UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
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IMPROVEMENT OF EXPANSIVE SOIL USING INDUSTRIAL WASTES

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Aram AZIZ
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Improvement of Expansive Soil Using Industrial Wastes

M.Sc. Thesis
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Supervisor
Assoc. Prof. Dr. Hanifi ÇANAKÇI

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Aram AZIZ
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Aram AZIZ

ABSTRACT

IMPROVEMENT OF EXPANSIVE SOIL USING INDUSTRIAL WASTES

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M.Sc. in Civil Engineering
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Expansive soils present significant geotechnical and structural engineering challenges the world over, with costs associated with expansive behavior estimated to run into several billion annually. Expansive soils are soils that experience significant volume change associated with changes in water contents. These volume changes can either in the form of swell or in the form shrinkage.

The idea of using recycled materials in construction applications is not a new concept. Reports on this subject can be found dating back to the 1970's. In this study, lignin, wire plastic, rice husk powder (RHP), rice husk ash (RHA) and tire ash (TA) were used for stabilization of expansive soils. The expansive soil is prepared in laboratory as a mixture of red clay and Bentonite. Lignin, wire plastic and rice husk powder were added to the expansive soil with percentage of stabilizer varying from 0 to 20 percent by mass, and different quantities of rice husk ash and tire ash from 0 to 10% by mass were added to expansive soil. Atterberg limits,swelling percentage and unconfined compressive strength were determined for the samples.

It was found that all samples except the 20% lignin treated sample show a decrease in liquid limit and plastic index. Also, Swelling percentage decreased with increasing wire plastic, RHP and RHA percentages, while up to10% lignin and 5% TA swelling percent was decreased. Further increased of lignin and TA (10%lignin and 5%TA) was found to be the optimum with regard to swelling percent.

It was found that lignin, RHP, RHA and curing duration had a significant positive influence on the unconfined compressive strength of the clay.

Keywords: Soil Stabilization, Expansive Soil, Swelling, Waste Materials.

ÖZET

ŞİŞEN KİLLERİN ENDÜSTRİYEL ATIK KULLANILARAK İYİLEŞTİRİLMESİ

AZIZ, Aram Othman
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Şişen killer dünyada geoteknik ve yapı mühendisliği açısından sorun oluşturan bir zemin türüdür. Dünyada yıllık milyarlarca dolarlık maliyetlere onarılabilen hasarların oluşturmasına sebep olmaktadır. Şişen killer suyla temasa geçmeleri durumunda önemli oranda hacim artışıyla karşılaşılmaktadır. Bu hacim değişimi şişme ve büzülme olarak kendini göstermektedir.

Endüstriyel atıkların inşaat sektöründe kullanılmaya başlaması yeni bir fakir olarak ortaya çıkmamıştır. Bu konu ile ilgili çalışmalar 1970 li yıllara kadar gitmektedir. Bu çalışmada, lignin, kablo kaplaması plastik, pirinç kabuğu unu (RHP), pirinç kabuğu külü (RHA) ve araba lastiği külü (TA) kullanılarak şişen killerin iyileştirilmesi çalışılmıştır. Deneylerde kullanılan şişen kil kırmızı kil ile bentonitin karıştırılmasıyla elde edilmiştir. Lignin, kablo kaplaması plastik ve pirinç kabuğu unu ağırlıkça %20 ye kadar ve pirinç kabuğu külü (RHA) ile araba lastiği külü (TA) ise %10 a kadar değişik oranlarda şişen kile katılmıştır. Hazırlana numuneler üzerinde kıvam limitleri, şişme ve serbest basınç deneyleri yapılmıştır.

Deney sonuçlarında %20 lignin katılan numune hariç bütün numunelerde likit limit ve plastisite indeklerinde azalma gözlendi. Ayrıca, kablo kaplaması plastik, RHP ve RHA artmasıyla şişme yüzdesinde azalma gözlendi. Bununla beraber, ligninde %10 a kadar ve TA %5 e kadar şişme oranında azalma gözlendi. Ligninin ve TA in oranlarının artmasıyla şişmede yüzdesinde artış gözlendi. Lignin için %10 ve TA için %5 şişme yüzdesi açısından değerlendirildiğinde optimum olarak belirlendi.

Lignin, RHP ve RHA katılması ve ayrıca kür zamanının şişen kilin serbest basınç dayanımı üzerinde iyileştirirci etkisi olduğu gözlendi.

Anahtar kelimeler: Zemin iyileştirme, Şişen killer, Şişme, Atık maddeler

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LIST OF SYMBOLS/ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Official
ASTM	American society for Testing and Material
C	Percentage of Clay Fraction
FA	Fly Ash
GBFS	Granulated Blast Furnace Slag
Gs	Specific Gravity
IP	Plasticity Index
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PL	Plastic Limit
PVC	Polyvinyl Chloraide
RHA	Rice Husk Ash
RHP	Rice Husk Powder
TA	Tire Ash
UCS	Unconfined Compressive Strength
WP	Wire Plastic
XLPE	Xross-Linked Polythenele

CHAPTER 1

INTRODUCTION

1.1 General

Essentially expansive soil is one that changes in volume in relation to changes in water content. Here the focus is on soils that exhibit significant swell potential and in addition shrinkage potential also exists. Changing water content may be due to seasonal variations (often related to rainfall and the evapo-transpiration of vegetation), or brought about by local site changes such as leakage from water supply pipes or drains, changes to surface drainage and landscaping (including paving).

These types of soil occur in many part of the world, but they are especially abundant in arid and semi-arid zones, where environments are convenient for the formation of clayey minerals (Huang and Wu, 2007; Sabtan, 2005 and Al-Rawas, 2006). The clay mineral that has a high potential to expansiveness belong to smectite group such as montmorillonite or some types of illite (Al-Rawas and Gossen, 2006). These clays are characterized by presence a very small particle size, a large specific surface area and a high Cation Exchange Capacity (CEC) (Fityus and Buzzi, 2009; Nalbantoglu, 2004; Nalbantoglu and Gucbilmez, 2001).The swelling soil may use enough pressure to crack sideways, driveways, basement floors, pipelines and even foundations; causing extensive damage to structures if not adequately treated (Al-Rawas et al. 2002). The annual cost of damage done to non-military engineering structures constructed on expansive soils is estimated at $220 million in the United Kingdom and many billions of dollars worldwide (Gourly et al., 1993).

As a result of the increase in the amount of solid waste all over the globe, engineers and researchers carry out many investigations to find use for such wastes. To improved the problems associated expansive soils, many innovative techniques have been developed. Belled piers (Chen, 1988), granular pile-anchors (Phanikumar, 1997; Phanikumar et al., 2004) and chemical stabilization with lime and fly ash

(Chen, 1988; Hunter, 1988; Cokca, 2001; Phanikumar and Sharma, 2004) have been suggested for mitigating heave problems.

Cokca et al. (2008) studied the possibility of using granulated blast furnace slag (GBFS) and GBFS-cement in stabilization of expansive clays. Brook (2009) studied the use fly ash & RHA in soil stabilization. Attom (1997) studied the use burned olive waste in soil stabilization. Tension cracking and volume change due to swell/shrink in compacted clays decreased when reinforced with polypropylene fibers (Al Wahab and El-Kedrah, 1995; Nataraj and McManis, 1997).

The improvement of soil at a site is indispensible due to rising cost of the land, and there is huge demand for high-rise buildings. There is a need to concentrate on improving properties of soils using cost-effective practices like treating with industrial wastes those having cementations value (Sabbara et al., 2011).

In this study, industrial wastes like lignin, wire plastic, rice husk powder (RHP), rice husk ash (RHA) and tire ash (TA) are used to be reduce an swelling of a soil, at the same time lignin, RHP and RHA is used in increasing strength of the soil.

The soil used in this study are artificial was prepared by mixing 70% red clay (Gs=2.61) and 30% bentonite (Gs=2.40), based on the swelling percentage of the soil, it can be classified as having "high" degree of expansion .

No research had been done (with respect to swelling) on RHP, Wire plastic and tire ash. Therefore the results will be of immense benefit

Geotechnical properties studied in this research includes Index properties such as liquid limit, plastic limit and swelling potential, and unconfined compressive strength of soil with and without non swell materials

. The objective of this research is to evaluate the effect of using industrial waste on soil expansion, Atterberg limits and unconfined compressive strength.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Expansive soils are typically clayey soils that undergo large volume changes in direct response to moisture changes in the soil. Unlike collapsible soils, expansive soils tend to increase in volume (i.e., shrink) as the moisture content of the soil is decreased (Sabatini et al., 2002).

Expansive soils occur in many parts of the world but especially in arid and semi-arid regions. In these regions, evaporation rates are higher than the annual rainfall so that there is almost always a moisture deficiency in the soil (Al-Rawas and Mattheus, 2006).

Swell/shrink is not an inherent property of the clay soil, but a result of interaction between suction (the affinity for water to enter the soil mass) and soil property intrinsic expansiveness. The swell/shrink phenomenon is controlled mainly by the type of clay mineralogical compositions (e.g. Smectite, Kaolinite, Illite and Chlorite), quantity, shape, size and the adsorption capacity of the soil particles, thickness of the active zone, living organisms, age, site topography, duration of weathering and climate (Mitchell, 1993; Chen, 1998; Coduto, 2001; Day, 2001 and Lucian et al., 2006). The direct consequence of swell-shrink behaviour is associated with soils containing clay mineral smectite (montmorillonite).

2.2 Soil as well as Clay Minerals

For engineering purposes, soil is defined as uncemented aggregate of mineral grains and decayed organic matter with liquid and gas in the empty spaces between the solid particles (Wang, 2002). Soils are generally called gravel (>2mm), sand

(>0.075mm), silt (>0.002mm), or clay (<0.002mm), depending on the predominant particle size in the soil. Clay minerals are complex aluminum silicates.

2.2.1Soil formation and constituents

Most soils have been formed by the disintegration of rock as a result of either mechanical or chemical weathering processes. Any sample of soil will be found to contain some or all of following phases: solid, liquid and gas. The solid phase of a soil may contain various amounts of crystalline clay and non-clay minerals, non-crystalline clay mineral, organic matter, and precipitated salts. The crystalline minerals comprise the greatest proportion. Clay minerals in a soil usually influence properties in a manner far greater than their abundance (Wang, 2002).

2.2.2 Clay minerals

The term 'clay minerals' refers to hydrous aluminium phyllosilicates minerals that are fine grained (<0.002 mm) with sheet-like structures and very high surface areas (Cameron, 1992). The clay minerals consist of silcon-oxygen tetrahedral ($(Si_4O_{16})^{2-}$) layer and aluminium ($Al_2(OH)_6$) or magnesium ($Mg_3(OH)_6$), the brucite or gibbsite sheet in the octahedral layer (Wu, 1978). Of the three important clay minerals as shown in Figure2.1. kaolinite consists of repeating layers of element silica tetrahedron, which is linked to form a silica sheet, and aluminum octahedral, which is usually linked to form a gibbsite sheet. The layers are held together by hydrogen bonding (Wang, 2002). Illites consist of one octahedral sheet of either Fe^{3+} and/or Mg^{2+}irons and two tetrahedral sheets in which Al^{3+} occurs as a substituted ion in place of some of the Si^{4+}. Furthermore, illites contain unhydrated interlayer cation K^+ (i.e. they are potassium rich) between layers, and therefore have strong ionic bonding (Grunwald, 2006). The presence of either Na^+, K^+, Mg^{2+} or Ca^{2+} cations in the interlayer prevents the entrance of water into the structure. Montmorillonite has a structure similar to that of illite and there is isomorphous substitution of magnesium and iron for aluminum in the octahedral sheets. Large amounts of water can be attracted into the space between the layers. In the clay minerals, some of the tetrahedral and octahedral spaces are occupied by cations other than those in the ideal structure. This isomorphous substitution in clay minerals, with the breaking of the structure at their edges, gives clay particles a net negative charge. To preserve electrical neutrality, cations are attracted and held between the layers and on the surfaces and edges of the particles. When the clay is placed in water, some of the attracted cations will go into solution. Because the adsorbed cations produce a much higher concentration near the surfaces of particles, they try to diffuse away in order to equalize concentration throughout. The escaping tendency due to diffusion and the opposing electrostatic attraction lead to ion distributions adjacent to a clay particle in suspension as shown in Figure 2.2 the charged surface and the distributed charge in the adjacent phase are together termed the diffuse double layer. The double layer may have some important influences on soil structure and its stability (Wang, 2002).

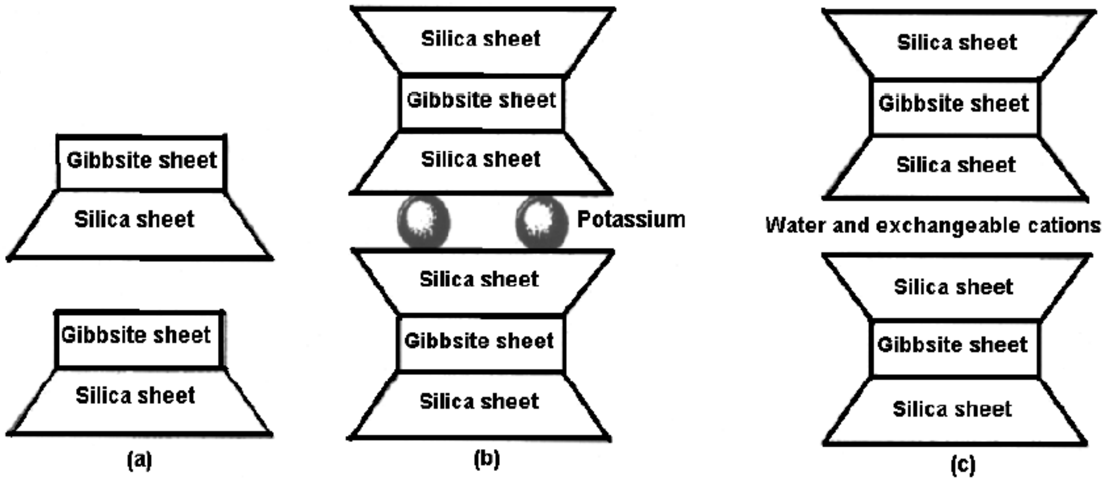


Figure 2.1 Diagram of the structure of (a) kaolinite: (b) illite; (c) montmorillonite (from Das 1997)

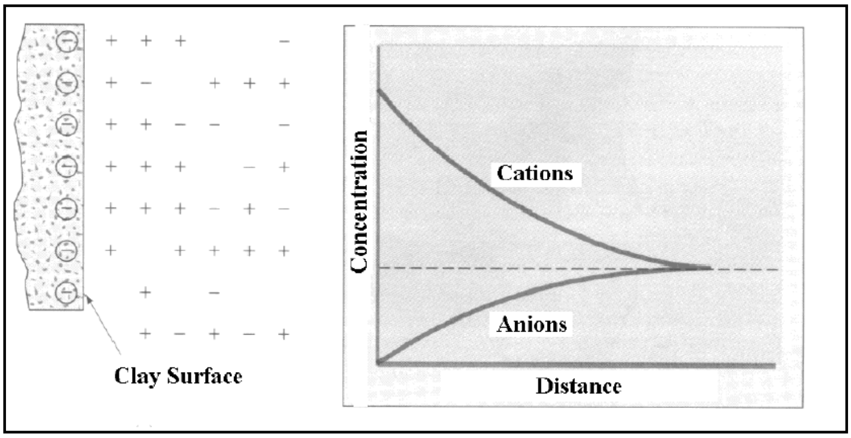


Figure 2.2 Concept of the diffuse double layer (from Das 1997)

2.3 Swelling Parameters

2.3.1 Swelling Potential:

The available literature introduced various definitions for the swell potential. It is defined as the percentage of swell of a laterally confined sample in an oedometer test which is soaked under a surcharge load of 7 kPa (1 lb/in2) after being compacted to maximum dry density at optimum moisture content according to the AASHTO compaction test (Murthy, 2001).

2.3.2 Swelling Pressure:

There are several various definitions with the same purpose for the swell pressure. Swelling pressure is a very useful index of the trouble potential of an expansive soil. This pressure is the maximum force per unit area that required to maintain the initial soil volume when soil specimen is contacted with water (void ratio equal to initial void ratio). A swelling pressure of less than 20 kPa may not be considered as of high value (Al-Rawas and Mattheus, 2006).

It should be noted here that the swelling pressure calculated in a laboratory oedometer is not the same of that in the field. On other hand, the swelling pressure measured is always more than the actual field swelling pressure (Lucian, 2008).

2.4 Factors Influencing Swell potential and Swell pressure

There are many factors that govern the expansion behavior of soil namely: the type and quantities of clay minerals present, the initial dry density (void ratio) and moisture content of the soil specimen, the nature of pore fluid, the type of exchangeable cations, the magnitude of the surcharge pressure, the wetting and drying effects and Other important factors affecting the expansion behavior include amount of nonexpansive material such as gravel or cobble size particles (Ladd and Lambe, 1961; Kassiff and Baker, 1971; Chen, 1988; Day, 1991b, 1992;Yong and Warkentin, 1975; Subba Rao and Satyadas,1987; and Nelson and Miller, 1992).
As clay content and dry density increase, the swell potential and swell pressure increase.While increasing in initial water content, overburden pressure, pore salt

concentration, and exchangeable cation valence lead to decrease the swell potential and swell pressure (Chen, 1988; Seed et al., 1962; Holtz and Gibbs1956; Mitchell, 1976). It has hence been suggested that clay soils could be compacted at water contents in excess of their OMC values to control their swell potentials (Gromko, 1974).These main factors are individually discussed below:

2.4.1 Amount of Clay Size Particles.

A specific type of clay with more clay size particles has a higher swelling (all other factors the same). Clay size particles have a high capacity to water attraction due to double layer effect. Water is also drawn into the soil due to the negative pore water pressures associated with dried clay. Figure 2.3 shows the effect of clay content on swelling (El-Sohby and Rabba, 1981), as can seen, according to test results; the swelling increases when the clay content increases (depending on the soil properties and applied load).

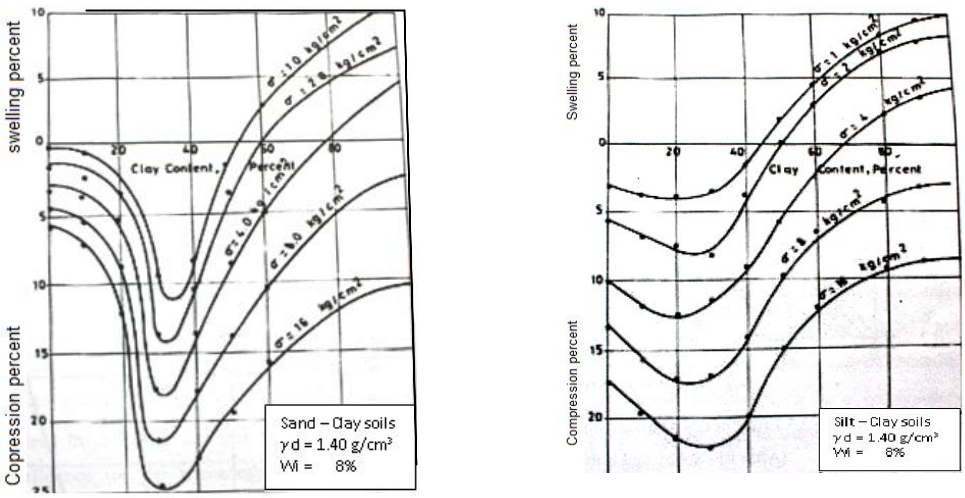


Figure 2.3 Effect of clay content on swlling (After El-Sohby and Rabba, 1981)

2.4.2 Type of Clay Size Particles.

The type of clay size particles is the main factor considerably affects swell potential. For the same dry weight of Kaolinite and Montmorillonite, kaolinite clay particles (activity between 0.3 and 0.5) are much less expansive than sodium montmorillonite clay particles (activity between 4 and 7) (Holtz and Kovacs, 1981), this is due to

Montmorillonite is a much smaller and more active clay mineral than kaolinite. This leads to much more attracted water per unit dry mass of clay particles.

Lambe and Whitman (1969) concluded that swelling capacity changes with the type of clay mineral and decreases in the order; montmorillonite, illite, attapulgite and also depends considerably on exchangeable ions. Particle charaecteristic and engineering properties of the important clay minerals are showed in table.

2.4.3 Density and Water Content.

The dry density and water content have a significant role in the amount and magnitude of swelling of expansive siol. In general, swelling potential increases with increases dry density and decreases moisture content. The most expansive phenomenon take place in high dry density and low moisture content condition Clays that have a low dry density and high water content may not have additional swell, but they could still cause the structure to experience downward movement if they should dry out (Robert, 2010).

El-Sohby and Rabba (1981) studied the influence of (initial moisture content and initial dry density).In order to investigate the effect of initial water content. They prepared remolded samples with different water content at the same dry density. The results show the swelling potential decreases as the water content increases Figure 2.4.

At the same time, to study the effect of dry density on swelling, the above researchers carried out oedometer test. For each specimen the swelling under different loads measured. The test results showed that the increasing in dry density leads to swelling Figure 2.5.

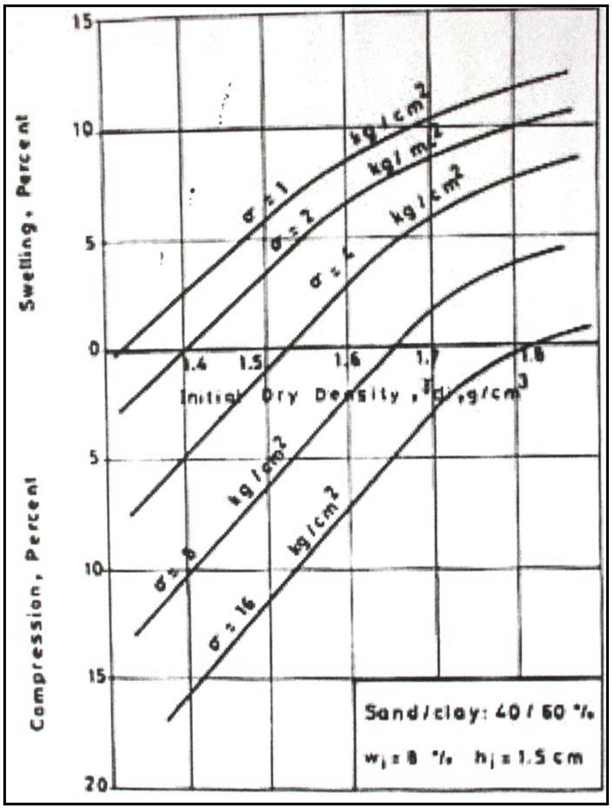


Figure 2.4 Effect of initial dry density of swelling (After El- Sohby and Rabba, 1981)

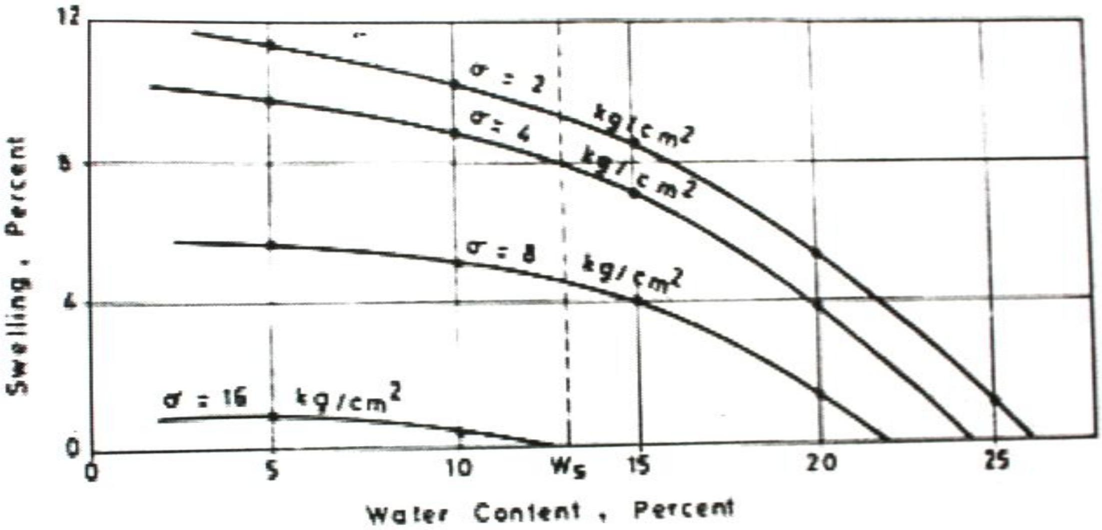


Figure 2.5 Effect of initial water contentof swelling (After El- Sohby and Rabba, 1981)

2.4.4 Surcharge Pressure.

As surcharge pressure increases the amount of swelling potential will decrease. Laboratory and field studies proved that. Usually light weight such as concrete flatwork, pavements, slab-on-grade foundations, or concrete canal liners that are of influenced by expansive soil. Hence the effect of surcharge is important (Robert, 2010).

2.5 Identification and classification of expansive soils

This section deals with the identification and classification of the degree of the expansiveness of soil. Some of the tests and methods have been use for identification of expansive soils. These include direct and indirect estimation.

The parameters of expansive soil can be directly evaluated from special oedometer tests or indirectly from their index properties (liquid limit and plastic index).

2.5.1 Direct measurement:

The direct method of is the actual physical measurement swelling through mineralogical identification of soil.

Many of laboratory tests have been developed to directly measurement the swelling a soil undergoes as water content varies. These include free swell, expansive index, consolidation-swelling, California Bearing Ratio and potential value change

2.5.1.1 Oedometer Test

In case where it is necessary to use disturbed soil samples, the soil sample should be compacted to the required field density and water content in a Proctor Compaction mould. The swell potential and swell pressure of a soil specimen can be determined by a method specified by ASTM Standards (ASTM D 4546–90 Standard for One Dimensional Swell).

Procedure:

The seating pressure (at least 1 kPa) is applied to the clay specimen. After the initial deformations at the seating pressure are complete, the specimen is inundated with water in the oedometer cell and is allowed to swell vertically. The time-swell curve typically consists of three regions. An initial swell region, primary swell region, and secondary swell region Figure 2.6. The minor initial swell is attributed to swelling of the macrostructure, while the major primary swell and minor secondary swell is attributed to microstructural swelling (Rao et al., 2006).

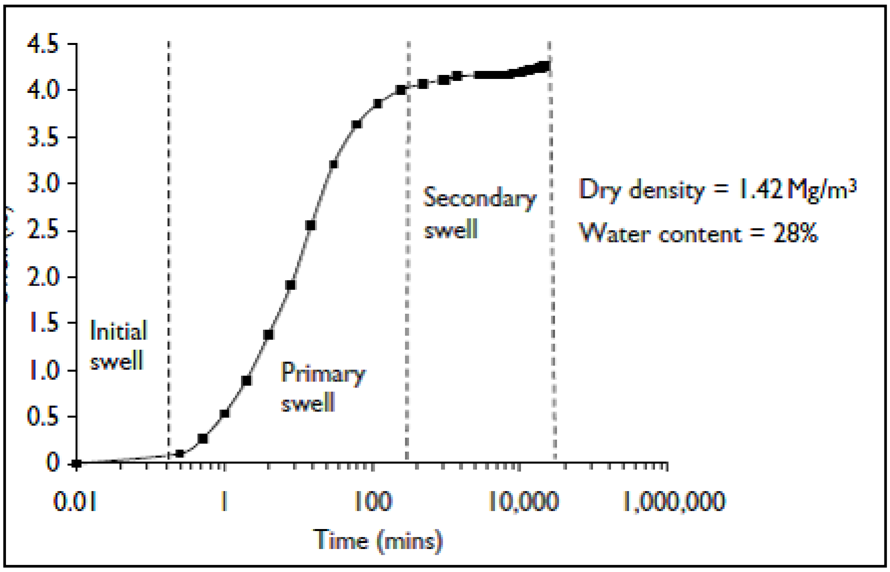


Figure 2.6 Time - swell behavior of compacted black cotton soil(after Al-Rawas, 2006)

Based on the oedometer swell potential values, Holtz and Gibbs (1956) and Seed *et al.* (1962) have classified the relative expansivity of the swelling soils. Holtz and Gibbs' (1956) classification is based on the swell potentials of undisturbed specimens that were inundated under 1 psi (approximately 7 kPa) pressure. Seed et al. (1962) criterion is based on the swell potential of remoulded specimens that were compacted at their Standard Proctor MDD and OMC values and inundated under 1 psi pressure. Table 2.1 gives the expansivity categories proposed by these workers.

Table.2.1 Classification of expansive soils.

Degree of expansion	Holtz and Gibbs (1956) classification of percent swell	Seed et al´s (1962) Classification of percent swell
Low	0-10	0-15
Medium	10-20	1.5-5
High	20-35	5-25
Very High	>35	>25

2.5.2 Indirect evaluation of swell potentials

Besides direct measurement of swell potentials from the oedometer tests, the swelling can be indirectly evaluates without resorting to direct estimate.

The indirect method depend on simple indices such as Attemberg limite, clay content and shrinkage limit.

The Attemberg limit and swelling potential depend on the amount water that clay can be absorbed. The higher plastic index indicates the greater swell potential Figure 2.7. Likewise, a low shrinkage limit indicates that a soil would begin to swell at low water content. The colloid content (1µm) is the most important fraction of the soil providing to swelling and high colloid content indicates high possibility of expansion (AL-Rawas and Mattheus, 2006). The United States Bureau of Reclamation uses these three parameters to indicate the criterion for identification of expansive soils, which are reproduced in Table 2.2.

Table 2.2 Identification of criteria for expansive clays.

Colloid content(%)	Plasticity Index(%)	Shrinkage limit (%)	Degree of expansion	Probably expansion(% total volume change)
<15	<18	<10	Low	<10
13-23	15-28	10-20	Medium	10-20
20-31	25-41	20-30	High	20-30
>28	>35	>30	Very High	>30

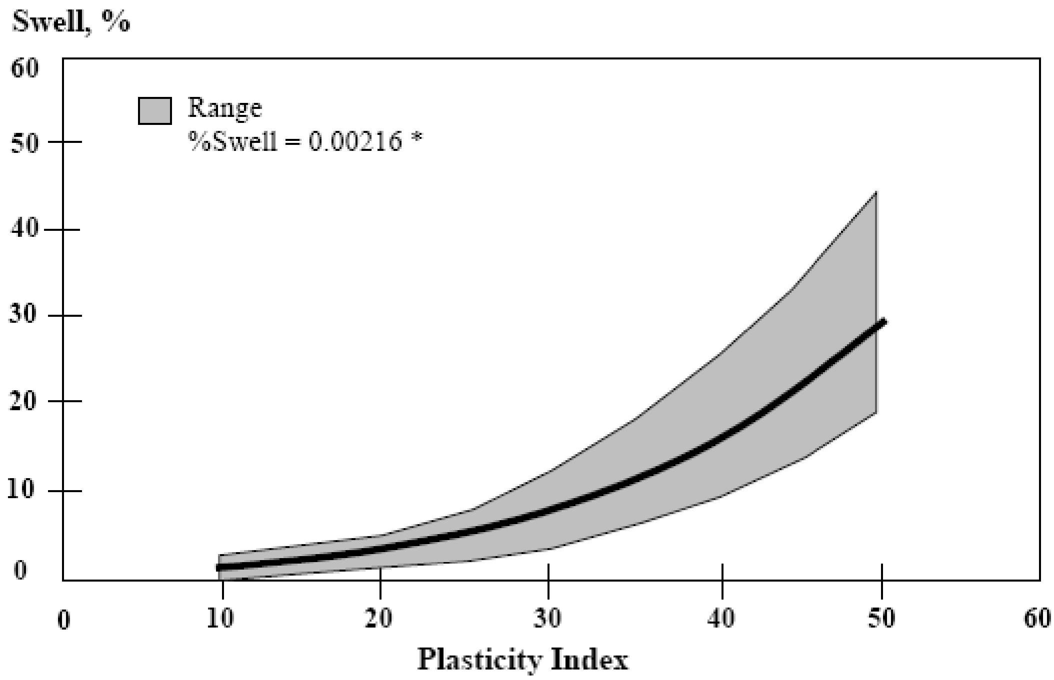


Figure 2.7 Swell potential as a function of plasticity index (Mallela et al., 2004).

2.5.2.1 Identification by Atterberg Limits

Holtz and Gibbs (1956) demonstrated that the plasticity index, Ip, and the liquid limit, are useful indices for determining the swelling characteristics of most clays. Since the liquid limit and swelling of clays both depend on the amount of water a clay tries to absorb, it is natural that they are related. The relation between the swelling potential of clays and the plasticity index has been established as given in Table 2.2.

2.5.2.2 Linear Shrinkage

The swell potential is presumed to be related to the opposite property of linear shrinkage measured in a very simple test. Altmeyer (1955) suggested the values given in Table 2.3 as a guide to the determination of potential expansiveness based on shrinkage limits and linear shrinkage.

2.5.2.3 Colloid Content

There is a direct relationship between colloid content and swelling potential as shown in Fig.2.8. (Chen, 1988). For a given clay type, the amount of swell will increase with the amount of clay percent in the soil.

Table 2.3 Relation between swelling potential, shrinkage limit, and liner shrinkage

Shrink limit %	Liner shrinkage %	Degree of expansion
<10	>8	Critical
10-12	5-8	Marginal
>12	0-5	Non-critical

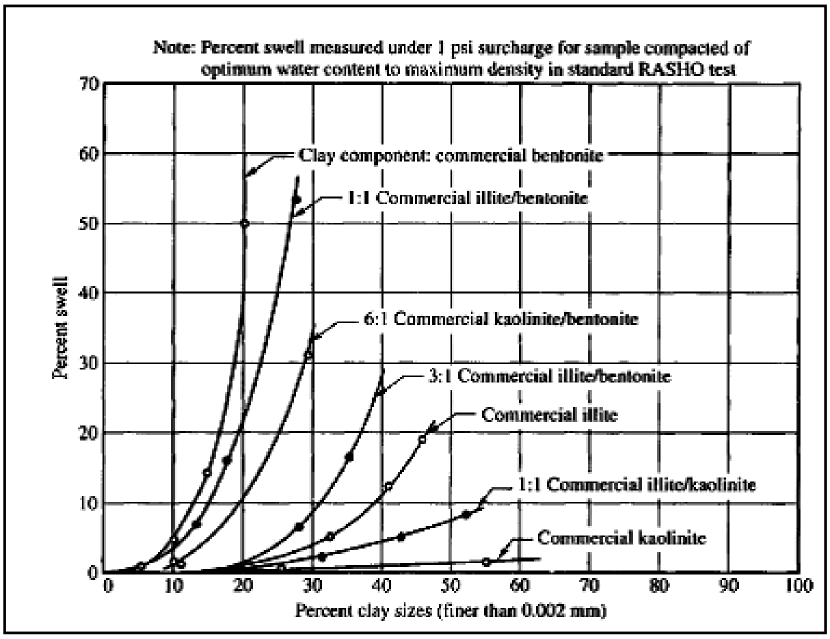


Figure 2.8 Relationship between percentage of swell and percentage of clay size for experimental soils (after saeed et al., 1962)

2.5.3 Expansive Soil Classification Chart.

2.5.3.1 Based on Activity

The expansion potential can also be estimated from expansive soil classification charts. For example, Seed et al. (1962) developed a classification chart based solely on the amount and type (activity) of clay size particles Figure 2.9. When using this chart, the percent clay size refers to the clay fraction of the whole sample and the activity *A* is defined in Equation 2.1.

Skempton (1953) defined activity by the following expression

$$A = Ip/C \qquad 2.1$$

Where:

IP= plasticity index.

C = percentage of clay size finer than 0.002 mm by weight.

The activity method prepared by Seed, Wood ward and lundgen (1962) was based on remolded, artificially prepared soils comprising of mixture of bentonite, illite, kaolinite and fine sand in different proportion. The activity for the artificially prepared sample was defined as:

$$\text{Activity } A=Ip / (C-n) \qquad 2.2$$

Where *n* - 5 for natural soils and, *n* = 10 for artificial mixtures. The proposed classification chart is shown in Figure 2.9.

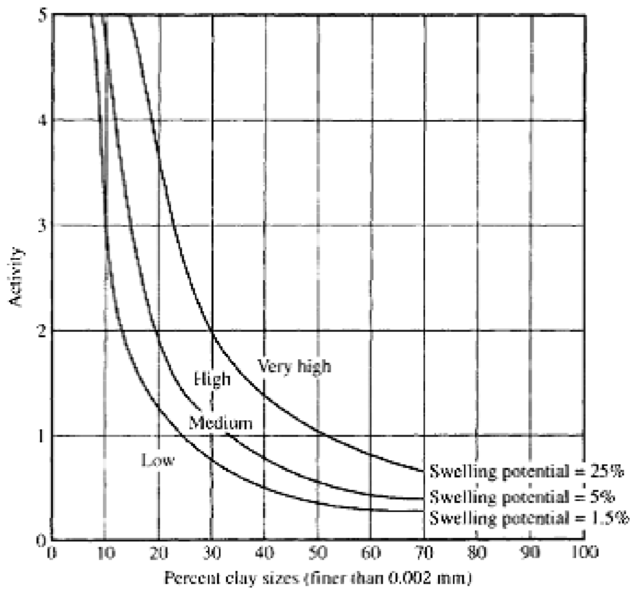
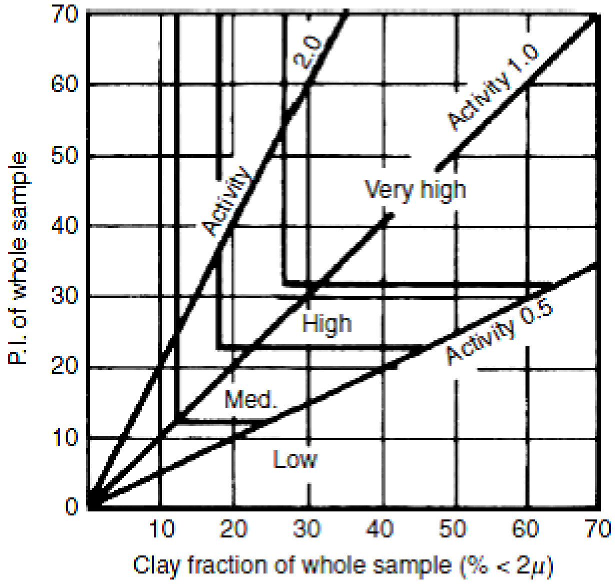


Figure 2.9 Classification chart for swelling potential(after seed, woodward& Lundgren,1962)

2.5.3.2 Based on clay content

Figure 2.10 shows another example of an expansive soil classification chart. For this chart, two of the following three items are required: plasticity index of the whole sample, percent clay of the whole sample, and activity of the clay size particles.



Fiure.2.10 Classification chart for swelling potential (from Van der Merwe, 1964)

CHAPTER 3

SOIL STABILIZATION

3.1 Stabilization Type

Stabilization is the permanent improvement of engineering performance. Two major forms of stabilization were encountered, chemical and mechanical stabilization. Desired engineering characteristic usually include increasing the soil shear strength and/or stiffness, reducing the soil compressibility and/or swell potential. Mechanical stabilization methods can include soil state modifications (such as static or dynamic compaction), consolidation (e.g., preloading, surcharging) and admixing of other geo-materials. Chemical stabilization might be accomplished by admixing of compounds such as lime, Portland cement and bitumen (Wiechert, 2011 and Brandon et al., 2009).

3.1.1Chemical Stabilization

Chemical stabilization is associated with modification of the actual chemical make-up of the soil matrix. Soil stabilization using chemical admixtures is the oldest and most widespread method of ground improvement. Chemical stabilization is mixing of soil with one of or a combination of admixtures of powder, slurry, or liquid for the general objectives of improving or controlling its volume stability, strength and stress-strain behavior, permeability, and durability (Winterkorn and Pamukçu, 1990).

3.1.2 Mechanical Reinforcement

It is also hypothesized that the engineering properties of clays can be improved by reinforcement.

Mechanical reinforcement materials are most commonly made from polymers and plastics, but can also be made from wood fibers, or glass fibers (i.e. fiberglass).

Mechanical reinforcement as a stand-alone stabilizer is limited to coarse-grained materials due to their highly frictional nature. Clay soils can be stabilized with mechanical reinforcement in combination with lime or cement stabilization (Brandon et al., 2009).

3.2 Stabilization Processes

Cementitious materials stabilize soils and modify their properties through cation exchange, flocculation and agglomeration, and pozzolanic reactions. Additionally, cement provides hydration products, which increase the strength and support values of the base materials as well as enhance the performance of the treatment.

3.2.1 Cation exchange

Cation exchange initiates the stabilization process very quickly, and is followed by flocculation and agglomeration.

Clay will absorb cations of specific type and amount to form a double layer. Exchange reactions can occur in response to changes in the environmental conditions, and important changes in the physical and physicochemical properties of the soil may result. For example, the monovalent cations can be readily exchanged with cations of higher valence such as calcium. Upon ion exchange, the higher charge density of divalent or trivalent ions results in a significant reduction of the double-layer thickness, and reduction of the activity and plasticity. Thus, swelling potential decreases. The ease of replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valence cations easily replace cations of lower valence. For ions of the same valence, the size of the hydrated ion becomes important; the larger the ion, the greater the replacement power. If other conditions are equal, trivalent cations are held more tightly than divalent and divalent cations are held more tightly than monovalent cations (Mitchell and Soga, 2005; and Wang, 2002). A typical replaceability series is

$Na^{+} < Li^{+} < K^{+} < Rb^{+} < Cs^{+} < Mg^{2+} < Ca^{2+} < Ba^{2+} < Cu^{2+} < Al^{3+} < Fe^{3+} < Th^{4+}$

The exchangeable cations may be present in the surrounding water or be gained from the stabilizers.An example of the cation exchange (Sivapullah, 2006).

$$Ca^{2+} + Na^{+}\text{-Clay} \Longrightarrow Ca^{2+}\,\text{Clay} + (Na^{+})$$

3.2.2 Flocculation and agglomeration

Flocculation and agglomeration change the clay texture from that of a plastic, fine grained material to that of a granular soil. Flocculation is the process of clay particles altering their structure from a flat, parallel structure to a more random orientation. Agglomeration is thought to occur as the flocculated clay particles begin to form weak bonds at the edge-surface interfaces of the clay particles, because of the deposition of cementitious material at the clay-particle interfaces.

3.2.3 Pozzolanic reaction

Pozzolanic reaction is a secondary process of soil stabilization. One prerequisite for the formation of additional cementing materials is the solution of silica and alumina from clay components. The high pH environment of a soil cement system increases the solubility and reactivity of the silica and alumina present in clay particles. The degree of the crystallinity of the minerals and particle size distribution are some factors influencing solubility. It is postulated that calcium ions combine with silica and alumina dissolved from the clay lattice to form additional cementitious material (C-S-H and C-A-H).

3.2.4 Cementitious hydration

Cement hydration produces cementitious material. Calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) form a network and serve as the “glue” that provides structure and strength in a cement treated soil. The most rapid strength increases occur between one day and one month; smaller gains in strength (due to continued hydration and formation of cementitious material) continue to occur for years (Wang,2002).

3.3 Previous studies

Scientific techniques in soil improvement have been used for many years with degree of of success the engineering properties of the swelling soils may be improved to make them more suitable for construction. Recent projects illustrate that successful waste utilization can result in considerable savings in construction costs (Kamon and Nontananandh, 1990; Edil and Benson, 1998). Fly ash, lime, cement, for example, is widely chosen as a stabilizer to modify (chemically) and improve unstable soils. In clay-bearing soils, these stabilizers induce a textural change resulting and helping to mitigating swelling as well as responsible for improving mechanical properties of soil.

This part of shows foregone various results for different wastes. In generally agro-material was used in improvement of expansive soils.

Mousa F.Attom et al (1997) used burned olive waste as a stabilizer material. The effect on parameters like Attemberg limit, Umconfined compressive strength, grain size distribution maximum dry density and swell pressure of four type of soils (at their natural condition) was studied.

A large number of samples were prepared at MDD and MOC, and placed in the laboratory temperature for 72 hours. The added burned olive wastes were (0, 2.5, 5, and 7.5% by weight).

From view point of consistency limit results, it was noted that as the burned olive ash has a great effect on the plastic index of soils that have high plasticity index(with increasing burned olive waste the plasticity index decreases). At the same time, the burned olive waste has a very small or no effect on the sample which already have a relative plasticity index. This was attributed to the samples partially replaced by non-expansive material.

For strength properties, it found that the addition of 2.5% by weight of burned olive waste leads to increases unconfined compressive strength, while further addition leads to decreases of unconfined compressive strength.

Al-Rawas (2005) studied the effects of Lime, cement and Sarooj (artificial pozzolan) on expansive soil from Oman. The effect of above material on parameters like

Atterberg limit, swelling potential and swelling pressure. He used the lime, cement, comination of lime and cement, Sarooj (burning production of clay or calcining) and heat treatment. The added stabilizer were(3, 6 and 9%), and combination of lime and cemet(3%lime +3,6 and 9% cement) and (5% lime +3,6,and 9% cement). As a test results inferred that for all samples (except for samples treated with combination 5%+cement) the liquid limit increases at addition of 3% stabilizers, further additions of stabilizers, liquid limit slightly decreases. And initial increasing of plastic index is seen when the additive materials was added in 3%, with further addition plastic index gradually decreases. On other hand plastic index decresed as the soil treated with combination of 3%lime+3# cement and 5% lime+ 3% cement. Both swelling potential and swelling pressure of treated samples except for samples treated with 6% and 9% sarooj showed decrease. 6% and 9% Sarroj exhibited an increase in swelling pressure. 6% of lime induced swelling pressure reduced to zero.

Yi Cai et al. (2006) In order to investigate the impact of polypropylene and lime admixture on engineering properties of clayey soil, (Yi Cai et al.; 2006) prepared some specimens with different stabilizer percent.

It was concluded that the addition in admixture of polypropylene fiber and lime causes the beneficial changes in the engineering properties like UCS, swelling potential and shear strength of the clayey soil. And the test results tell us that the optimum gain in strength appears to be with about 5% lime, the addition of percentages greater than 5% will decrease UCS slightly.

An increases in fiber percentage leads to increases in strength.

The swelling potential of clayey soil reduce with an increase in lime content. The unconfined compressive strength, cohesion and friction angles increase while increasing the length of curing.

with the combination of lime stabilization and fibre reinforcement techniques, the fibre–lime soil exhibits more gains in strength, cohesion and internal friction angle than lime stabilized soil does.

Radhey S.Sharma et al. (2008) used lime, Calcium chloride and Rice husk ash as a stabilizer. In the investigation Hydrate lime was used. It is composed mainly of calcium hydroxide (75-80%) and 7% silica, the lime blended expansive soil with lime content 0, 2, 3, 4 and 5%. The calcium chloride contained 98% CaCl2 was used and it added to expansive soil with content of 0, 0.5, 1, 1.5 and 2%. Well burnt RHA passing through 425μm, it also blende with RHA content 0, 4, 8, 12 and 16%.

The experimental tests exhabited that the addition of RHA increased UCS and CBR of clay-CaCl2 mixes. UCS increased by 56% when the calcium chloride content was increased from 0 to 1% at a RHA content of 12%. However, UCS decreased when the calcium chloride content was increased to higher percentages at all RHA contents. And noted that 12% RHA is the optimum value. At any calcium chloride content UCS decreased at RHA% more than 12%.

UCS and CBR of clay-lime mixes increased on addition of RHA. UCS increased by 127% when the lime content was increased from 0 to 4% at a RHA content of 12%. However, the UCS decreased when lime content was further increased to 5% at all RHA contents. A RHA content of 12% was found to be the optimum as UCS decreased at RHA content higher than 12% for any lime content.

Viswanadham et al. (2008) undertake a laboratory study for evaluating the feasibility of using geofiber in expansive soil to reduce arresting heave. The fiber used for reinforcing the expansive soil specimens was a polypropylene fiber (840-TF15090). It had a width of 2 mm and thickness of about 0.021 mm and specific gravity of 0.91. The fiber content (f) was varied as 0.25% and 0.50% by dry weight of expansive soil. The aspect ratio l/b of the fibers was varied as 15, 30 and 45. Aspect ratio is defined as the ratio of length to width of the fiber. For example, l/b=15 implies 2 mm wide fibers of 30 mm long. The specimens (unreinforced and fiber reinforce specimen) were subjected to swell consolidation test. The researchers pointed that for all aspect ratios, swelling decreases as fiber content increases, and also have decreased, indicating that fiber reinforcement was effective in controlling heave.

BROOKS (2009) studied stabilization of soil with fly-ash class C and rice husk ash. He performed possibility using RHA and FA and added into the expansive soil at 0-12% RHA and 0-30%FL. The RHA passing through No.100 sieve (150 micrometer) was used.

In the conclusion pointed that unconfined compressive strength increased by 97% as the RHA percent increased from 0-12%.

With increasing FA from 0-25% UCS increases, further increase in fly ash decreased UCS, indicating that 25% is the optimum value of fly ash.
At any fly ash content, increase in RHA up to 12% increases UCS, greater addition of RHA decreases UCS, indicating that 12% is the optimum value of RHA.

Fidelis O. et al. (2009) investigated the effects of RHA on some geotechnical properties of lateritic soil. Depend on the consistency limit results is appeared that plastic index decreases while RHA is increases.

Khandaker M. (2011) studied the effects of rice husk ash - Kiln dust (CKD) combination on UCS of soils. The addition used of RHA and CKD were (0, 2, 5, 10, 15, and 20%) of total weight of the mixture. It was concluded that the combination of stabilizers with high CKD/RHA produces better mechanical and durability of the soil.

Rama Subbarao et al. (2011) studied the effects of Rice husk ash RHA, RHA-fly ash FA and fly ash – lime L on compaction, strength, index properties and differential free swell index of expansive soil. From view point index properties was concluded that replacement of soil with 4% RHA is the optimum. Thus, with replacement 4% liquid limit and plastic index decrease and also differential free swell index (DFSI) was reduced. Strength properties of soil(UCS) is increased with RHA content for all percentages, but the increase in strength is higher when 4%RHA was replaced as compared to 6%RHA. Therefore also 4% was determined as the optimum point. Also they observed that the curing further improved strength of RHA treated soil.

CHAPTER 4

EXPERIMENTAL STUDY

General

The primary goal of the effort in this study is to determine the effects of industrial wastes (lignin, wire plastic, rice husk ash, rice husk powder and tire ash) on Atterberg limits, swelling and unconfined compressive strength of expansive soil. Laboratory tests were carried out to attest the potential expansiveness and increase in strength of the soils by Atterberg limits swell tests and unconfined compressive strength.

4.1 Materials

4.1.1 Soil

In nature, expansive soils are widely present. However, possible non-homogeneity or disturbance of these soils may prevent to show actual effects of the stabilizers. Thus, an artificially expansive soil sample was prepared in laboratory. An artificial, potentially expansive soil used in this study was prepared by mixing 70% red clay (Gs=2.61, LL=34.25% and PL=19) and 30% bentonite (Gs=2.40). Laboratory tests to determine Atterberg limit, standard proctor compaction test were determined according to ASTM standards.

Table 4.1 summarizes the various properties of the mixture.

Properties	Value
Liquid Limit	148%
Plastic limit	22.37
Swell percent	13%
Degree of expansivity	High
Maximum dry density(MDD)	1.395g/cm³
Optimum moisture content(OMC)	25%

4.1.2 Lignin

Lignin is one of the most abundant polymers in nature and the second in abundance as consistituents of cell walls of plants after cellulose. The chemical composition of lignin varies from plant (Glasser et al. 1981). The chemical structure of lignin can not be describe by a simple structural formula, because it is a stastically amourphous branched biopolymer (Frenderberg and Neish, 1968; sakakibare, 1980; Hawang et al., 1989).

Between 40 and 50 million tons per annum are produced worldwide as a mostly non commercialized waste product.

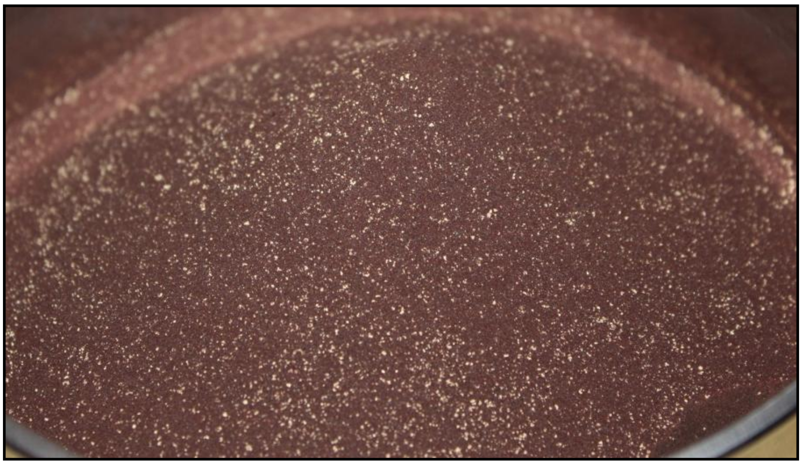


Figure 4.1 shows the view of lignin

4.1.3 Wire Plastic

As with all industrial activity, waste is generated during the manufacturing of cables and when cables are scrapped. For economical and environmental reasons recycling or recovery of the material components from this waste is essential. The need for effective recycling solutions is based on the increasing scarcity of natural resources and the need to reduce the environmental burden (Helmesjö, 2003). The main plastic components in cable waste from cables recycled today are PVC and polyethylene, either in cross linked (XLPE) or thermoplastic (PE) form (Sekiguch et.al, 2007). Cable waste comes from:

• Cable production

• End of the functional life of the cables

• Scrapped cables when there is no need.

As seen from Figure 4.2, the particle size ranges from 0.3 to 1.18 mm, The wire plastic particles pass through a No. 16 sieve an retain on No 50.

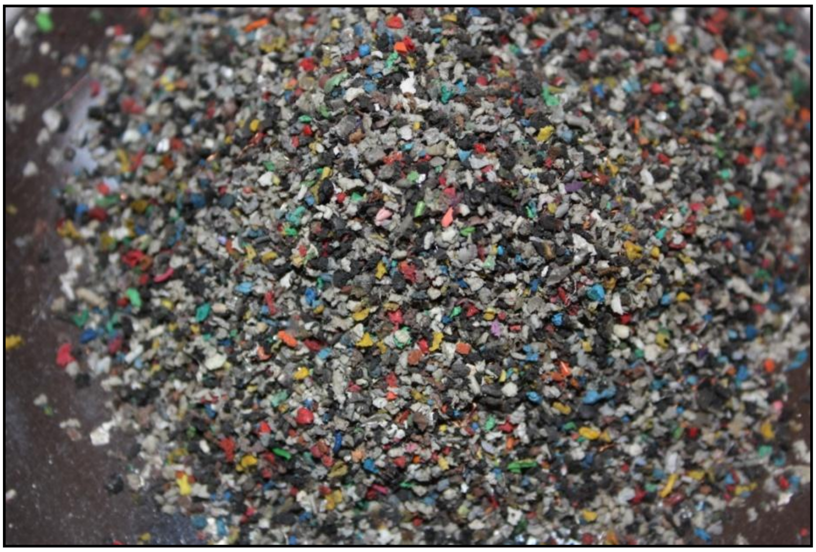


Figure 4.2 view of wire plastic

4.1.4 Rice Husk

Rice husk is an agro- waste material abundantly available in rice producing countries. It is estimated that rice husk of approximately 20% is obtained from the total rice by the milling process. Rice husk roughly contains 35% cellulose, 35% hemicellulose, 20% lignin and 10-20 % ash (94% silica), by dry weight basis (Luh, 1980). This intimate blend of silica and lignin makes the rice hull resistant to water penetration and fungal.

More than 100,000,000 metric tons of rice husk are generated each year throughout the world (Velupillai, 1996). In this study rice husk was used as:

Rice Husk Powder: It was obtained from the grounding of rice husk in a grounding machine for 4 minute under 1000 revolvasion per minute Figure 4.3. As seen from Figure 4.4, the particle size ranges from 0.6 to 0.0053 mm. The RHP pass through a No. 30 sieve and retain on No.270. Table 4.2 shows the chemical constituents of RHP.

Table 4.2 Chemical constituents of rice husk powder (After Han-Seung Yang et al, 2004).

Consistent	Percentage
Holocellulose	60
Lignin	20
Ash	17
Others	3

Figure 4.3 Grounding machine

Figure 4.4 Rice husk after grounding (RHP)

Rice Husk Ash-RHA: It was burnt approximately 1 hour under controlled combustion process. The burning temperature was 600 C°. The particles had a non-uniform shape and its appearance color was grey Figure 4.5. From literature review it can be found that the RHA composed mainly of silicon dioxide SiO_2. The chemical composition of RHA at 600C° are mentioned in table 4.3.

Table 4.3 Chemical composition of rice husk ash (After Ramezanianpour A.A, 2009)

Consistent	**percentage**
Silica (SiO_2)	80.55
Alumina (Al_2O_3)	0.02
Calcium Oxide (CaO)	0.59
Ferric Oxide (Fe_2O_3)	0.24
Sodium (Na_2O)	0.06
Sulphur (Na_2O)	0.34
Magnesium Oxide (MgO)	0.39
Potassium Oxide (K_2O)	1.65
Titanium Oxide(TiO_2)	0.02
Loss on ignition	15.33

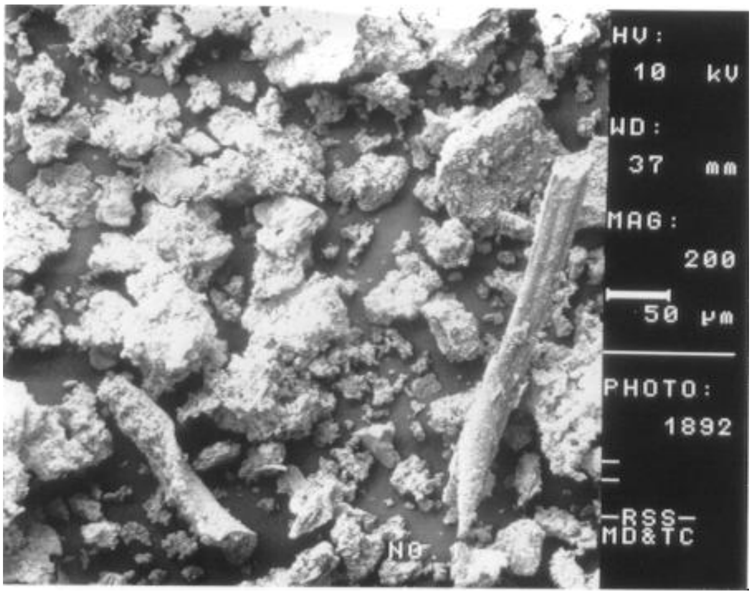
Figure 4.5 Rice husk after burning at 600C°(RHA)

4.1.5 Tire Ash-TA

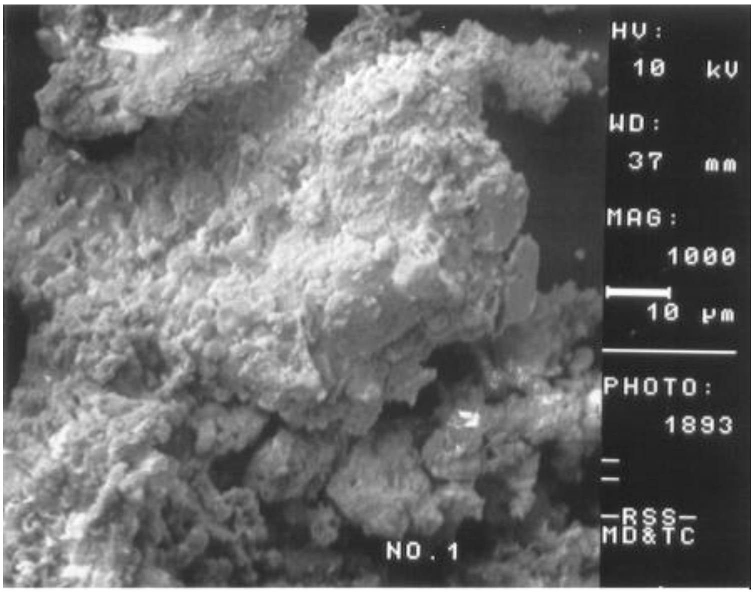
Tire ash was obtained by incinerating quantities of tire chips in an oven at a controlled temperature of 600 °C for 25 hours. The TA was collected from the oven and fine ground Figure 4.7. Chemical composition of TRA are presented in Table 4.4.The SiO_2 and CaO content of the TA are 26.5% and 12.9%, respectively. The scanning electron micrograph examination of TA particles Figure4.6 shows that most particles of TRA are porous and irregular in shape (some particles are sticky).

Table 4.4 Chemical composition of Tire Ash (After Al-Akhras,2003).

Consistent	**Percentage**
Silica Oxide (SiO2)	26.5
Alumina Oxide (Al2O3)	8.7
Calcium Oxide (CaO)	12.9
Ferric Oxide (Fe2O3)	9.3
Sodium Oxide (Na2O)	1.4
Sulphur Oxide (SO3)	1.6
Magnesium Oxide (MgO)	6.4
Potassium Oxide (K2O)	1.1
Titanium Oxide(TiO2)	1.0
Chloride	0.1
Zinc	20.2
Loss of ignition	10.6



(a) magnification 200x (After Al-Akhras, 2003)



(b) 1000 magnification (After Al-Akhras, 2003)

Figure 4.6 Scanning electron micrographs of TRA particles

(a)

(b)

Figure 4.7 (a) Shred of Tire, (b) Tire Ash

4.2 Preparation of Samples

An artificial, potentially expansive soil (mixture), was prepared by mixing 70% red clay(Gs=2.61) and 30% bentonite(Gs=2.40), by dry mass Figure 4.10. The purpose of preparing the mixture soil is to make a more expansive soil. Prior to mixing, the red clays were dried and pass through a No. 40 (0.425 mm) sieve (ASTM D 422-90 1990). After weighing the constituents, Na-Bentonite and red clay were mixed using a trowel. A preliminary swelling test on (expansive soil) resulted in 13% 1-d vertical swell Figure 4.8a, according (Seed et al, 1962 classification) indicating a highly expansive soil. To mitigate the swelling potential and increase of strength of samples, lignin wire plastic and rice husk powder were added in amounts ranging from 5, 10, 15 and 20% in dry mass to expansive soil. And rice husk ash and tire ash were added in amounts ranging from 2.5, 5, 7.5 and 10% in dry mass. Stabilized specimens were prepared by mixing a pre-calculated amount of additives and expansive soil at a moisture content of 25%. For swelling tests the sample expansive soil-additives blends were compacted directly into consolidation ring at 25%

moisture content and sealed in the plastic bags to prevent loss of moisture. Samples were left for 24 hours. For unconfined compressive strength, at the same condition the samples were left for 3 days and 7 days (curing).

4.2.1 Atterberg Limits

When clay minerals are present in fine-grained soil it can be remolded in the presence of some moisture without crumbling. This cohesive nature is caused by the adsorbed water surrounding the clay particles. Liquid limit increases with the increasing of the quantity of expansive clay minerals such as montmorillonite, etc. The liquid limit and plastic limit values of the samples were determined according to the procedure outlined in British Standard BS 1377: Part 2:1990 (ASTM D4318)

4.2.2 Swelling Test Procedure

In this experimental study, the ‘‘Swelling Method’’ (ASTM -D4546- 2008) was used to determine the amount of swell. Single preparation water content was used for all specimens to simulate routine field compaction specifications. Each specimen was prepared 60 gm dry mass and 15 ml water was added to the sample to obtain 25% water content. The total weight of each sample was 70g in the consolidation ring of the oedometer apparatus (height = 20 mm and diameter = 50 mm) ASTM D4546-2008. Each specimen was fitted with dry top and bottom porous stones, and loaded with a predetermined surcharge stress of σ =1 psi or 6.9 kpa. After the oedometer was mounted on the loading device, the dial gauge measuring the vertical deflection was set to zero. After compression ceased, each specimen was inundated with water, and swell was monitored for 4 days (96 hours).

F swell percent was calculated from Eq. 4.1:

$$\text{Swell (\%)} = 100\ dH/H \qquad (1)$$

Where dH is the change in the initial height of the specimen after it is inundated, and H is the original height of the specimen just before the inundation.

4.2.3 Unconfined Compressive Strength test

Single preparation water content (25%) was also used for all samples.the tests were conducted on pure and treated cylindrical samples (46 mm diameter and 100 mm length). The additive materials of lignin, RHP and RHA were chosen in this test. The percentages used of lignin and RHP were 0,5,10,15 and 20% by dry weight of the expansive soil. And 0,2.5,5,7.5 and 10% of RHA were mixed with the expansive soil. The samples were kept in plastic bags and allowed to cure for 3 days and 7 days Figure 4.8b. After curing, the tests were then carried out in accordance with ASTM standard method D2166 (ASTM, 1994), up to failure under constant strain rate (1.2 mm/min).

Figure 4.8 (a) unconfined compressive strength- UCS device, (b)UCS specimens, (C) Oedometer device and (d) specimen after swelling test

CHAPTER 5

RESULTS AND DISCUSSION

5.1Atterberg limit

The liquid limit, plastic limit and plastic index of the untreated and treated samples are shown in Table 5.1.

Figure 5.1 to 5.5 show the effect of additive materials on Liquid limit. In general the LL decreases with increase of all type of the additives.

Figure 5.1 represents the variation of LL with lignin content. It is obvious that all samples except the 20% treated sample show a decrease in liquid limit. The liquid limit decreased from 148% to 67.9% with increase in lignin from 0% to 15%, respectively. This can be considered to be as a result of the binding soil particles and dispersion of the clay fraction by lignin (lignin acts as binder to glue the soil particles together). As the lignin was further increased from 15% to 20%, the liquid limit increased from 67.9% to 86.4% respectively. At this stage the lignin quantity increased to the extent that more water will be required to turn the soil-lignin mix to fluid.

The most decreasing (percentage change) in LL was obtained for the expansive soil treated with 15% lignin Table 5.2. Thus 15%lignin caused a decrease of 54% in LL when compared to the LL of the origin samples (artificial soil). Therefore 15% is considered as the optimum percent of lignin.

The relation between liquid limit and wire plastic waste content is shown in Figure 5.2. It can be seen that the LL of all treated samples showed a decrease at any wire plastic content, at the range of the experimental work carried out in this study. This trend can be attributed to the changing of soil grain size due to the addition of plastic wire, and replacement of the soil fines by wire plastic. The latter has bigger size and no affinity for water, causing a drop in liquid limit. The 20%wire plastic gave the minimum value (113.8) and maximum reduction (23%) in LL as shown in Tables 5.1 and 5.2.Figure 5.3 show the effect of RHP on liquid limit of the expansive soil. Generally, the liquid limit decreases with increase in RHP percentage. This due to the substitution of swelling soil by RHP. The latter has a small ability for water attraction.

It is clear from the curve that up to 10%RHP, the reduction in liquid limit is quite significant beyond which become straight line. This tell us that beyond 10%, the reduction in LL slightly increases. Consequently, the lowest value and maximum reduction in LL is obtained at 20% RHP, thic can be seen in Tables 5.1 and 5.2.

Figure 5.4 shows the variation of LL with RHA percent. As can be seen, the liquid limit decreases with increase of RHA. When the RHA content was increased from 0 to 10%, LL decreased from 148 t0 137.2%, respectively. This due to the increase in particle sizes for the agglomeration of caly particles with RHA. From Table 5.1 it is clear that the addition of RHA in percentages of 2.5% and 5% was not enough to create a considerable reduction in the expansivity of the soil, this improved when the percentages goes to up to 10%. This shows that 7.5% and 10% were more effective. Also maximum reduction was 7% for 10% RHA added sample.

Figure 5.5 illustrates the variation of LL with Tire ash. It is observed that for any particular TA content, an increase in TA content causes a decrease in liquid limit.

It is clear from the curve that up to 5%RHP, the slope of the curve is steeper, after 5% TA the steepness will be decreased.

The minimum value of liquid limit recorded as118% with addition amount of 10%TA when compared to the LL of the origin sample (Artificial soil), that leads to decreases in LL by 20.%.

Basis on the results, it is observed that lignin shows a significant decrease in LL values as compared to the wire plastic and RHP Figure 5.6.consquently, Figure 5.7 shows that tire ash was more effective when compared to RHA.

From Figure 5.8 to Figure 5.12 show the variation of PL with additive materials. It is clear from the curves that lignin, wire plastic and tire ash have a very small or no effect on the plastic limit of the expansive soil (the small change in PL may be due to sensitive balance wrong, rolling to 3 mm). While RHP and RHA show a considerable effect on PL of the expansive soil. This increase of plastic limit implies that RHP and RHA treated soil required more water to change it plastic state to semisolid stat (similar behavior of RHA was noticed by Grytan Sarkar, 2012).

It is indicated from Figure 5.13 to Figure 5.17 that PI of all treated samples(except for samples treated with 20% lignin content) showed a decrease at any additive content. But in the case 20% lignin PI slightly increases. The plastic index was shown in Table 5.1 it is clear that the lignin has a most influence on the expansive soil when it is compared to the other additives materials. Also according to the PI results, 15% lignin, 20%RHP, 10%RHA and 10% TA have a most effect on the PI of the expansive soil.

Table 5.1 Atterberg limit test results

Additive%	LL	PL	PI
0.00%	148	22.37	125.63
5% Lignin	99.5	21.85	77.65
10%Lignin	81.4	22.22	56.9
15% Lignin	67.9	22.8	45.1
20% Lignin	86.4	24.5	61.4
5% W.P	144.5	22.02	122.48
10%W.P	138.12	20.08	118.04
15% W.P	126.4	20.22	106.18
20% W.P	113.79	20.49	93.31
5% RHP	144	24.72	119.28
10% RHP	137.5	28.5	104
15% RHP	133.6	31.78	101.82
20%RHP	132.22	32.94	99.28
2.5%RHA	146.4	22.51	123.89
5% RHA	144	24.24	119.76
7.5% RHA	141.4	26.49	114.9
10%RHA	137.2	26.1	111.1
2.5%TA	142.7	22.1	120.6
5%TA	124.78	23.77	101.01
7.5%TA	123	23.87	99.13
10%TA	118	28	90.03

Table 5.2 Percentage Changes in Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)

Additive%	LL%	PL	PI
5% Lignin	-33	-2	-38
10%Lignin	-45	-1	-55
15% Lignin	-54	2	-64
20% Lignin	-42	10	-51
5% w.P	-2	-2	-3
10%W.P	-7	-10	-6
15% W.P	-15	-10	-15
20% W.P	-23	-8	-26
5% RHP	-3	11	-5
10% RHP	-7	27	-17
15% RHP	-10	42	-19
20%RHP	-11	47	-21
2.5%RHA	-1	1	-1
5% RHA	-3	8	-5
7.5% RHA	-4	18	-9
10%RHA	-7	17	-12
2.5%TA	-4	-1	-4
5%TA	-16	6	-20
7.5%TA	-17	7	-21
10%TA	-20	25	-28

(+)= Increase

(-)= Decrease

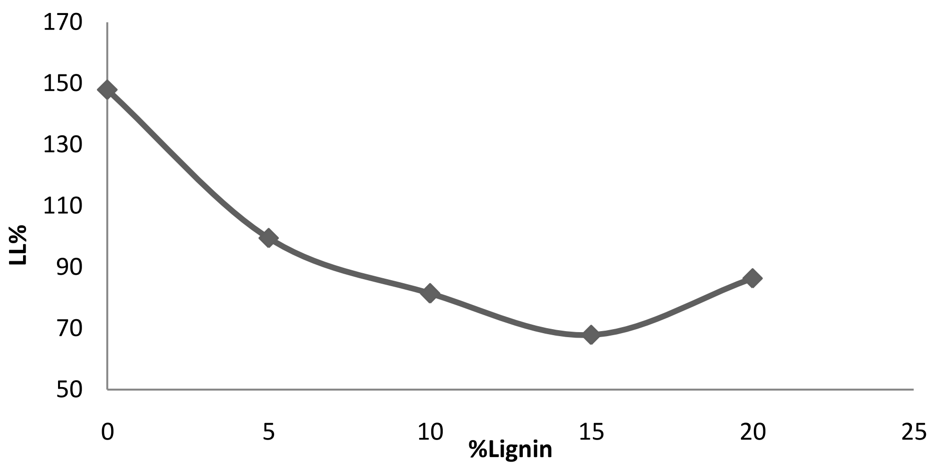


Figure 5.1 variation of LL with Lignin

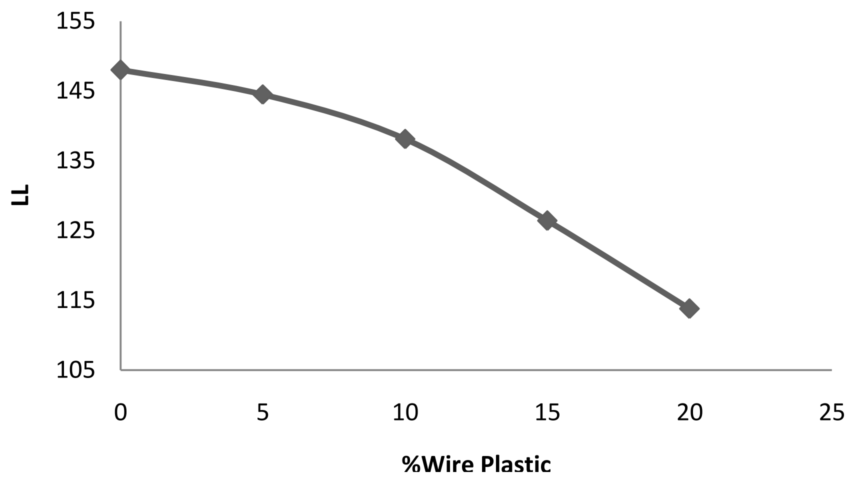


Figure 5.2 variation of LL with Wire plastic

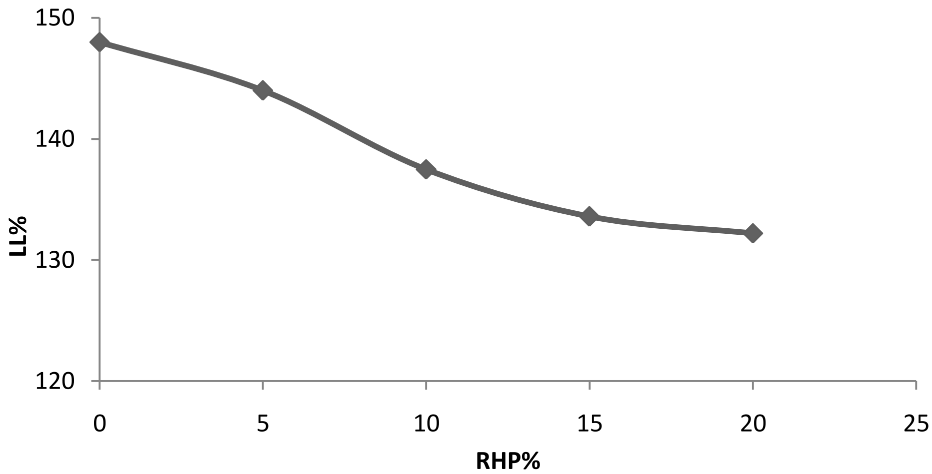


Figure 5.3 variation of LL with RHP

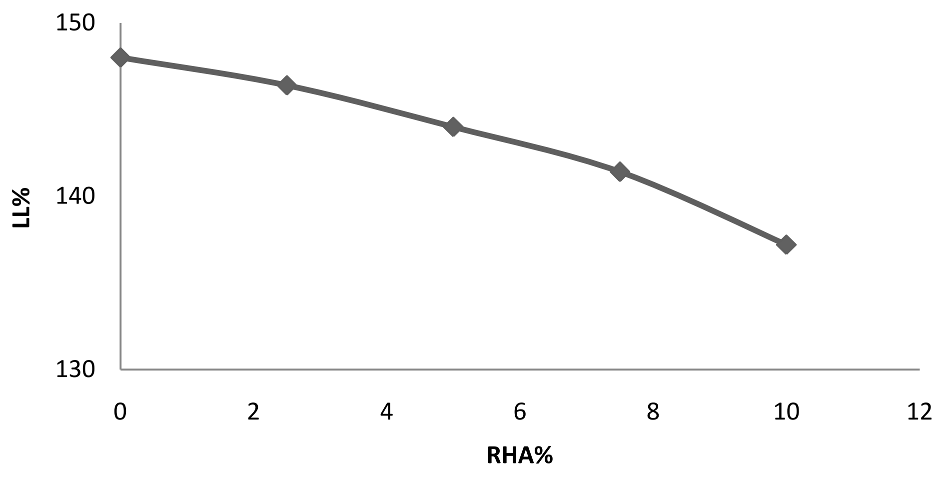


Figure 5.4 variation of LL with RHA

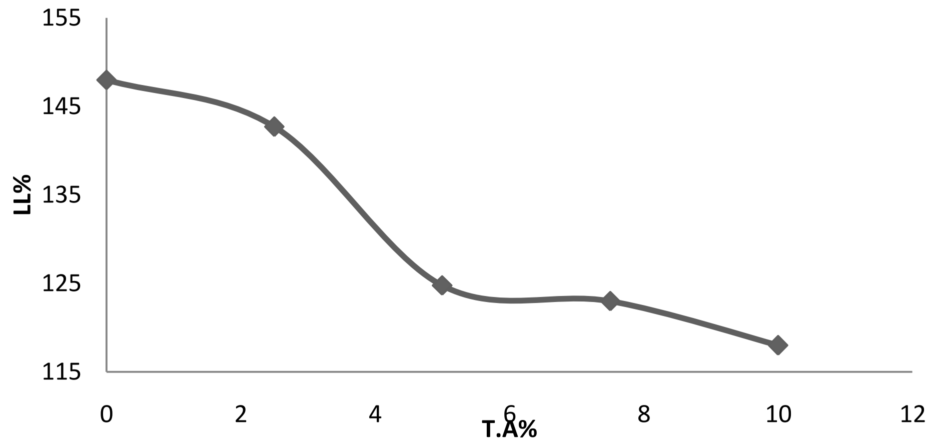


Figure 5.5 variation of LL with TA.

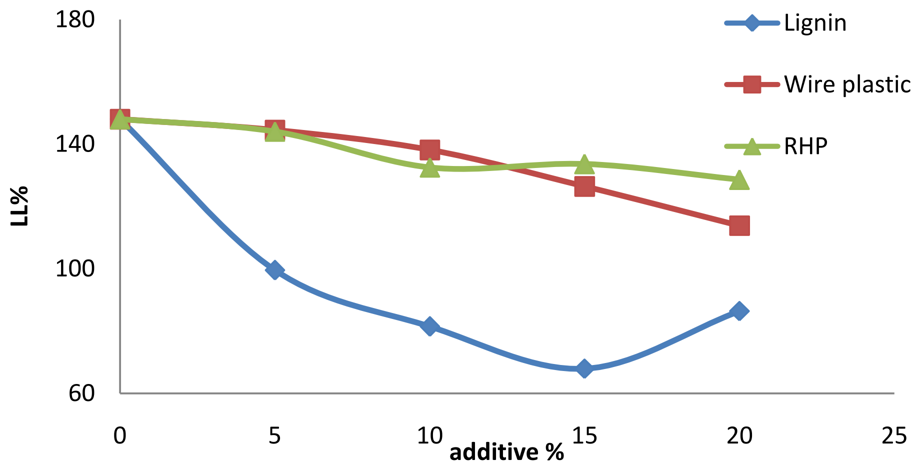


Figure 5.6 Variation of LL with Lignin, Wire plastic and RHP

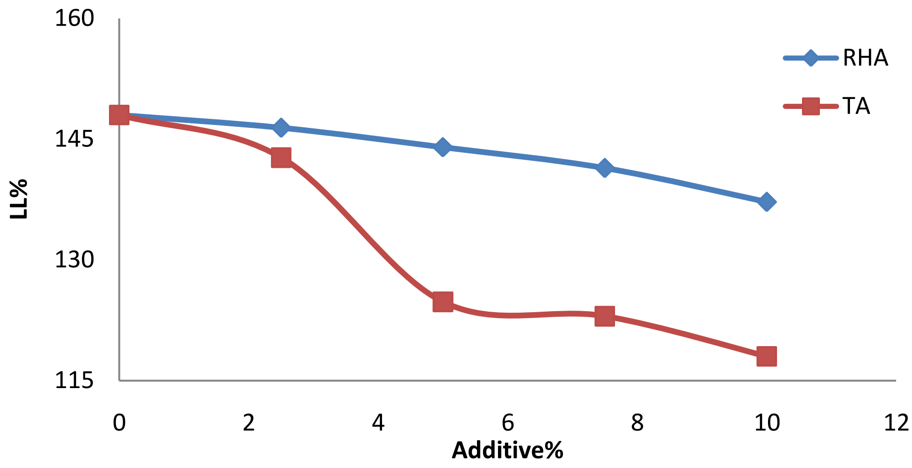


Figure 5.7 variation of LL with RHA and TA

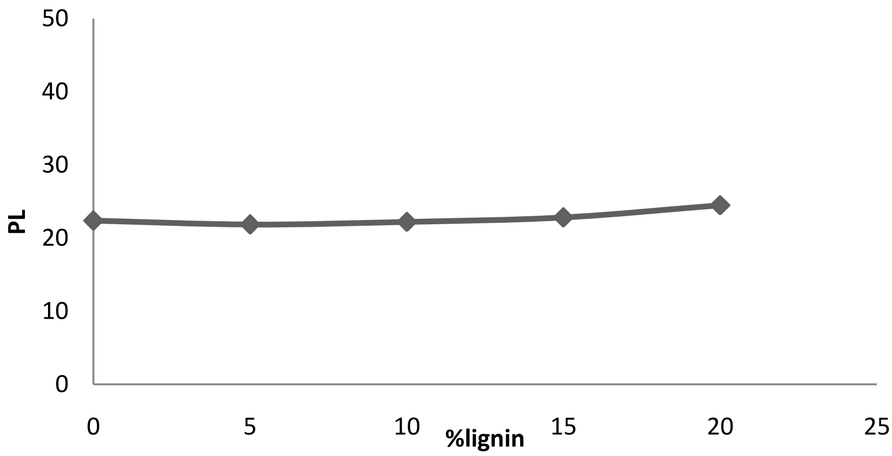


Figure 5.8 variation of PL with lignin

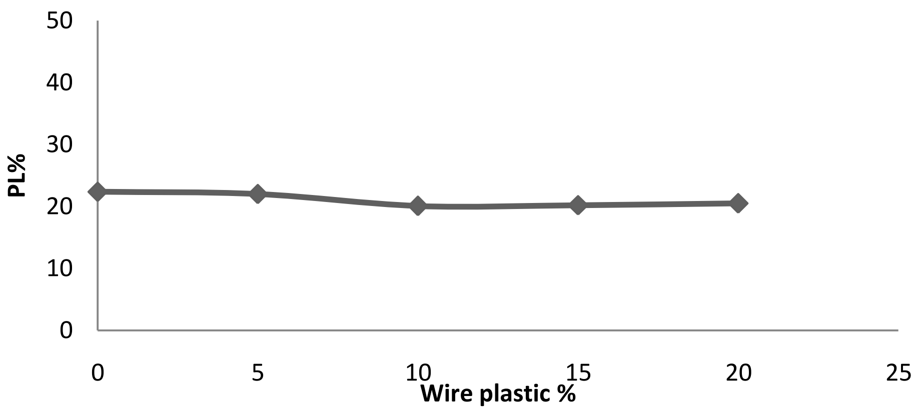


Figure 5.9 variation of PL with wire plastic

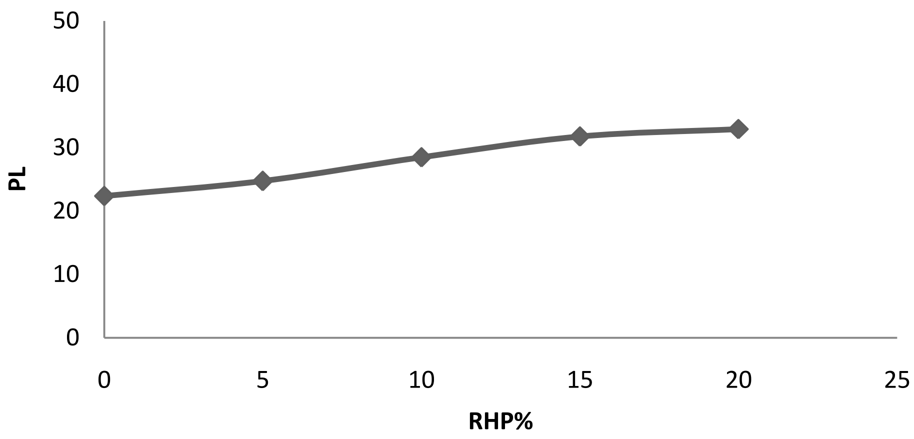


Figure 5.10 variation of PL with RHP

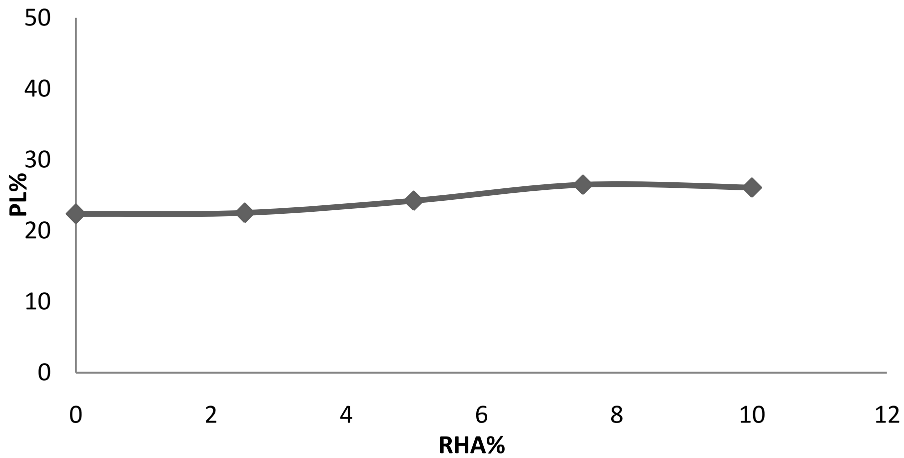


Figure 5.11 variation of PL with RHA.

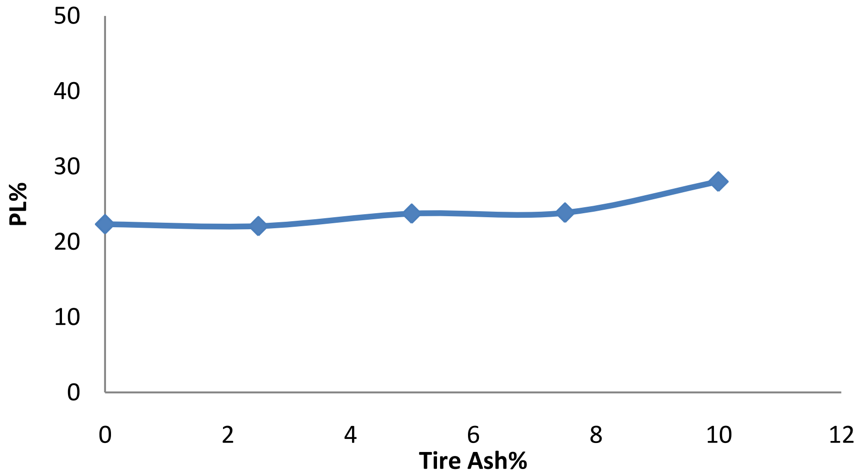


Figure 5.12 variation of PL with RHA

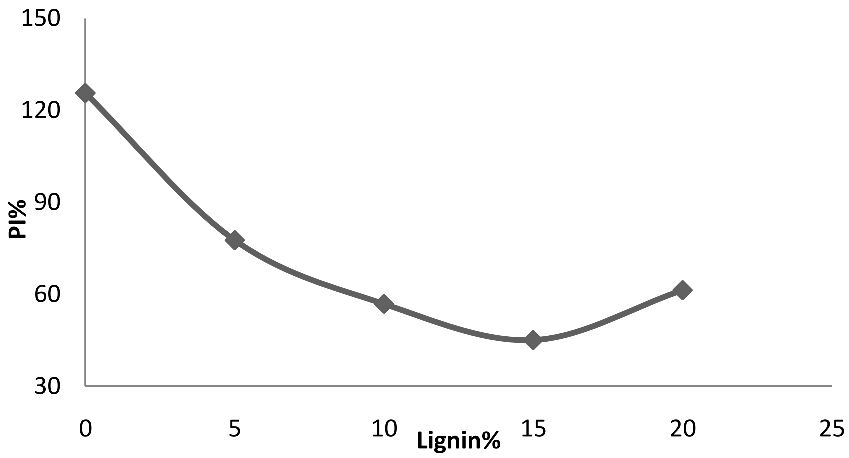


Figure 5.13 variation of PI with Lignin

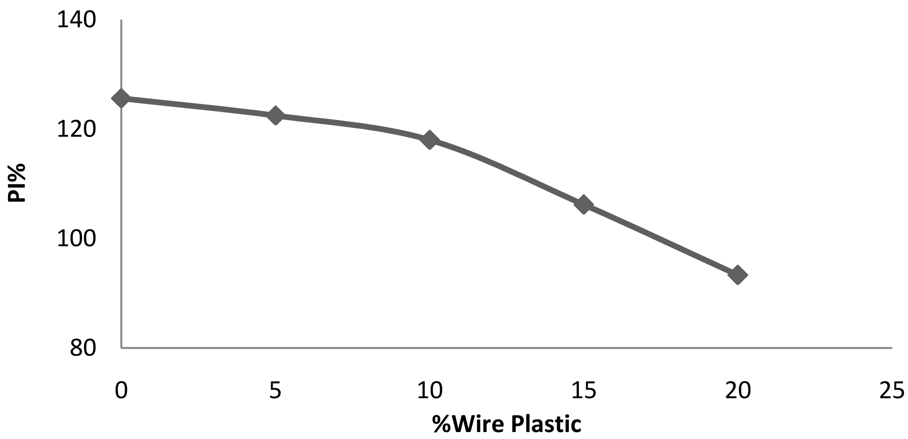


Figure 5.14 variation of PI with Wire Plastic

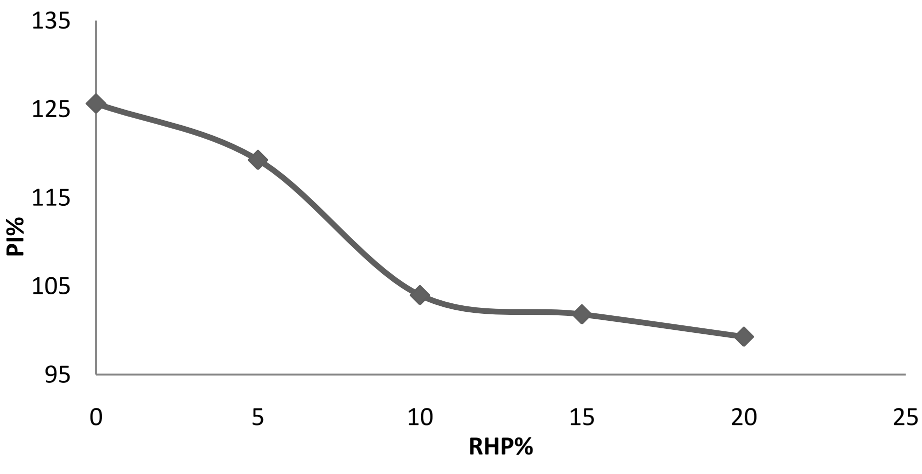


Figure 5.15 variation of PI with RHP

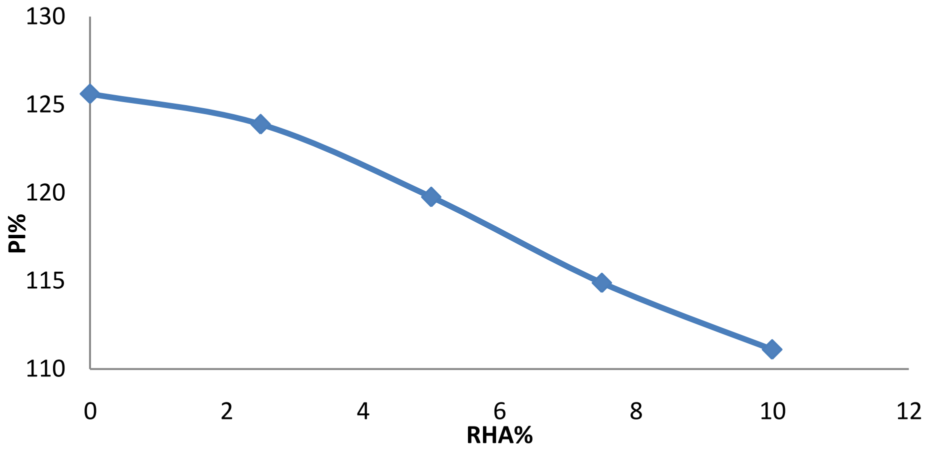


Figure 5.16 variation of PI with RHA

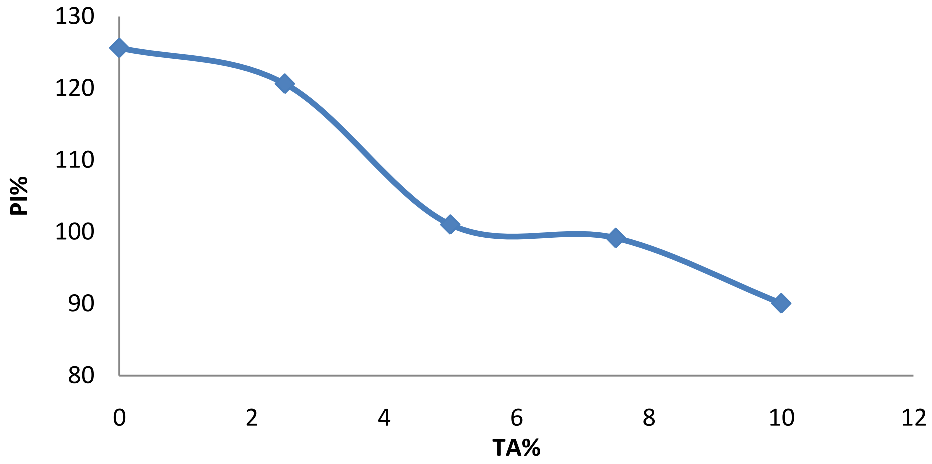


Figure 5.17 variation of PI with TA

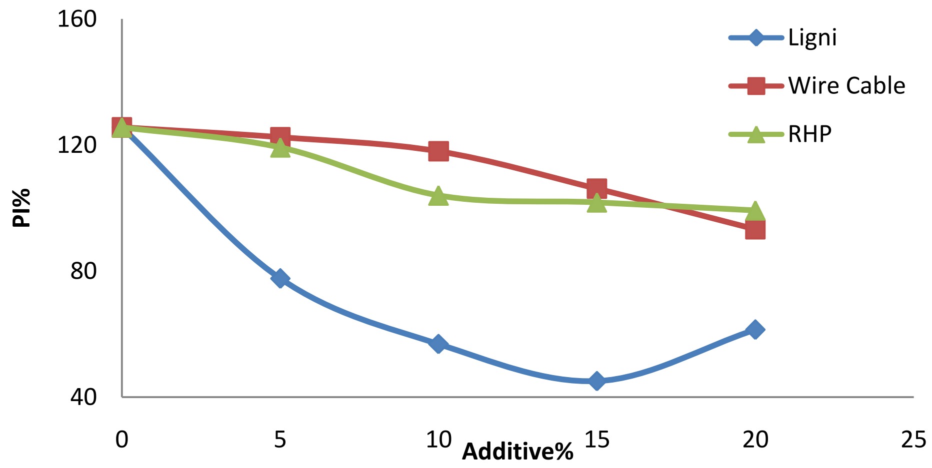


Figure 5.18 Variation of PI with Lignin, Wire Plastic and RHP

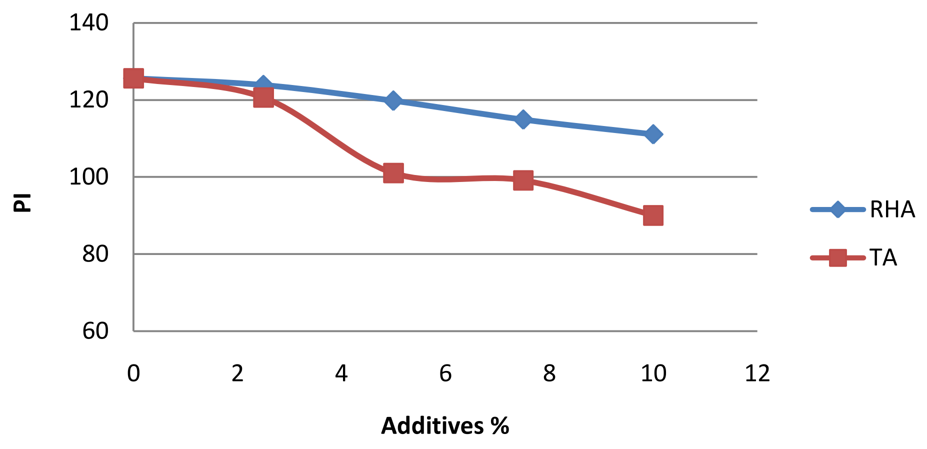


Figure 5.19 Variation of PI with RHA and TA

5.2 Swelling Test Results

Swelling percent test was carried out on the pure expansive soil to measure swelling parameter in order to examine the effect of various additives on the eliminating of the swelling potential of the soil. The swelling value original soil was 13%.

Swelling potential results of untreated and treated specimens are presented in Table 5.3. From Figure 5.20 to Figure 5.24 show the results of swelling test for each stabilizer. From the curves, it is noticed that the swelling percentage of specimens (except the samples treated with 20% lignin and 7.5% and 10% TA) were decreased (with different degree of decreasing) by all types and amount of additives. Hence all of the curves have the same direction that is the minimizing trend.

Figure 5.20 shows the variation of swelling percent with lignin percentages. It was observed that swelling percent decreases with increase in lignin percentages (except 20%). The reason due to the dispersion of clay fraction by lignin, the binder (lignin) caused to plugging of voids and increasing the effective surface area of the binder fraction. Gow et al, 1961 has demonstrated that the dispersion of clay fraction benefits stability of the soil (decreases swelling percent). Consequently, it can be seen that the swelling percentage decreased from 13% to 5% when the lignin content increases from 0.0% to 15%.further increase of lignin the swelling percentage slightly increases. Thus, the most decreasing in swelling potential was obtained for the soil treated with 15% lignin, Table 5.4. Therefore 15% lignin may be considered as optimum percentage.

Figure 5.21 shows the variation of swelling percent with wire plastic. From the curves it is clear that the swelling percent decreases with increase in wire plastic content. The swelling percent decreased from 13% to 6.85% with increase in wire plastic from 0% to 20%, respectively. In this case, swelling percent is reduced through (i) replacement of swelling clay by non-swelling particles of wire plastic, and (ii) resistance offered by the wire plastic to swelling which depends on soil-wire plastic proportion.

The maximum decreasing of swelling potential are obtained as 47% with addition of 20% of wire plastic Table 5.4.

Figure 5.22 illustrates the variation of swelling percent with RHP content. The results show that the swelling percent was affected by the RHP content and the effect decreased by increasing of RHP. This due to the addition of RHP that it is a none plastic material and has a highly resistant to moisture penetration and contain high silica (SiO2) contents.

The maximum reduction percent of the swelling percent is found as 37% in the case of 20% RHP as shown in Table 5.4.

Swelling percentage versus time relationship for RHA treated samples is plotted in Figure 5.23.In general, swelling percent decreased with increase in RHA content. Thus, swelling percent decreased from 13 to 5.65% when RHA increased from 2.5 to 10%. This can be explained by chemical effect due to presence of around 85 % - 90 % amorphous silica.

RHA caused the maximum decreasing in swelling (36%) at the addition of 10%RHA Table 5.4. It is interesting to note that with the addition 5% and7.5%, the swelling percent values were very close ranging from 10.6 to 10.4, respectively.

Figure 5.24 shows the effect of tire ash on swelling percent of the expansive soil. it can be seen from 0 up to 5% TA the swelling percent decreases from 13% to2.85 %, respectively. The decrease in swelling percent may be attributed to the pozzolanic action between the silica and alumina present in clay and the CaO present in TA in the presence of water. As the TA was further increased from 5 to 10%, the swelling percent increased from 2.85 to 4.3 %, respectively. In this case 5%TA can be considered as the optimum percent of the tire ash.

Basis on the results it can be said that tire ash was the highest effective and RHP was the least effective among the stabilizer used.

Table 5.3 swelling potentials of the specimens

additive %	**swelling%**
0.00%	13
5% Lignin	5.625
10%Lignin	5
15% Lignin	4.4
20% Lignin	6.35
5% W.P	12.55
10%W.P	11.95
15% W.P	8
20% W.P	6.85
5% RHP	11
10% RHP	9.25
15% RHP	8.55
20%RHP	8.25
2.5%RHA	11.1
5% RHA	10.6
7.5% RHA	10.4
10%RHA	5.65
2.5%TA	4.85
5%TA	2.85
7.5%TA	4.1
10%TA	4.3

Table5.4 Percentage Change in swelling percent

additive %	% Change in Swelling
5% Lignin	-57
10%Lignin	-62
15% Lignin	-66
20% Lignin	-51
5% W.P	-3
10%W.P	-8
15% W.P	-38
20% W.P	-47
5% RHP	-15
10% RHP	-29
15% RHP	-34
20%RHP	-37
2.5%RHA	-15
5% RHA	-18
7.5% RHA	-20
10%RHA	-57
2.5%TA	-63
5%TA	-78
7.5%TA	-68
10%TA	-67

(-) = Dercease

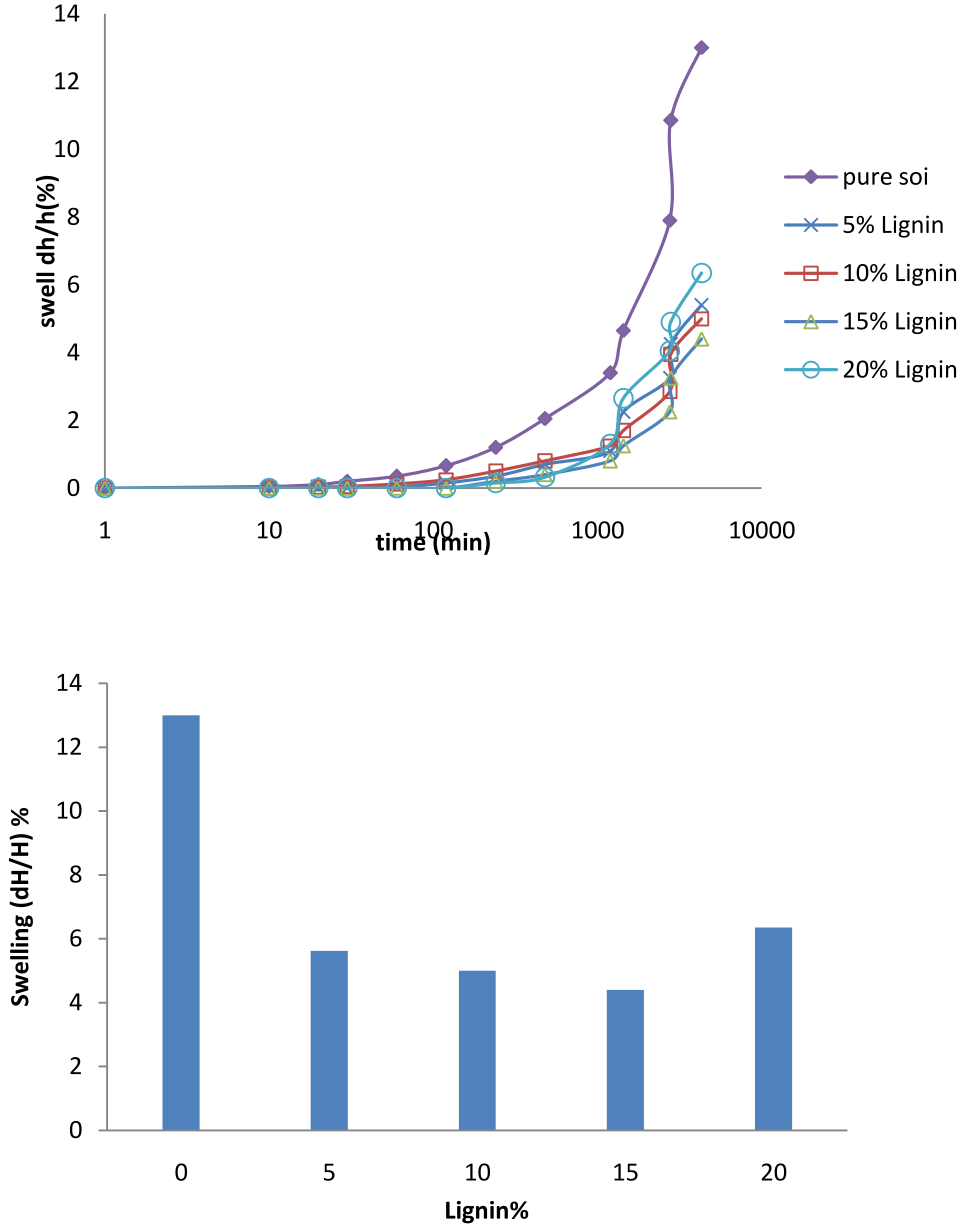
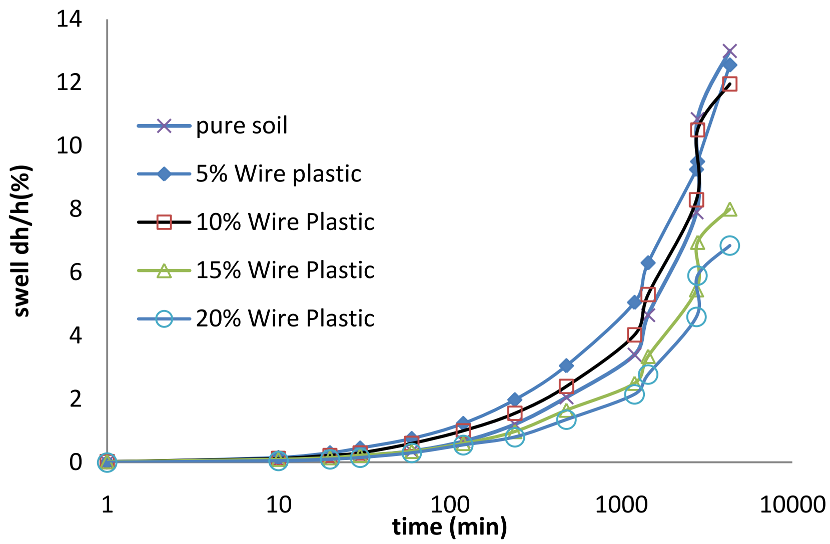


Figure 5.20 Effect of lignin addition on swelling percent, (above) Swelling curves and (below) Swelling Percent



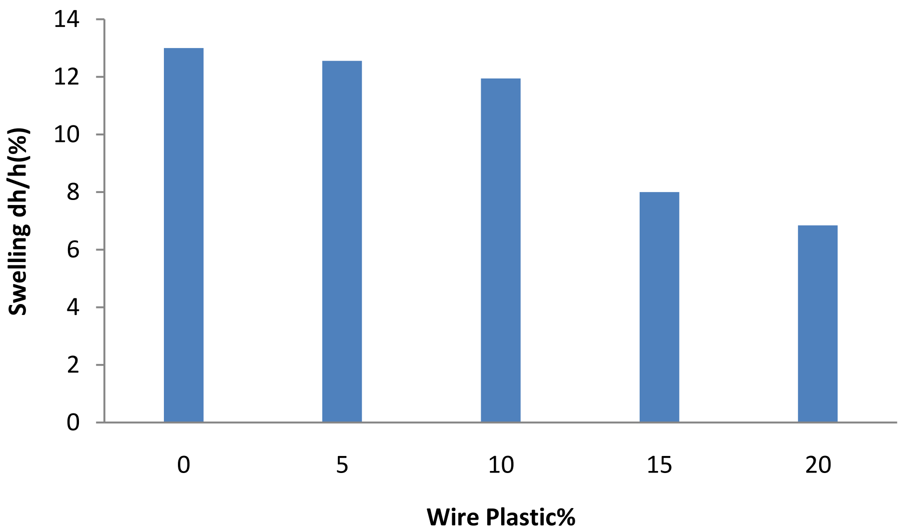
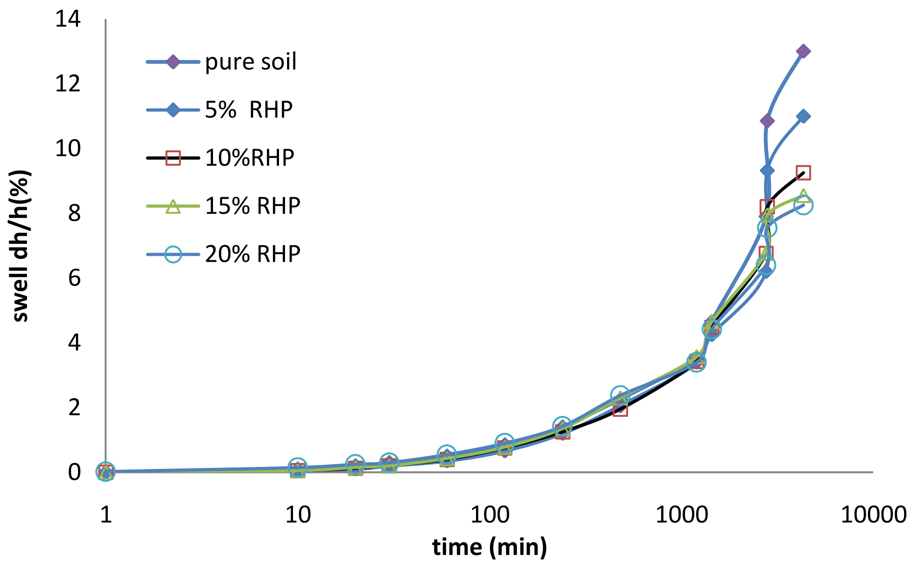


Figure 5.21 Effect of wire plastic addition on swelling percent, (above) Swelling curves and (below) Swelling Percent



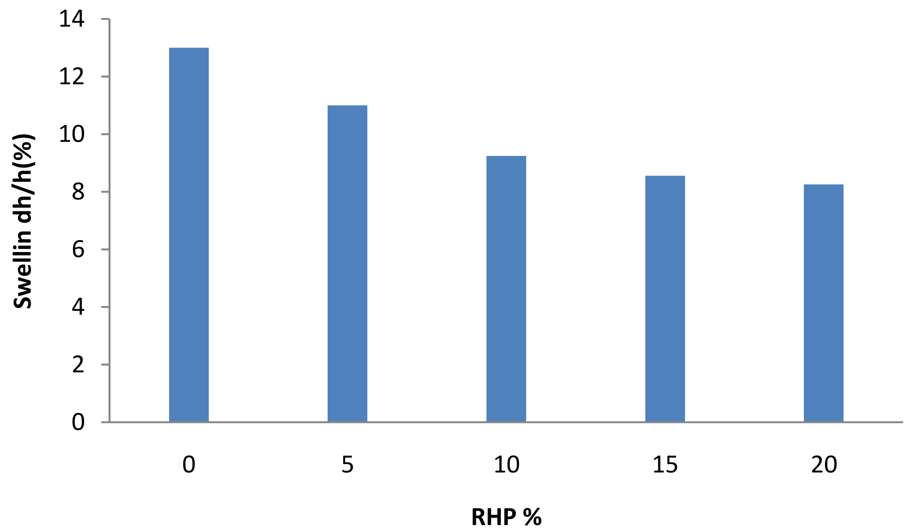
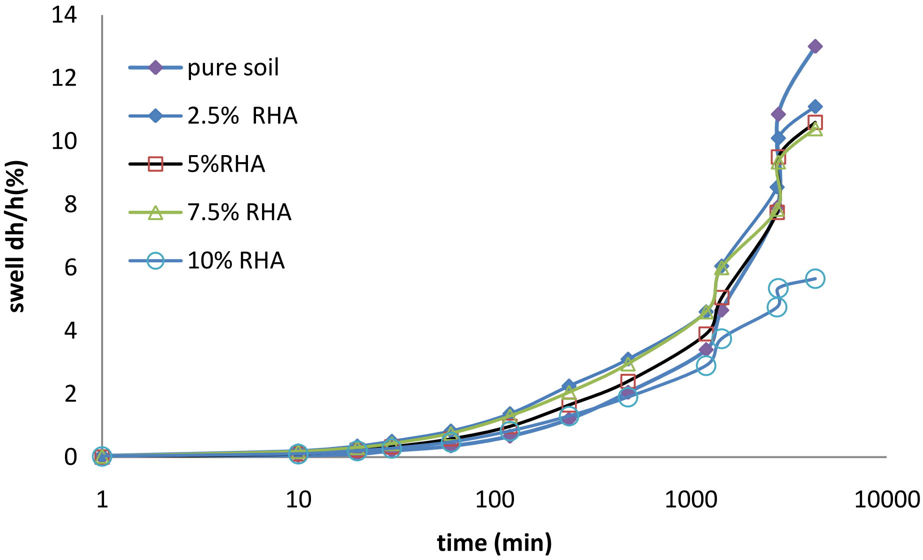


Figure 5.22 Effect of RHP addition on swelling percent, (above) Swelling curves and (below) Swelling percent



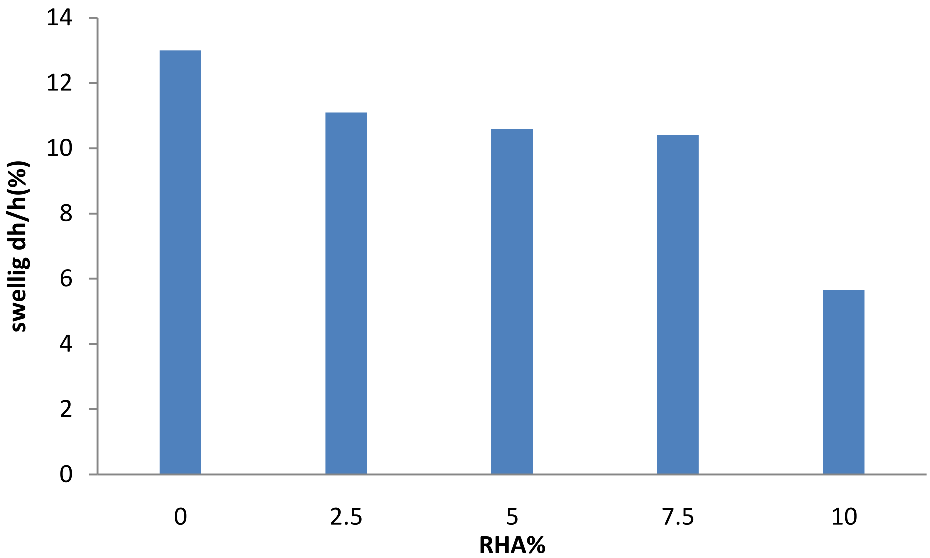
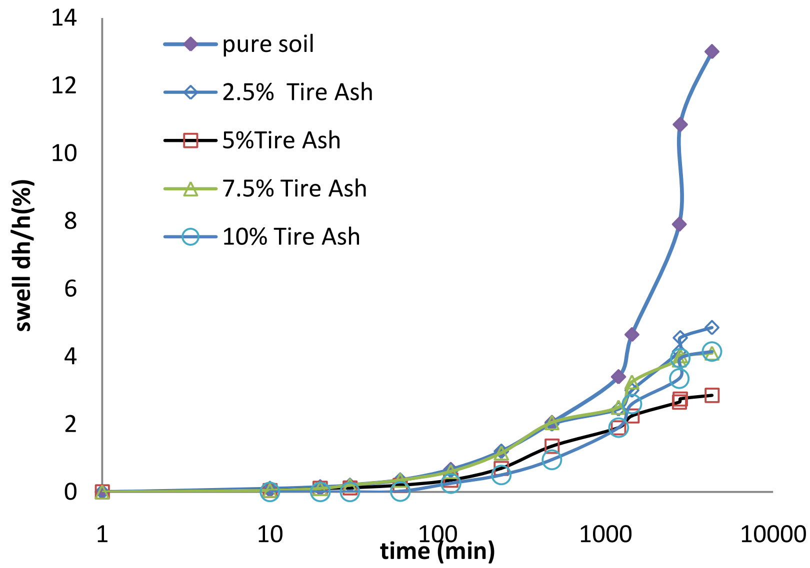


Figure 5.23 Effect of RHA addition on swelling percent, (above) Swelling curves and (below) Swelling percent



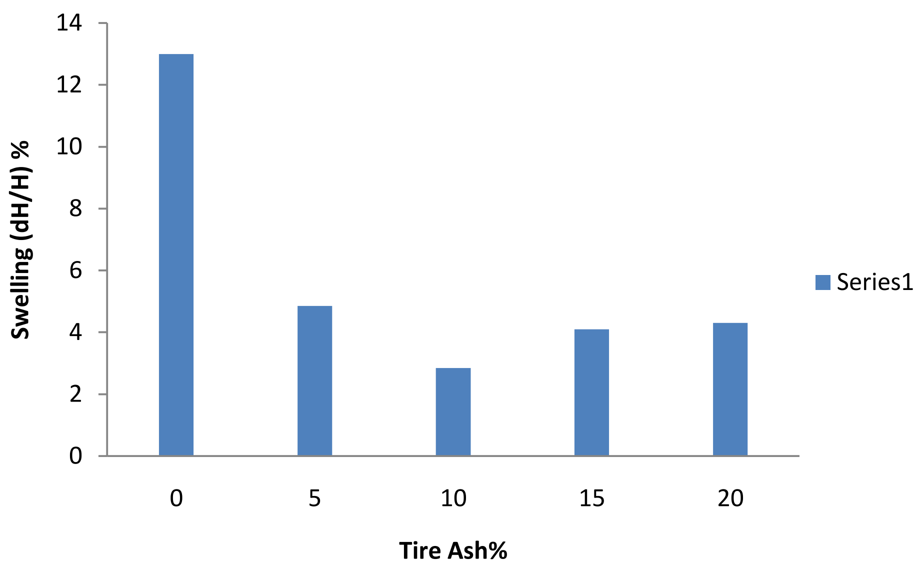


Figure 5.24 Effect of TA addition on swelling percent, (above) Swelling curves and (below) Swelling percent

5.3 Unconfined compressive strength

Unconfined compressive strength tests (ASTM) were conducted on specimens with and without additives (lignin, THP and RHA) for 3- and 7-days curing.

Figure 5.25 and Table 5.5 show the development of unconfined compressive strength stabilized soils with various percentages of lignin for 3 and 7 days curing. Generally, UCS increases with increase lignin content. Thus, UCS for 3-and 7 days cured specimens added with 20% lignin increases to 452kpa and 495kpa, respectively. These values are the maximum values of UCS (in the range of the experimental work carried out in this study) that represent the most increasing percent (change percent) in UCS Table 5.6. Increase in strength is due to increase in cohesiveness of the specimen through binding of soil particles by glue material (lignin), adding lignin to clay soils increases the soil stability by causing dispersion of the clay fraction (Gow et al. 1961; Davidson and Handy 1960).

Figure 5.26 shows the maximum values of unconfined compressive strength for various percentages of lignin at 3-day and 7-days cure. It is observed that the UCS values of treated soil increase further with increase in curing time, in other words, the UCS values for 7-days cured soil is higher than the 3-days cured specimens. For example, UCS for 3-days and 7-days cured samples added with 10%lignin increases to 156.7kpa and 291kpa, respectively.

Figure 5.27 and Table 5.6 present the maximum values of UCS (3-day and 7-day) for various percentages of RHP content. As can be seen, the 3-day compressive strength is found to increase with an increases RHP content from 0 to 15%. While the 7-day compressive strength is shown to increase for all percentages of RHP. This result can be attributed to improved compatibilization between RHP and expansive soil that increases the cohesiveness of the RHP treated expansive soil. In the case of 20%RHP, the 3-day compressive strength slightly decreases. In this case (20% RHP) the sample became brittle (see Appendix A).

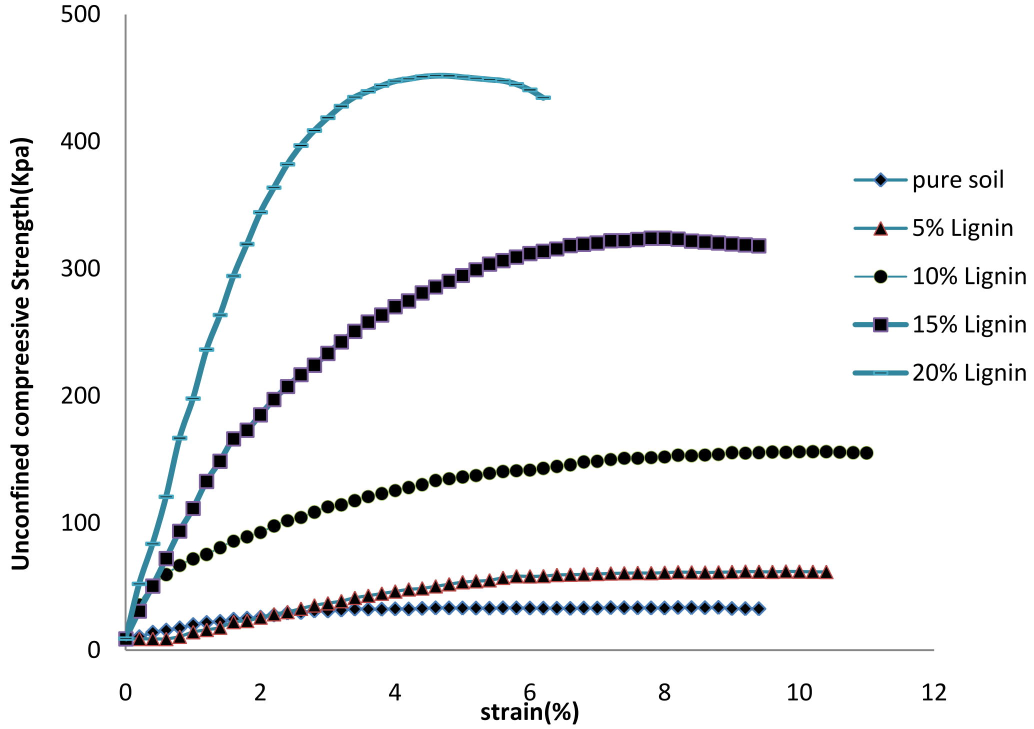
The 3-day compressive strength of soil treated with 20% RHP is 412.5 kpa, compared to 640 kpa of 7-day compressive strength of the same content of RHP. This indicated that the curing further improved strength of RHP treated soil.

Figures 5.29 show the influence of RHA on UCS of the specimen for 3 and 7-days curing. The results show that the stress- strain behavior was markedly affected by the RHA and the effect increased by increasing RHA content. It can be concluded that the RHA has a significant effect on the mechanical properties of the expansive soil and the strength of the soil increases with increasing the RHA content. The results indicate that there is a direct relationship between the strength and amount of RHA in soil mass (at the range of the experimental work carried out in this study). Similar behavior was found by (Robbert, 2009, Radhey et al.2008,) who concluded that when the RHA content was increased from 0 to 12%, unconfined compressive strength increased by 97%. Increase in strength of RHA treated specimens is due to the pozzolanic action.

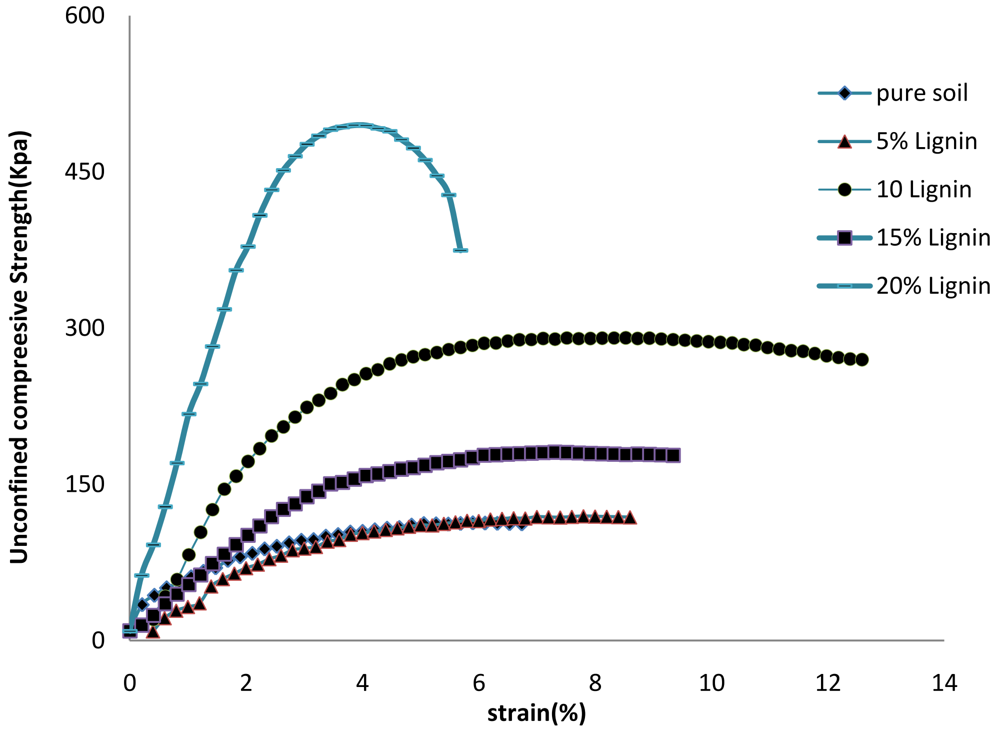
Table 5.7 presents the peak values of the UCS (3-days and 7-days) for various percentages of RHA. The results indicating the increasing in UCS when length of curing is increased. The 3-day compressive strength of soil treated with 10% RHA is 184 kpa, compared to 400 kpa of 7-day compressive strength of the same content of RHA. As is commonly known, pozoolanic action improves with curing period.

Table 5.5 Unconfined compressive strength (UCS) of lignin treated samples

%	3days	7days	% Change
0	33.35	112.23	238.65
5	61.87	118	90.72
10	156.31	290.70	85.97
15	324.13	382.28	17.94
20	451.75	494.80	9.52



(a)



(b)

Figure 5.25 Stress strain plots for lignin treated samples, (a) 3-days (b) 7-days

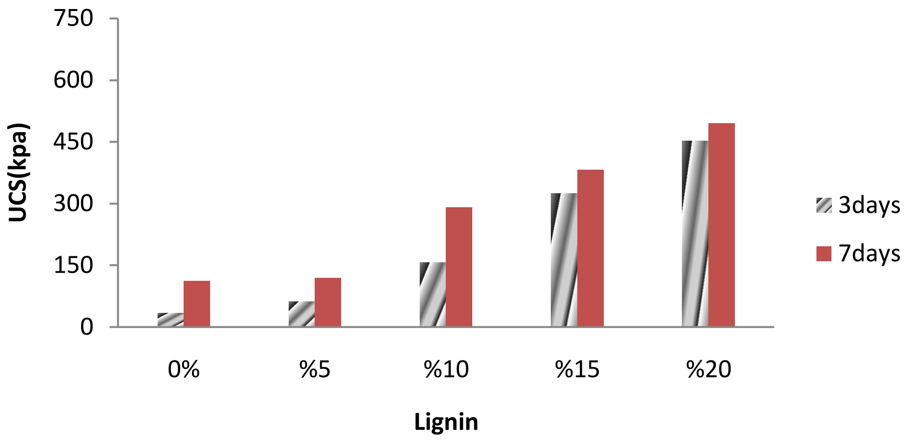
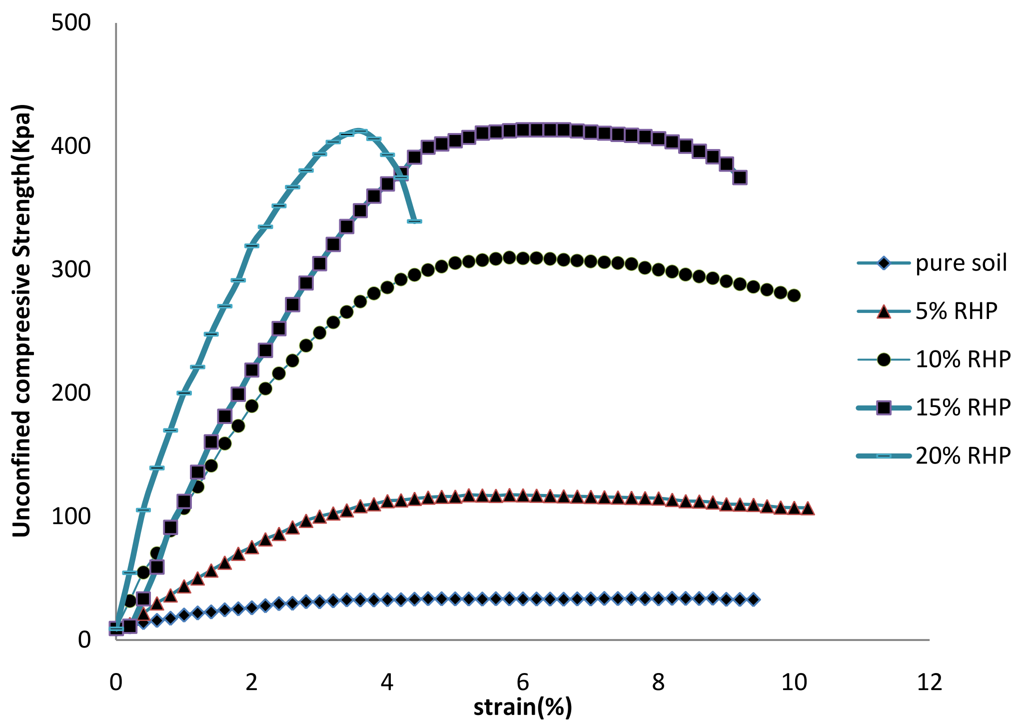


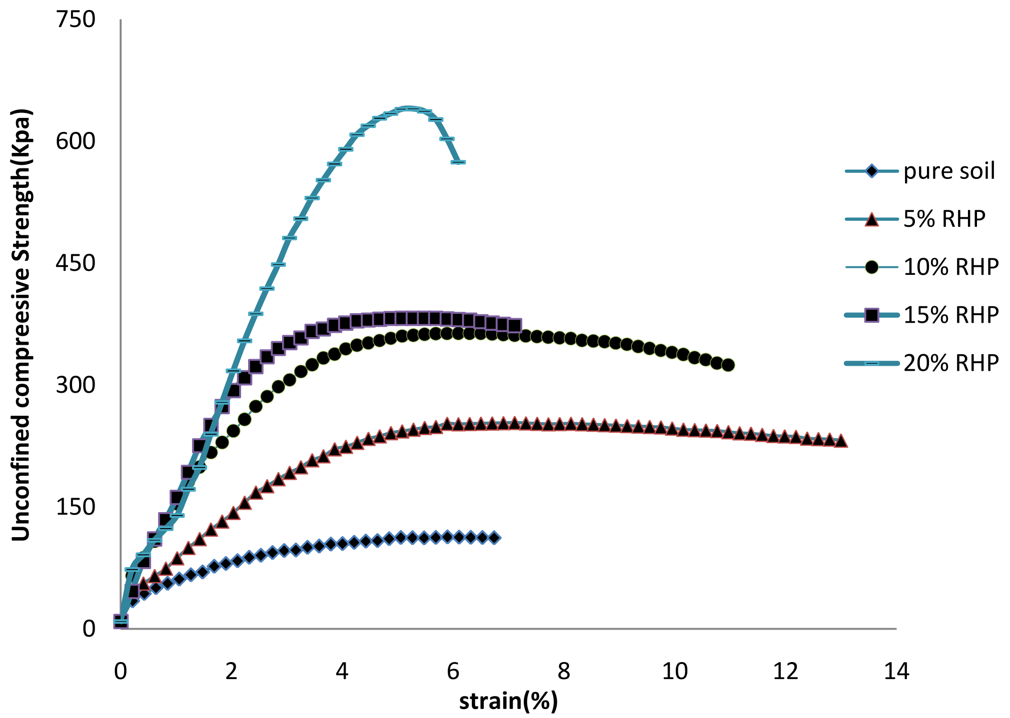
Figure 5.26 Effect of curing on lignin treated samples

Table 5.6 Unconfined compressive strength (UCS) of RHP treated samples.

%	3 days	7days	**% Change**
0	33.35	113	238.62
5	117.55	253.7	115.81
10	309.77	363.86	17.45
15	413.19	494.10	19.583
20	412.30	640.03	55.23



(a)



(b)

Figure 5.27 Stress strain plots for RHP treated samples, (a) 3-days (b) 7-days

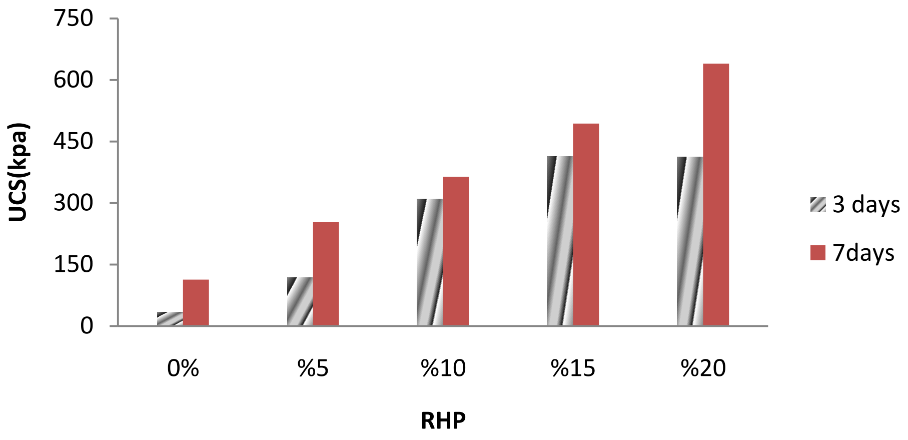
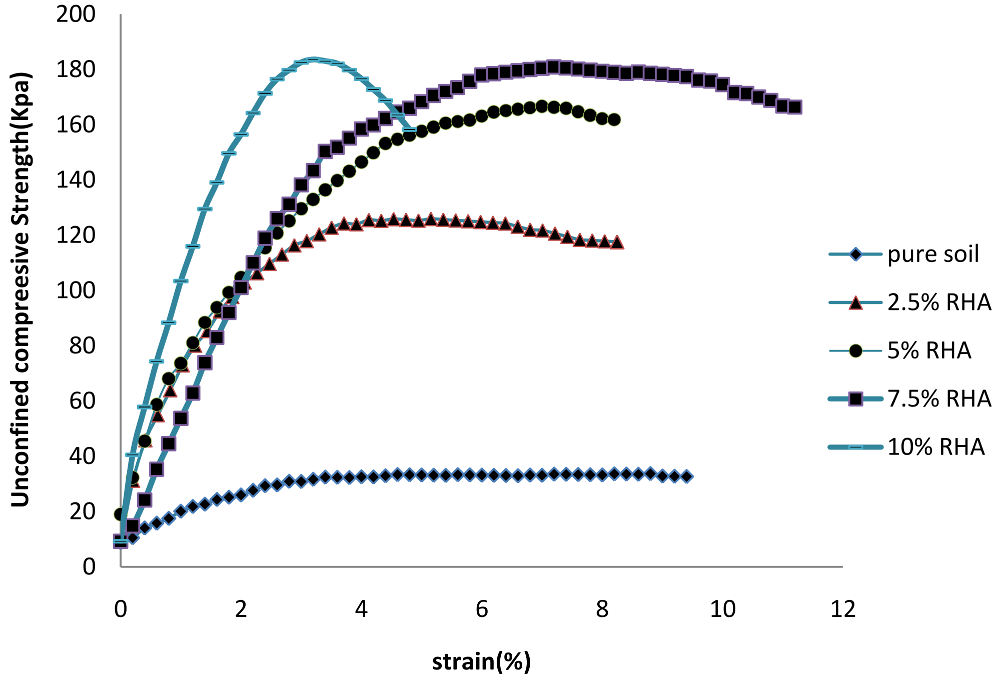


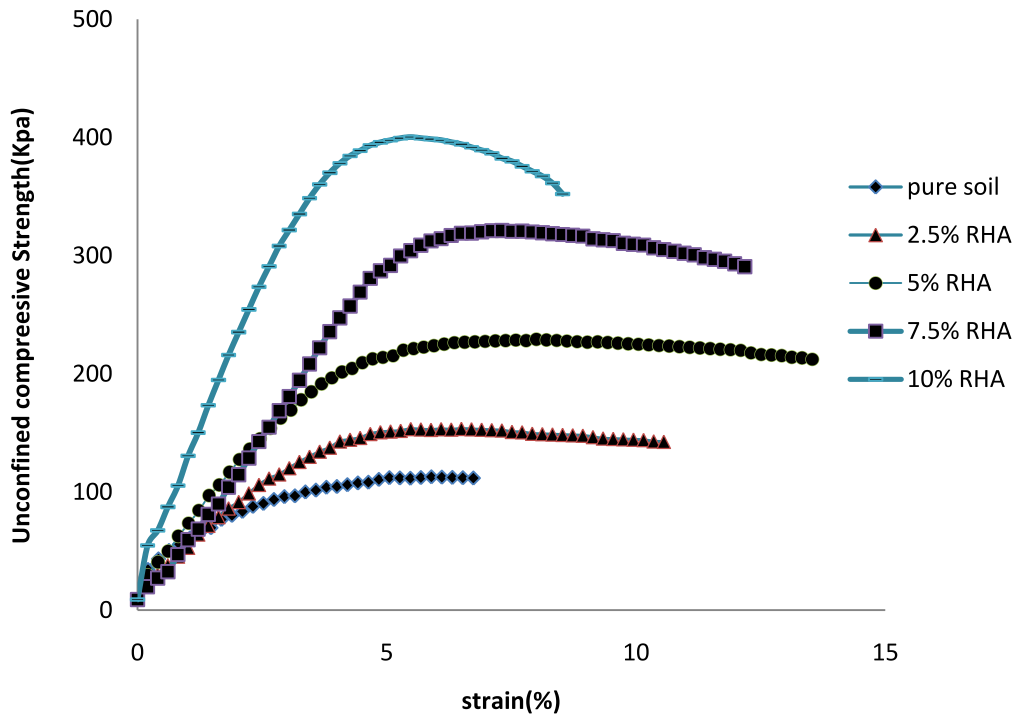
Figure 5.28 Effect of curing on RHP treated samples

Table 5.7 Unconfined compressive strength (UCS) of RHA treated samples.

%	3 days	7days	%Change
0	33.35	112.94	238.65
2.5	125.82	153.20	21.76
5	95.19	229.17	37.22
7.5	180.924	321.31	77.59
10	183.63	400.30	117.99



(a)



(b)

Figure 5.29 Stress strain plots for RHA treated samples, (a) 3-days (b) 7-days

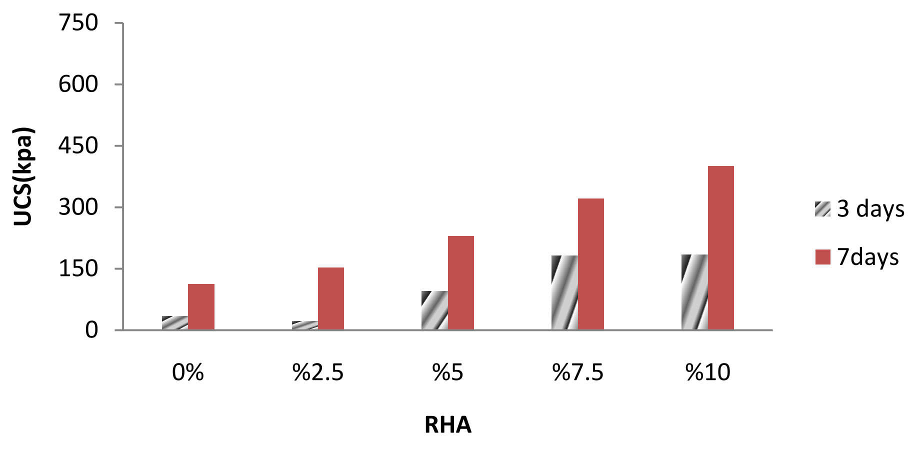


Figure 5.30 Effect of curing on RHA treated samples

CHAPTER 6

CONCLUSION

The swelling characteristic of expansive soils (artificial) were improved by the use of usual and non-conventional additives as used in this study. The different additives (industrial wastes) show tremendous potential for the stabilization of the specific soil.

Treatment of expansive soils using lignin, wire plastic, RHP, RHA and TA which require costly disposal provides an inexpensive source of high swelling stabilization agent. The results obtained suggest that the use of these additives a lone can improve important engineering properties. They have demonstrated a significant reduction of the swelling potential as well as the improving strength of the soil.

Based on this study of using lignin, wire plastic, RHP, RHA and TA as a stabilizer agent on expansive soil the following conclusion can be drawn.

From view point of index properties

1- Liquid limit and Plasticity index of all treated specimens except for sample treated with 20% were decreased by all type and amount of additives. Lignin caused a slightly increase in LL and PI of expansive soil with addition of 20%.
2- The maximum reduction in PI recorded as 45%, 93%, 99%, 111% and 90% with addition of 15% lignin, 20% WP, 20% RHP, 10% RHA and 10% TA, respectively.
3- Basis on the results, it can concluded that lignin shows a significant decrease in PI and LL values as compared to the wire plastic and RHP. Consequently, tire ash was more effective when compared to RHA.
4- Lignin, wire plastic and tire ash (except 10% tire ash) have a very small or no effect on the plastic limit of the expansive soil (the small change in PL may be due to sensitive balance wrong and mistake in estimation of the 3mm-

thickness of the soaked soil). While RHP and RHA show a considerable effect on PL of the expansive soil.

View point Swelling

5- Swelling percentage of specimens (except 20% lignin and up to 5% TA) were decreased (with different degree of decreasing) by all types and amount of additives.
6- It can be concluded that TA and lignin reduced the swelling potential of the expansive soil significantly only up to an addition of 2.5% and 5%, respectively, above this amount improve less significant.
7- 20%Lignin and 7.5%TA and 10%TA caused a slightly increase in swelling percent of expansive soil when compared to other percentages of lignin and tire ash. Therefore 15% lignin and 5% TA are considered as a optimum content.
8- Basis on the swelling test results it can be said that tire ash was the highest effective and RHP was the least effective among the stabilizer used.
9- The lowest swelling percents are obtained at 15% lignin,20 wire plastic, 20% RHP,10%RHA and 5%TA.

Unconfined Compressive Strength view point

12 - A significant improvement on the unconfined compressive strength was obtained by using lignin, RHP and RHA. The UCS of the samples proportionally increased with above additives for all samples except 20% RHP.

13 3-day UCS increased with increase RHP content from 0 to15%, further addition of RHP the 3-day UCS slightly decreased. While the 7-day UCS was shown to increases for all percentages of RHP.

14 Curing further improved strength of treated soil. For example, the 3-day UCS soil treated with 10% lignin,10% RHP and 10% RHA were 156 kpa,310 kpa and 184 kpa, respectively, compared to291 kpa,364 kpa and 400 kpa of 7-day UCS at the same content of lignin, RHP and RHA, respectively.

15 In both cases of 3- and 7- days cure, the addition of 5% lignin had low effect on UCS. Above this amount improvement being more.

16 RHA more affected by curing when compared to lignin and RHP. Maximum percentage change recorded as 117% with addition of 10% RHA.

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APPENDIX A

Additive %	3 days	7 days
0%		
5% Lignin		
10% Lignin		

15% Lignin		
20% Lignin		
5%RHP		
10%RHP		

15%RHP		
20%RHP		
2.5%RHA		
5%RHA		

7.5%RHA		
10%RHA