content (OMC) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (6%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	111.49	18.58167	0.805657
Row 2	6	116.3	19.38333	0.630347
Row 3	6	117.54	19.59	0.62952
Row 4	6	111.48	18.58	1.01548
Column 1	4	80.51	20.1275	0.065025
Column 2	4	78.89	19.7225	0.251758
Column 3	4	77.19	19.2975	0.468292
Column 4	4	75.37	18.8425	0.427492
Column 5	4	73.63	18.4075	0.326292
Column 6	4	71.22	17.805	0.374833

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	5.051346	3	1.683782	36.61833	3.84E-07	3.287382
Columns	14.71529	5	2.943058	64.00463	1.4E-09	2.901295
Error	0.689729	15	0.045982			
Total	20.45636	23				

Table E77: Effect of Elapsed Time on Optimum Moisture Content (OMC) of Black cotton soil –lime – IOT Mixtures.(BSH)(ANOVA) (8%lime)

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	6	117.99	19.665	2.20387
Row 2	6	114.39	19.065	0.66599
Row 3	6	115.01	19.16833	1.004217
Row 4	6	120.27	20.045	1.21275
Column 1	4	84.05	21.0125	0.779692
Column 2	4	81.57	20.3925	0.362892
Column 3	4	78.66	19.665	0.175367
Column 4	4	76.25	19.0625	0.256425
Column 5	4	74.75	18.6875	0.155625
Column 6	4	72.38	18.095	0.078967

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3.73605	3	1.24535	11.04785	0.000439	3.287382
Columns	23.74328	5	4.748657	42.12665	2.63E-08	2.901295
Error	1.69085	15	0.112723			
Total	29.17018	23				

Table E.78:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the OMC of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
BSH	0	Time	3	122.1108	9.2E-11	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	35.2459	8.94E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	73.4432	3.4E-09	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	67.6031	9.47E-10	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	178.4378	5.91E-12	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	115.6333	1.98E-11	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	36.6183	3.84E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	64.0046	1.4E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	11.0479	0.000439	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	42.1267	2.63E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

APPENDIX F: UNCONFINED COMPRESSIVE STRENGTH

Table F1: Variation of Unconfined Compressive Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content (BSL)(7days) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	85.63	153.53	307.79	413.02	622.05
2	118.41	223.11	436.53	511.2	757.58
4	148.42	303.3	603.04	784.3	972.54
6	183.5	384.29	801.49	1093.09	1198.29
8	217.22	526.59	1071.28	1459.12	1562.88
10	192.8	475.39	922.93	1237.73	1425.58

Table F.9:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:BSL-7days	0	Lime	4	37.4490	5.05E-09	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	13.4553	7.98E-06	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	1	Lime	4	55.9081	1.41E-10	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	18.9105	5.76E-07	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Lime	4	67.9760	2.35E-11	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	22.3253	1.49E-07	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	3	Lime	4	46.8829	6.93E-10	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	20.0745	3.56E-07	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F.16:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: BSL-7days	0	Time	3	15.2891	7.86E-05	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	27.9719	4.24E-07	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	25.8564	3.54E-06	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	43.7436	2.03E-08	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	48.4072	5.99E-08	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	169.7105	1.2E-12	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	46.7636	2.57E-08	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	177.1222	8.73E-13	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	46.2113	8.19E-08	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	101.663	5.04E-11	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F17: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content (14days)(BSL) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	124.21	200.96	336.04	468.67	709.63
2	162.94	272.49	591.63	668.81	965.89
4	195.47	477.7	756.87	896.37	1195.24
6	220.49	596.18	943.14	1126.23	1328.71
8	315.63	791.25	1144.89	1527.78	1601.77
10	251.92	634.55	981.36	1265.27	1453.28

Table F.25:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:BSL-14days	0	Lime	4	57.9792	1.02E-10	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	20.8945	2.57E-07	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	1	Lime	4	55.7354	1.46E-10	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	24.0383	8.04E-08	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Lime	4	66.4222	2.91E-11	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	26.6426	3.37E-08	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	3	Lime	4	61.6789	5.76E-11	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	22.8077	1.25E-07	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F.32:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: BSL-14days	0	Time	3	20.8459	1.32E-05	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	23.4476	1.35E-06	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	42.9962	1.33E-07	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	112.6095	2.4E-11	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	42.9003	1.35E-07	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	110.6896	2.72E-11	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	47.7634	6.56E-08	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	151.7207	2.72E-12	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	32.3921	8.51E-07	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	63.7320	1.44E-09	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F33: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content (28days)(BSL) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	163.31	311.45	488.84	696.95	771.79
2	203.11	413.18	739.81	913.07	1105.88
4	288.96	532.31	928.49	1142.58	1385.77
6	332.8	704.22	1086.65	1332.63	1547.31
8	497.48	961.74	1374.5	1633.63	1996.55
10	412.89	780.74	1184.52	1494.1	1738.61

Table F.41:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:BSL-28days	0	Lime	4	79.3801	5.55E-12	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	29.2477	1.51E-08	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	88.7108	1.96E-12	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	28.7467	1.76E-08	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	60.7595	6.61E-11	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	23.3017	1.04E-07	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	60.2372	7.16E-11	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	18.8836	5.83E-07	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table F.48:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: BSL-28days	0	Time	3	13.7782	0.00014	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	42.7171	2.39E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	39.8925	2.18E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	123.0937	1.25E-11	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	35.3808	4.8E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	160.4697	1.8E-12	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	26.3891	3.12E-06	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	114.3461	2.15E-11	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	26.4145	3.1E-06	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	113.6332	2.25E-11	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table F49: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content (7days)(WAS) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	188.6	271.99	387.22	544.91	696.78
2	353.24	467.18	580.07	732.27	871.52
4	458.81	528.19	724.73	928.61	1011.21
6	554.07	617.07	922	1097.74	1161.99
8	754.74	943.07	1245.83	1484.12	1560.02
10	663.72	736.17	1045.35	1265.64	1326.39

Table F.57:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:WAS-7days	0	Lime	4	98.7633	7.1E-13	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	96.0362	2.8E-13	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	108.9463	2.92E-13	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	59.0425	2.74E-11	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	175.0633	2.92E-15	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	78.4409	1.92E-12	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	90.1151	1.69E-12	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	35.1916	3.01E-09	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table F.64:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: WAS-7days	0	Time	3	32.1911	8.86E-07	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	48.4249	9.98E-09	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	36.8230	3.7E-07	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	43.1765	2.22E-08	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	65.6444	7.43E-09	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	59.3020	2.4E-09	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	66.4628	6.82E-09	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	53.4815	4.97E-09	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	153.8791	1.73E-11	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	73.7869	5.07E-10	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F65: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content (14days)(WAS) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	258.44	380.28	506.8	775.47	881.19
2	388.74	597.65	721.27	914.28	1019.68
4	585	678.57	914.07	1182.13	1248.11
6	717.05	813.53	1027.91	1292.69	1515.07
8	1086.99	1261.91	1405.6	1616.42	1961.53
10	921.03	1002.54	1105.69	1484	1765.95

Table F.73:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:WAS-14days	0	Lime	4	132.1781	4.4E-14	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	135.0139	1.06E-14	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	1	Lime	4	360.3553	2.5E-18	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	203.2253	1.98E-16	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Lime	4	258.4908	6.54E-17	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	131.7037	1.35E-14	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	3	Lime	4	232.5206	1.84E-16	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	96.7846	2.6E-13	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F81: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content(WAS) (28days) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	554.25	811.28	952.49	1184.94	1373.84
2	696.96	981.62	1276.89	1447.61	1704.81
4	866.14	1197.56	1493.11	1675.25	1850.5
6	1087.58	1377.86	1690.87	1847.64	2095.41
8	1484.98	1846.71	2097.01	2307.67	2592.25
10	1193.67	1596.66	1833.98	2078.37	2216.96

Table F87: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content (WAS)(28days) 3hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	411.19	701	962.9	1211.2	1555.8
2	587.56	974.74	1486.5	1538.5	1793.8
4	909.39	1240.6	1726.4	1853.2	2089.9
6	1077.6	1433.3	1984	2070.1	2289.5
8	1391	1867.7	2216.3	2350.6	2788.5
10	1199.5	1672.9	2013.8	2172.7	2509.7

Table F.89:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:WAS-28days	0	Lime	4	403.5116	8.21E-19	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	346.6119	1.04E-18	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	628.0685	1.03E-20	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	350.3835	9.37E-19	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	328.154	6.29E-18	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	236.4262	4.5E-17	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	340.5021	4.37E-18	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	217.5561	1.02E-16	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table F.96:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: WAS-28days	0	Time	3	95.1776	5.46E-10	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	131.0703	7.93E-12	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	115.1041	1.41E-10	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	152.5068	2.62E-12	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	214.6122	1.54E-12	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	264.379	4.54E-14	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	165.1824	1.04-11	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	144.5676	3.87E-12	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	270.0999	2.84E-13	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	212.5399	2.28E-13	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table F97: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content(BSH) (7days) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	196.43	806.17	1175.91	1213.29	1452.03
2	495.13	1107.5	1361.89	1542.38	1784.5
4	652.91	1410.02	1579.37	1726.68	1993.3
6	729.83	1600.83	1747.77	1925.09	2195.11
8	913.81	1821.23	1944.48	2208.58	2346.48
10	325.02	890.45	1266.94	1390.72	1643.3

Table F.105:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:BSH-7days	0	Lime	4	407.5791	7.43E-19	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	140.7895	7.07E-15	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	1	Lime	4	366.7314	2.11E-18	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	125.7094	2.11E-14	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Lime	4	526.7643	5.89E-20	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	197.8068	2.58E-16	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	3	Lime	4	901.4169	2.86E-22	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	3320435	1.59E-18	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F.112:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: BSH-7days	0	Time	3	101.2462	3.52E-10	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	205.5234	2.42E-13	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	72.3126	3.79E-09	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	133.6517	6.88E-12	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	57.4126	1.87E-08	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	82.5096	2.27E-10	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	119.0751	1.1E-10	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	122.3305	1.31E-11	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	128.7663	6.28E-11	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	132.7381	4.23E-12	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F113: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content(BSH) (14days) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	423.8	1031.34	1291.54	1627.21	1848.01
2	740.89	1370.39	1687.74	2091.71	2323.43
4	1057.96	1574.32	1993.42	2373.78	2585.98
6	1253.11	1848.01	2266.44	2654.18	2863.86
8	1357.8	2053.01	2555.41	2980.04	3191.79
10	1088.44	1230.77	1431.94	1882.91	2081.42

Table F.121:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:BSH-14days	0	Lime	4	133.3439	4.05E-14	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	58.8789	2.82E-11	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	1	Lime	4	103.8021	4.43E-13	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	44.8331	3.43E-10	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Lime	4	114.8597	1.69E-13	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	59.0058	2.76E-11	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	3	Lime	4	157.8309	7.97E-15	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	84.5117	9.46E-13	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect

Table F.128:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: BSH-14days	0	Time	3	81.9794	1.51E-09	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	197.188	3.96E-13	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	459.6444	5.59E-15	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	799.1446	1.21E-17	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	71.0322	4.29E-09	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	221.5567	1.68E-13	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	235.4539	7.79E-13	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	701.655	3.2E-17	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	190.6122	3.65E-12	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	543.6353	2.15E-16	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table F129: Variation of Unconfined Compression Strength (UCS) of Black Cotton Soil -Lime Mixture with IOT Content (BSH)(28days) 0hr

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	557.49	1135.85	1373.62	1781.58	1987.67
2	863.52	1510.11	1740.48	2145.33	2411.2
4	1143.39	1762.64	2097.15	2397.7	2656.34
6	1463.86	1936.59	2355.14	2674.03	2962.55
8	1695.36	2163.52	2590.99	2984.17	3276.29
10	1264.2	1826.19	2177.55	2512	2713.89

Table F.137:- Two –Way Analysis of variance (ANOVA) on the Unconfined Compressive Stress (UCS)

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS:BSH-28days	0	Lime	4	998.45	1.03E-22	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	406.0474	2.18E-19	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	500.7848	9.72E-20	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	275.1316	1.02E-17	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	249.9632	9.09E-17	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	172.2382	9.97E-16	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	284.6953	2.54E-17	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	157.3699	2.4E-15	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table F.144:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Unconfined Compressive Stress of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
UCS: BSH-28days	0	Time	3	70.2885	4.62E-09	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	119.9428	1.51E-11	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	100.7452	3.65E-10	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	125.9005	1.06E-11	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	102.7994	3.16E-10	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	179.6197	7.87E-13	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	203.9369	2.23E-12	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	447.4899	9.14E-16	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	86.2890	1.09E-09	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	216.295	2E-13	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

APPENDIX G: CALIFORNIA BEARING RATIO

Table G1: Variation of California Bearing Ratio (CBR) of Black Cotton Soil -Lime Mixture with IOT Content (BSL) (SOAKED)

SOAKED GRAPH					
0HR					
IOT	0%L	2%L	4%L	6%L	8%L
0	1.18	2.18	6.71	9.43	13.60
2	1.45	3.26	9.24	13.23	18.13
4	2.18	5.08	11.96	15.95	27.73
6	3.08	6.89	15.77	20.85	34.62
8	4.53	8.7	19.03	28.1	54.62
10	3.76	5.62	13.78	17.58	45.32
1HR					
IOT	0%L	2%L	4%L	6%L	8%L
0	1.49	3.81	7.61	10.33	18.49
2	2.36	4.89	11.96	16.31	22.30
4	4.71	7.25	14.86	21.03	31.72
6	5.8	9.43	19.58	26.65	41.51
8	7.43	12.15	23.75	32.63	56.19
10	6.96	7.93	17.76	23.75	48.94
2HR					
IOT	0%L	2%L	4%L	6%L	8%L
0	2.72	5.98	9.06	13.23	32.63
2	4.53	9.79	14.32	18.13	45.50
4	6.16	12.51	19.76	24.11	52.32
6	7.43	15.95	25.2	29.91	56.19
8	12.15	18.67	34.62	45.32	63.72
10	9.97	14.32	20.6	27.19	60.18
3HR					
IOT	0%L	2%L	4%L	6%L	8%L
0	1.63	3.99	7.07	9.06	21.75
2	3.44	5.44	9.24	12.33	33.72
4	5.08	9.24	14.14	17.22	43.14
6	7.07	11.42	17.22	22.3	52.93
8	10.15	14.86	22.11	29.73	58.01
10	7.98	12.15	15.59	20.85	53.47

Table G.13:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the California bearing ratio (Soaked) of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
CBR: BSL	0	Time	3	20.7273	1.36E-05	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	25.4705	7.87E-07	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	52.8304	3.31E-08	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	64.3294	2.7E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	19.5739	1.91E-08	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	37.8863	5.46E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	18.0239	3.09E-05	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	51.2806	6.68E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	38.2436	2.89E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	65.3734	1.2E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table G14: Variation of California Bearing Ratio (CBR) of Black Cotton Soil -Lime Mixture with IOT Content(BSL)(UNSOAKED)

UNSOAKED GRAPH					
0HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	2.54	8.16	16.31	28.46	43.32
2	3.99	14.86	26.28	40.24	61.27
4	5.08	22.11	30.09	55.29	75.23
6	7.25	30.27	40.24	68.88	89.37
8	10.15	40.06	52.21	84.29	104.23
10	6.16	23.38	35.17	65.26	77.40
1HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	4.17	10.51	31.36	40.42	53.11
2	6.16	21.93	40.6	60.54	78.31
4	8.34	27.37	51.3	73.41	97.34
6	10.33	36.44	64.53	87.92	105.32
8	13.41	45.5	78.49	104.23	129.24
10	9.61	28.28	58.55	81.57	100.79
2HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	7.07	14.5	50.21	66.34	75.59
2	8.16	27.37	64.35	80.3	92.27
4	10.15	36.8	75.23	100.24	112.39
6	12.51	44.23	84.29	112.21	125.62
8	16.31	56.19	99.52	120.36	147.55
10	11.24	40.06	80.12	106.22	118.19

3HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	5.26	12.15	42.24	57.28	62.79
2	7.07	24.11	53.47	71.42	83.20
4	9.06	33.17	62.72	92.45	107.31
6	11.06	40.24	76.5	102.6	118.55
8	14.88	51.3	88.46	110.76	138.23
10	10.33	36.25	69.61	96.62	111.30

Table G.26:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the (un-soaked)California bearing ratio of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
CBR: BSL	0	Time	3	161.3337	1.23E-11	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	230.9517	1.23E-13	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	2	Time	3	57.4959	1.85E-08	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	185.3684	6.25E-13	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	4	Time	3	294.1555	1.52E-13	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	145.9343	3.62E-12	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	6	Time	3	310.9345	1.01E-13	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	284.6006	2.63E-14	2.9013	F_{CAL}>F_{CRIT}, Significant Effect
	8	Time	3	151.4503	1.95E-07	3.2874	F_{CAL}>F_{CRIT}, Significant Effect
		IOT	5	249.4357	6.99E-14	2.9013	F_{CAL}>F_{CRIT}, Significant Effect

Table G27: Variation of California Bearing Ratio (CBR) of Black Cotton Soil -Lime Mixture with IOT Content(WAS) (SOAKED)

SOAKED					
0HR	0%L	2%L	4%L	6%L	8%L
0	1.63	3.08	7.61	11.96	19.21
2	2.36	5.08	11.6	18.67	27.19
4	4.35	7.07	14.14	22.11	36.25
6	6.34	11.42	18.31	32.27	44.41
8	7.79	13.78	21.75	42.96	67.07
10	5.08	9.97	16.86	30.82	53.66
1HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	2.36	5.08	9.61	14.68	24.83
2	3.26	7.07	15.05	23.38	38.52
4	6.34	9.97	18.49	31.9	47.85
6	9.24	13.41	23.2	40.79	58.73
8	11.42	16.31	27.73	51.84	80.66
10	7.25	11.6	21.57	35.89	64.53
2HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	3.44	7.61	13.6	22.48	34.80
2	6.16	12.33	18.13	28.64	48.76
4	8.7	15.95	22.68	42.24	52.75
6	13.23	20.3	27.37	56.56	70.69
8	15.41	22.48	37.7	70.15	92.70
10	10.88	17.22	25.02	50.39	86.28
3HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	2.9	6.16	11.06	19.94	27.19
2	4.53	7.43	16.31	25.2	42.78
4	7.07	11.06	19.58	37.89	49.12
6	10.51	15.23	25.2	45.32	63.44
8	12.87	17.22	30.27	58.01	85.38
10	7.79	13.23	23.38	41.69	76.31

Table G.38:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the California bearing ratio (Soaked) of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
CBR: WAS	0	Time	3	31.2628	1.07E-06	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	57.2754	3.07E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	91.0952	7.46E-10	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	118.5694	1.65E-11	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	34.6181	5.54E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	70.7589	6.84E-10	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	37.9421	3.04E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	78.9327	3.13E-10	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	48.8766	5.61E-08	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	139.6114	5E-12	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table G39: Variation of California Bearing Ratio (CBR) of Black Cotton Soil -Lime Mixture with IOT Content(WAS) (UNSOAKED)

UNSOAKED					
0HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	3.08	10.69	21.57	37.34	53.29
2	4.89	17.95	30.63	51.3	70.15
4	6.34	28.1	42.24	72.15	93.17
6	8.52	41.33	53.47	89.91	112.21
8	12.33	51.3	63.26	100.24	126.16
10	7.25	33.72	47.13	81.03	99.34
1HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	5.26	12.15	36.62	48.22	62.54
2	7.07	25.56	45.14	71.24	89.18
4	9.61	32.27	63.63	90.45	115.47
6	12.33	43.14	77.76	106.77	123.08
8	15.59	54.2	93.9	122.18	151.36
10	10.69	35.17	70.69	97.16	119.09
2HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	8.16	16.68	63.44	82.48	99.15
2	9.79	30.82	77.95	100.42	122.18
4	11.78	42.05	85.2	127.25	137.76
6	14.86	51.3	92.45	135.95	154.08
8	18.31	62.72	108.76	145.02	172.21
10	12.87	43.69	89.18	131.6	141.03
3HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	6.71	14.86	42.24	62.75	82.30
2	8.34	27.55	58.37	88.1	104.95
4	10.15	35.53	69.06	112.02	120.73
6	13.23	46.22	81.93	123.63	134.14
8	17.22	57.1	97.52	130.69	160.06
10	11.6	37.34	85.56	119.64	123.08

TABLE G.51:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the California bearing ratio of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
CBR: WAS	0	Time	3	284.0951	1.96E-13	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	431.0318	1.21E-15	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	55.3697	2.4E-08	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	403.6269	1.97E-15	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	115.7044	1.36E-10	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	74.5524	4.71E-10	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	261.5966	3.59E-13	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	244.9319	8E-14	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	152.2944	1.87E-11	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	206.4693	2.82E-13	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

Table G52: Variation of California Bearing Ratio (CBR) of Black Cotton Soil -Lime Mixture with IOT Content(BSH) (SOAKED)

SOAKED					
0HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	2.72	6.71	17.22	36.44	58.73
2	6.16	12.51	29.91	52.39	73.05
4	8.34	20.12	38.07	61.63	84.11
6	10.69	31.9	49.12	73.05	109.12
8	12.87	43.14	71.06	107.31	137.40
10	8.7	21.21	40.42	70.51	96.44
1HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	5.8	10.33	28.46	55.47	78.31
2	8.16	18.13	43.14	69.61	89.18
4	11.24	28.18	52.21	80.66	103.69
6	13.23	42.05	68.34	91.18	125.44
8	17.58	55.83	89.37	120.36	153.17
10	12.15	37.16	58.19	83.2	110.57
2HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	7.79	13.6	32.27	60.73	88.28
2	9.97	20.48	47.31	73.6	99.15
4	13.6	32.27	56.56	86.28	115.65
6	16.31	45.14	72.33	97.52	146.56
8	19.4	60.54	95.17	128.34	180.73
10	14.14	40.42	63.44	90.82	120.54
3HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	5.44	11.24	30.63	57.1	80.12
2	7.43	19.4	44.05	70.33	92.45
4	10.51	30.82	54.38	82.11	106.59
6	11.6	43.5	70.51	93.35	135.41
8	18.13	58.01	91.54	122.9	160.79
10	10.69	38.07	60.73	87.19	112.02

TABLE G.64:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the California bearing ratio (Soaked) of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
CBR: BSH	0	Time	3	70.2885	4.62E-09	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	119.9428	1.51E-11	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	2	Time	3	100.7452	3.65E-10	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	125.9005	1.06E-11	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	4	Time	3	102.7994	3.16E-10	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	179.6197	7.87E-13	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	6	Time	3	203.9369	2.23E-12	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	447.4899	9.14E-16	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect
	8	Time	3	86.2890	1.09E-09	3.2874	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	216.295	2E-13	2.9013	F_{CAL}>$F_{CRIT,}$ Significant Effect

Table G65: Variation of California Bearing Ratio(CBR) of Black Cotton Soil -Lime Mixture with IOT Content(BSH) (UNSOAKED)

UNSOAKED					
0HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	5.44	13.41	33.9	64.17	88.28
2	9.06	21.75	46.4	88.28	105.68
4	12.33	48.04	53.84	110.94	129.61
6	15.41	56.19	66.34	132.69	156.44
8	18.31	59.82	87.01	143.75	176.74
10	13.23	34.98	57.28	120.36	146.83
1HR					
1HR					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	8.52	16.68	52.02	89.18	109.31
2	10.69	31.72	83.75	107.13	125.44
4	14.86	49.31	92.45	129.06	159.70
6	17.58	59.82	112.57	154.08	190.33
8	20.33	68.16	128.7	163.14	215.35
10	16.31	38.97	106.95	145.56	174.02
2HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	12.3	21.75	76.13	94.26	138.13
2	14.32	36.25	103.32	125.62	161.33
4	17.58	54.38	119.48	154.08	185.44
6	20.85	66.71	143.2	165.3	209.37
8	23.56	72.33	151.18	181.27	229.31
10	19.03	45.68	125.44	158.61	194.86
3HRS					
IOT/LIME	0%L	2%L	4%L	6%L	8%L
0	10.15	18.49	66.16	91.36	125.44
2	12.51	34.44	85.56	112.93	133.05
4	15.41	51.66	101.51	147.19	164.23
6	18.31	61.27	121.99	160.06	192.51
8	21.39	70.15	130.15	174.02	221.15
10	16.31	40.42	109.12	154.08	181.27

TABLE G.77:- Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the California bearing ratio of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
CBR: BSH	0	Time	3	193.5068	3.27E-12	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	421.5178	1.43E-15	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Time	3	38.6971	2.67E-07	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	475.983	5.77E-16	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	4	Time	3	127.6902	6.67E-11	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	68.3755	8.73E-10	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	6	Time	3	127.511	6.74E-11	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	302.9074	1.66E-14	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect
	8	Time	3	151.7386	1.92E-11	3.2874	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	264.685	4.5E-14	2.9013	$F_{CAL}>F_{CRIT}$, Significant Effect

APPENDIX H: DURABILTY

Table H1. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 0 hour using BSL compaction

BSL UCS- 0HR -14DAYS

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	124.21	200.96	336.04	468.67	709.63
2	162.94	272.49	591.63	668.81	965.89
4	195.47	477.7	756.87	896.37	1195.24
6	220.49	596.18	943.14	1126.23	1328.71
8	315.63	791.25	1144.89	1527.78	1601.77
10	251.92	634.55	981.36	1265.27	1453.28

BSL UCS-0HR -7DAYS CURING + 7DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	3.3	10.9	14.8	20	31
2	4.2	14	20.5	25.2	40
4	5.3	18	34	42	51
6	7.5	28	43	49	60
8	11	32	51.5	57	67
10	6.8	20.2	37	44	53

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	2.66	5.42	4.40	4.27	4.37
2	2.58	5.14	3.47	3.77	4.14
4	2.71	3.77	4.49	4.69	4.27
6	3.40	4.70	4.56	4.35	4.52
8	3.49	4.04	4.50	3.73	4.18
10	2.70	3.18	3.77	3.48	3.65

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	97.34321	94.57604	95.59576	95.73261	95.63153
2	97.42236	94.8622	96.535	96.23211	95.85874
4	97.28859	96.23194	95.50782	95.31443	95.73307
6	96.59849	95.30343	95.44076	95.6492	95.48434
8	96.51491	95.95577	95.50175	96.2691	95.81713
10	97.30073	96.81664	96.22972	96.52248	96.35308

Table H2. Anova of variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 0 hour using BSL compaction

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	21.12086	4.224172	0.987825
Row 2	5	19.08959	3.817917	0.877999
Row 3	5	19.92414	3.984829	0.624149
Row 4	5	21.52378	4.304756	0.270181
Row 5	5	19.94135	3.98827	0.155126
Row 6	5	16.77735	3.355469	0.183032
Column 1	6	17.53172	2.921953	0.165977
Column 2	6	26.25398	4.375664	0.73668
Column 3	6	25.18919	4.198198	0.21399
Column 4	6	24.28007	4.046678	0.210153
Column 5	6	25.12211	4.187019	0.088226

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2.872557	5	0.574511	2.734095	0.048596	2.71089
Columns	8.19068	4	2.04767	9.744845	0.000153	2.866081
Error	4.202571	20	0.210129			
Total	15.26581	29				

Table H3. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 1 hour using BSL compaction

BSL UCS- 1HR -14DAYS

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	179.86	235.16	450.81	532.57	722.37
2	210.16	416.86	735.09	903.13	1111.88
4	270.06	634.99	1126.3	1243.28	1407.3
6	332.56	776.21	1244.12	1346.33	1621.12
8	420.79	992.99	1466.13	1634.78	1997.84
10	373.54	847.48	1342.77	1450.32	1740.44

BSL UCS -1HR -7DAYS CURING +7 DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	7.1	12.3	18.1	24.5	31.2
2	9.5	17.1	27	30.4	41
4	12	24.2	40	46.3	55
6	15	32	47.9	54	65
8	19.2	36.7	53.6	64	73
10	13	25.4	42.5	48.2	59

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	3.95	5.23	4.01	4.60	4.32
2	4.52	4.10	3.67	3.37	3.69
4	4.44	3.81	3.55	3.72	3.91
6	4.51	4.12	3.85	4.01	4.01
8	4.56	3.70	3.66	3.91	3.65
10	3.48	3.00	3.17	3.32	3.39

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	96.05249	94.76952	95.985	95.39967	95.68088
2	95.47963	95.8979	96.32698	96.63393	96.31255
4	95.55654	96.18892	96.44855	96.27598	96.09181
6	95.48954	95.8774	96.14989	95.9891	95.99043
8	95.43715	96.30409	96.34412	96.0851	96.34605
10	96.51978	97.00288	96.8349	96.6766	96.61005

Table H4. Anova of variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 1 hour using BSL compaction

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	22.11244	4.422488	0.271705
Row 2	5	19.349	3.8698	0.200729
Row 3	5	19.43821	3.887641	0.113752
Row 4	5	20.50365	4.10073	0.061887
Row 5	5	19.48348	3.896697	0.15033
Row 6	5	16.35579	3.271158	0.036723
Column 1	6	25.46486	4.244144	0.192019
Column 2	6	23.95929	3.993214	0.534638
Column 3	6	21.91056	3.65176	0.083731
Column 4	6	22.93963	3.823272	0.223236
Column 5	6	22.96822	3.828037	0.104507

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3.547063	5	0.709413	6.61893	0.000871	2.71089
Columns	1.196916	4	0.299229	2.791853	0.054256	2.866081
Error	2.143587	20	0.107179			
Total	6.887566	29				

Table H5. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 2 hour using BSL compaction

BSL UCS -2HRS -14DAYS

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	202.2	390.32	519.71	702.87	907.11
2	247.47	577.88	1066.01	1211.87	1462.08
4	344.08	753.16	1234.43	1441.36	1774.38
6	465.52	925.89	1441.97	1591.93	2004.5
8	613.31	1296.36	1685.85	1934.52	2564.81
10	517.9	1024.67	1525.28	1743.62	2195.1

BSL UCS 2HRS - 7DAYS CURING +7DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	8.5	15.7	21.4	29.2	40
2	10.6	20.4	30.9	33.1	51
4	14.8	26.3	45	51	65
6	17.9	36.1	51.2	60	74
8	21.3	39.3	57.1	69	83
10	16	30.5	47	53	64

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	4.20	4.02	4.12	4.15	4.41
2	4.28	3.53	2.90	2.73	3.49
4	4.30	3.49	3.65	3.54	3.66
6	3.85	3.90	3.55	3.77	3.69
8	3.47	3.03	3.39	3.57	3.24
10	3.09	2.98	3.08	3.04	2.92

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	95.79624	95.97766	95.88232	95.8456	95.59039
2	95.71665	96.46986	97.10134	97.26868	96.51182
4	95.69867	96.50805	96.35459	96.46168	96.33675
6	96.15484	96.10105	96.4493	96.23099	96.30831
8	96.52704	96.96843	96.61298	96.43322	96.76389
10	96.9106	97.02343	96.9186	96.96035	97.08442

Table H6. Anova of variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 2 hour using BSL compaction

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	20.90778	4.181557	0.020667
Row 2	5	16.93165	3.38633	0.375641
Row 3	5	18.64026	3.728053	0.107853
Row 4	5	18.75552	3.751103	0.01868
Row 5	5	16.69442	3.338884	0.044309
Row 6	5	15.10261	3.020521	0.00544
Column 1	6	23.19595	3.865992	0.247158
Column 2	6	20.95152	3.491921	0.185199
Column 3	6	20.68086	3.44681	0.187574
Column 4	6	20.79948	3.466579	0.260524
Column 5	6	21.40443	3.567404	0.254969

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	4.10413	5	0.820826	10.43649	4.9E-05	2.71089
Columns	0.717362	4	0.179341	2.280246	0.096474	2.866081
Error	1.572993	20	0.07865			
Total	6.394485	29				

Table H7. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 3 hour using BSL compaction

BSL UCS -3HRS -14DAYS

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	159.38	250.72	406.38	552.01	705.76
2	197.71	408.42	717.1	1034.4	1160.3
4	247.82	535.42	923.69	1248.2	1342.6
6	297.05	760.6	1205.3	1362.4	1519
8	390.58	926.68	1401	1617.2	1825.4
10	321.09	820.67	1291.6	1434.1	1689.2

BSL UCS -3HRS - 7DAYS CURING +7DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	2.8	8.1	13.5	18.3	27
2	4	12.2	18.3	22.1	35
4	4.9	15.7	25	32	43
6	6.5	20.9	30.3	43	53
8	9.3	25.4	35.4	50	58
10	6.1	18	27	36	46

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	1.76	3.23	3.32	3.32	3.83
2	2.02	2.99	2.55	2.14	3.02
4	1.98	2.93	2.71	2.56	3.20
6	2.19	2.75	2.51	3.16	3.49
8	2.38	2.74	2.53	3.09	3.18
10	1.90	2.19	2.09	2.51	2.72

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	98.24319	96.7693	96.67799	96.68484	96.17434
2	97.97683	97.01288	97.44805	97.8635	96.98354
4	98.02276	97.06772	97.29346	97.43631	96.79726
6	97.81182	97.25217	97.4861	96.84381	96.51086
8	97.61893	97.25903	97.47323	96.90824	96.82261
10	98.10022	97.80667	97.90957	97.48971	97.27682

Table H8. Anova of variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 3 hour using BSL compaction

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	15.45034	3.090068	0.610731
Row 2	5	12.7152	2.543039	0.214239
Row 3	5	13.38249	2.676497	0.211235
Row 4	5	14.09524	2.819049	0.264717
Row 5	5	13.91796	2.783592	0.11996
Row 6	5	11.41701	2.283401	0.10935
Column 1	6	12.22625	2.037709	0.048468
Column 2	6	16.83222	2.80537	0.122418
Column 3	6	15.71159	2.618598	0.161065
Column 4	6	16.7736	2.795599	0.211455
Column 5	6	19.43457	3.239095	0.145489

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.860265	5	0.372053	4.69701	0.005342	2.71089
Columns	4.536716	4	1.134179	14.31852	1.13E-05	2.866081
Error	1.584213	20	0.079211			
Total	7.981194	29				

Table H9. Two –Way Analysis of variance (ANOVA) on the Durability(resistance to loss in strength).

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
DUR:BSL	0	Lime	4	9.7449	0.000153	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	2.7341	.04860	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	1	Lime	4	2.7919	0.05426	2.8661	$F_{CAL}<F_{CRIT,}$NotSignificant Effect
		IOT	5	6.6189	0.000871	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Lime	4	2.2803	0.09647	2.8661	$F_{CAL}<F_{CRIT,}$NotSignificant Effect
		IOT	5	10.4365	4.9E-05	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect
	3	Lime	4	14.3185	1.13E-05	2.8661	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	4.6970	0.005342	2.7109	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table H10. Variation of Durability (resistance to loss in strength) with elapsed time for the VariousIOT mixtures at 0%; 2%; 4%; 6% and 8% lime treatment , using BSL compaction.

ELAPSED TIME - UCS BSL- 14DAYS

0% LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	124.21	162.94	195.47	220.49	315.63	251.92
1	179.86	210.16	270.06	332.56	420.79	373.54
2	202.2	247.47	344.09	465.52	613.31	517.9
3	159.38	197.71	247.82	297.05	390.58	321.09

ELAPSED TIME - UCS BSL-7DAYS CURING + 7DAYS SOAKED

0% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	3.3	4.2	5.3	7.5	11	6.8
1	7.1	9.5	12	15	19.2	13
2	8.5	10.6	14.8	17.9	21.3	16
3	2.8	4	4.9	6.5	9.3	6.1

Resistance to loss in strength

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	97.34321	97.42236	97.28859	96.59849	96.51491	97.30073
1	96.05249	95.47963	95.55654	95.48954	95.43715	96.51978
2	95.79624	95.71665	95.6988	96.15484	96.52704	96.9106
3	98.24319	97.97683	98.02276	97.81182	97.61893	98.10022

ELAPSED TIME - UCS BSL- 14DAYS

2% LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	200.96	272.49	477.7	596.18	791.25	634.55
1	235.16	416.86	634.99	776.21	992.99	847.48
2	390.32	577.88	753.16	925.89	1296.36	1024.67
3	250.72	408.42	535.42	760.6	926.68	820.67

ELAPSED TIME - UCS BSL-7DAYS CURING + 7DAYS SOAKED

2% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	10.9	14	18	28	32	20.2
1	12.3	17.1	24.2	32	36.7	25.4
2	15.7	20.4	26.3	36.1	39.3	30.5
3	8.1	12.2	15.7	20.9	25.4	18

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	94.57604	94.8622	96.23194	95.30343	95.95577	96.81664
1	94.76952	95.8979	96.18892	95.8774	96.30409	97.00288
2	95.97766	96.46986	96.50805	96.10105	96.96843	97.02343
3	96.7693	97.01288	97.06772	97.25217	97.25903	97.80667

4% LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	336.04	591.63	756.87	943.14	1144.89	981.36
1	450.81	735.09	1126.3	1244.12	1466.13	1342.77
2	519.71	1066.01	1234.43	1441.97	1685.85	1525.28
3	406.38	717.1	923.69	1205.3	1401	1291.6

4% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	14.8	20.5	34	43	51.5	37
1	18.1	27	40	47.9	53.6	42.5
2	21.4	30.9	45	51.2	57.1	47
3	13.5	18.3	25	30.3	35.4	27

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	95.59576	96.535	95.50782	95.44076	95.50175	96.22972
1	95.985	96.32698	96.44855	96.14989	96.34412	96.8349
2	95.88232	97.10134	96.35459	96.4493	96.61298	96.9186
3	96.67799	97.44805	97.29346	97.4861	97.47323	97.90957

6% LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	468.67	668.81	896.37	1126.23	1527.78	1265.27
1	532.57	903.13	1243.28	1346.33	1634.78	1450.32
2	702.87	1211.87	1441.36	1591.93	1934.52	1743.62
3	552.01	1034.4	1248.2	1362.4	1617.2	1434.1

6% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	20	25.2	42	49	57	44
1	24.5	30.4	46.3	54	64	48.2
2	29.2	33.1	51	60	69	53
3	18.3	22.1	32	43	50	36

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	95.73261	96.23211	95.31443	95.6492	96.2691	96.52248
1	95.39967	96.63393	96.27598	95.9891	96.0851	96.6766
2	95.8456	97.26868	96.46168	96.23099	96.43322	96.96035
3	96.68484	97.8635	97.43631	96.84381	96.90824	97.48971

8% LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	709.63	965.89	1195.24	1328.71	1601.77	1453.28
1	722.37	1111.88	1407.3	1621.12	1997.84	1740.44
2	907.11	1462.08	1774.38	2004.5	2564.81	2195.1
3	705.76	1160.3	1342.6	1519	1825.4	1689.2

8% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	31	40	51	60	67	53
1	34.2	44	55	65	73	59
2	40	51	65	74	83	64
3	27	35	43	53	58	46

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	95.63153	95.85874	95.73307	95.48434	95.81713	96.35308
1	95.26558	96.04274	96.09181	95.99043	96.34605	96.61005
2	95.59039	96.51182	96.33675	96.30831	96.76389	97.08442
3	96.17434	96.98354	96.79726	96.51086	96.82261	97.27682

Table H 11. Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Durability (resistance to loss in strength) of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
DUR: BSL	0	Time	3	47.1036	7.2E-08	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	2.2291	0.10514	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	25.5932	3.78E-06	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	11.6235	9.99E-05	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	43.5006	1.23E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	7.9115	0.000799	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	26.7141	2.89E-06	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	10.4923	0.000178	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	34.8388	5.31E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	20.1584	3.57E-06	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table H12. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 0 hour using WAS compaction

WAS UCS-14DAYS -0HR

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	258.44	380.28	506.8	775.47	881.19
2	388.74	597.65	721.27	914.28	1019.68
4	585	678.57	914.07	1182.13	1248.11
6	717.05	813.53	1027.91	1292.69	1515.07
8	1086.99	1261.91	1405.6	1616.42	1961.53
10	921.03	1002.54	1105.69	1484	1765.95

WAS UCS - 0HR-7DAYS CURING +7DAYSSOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	3.8	15	24	27	36.1
2	7.4	25	35.5	39	49
4	10.2	32	45.1	47	65
6	14.9	42.6	52	55	70
8	19	46.5	60	64	76
10	16	36	44	48	55

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	1.47	3.94	4.74	3.48	4.10
2	1.90	4.18	4.92	4.27	4.81
4	1.74	4.72	4.93	3.98	5.21
6	2.08	5.24	5.06	4.25	4.62
8	1.75	3.68	4.27	3.96	3.87
10	1.74	3.59	3.98	3.23	3.11

IOT%		0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
	0	98.52964	96.05554	95.2644	96.51824	95.90327
	2	98.09641	95.81695	95.07813	95.73435	95.19457
	4	98.25641	95.2842	95.06602	96.02413	94.79213
	6	97.92204	94.76356	94.94119	95.74531	95.37975
	8	98.25205	96.31511	95.73136	96.04063	96.12547
	10	98.26281	96.40912	96.02058	96.7655	96.88553

Table H13. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 1 hour using WAS compaction

WAS UCS-14DAYS -1HR

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	309.47	726.64	962.81	1209.76	1700.78
2	551	1060.12	1360.93	1574.56	1996.47
4	777.17	1390.79	1733.28	1969.71	2234.2
6	990	1618.29	1966.66	2159.86	2374.42
8	1384.27	1987.73	2302.42	2539.68	2721.68
10	1097.39	1776.16	2133.8	2337.53	2533.78

WAS UCS -1HR-7DAYS CURING +7DAYSSOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	5.5	19	28	37	42.1
2	8.8	28.4	40	44	54
4	11.2	36	50.1	54	69
6	17.9	47.8	60	66.3	74
8	23.1	51.8	66	73	82
10	18.4	42.3	50	58	63

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	1.78	2.61	2.91	3.06	2.48
2	1.60	2.68	2.94	2.79	2.70
4	1.44	2.59	2.89	2.74	3.09
6	1.81	2.95	3.05	3.07	3.12
8	1.67	2.61	2.87	2.87	3.01
10	1.68	2.38	2.34	2.48	2.49

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	98.22277	97.38523	97.09185	96.94154	97.52467
2	98.4029	97.32106	97.06083	97.20557	97.29523
4	98.55887	97.41154	97.10953	97.25848	96.91165
6	98.19192	97.04626	96.94914	96.93036	96.88345
8	98.33125	97.39401	97.13345	97.12562	96.98715
10	98.32329	97.61846	97.65676	97.51875	97.5136

Table H13. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 2 hours using WAS compaction.

WAS UCS-14DAYS -2HRS

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	418.32	860.74	1123.36	1332.86	1957.56
2	654.55	1339.94	1766.25	1974.98	2246.78
4	810.94	1621.84	1926.38	2142.89	2484.87
6	1079.38	1885.57	2108.4	2379.32	2621.15
8	1642.67	2242.15	2493.62	2790.67	2990.19
10	1337.62	1897.14	2215.75	2521.94	2786.29

WAS UCS -2HRS-7DAYS CURING +7DAYSSOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	9	21	37	43.1	53
2	14.4	29.9	45.7	50.7	59.9
4	16.8	38.3	55.6	59.1	76
6	20.1	56.5	65.9	72	82
8	25.3	60.9	73.1	83	89
10	22.1	45.8	53	67	72

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	2.15	2.44	3.29	3.23	2.71
2	2.20	2.23	2.59	2.57	2.67
4	2.07	2.36	2.89	2.76	3.06
6	1.86	3.00	3.13	3.03	3.13
8	1.54	2.72	2.93	2.97	2.98
10	1.65	2.41	2.39	2.66	2.58

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	97.84854	97.56024	96.70631	96.76635	97.29255
2	97.80002	97.76856	97.4126	97.43289	97.33396
4	97.92833	97.63848	97.11376	97.24204	96.94149
6	98.13782	97.00356	96.87441	96.97393	96.8716
8	98.45982	97.28386	97.06852	97.0258	97.0236
10	98.34781	97.58584	97.60803	97.34332	97.41592

Table H14. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 3 hours using WAS compaction.

WAS UCS-14DAYS -3HRS

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	308.48	611.93	862.69	1011.4	1434.3
2	395.48	728.99	1133.69	1352.5	1763.7
4	508.8	1024.6	1313.5	1547.8	1931.8
6	734.29	1170.5	1565.7	1773.5	2086.2
8	1054.8	1428.6	1962.5	2243.9	2407.8
10	984.87	1226.6	1792.8	2087.2	2256.11

WAS UCS -3HRS-7DAYS CURING +7DAYSSOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	3.2	13.8	22	24.2	34.1
2	5.8	20.2	29.5	33.1	42.7
4	9.1	25.1	35.1	40.2	58.2
6	11.4	30	45	52.1	62.1
8	15.1	33.4	54	60.1	67.2
10	13.9	29.1	36.1	44.4	53.2

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	1.04	2.26	2.55	2.39	2.38
2	1.47	2.77	2.60	2.45	2.42
4	1.79	2.45	2.67	2.60	3.01
6	1.55	2.56	2.87	2.94	2.98
8	1.43	2.34	2.75	2.68	2.79
10	1.41	2.37	2.01	2.13	2.36

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	98.96266	97.74484	97.44984	97.60728	97.62253
2	98.53343	97.22904	97.39788	97.55268	97.57895
4	98.21148	97.55026	97.32775	97.40277	96.98727
6	98.44748	97.43699	97.12589	97.06231	97.0233
8	98.56845	97.66205	97.24841	97.32163	97.20907
10	98.58865	97.62759	97.98639	97.87275	97.64196

Table H 15. Two –Way Analysis of variance (ANOVA) on the Durability (resistance to loss in strength).

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
DUR:WAS	0	Lime	4	72.1184	1.36E-11	2.8661	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	8.6335	.000173	2.7109	F_{CAL}>$F_{CRIT,}$ Significant Effect
	1	Lime	4	57.0683	1.17E-10	2.8661	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	5.2452	0.003085	2.7109	F_{CAL}>$F_{CRIT,}$ Significant Effect
	2	Lime	4	19.6347	1.06E-06	2.8661	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	3.2506	0.02615	2.7109	F_{CAL}>$F_{CRIT,}$ Significant Effect
	3	Lime	4	43.68755	1.3E-09	2.8661	F_{CAL}>$F_{CRIT,}$ Significant Effect
		IOT	5	6.27036	0.001184	2.7109	F_{CAL}>$F_{CRIT,}$ Significant Effect

Table H16. Variation of Durability (resistance to loss in strength) with elapsed time for the VariousIOT mixtures at 0%; 2%; 4%; 6% and 8% lime treatment, using WAScompaction.ANOVA.

ELAPSED TIME WAS -14DAYS

0%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	258.44	388.74	585	717.05	1086.99	921.03
1	309.47	551	777.17	990	1384.27	1097.39
2	418.32	654.55	810.94	1079.38	1642.67	1337.67
3	308.48	395.48	508.8	734.29	1054.8	984.87

ELAPSED TIME WAS - 7DAYS CURING + 7DAYS SOAKED

0% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	3.8	7	10.2	14.9	19	16
1	5.5	8.8	11.2	17.9	23.1	18.4
2	9	14.4	16.8	20.1	25.3	22.1
3	3.2	5.8	9.1	11.4	15.1	13.9

Resistance to loss in strength

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	98.52964	98.19931	98.25641	97.92204	98.25205	98.26281
1	98.22277	98.4029	98.55887	98.19192	98.33125	98.32329
2	97.84854	97.80002	97.92833	98.13782	98.45982	98.34787
3	98.96266	98.53343	98.21148	98.44748	98.56845	98.58865

2%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	380.28	597.65	678.57	813.53	1261.91	1002.54
1	726.64	1060.12	1390.79	1518.29	1987.73	1776.16
2	860.74	1339.94	1621.84	1772.79	2242.15	1897.14
3	611.93	728.99	1024.6	1170.5	1428.6	1226.6

2% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	15	25	32	42.6	46.5	36
1	19	28.4	36	47.8	51.8	42.3
2	21	29.9	38.3	56.5	60.9	45.8
3	13.8	20.2	25.1	30	33.4	29.1

2%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	96.05554	95.81695	95.2842	94.76356	96.31511	96.40912
1	97.38523	97.32106	97.41154	96.85172	97.39401	97.61846
2	97.56024	97.76856	97.63848	96.81293	97.28386	97.58584
3	97.74484	97.22904	97.55026	97.43699	97.66205	97.62759

4%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	506.8	721.27	914.07	1027.91	1405.6	1105.69
1	962.81	1350.93	1733.28	1966.66	2302.42	2133.8
2	1123.36	1766.25	1926.38	2108.4	2493.67	2215.75
3	862.69	1133.6	1313.5	1565.7	1962.5	1792.8

4% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	24	35.5	45.1	52	60	42
1	28	40	50.1	60	66	46
2	37	45.7	55.6	65.9	73.1	53
3	22	29.5	36.1	45	54	32

4%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	95.2644	95.07813	95.06602	94.94119	95.73136	96.20147
1	97.09185	97.03908	97.10953	96.94914	97.13345	97.84422
2	96.70631	97.4126	97.11376	96.87441	97.06858	97.60803
3	97.44984	97.39767	97.25162	97.12589	97.24841	98.21508

6%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	775.47	914.28	1182.13	1292.69	1616.42	1484
1	1209.76	1574.55	1969.71	2159.86	2539.68	2337.53
2	1332.86	1974.98	2142.89	2379.32	2790.67	2521.94

3	1011.4	1352.5	1547.8	1773.5	2243.9	2087.2

6% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	27	39	47	55	64	50
1	37	44	54	66.3	73	58
2	43.1	50.7	59.1	72	83	67
3	24.2	33.1	40.2	52.1	60.1	44.4

6%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	96.51824	95.73435	96.02413	95.74531	96.04063	96.63073
1	96.94154	97.20555	97.25848	96.93036	97.12562	97.51875
2	96.76635	97.43289	97.24204	96.97393	97.0258	97.34332
3	97.60728	97.55268	97.40277	97.06231	97.32163	97.87275

8%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	881.19	1019.68	1248.11	1515.07	1961.53	1765.95
1	1700.78	1996.47	2234.2	2374.4	2721.68	2533.78
2	1957.56	2246.78	2484.87	2621.15	2990.19	2786.29
3	1434.3	1763.7	1931.8	2086.2	2407.8	2256.11

8% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	36.1	49	65	70	76	55
1	42.1	54	69	74	82	63
2	53	59.9	76	82	89	72
3	34.1	42.7	58.2	62.1	67.2	53.2

8%LIME

HR	0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT
0	95.90327	95.19457	94.79213	95.37975	96.12547	96.88553
1	97.52467	97.29523	96.91165	96.88342	96.98715	97.5136
2	97.29255	97.33396	96.94149	96.8716	97.0236	97.41592
3	97.62253	97.57895	96.98727	97.0233	97.20907	97.64196

Table H 17. Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Durability (resistance to loss in strength) of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
DUR: WAS	0	Time	3	4.5659	0.01832	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	0.7843	0.57663	2.9013	$F_{CAL}<F_{CRIT,}$NotSignificant Effect
	2	Time	3	45.9720	8.48E-08	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	3.8708	0.01878	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	134.8104	4.91E-11	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	12.2418	7.41E-05	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	42.5286	1.43E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	3.7832	0.02043	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	33.9663	6.26E-07	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	4.7873	0.008105	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect

Table H18. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 0 hour using BSH compaction.

BSH UCS 14DAYS-0HR

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	423.8	1031.34	1291.54	1627.21	1848.01
2	740.89	1370.39	1687.74	2091.71	2323.43
4	1057.96	1574.32	1993.42	2373.78	2585.98
6	1253.11	1848.01	2266.44	2654.18	2863.86
8	1357.8	2053.01	2555.41	2980.04	3191.79
10	1088.44	1230.77	1431.94	1882.91	2081.42

BSH UCS- 0HR- 7DAYS CURING +7DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	10.8	28	40	62	76
2	12.3	38	58	78	90
4	15.2	47	71	93	99
6	18	58	86	113	127
8	22.5	67	98	136	151
10	16.4	50	75	102	114

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	2.55	2.71	3.10	3.81	4.11
2	1.66	2.77	3.44	3.73	3.87
4	1.44	2.99	3.56	3.92	3.83
6	1.44	3.14	3.79	4.26	4.43
8	1.66	3.26	3.84	4.56	4.73
10	1.51	4.06	5.24	5.42	5.48

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	97.45163	97.28509	96.90292	96.1898	95.88747
2	98.33983	97.22707	96.56345	96.27099	96.12642
4	98.56327	97.01458	96.43828	96.0822	96.17166
6	98.56357	96.86149	96.2055	95.74256	95.56543
8	98.34291	96.7365	96.165	95.4363	95.26911
10	98.49326	95.9375	94.76235	94.58285	94.52297

Table H19. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 1 hour using BSH compaction.

BSH UCS 14DAYS-1HR

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	667.5	1206.57	1478.64	1827.14	2048.55
2	980.54	1626.12	1933.74	2287.4	2589.83
4	1194.74	1821.94	2208.93	2574.52	2787.76
6	1432.66	2032.49	2497.53	2950.78	3160.48
8	1576.93	2237.79	2724.41	3184.38	3464
10	1374.16	1439.44	1653.13	2106.07	2301.57

BSH UCS- 1HR- 7DAYS CURING +7DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	12	36	55.4	73	92
2	14	45	77	90	112
4	18	56	89	107	123
6	22	74	108	129	154
8	26	86	127	152	175
10	19.9	64	96	117	130

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	98.20225	97.01634	96.25331	96.00468	95.50902
2	98.57222	97.23268	96.01808	96.0654	95.67539
4	98.4934	96.92635	95.9709	95.84389	95.58786
6	98.46439	96.35915	95.67573	95.62827	95.12732
8	98.35123	96.15692	95.33844	95.2267	94.94804
10	98.55184	95.55383	94.19283	94.44463	94.35168

Table H20. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 2 hours using BSH compaction.

BSH UCS 14DAYS-2HR

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	839.21	1416.73	1672.75	1963.18	2207.96
2	1263.97	1814.96	2215.3	2423.04	2683.64
4	1384.21	2045.07	2463.12	2692.19	2968.6
6	1636.03	2334.78	2687.33	3087.03	3264.78
8	1868.9	2505.1	2996.87	3253.41	3661.18
10	1547.49	1657.19	1893.84	2260.86	2485.91

BSH UCS- 2HR- 7DAYS CURING +7DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	15	42.5	74	91	110
2	17	62	95	103	118
4	22	74	109	114	128
6	26.2	91	131	138	169
8	30.8	110	155	164	181
10	24.1	78	116	123	139

RESISTANCE TO LOSS IN STRENGTH

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	1.79	3.00	4.42	4.64	4.98
2	1.34	3.42	4.29	4.25	4.40
4	1.59	3.62	4.43	4.23	4.31
6	1.60	3.90	4.87	4.47	5.18
8	1.65	4.39	5.17	5.04	4.94
10	1.56	4.71	6.13	5.44	5.59

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	98.2126	97.00013	95.57615	95.36466	95.01803
2	98.65503	96.58395	95.71164	95.74914	95.60299
4	98.41065	96.38154	95.57472	95.76553	95.6882
6	98.39856	96.10242	95.12527	95.52968	94.82354
8	98.35197	95.60896	94.82794	94.95914	95.05624
10	98.44264	95.29324	93.87488	94.55959	94.40849

Table H21. Variation of Durability (resistance to loss in strength) with the IOT content for various lime treatment at 3 hours using BSH compaction.

BSH UCS 14DAYS-3HR

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	600.22	952.6	1390.5	1543.6	1778.7
2	870.91	1255.3	1618.8	1870.8	2194.3
4	1043.1	1477.46	1830.5	2164.9	2302.1
6	1323	1731.1	2225.7	2471.1	2684.8
8	1575.2	1954	2515.7	2764.5	2994.6
10	1167.2	1358.7	1550.4	1890.7	1983.3

BSH UCS- 3HR- 7DAYS CURING +7DAYS SOAKED

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	8	25.7	35	57	71
2	11	35	51	74	85
4	13	40	67	83	92
6	17	52	80	96	116
8	20	61	91	111	130
10	15	47	71	87	102

IOT%	0%LIME	2%LIME	4%LIME	6%LIME	8%LIME
0	98.66716	97.30212	97.48292	96.30733	96.00832
2	98.73695	97.21182	96.84952	96.04447	96.12633
4	98.75371	97.29265	96.3398	96.1661	96.00365
6	98.71504	96.99613	96.40563	96.11509	95.67938
8	98.73032	96.8782	96.38272	95.98481	95.65885
10	98.71487	96.54081	95.42054	95.39853	94.85706

Table H 22. Two –Way Analysis of variance (ANOVA) on the Durability (resistance to loss in strength).

Property	Time	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
DUR:BSH	0	Lime	4	42.0429	1.83E-09	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	6.1609	.00131	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	1	Lime	4	98.0570	7.6E-13	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	11.1446	3.11E-05	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	2	Lime	4	108.3765	2.94E-13	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	8.4381	0.0002	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect
	3	Lime	4	110.0809	2.53E-13	2.8661	$F_{CAL}>F_{CRIT}$, Significant Effect
		IOT	5	7.2443	0.000513	2.7109	$F_{CAL}>F_{CRIT}$, Significant Effect

Table H23. Variation of Durability (resistance to loss in strength) with elapsed time for the VariousIOT mixtures at 0%; 2%; 4%; 6% and 8% lime treatment, using BSHcompaction.ANOVA.

BSH UCS 14DAYS ELAPSED TIME

0% LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	423.8	740.89	1057.96	1253.11	1357.8	1182.34
1	667.5	980.54	1194.74	1423.66	1576.93	1374.16
2	839.21	1263.97	1384.21	1636.03	1868.9	1547.49
3	600.22	870.91	1043.1	1323	1575.2	1168.8

ELAPSED TIME - BSH- UCS -7DAYS CURING +7DAYS SOAKED.

0% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	10.8	12.3	15.2	18	22.5	16.4
1	12	14	18	22	26	19.9
2	15	17	22	26.2	30.8	24.1
3	8	11	13	17	20	15

RESISTANCE TO LOSS IN STRENGTH

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	97.45163	98.33983	98.56327	98.56357	98.34291	98.61292
1	98.20225	98.57222	98.4934	98.45469	98.35123	98.55184
2	98.2126	98.65503	98.41065	98.39856	98.35197	98.44264
3	98.66716	98.73695	98.75371	98.71504	98.73032	98.71663

2% LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1031.34	1370.39	1574.32	1848.01	2053.01	1230.77
1	1206.57	1626.12	1821.94	2032.49	2237.79	1439.44
2	1416.73	1814.96	2045.07	2334.78	2505.1	1657.19
3	952.61	1255.3	1477.4	1731.1	1954	1158.7

2% LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	28	38	47	58	67	50
1	36	45	56	74	86	64
2	42.5	62	74	91	110	78
3	25.7	35	40	52	61	47

RESISTANCE TO LOSS IN STRENGTH

2%LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	97.28509	97.22707	97.01458	96.86149	96.7365	95.9375
1	97.01634	97.23268	96.92635	96.35915	96.15692	95.55383
2	97.00013	96.58395	96.38154	96.10242	95.60896	95.29324
3	97.30215	97.21182	97.29254	96.99613	96.8782	95.94373

4%
LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1291.54	1687.74	1993.42	2266.44	2555.41	1431.94
1	1478.64	1933.74	2208.93	2497.57	2724.41	1653.13
2	1672.75	2215.3	2463.12	2687.33	2996.87	1893.84
3	1390.5	1618.8	1830.5	2225.7	2515.7	1550.6

4%
LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	40	58	71	85	98	75
1	55.4	77	89	108	127	96
2	74	95	109	131	155	116
3	35	51	67	80	91	71

4%
LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	96.90292	96.56345	96.43828	96.24962	96.165	94.76235
1	96.25331	96.01808	95.9709	95.6758	95.33844	94.19283
2	95.57615	95.71164	95.57472	95.12527	94.82794	93.87488
3	97.48292	96.84952	96.3398	96.40563	96.38272	95.42113

6%
LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1627.21	2091.71	2373.78	2654.18	2980.04	1882.91
1	1827.14	2287.4	2574.52	2950.78	3184.38	2106.07
2	1963.18	2423.04	2692.19	3087.03	3253.41	2260.86
3	1543.6	1870.8	2164.9	2471.1	2767.5	1692.9

6% LIME

TIME	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	62	78	93	113	136	102
1	73	90	107	129	152	117
2	91	103	114	138	164	123
3	57	74	83	96	111	87

RESISTANCE TO LOSS IN STRENGTH
6%
LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	96.1898	96.27099	96.0822	95.74256	95.4363	94.58285
1	96.00468	96.0654	95.84389	95.62827	95.2267	94.44463
2	95.36466	95.74914	95.76553	95.52968	94.95914	94.55959
3	96.30733	96.04447	96.1661	96.11509	95.98916	94.86089

8% LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	1849.01	2323.43	2585.98	2863.86	3191.79	2081.46
1	2048.55	2589.83	2787.76	3160.48	3464	2301.57
2	2207.96	2683.64	2968.6	3264.78	3661.18	2485.91
3	1778.7	2192.8	2382.1	2684.8	2994.6	1984

8% LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	76	90	99	127	151	114
1	92	112	123	154	175	130
2	110	118	128	169	181	139
3	71	85	92	116	130	102

8% LIME

HRS	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10% IOT
0	95.88969	96.12642	96.17166	95.56543	95.26911	94.52308
1	95.50902	95.67539	95.58786	95.12732	94.94804	94.35168
2	95.01803	95.60299	95.6882	94.82354	95.05624	94.40849
3	96.00832	96.12368	96.13786	95.67938	95.65885	94.85887

Table H 24. Two –Way Analysis of variance (ANOVA) on Effect of Elapsed Time on the Durability(resistance to Loss in strength) of Black cotton soil-lime-iron ore tailing mixtures.

Property	%Lime	S. O.V	D.F	F_{CAL}	P-Value	F_{CRIT}	Remark
DUR: BSH	0	Time	3	4.8358	0.01504	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	3.1358	0.03907	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	2	Time	3	23.5084	6.37E-06	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	38.8407	4.6E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	4	Time	3	61.9440	1.11E-08	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	53.5565	4.93E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	6	Time	3	11.8463	0.000308	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	36.7418	6.73E-08	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect
	8	Time	3	26.8094	2.83E-06	3.2874	$F_{CAL}>F_{CRIT,}$ Significant Effect
		IOT	5	49.1344	9.02E-09	2.9013	$F_{CAL}>F_{CRIT,}$ Significant Effect