Effect of Silica Fume and Curing Time on Volume Change Characteristics of Rice Husk Ash Stabilized Expansive Soil

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ABSTRACT

This study encompasses an experimental investigation and dissemination of the findings of stabilization of an expansive soil obtained from EMU Campus by using rice husk ash (RHA) and silica fume (SF). The light buildings are continuosly subjected to structural distresses, hence repair and maintenance due to cyclic swelling-drying of the underlying expansive soils induced by climatic wetting and drying. There is a growing interest in utilizing industrial waste mainly for the mitigation of swelling-shrinking soils with a secondary aim of recycling.

Within the scope of this study, primarily the stabilization materials were tested for their suitability to be used as pozzolans. After the results of X-ray fluorescence (XRF) and reactivity tests, which indicated that RHA and SF are sufficiently active, they are used in 10% RHA, 15% RHA, 20% SF ve 10% RHA+10% SF proportions by dry mass of the soil. Physical properties and volume change behavior of the natural soil and treated soil were studied. After completing the experimental program which included the swelling-drying, and consolidation without and with curing of 28 days, it was concluded that there has been a notable mitigation mainly in the swelling and shrinkage behavior. Even though this study did not yield very consistent and significant results, it is observed that by increasing the curing time and the amount of additives better results could have been attained.

Finally, it was concluded that 10% RHA+10% SF addition has been more effective. Therefore silica fume and rice husk ash together formed the most active combination and is recommended to be mixed and compacted with the expansive soils subject to light loads, such as pavements, roads, and at most two story buildings.

Keywords: Expansive soils, Silica Fume, Rice Husk Ash.

ÖZ

Bu çalışma Doğu Akdeniz kampüsünden alınan şişen bir zeminin çeltik kabuğu külü (RHA) ve silis dumanı (SF) ile iyileştirilmesi üzerine yapılmış deneysel araştırmanın sonuçlarını içerir. Özellikle hafif yapılar altında mevsimsel ıslanıp kurumakla şişen ve büzülen bu zeminler yapıların çatlayarak sürekli tamir olunmasını gerektirmektedir. Endüstriel atıkların zeminleri iyileştirmek amacıyla kullanılması çevresel sorunlardan da arındıracağından son yıllarda tercih edilen yöntemlerdir. Bu çalışma bünyesinde öncelikle kullanılacak malzemelerin iyi bir pozolan olup olmadıkları araştırılmıştır. XRF ve reaktivite deneyleri ile pozolanik oldukları belirlenen malzemeler %10 RHA, %15 RHA, %20 SF ve %10 RHA+%10 SF oranlarında zeminle karıştırılıp öncelikle plastisite özellikleri irdelenmiş, daha sonra da hacimsel değişim çalışmaları yapılmıştır. Şişme-büzülme ve kompressibilite deneyleri sonucunda, ayrıca kür de uygulandığı zaman, özellikle büzülme davranışında belirgin bir iyileştirme gözlemlenmiştir. Her ne kadar da bu çalışma çerçevesinde önemli bir iyileştirme izlenememişse de, kür zamanı ve katkı oranı artırılırsa çok daha belirgin ve positif bir sonuç elde edilebileceği gözlemlenmiştir. Özellikle %10 RHA+%10 SF katkısı çok daha etkili olmuştur. Silis dumanı ve çeltik kabuğu külü birlikte daha reaktif olabilmekte, yalnız bu davranış uzun bir zaman sürecinde daha etkin olabilmektedir. Dolayısıyla, bu malzemelerin birlikte kullanılmaları, özellikle sorunlu bölgelerde zeminle karıştırılıp sıkıştırılmaları, kaldırım, yollar ve en fazla iki katlı binalar gibi hafif yapıların altında iyileştirme yapabileceği sonucuna varılmıştır.

Anahtar kelimeler: Şişen zeminler, çeltik kabuğu külü, silis dumanı.

DEDICATION

To my perfect Dad, my hero, thank you for teaching me the life lessons I needed to learn, for being able to share with you my vulnerability, for working hard to support me unconditionally to pursue my studies, for showing me your softer side, although I know you are strong and trying to protect me. No matter how old I am, I will always be your little daughter.

Dear Mom, thank you for allowing me to make mistakes, for listening to me without judgment, for teaching me to question things and solve problems on my own, for showing me that it is okay to be wrong, nobody knows everything.

Dearest Husband you are surely a blessing from God. I feel great to call myself as your wife. I appreciate each and everything you do for me. You are the one who was with me to make me rise. Thank you for always walking beside me and encouraging me not to give up.

My dear twins, as a parent I am so thankful to God for giving me such gifts. My life would have never been complete without you. You have always been the source of my joy. I hope someday I will see you both at this stage.

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Chapter 1

INTRODUCTION

1.1 Background

Expansive soil, which is also called shrink-swell soil, is the main cause of foundation problems. Depending on the amount of moisture in the ground, these soils will experience changes in volume. Such soils when used as foundation, can cause lifting of structures when subjected to high moisture, while desiccation causes shrinkage, hence settlement of buildings.

Therefore, if the moisture content of these soils can be stabilized, problems related to foundations can be often alleviated. There are several types of stabilizers used for solving this problem. One of the bio-waste stabilizers is rice husk ash (RHA). Rice husk ash is an agricultural waste, taken from rice mills after breakdown of the rice from paddy. It is often used as a fuel in the boiler furnaces in sugar and paper industries for producing steam.

Developing countries like India, Bangladesh, Malaysia and Iran, which have plenty of rice, produce large amounts of RHA annually. Main properties of RHA are first, having good adsorption characteristics (because of small particle size and large specific area). RHA is a good pozzolanic material, which can bind clay particles together and reduces the adsorption of water by clay particles, which reduces the swelling properties of expansive soils and improves their volume changes. Second property is having low cost and locally available.

According to the unpleasant properties of expansive soils and also to get rid of RHA as disposal waste, using this material as a stabilizer was decided. Since the temperature and time of incineration of rice husk directly affects the RHA specifications and may decrease the reactivity of it, a second pozzolanic material, silica fume (SF) is chosen. Silica fume is available in the form of an ultrafine waste, with high specific surface. It is a by-product of silicon and ferro-alloy manufactory. As mentioned above, silica fume activates RHA and helps the improvement of expansive soil.

1.2 Objectives and Scope

The main objective of this study was to improve the volume change characteristics of expansive soils using rice husk ash and silica fume as stabilizers, and to consider the effect of curing on influence of stabilization.

The scope of this research is as follows:

1. To study the effect of stabilizers on physical properties of an expansive soil gathered from EMU South Campus.

2. To determine the swelling, shrinkage and consolidation characteristics of stabilized soils.

2. To investigate the influence of curing time on properties of stabilized soils.

1.3 Outline of thesis

This thesis consists of five chapters. Chapter 1 includes the background and objectives of the study. Chapter 2 represents a literature review of the expansive soils and application of RHA and SF as stabilizers. Chapter 3 gives the laboratory work and experimental tests on soil and the mixture of soil with stabilizers to determine the material characteristics. Chapter 4 includes the results and discussions of the experimental study. Finally, Chapter 5 gives the conclusions and recommendations for future work.

Chapter 2

LITERATURE REVIEW

2.1 Expansive soil

Unsaturated clayey soils having high plasticity are very sensitive to changes in water content and indicate excessive volume changes. Such soils, which increase in volume due to increase in water content, are classified as expansive soils. These highly plastic soils may create cracks on pavements, railways, roadways, foundations, and structures (Figure 2.1).

Figure 2.1: Cracks in (a) pavements and (b) buildings

High swell-shrink characteristics of these soils often cause problems in the civil engineering construction projects. Expansive soils have the tendency to swell when they are in contact with moisture and shrink if moisture is removed from them (Figure 2.3). These volume changes in soils are the cause of many problems in structures and sub-structures [5].

Figure 2.2: (a) Shrinkage and (b) swelling of expansive soil

Expansive soils are widely distributed worldwide, and are a source of great damage to roads, pavements and light buildings. Figure 2.4 shows the movement of structures on expansive soils in wet and dry seasons.

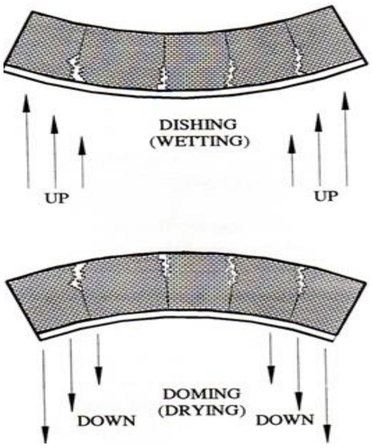


Figure 2.3: Foundation movement resulting from seasonal moisture changes

Expansive soils experience great changes in volume when their water content varies. Although they are abundantly found in arid zones, where conditions are suitable for the formation of clayey minerals of the smectite group or some types of illites, this type of soils are widely distributed all over the world. They are specified with having very small particle size, a large specific surface area and a high cation exchange capacity (CEC). The swelling of this type of clay is related to three types of factors: geological and engineering characteristics of the soil, and local environmental conditions. Among the engineering factors included are the soil moisture content, plasticity and dry density. The most important local environmental conditions to consider are the amount of the clay fraction in the soil, its initial moisture conditions, and confining pressure.

Since volume changes of these types of soils are the major cause of natural disasters, and that they cause extensive damage to the structures and infrastructure, it is essential to stabilize them using some additive materials [9]. The annual cost of damage done to civil engineering structures founded in expansive soils is estimated to be billions of pounds worldwide [7]. Therefore, there is a need to concentrate on improving properties of clayey soils using cost-effective practices like treating with industrial wastes having cementitious value [10]. In this study, industrial wastes like rice husk ash (RHA) and silica fume (SF) are used to improve geotechnical properties of expansive soil.

2.2 Stabilization of Expansive Soil

Owing to increase of economic growth and industrialization, a huge quantity of wastes generated need land for disposal and generally create problems for public health and ecology. So, need has arisen for adequate disposal of these wastes. Utilizing these materials as stabilizers in the construction or in the foundation, after improving their characteristics suitably can provide useful solution of this problem [11]. Improving soils with solid industrial by-product stabilizers is highly desirable. Stabilized soils are widely used in construction and foundation applications in many countries of the world, especially if locally natural/industrial resources are available [13].

Soils can be stabilized by mixing with the correct proportion of stabilizers to reduce volume changes, and to increase the strength and cohesion. Use of stabilizers is not new; natural oils, plant saps, animal dung, and crushed anthills have been used for many centuries [13].

Currently the common method to treat expansive soil is chemical improvement, and the stabilizers used are mainly lime, fly ash, cement, etc. Nowadays many investigators have being studying the effect of natural, fabricated, and by-product materials as a stabilizer to modify the fine-grained soils [9].

Stabilization of expansive soils with various mixtures of additives such as lime and rice husk ash, fly ash and rice husk ash have also been a viable technique for relieving the volume change problems.

2.3 Stabilizers

Pozzolanic stabilizers can bind soil particles together and reduce water absorption by clay particles. The potential for using industrial by-products such as blast furnace slag, fly ash, rich husk ash, foundry sand, foundry slag, and cement kiln dust for stabilization of clayey soils have been investigated [18].

The presence of the OH^- ions in pozzolans produces an increase of the soil pH up to values of approximately 12.4. In these conditions, pozzolanic reactions take place, when the Si and the Al, which form part of the sheets of the clay dissolve and combine with the available Ca^{2+} giving rise to cementing compounds such as Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrates (CAH). These compounds are responsible for improving the mechanical properties of the soil, as well as helping to reduce its expansion by their cementing action [14].

2.4 Rice Husk Ash

Rice husk ash (RHA) is used as a stabilizer for the improvement of compaction, swelling, shrinkage, and consolidation as well as the hydro-mechanical properties of highly plastic clayey soil. In the past, cement and lime were the two main materials used for stabilizing soils, which is now costly due to increase in the cost of energy since 1970s. RHA is the most cost-effective material, which acts as a binding agent like cement, improving geotechnical properties of soils. In most Asian countries and particularly in India, large quantity of rice husk ash is available [16]. Rice is the main source of food for billions of people all over the world. India is the second largest rice producer country after China in the world. Rice husk ash (RHA) is a by-product waste, without any food value. Husk covers the rice grain and accounts near 20% of dried rice paddy. 10% of the rice grain weight is rice husk. On burning the rice husk, about 20% turns to RHA [12]. Rice husk is an agricultural waste produced as by-product of rice milling. About 108 tons of rice husks are generated in the world annually [17]. In Bangladesh, about 39.3 million tons of rice is produced annually, which generates about 9.83 million ton of rice husk (RH) after milling which is used as animal food as well as fuel in rural areas. RH is considered as waste material and usually dumped backside of the kitchen of the village people [16]. RHA can be prepared from burning husk in free air or under controlled temperature. Most RHA is incinerated at high temperature (usually 1000ºC) or under uncontrolled condition in the air. Obtaining this effective form of RHA, in turn, requires rice husk to be incinerated at low temperature (less than 800ºC) to maximize the amorphous silica content, which is the most reactive form of SiO_2. Burning RH at high temperatures causes the amorphous SiO_2, the low-temperature form of SiO_2, to transform to cristobalite, which is high-temperature crystalline form, and finally worsens the pozzolanic activity of the resulting RHA [18].

Use of rice husk ash for soil stabilization attributes to the chemical composition and physical characteristics of ash, which indicates pozzolanic reactions. Rice husk ash is an attractive pozzolan due to its low cost and high activity [15]. Pozzolanas are materials containing reactive silica or alumina, which do not have binding property on their own, but when mixed with any other cementitous material in the presence of water, will form a complex and harden like cement [19].

After burning, RHA acts as a binder like cement to keep the soil particles together. So, it can improve the geotechnical properties of expansive soils such as Atterberg limits, compressibility, swell, shrinkage, and compaction characteristics.

Rice husk ash has high quantity of silica with small quantities of oxide and with a high specific surface, which is very suitable for activating the reaction of soil and acts as a binding material like cement [28]. It is manifested that the structural nature of the silica produced from RH is largely dependent on the incineration temperature used in the production process [11]. Burning RHA at high temperature (more than 1000ºC) reduces the amount of amorphous silica (SiO_2), therefore worsens the pozzolanic activity of the resulting RHA [18].

Rice husk ash contains high reactive silica, which is a very good pozzolanic material. Indeed, the main component of the rice husk ash is silica, which governs the reactivity of RHA [15]. The silica content in RHA depends on the burning temperature [16]. The percentage of silica (SiO_2) in the ash ranges between 87-92% [26]. When the rice husk is completely burnt at low temperature (below 800ºC), the produced ash has cellular microstructure and high percentage of amorphous SiO_2. This resulting RHA is very suitable for use as a pozzolanic material to improve the compressive strength and durability of clayey soils. The ability of RHA to act as a pozzolan comes from two sources. First, the fine RHA particles, which can physically fill in the voids between adjacent clay particles, that leads to increasing density and/or reducing the porosity of material. Second, it can act as a source of excess SiO_2, and bind the clay particles together. Much attention had been paid to the characterization of the properties of RHA, but little to the burning temperature dependence of its properties and structure. This dependence is important for the property optimization of RHA in a controllable manner [27]. However, most rice husk is typically burnt at temperatures higher than 1000ºC all over the world. Such high temperatures, coupled with lengthened incineration times can cause a major part of the amorphous SiO_2 to transform to cristobalite, the crystalline and less reactive form of SiO_2, and finally weaken the pozzolanic property of the RHA [20]. The suggested burning procedure is at 500ºC for 2 hours. However, due to the exothermal property of the burning rice husk, controlling the exact burning temperature is difficult. When RH is treated in solution before combustion, the complete combustion products are almost only silica, (more than 99 % in mass). The silica is porous and has abundant hydrophilic Si–OH groups, thus, adsorbing much moisture. In some cases, the nature of the silica decides the structure and property of RHA [2]. But, if this solubility doesn't take place, the RHA produced will have much less percentage of Si and it is needed to mix with another cementitous material like silica fume to relieve the lack of silica.

Based on the amount of silica formed and the carbon content, the rice husk ash is classified as C-RHA-burnt quickly in open-air containing large amount of carbon, Cr-RHA- obtained from slow burning at above 600ºC and contains a large amount of crystallized silica, and A-RHA- burnt at 500ºC in two hours and is considered to be the most active [15].

2.5 Silica Fume

One of the by-product materials used as a stabilizer is silica fume (SF). Silica fume is a very fine dust of silica, which generates from a furnace in silicon metal production factory [22]. It is also collected as a by-product in the production of other silicon alloys such as ferrochromium, ferromagnesium, ferromanganese, and calcium silicon.

Actually, SF is a chemical waste material of industrial applications, but it has become a valuable by-product material among the pozzolanic stabilizers due to its effective properties. Although SF is a waste industrial material, it has become one of the most valuable by-product pozzolanic materials due to its high pozzolanic properties [24]. Silica fume for use is available in slurry or dry forms. In either form, silica fume is a very reactive pozzolan due to its fine particles, large surface area, and the high silicon dioxide content [25]. Silica fume is generated during silicon metal production as very fine dust of silica from a blast furnace, to modify the fine-grained soil, considered a waste product, and has been used as a stabilizer [9]. The primary effect of silica fume on soil is to increase the cohesiveness. More water is required to wet the large surface area of the silica fume, and thus it increases the water content of soil [24].

Chapter 3

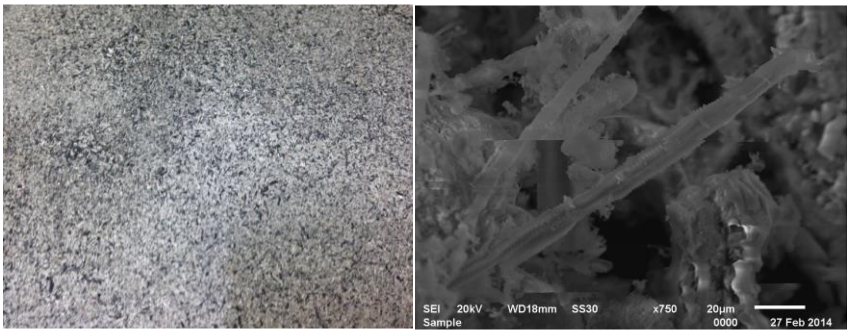
MATERIALS AND METHODS

3.1 Preparing Expansive Clayey Soil

The soil used in this study was expansive clay taken from Eastern Mediterranean University Campus in Famagusta, North Cyprus. Tests were implemented to measure the physical and hydro-mechanical properties and classify the soil and also its mixtures with 10% RHA, 15% RHA, 20% SF and 10% RHA mixed with 10% SF by dry mass. Laboratory tests were carried out according to standard procedures of American Society for Testing and Materials (ASTM). Soil used in this study was dried at 50ºC for one week, then was pulverized and again kept at 50ºC to be protected from ambient moisture.

3.2 Preparing RHA

The transformation of raw husk to clear white, grey or peaked grey ash is dependent on the temperature of incineration. For example, a temperature between 300-450ºC only transforms fresh rice husk to carbonized husk, while between 500-650ºC, generates white or grey ash. Rice husk ash is very rich in silica content, usually more than 80-85%. For RHA to be used as pozzolan in cement and concrete, it should satisfy requirements for chemical composition of pozzolans as per ASTM C618. The combined proportion of silicon dioxide (SiO2), aluminium oxide (Al2O3) and iron oxide (Fe2O) in the ash should not be less than 70%, and LOI (loss on ignition) should not exceed 12% as specified in ASTM requirement. Figure 3.1 (a) shows the ash produced by open-air incineration, which is grey in color with some black carbon residues and Figure 3.1 (b) is the scanning electron micrograph (SEM) image of the ash of x750 magnification.



(a) (b)

Figure 3.1: (a) Grey rice husk ash, (b) SEM image

The chemical composition of the rice husk ash was analyzed using an X-ray fluorescence spectrometer. The XRF determines the oxide compounds of the RHA, such as calcium oxide (CaO), silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3). Furthermore, minor compounds like MgO, SO_3, K_2O and Na_2O were also determined. On the other hand, un-burnt carbon existing in RHA was calculated by loss on ignition (LOI). Table 3.1 gives the oxide compositions of RHA used in this research based on XRF results.

RHA was passed through sieve 600 μm to remove impurities, which could affect test results before mixing with soil (Figure 3.2).

Table 3.1: Oxide composition of rice husk ash used

Oxide	Concentration (%)
Na2O	0.14
MgO	2.01
Al2O3	0.41
SiO2	68.03
K2O	3.92
MnO	0.093
Fe2O3	0.391
SO3	0.99

Table 3.2: Comparison of produced RHA with ASTM-C618-03 specifications

Chemical requirements	**ASTM**	**RHA results**
SiO_2+ Al_2O_3+ Fe_2O_3	70 % min	69%
SO_3	4% max	0.99
Moisture content	3% max	0
Loss On Ignition (LOI)	10%	12%

Figure 3.2: Sieving RHA through 600 µm sieve

3.3 Silica Fume

Figure 3.3 (a) and (b) depict the silica fume used in this study in the form of fine powder, and the SEM image of the particles respectively. The oxide composition of SF is given in Table 3.3. The total percentage of aluminium, iron and silica oxides adds to 70%, which is in good agreement with ASTM-C618-03.

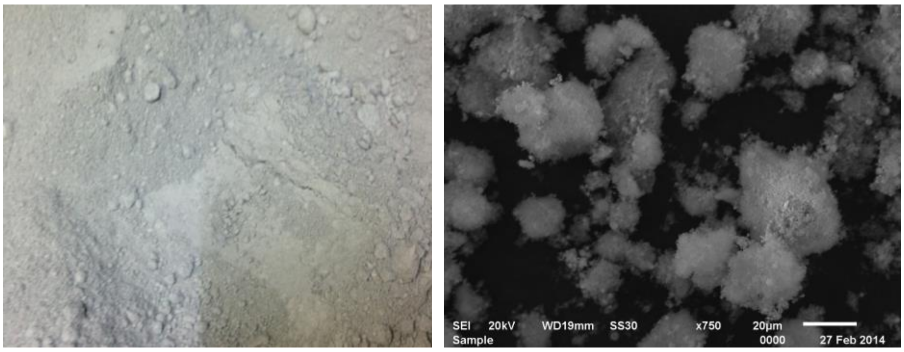


Figure 3.3: (a) Dry silica fume, (b) SEM image

Table 3.3: Oxide Composition of silica fume used

Oxide	Concentration (%)
Na_2O	0.87
MgO	4.36
Al_2O_3	0.33
SiO_2	69.25
K_2O	7.18
MnO	0.05
Fe_2O_3	0.51
SO_3	2.94

3.4 Reactivity Test

The pozzolanic activity test for rice husk ash can be performed by observing its reaction in the saturated solution of calcium hydroxide, based on the solubility of amorphous silica at high pH.

The chemical process is the dissolution of the amorphous silica from the RHA at high pH solution followed by the pozzolanic reaction. The chemical reactions:

$SiO_2 + 2H_2O \rightarrow 4H^+ + SiO^{4-}$

$SiO^{4-} + Ca^{2+} + 2OH^- \rightarrow CaSiO.H_2O$

According to the changes in ion concentration in these reactions, measurement of electrical conductivity in the solution is a reliable method to evaluate the activity of the materials. The electrical conductivity method of Luxán et al [17] was used to evaluate the pozzolanic activity of pozzolans (standard NEN-EN 197-1). 200 ml of saturated calcium hydroxide solution was put into glass beaker with the magnetic stirrer and kept at 40°C preliminarily. Then, pH electrode was installed and the test was started taking data time intervals of 10 seconds. When temperature was fixed at 40±1°C, 5 g of the sample was added into the solution and was kept on stirring all the time. In this study, only the pH could be measured.

3.5 Specific Gravity

This test is a method for determining the density of soil, which is the ratio of density of the material to density of water. In order to measure the G_s of clayey soil and its mixture with additives (stabilized soil), tests are conducted according to ASTM standard number D854-10. For doing this test, 30 gr undisturbed and oven dried soil and standard pycnometer (100 ml) were used. First the empty pycnometer was weighed then it was weighed with 30gr soil. After that soil was soaked with distilled water for 24 hours to make the soil saturated and let the water fill all the soil’s voids as shown in Figure 3.4. The day after, the pycnometers were vaccumed to remove all air bubbles inside the solution. Then the pycnometers stayed for a while allowing the particles to residue. Then the pycnometers were filled with distilled water and weighed. And finally they were fully filled with distilled water and were weighed again. This test was also repeated for different percentages of RHA and SF.

Figure 3.4: Specific gravity test on soil sample and stabilizers

3.6 Hydrometer Analysis

This test was accomplished for soil fractions finer than 75 µm, which could not be separated by means of sieves, so they were analyzed through ratio of their settlement gravity. According to ASTM standard number D422-54T, 50 gr undisturbed soil was mixed with 100 ml sodium hexa-meta-phosphate solution as a dispersing agent. This solution was mixed again on boiling water for 10 minutes. Then it was mixed in a cylinder for 15 minutes more with an end-over shaker. After that it was passed through sieve number 200 (0.075 mm) to separate the clay and silt particles, completely. Then poured to the cylinder and completed to 1000 ml volume by adding distilled water. Hydrometer readings were recorded at certain times and continued for at least 76 hours (Figure 3.5). Hydrometer test carried out also for different percentages of RHA and SF and mixtures of them. The hydrometer used, is shown in Figure 3.6.

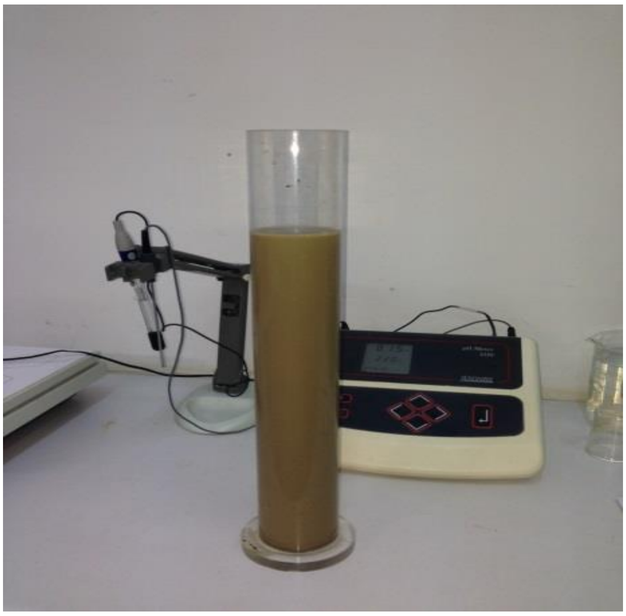


Figure 3.5: Recording of the readings and temperature of the solution in hydrometer cylinder

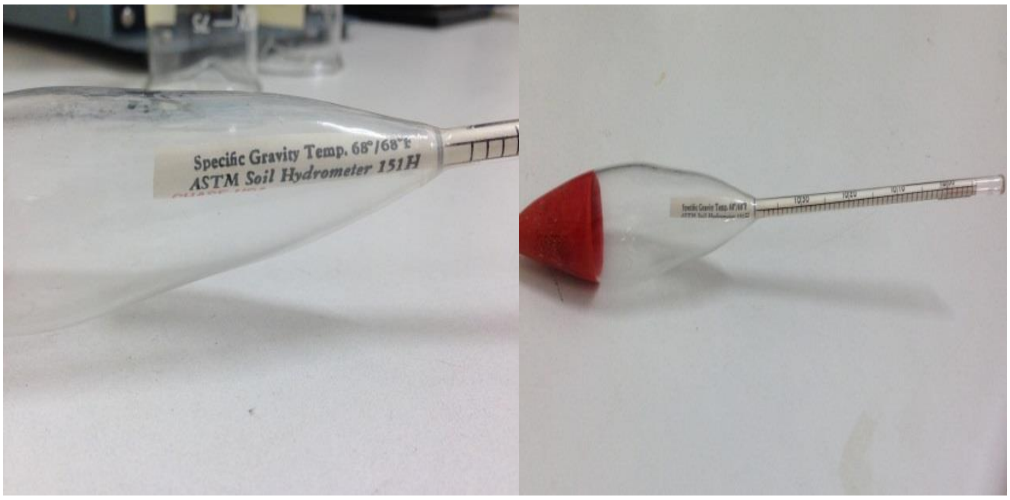


Figure 3.6: Standard hydrometer of model 151 H

3.7 Atterberg Limits

The liquid limit and plastic limit of soils are referred to as the Atterberg limits, which are used in the classification of fine-grained soils. The water content at which the soil passes from plastic situation to liquid is named liquid limit (LL) while the plastic limit (PL) is referred to as the lowest water content at which the soil remains in its plastic condition [29]. The Atterbeg limits of clayey soil lonely and its mixtures with different percentages of RHA and SF were determined and a number of samples were also prepared and stayed for 28 days to be cured then the liquid limit test was done on them for a comparative analysis of the changes in soil’s behavior with decreasing and increasing in SF and RHA content in the mixtures and also considering the effect of time (curing) on Atterberg limits.

3.8 Liquid Limit (LL)

According to standard (ASTM D4318-10) this test was carried out. Certain amount of pulverized and dried soil (about 400 gr) was mixed thoroughly in porcelain bowl and soaked in adequate amount of distilled water (Figure 3.7), stayed for 24 hours in desiccators in order to equilibrate water content. This practice was repeated by adding the certain percentages of RHA and SF. The day after, the initial paste was squeezed down to the cup of standard device and flattened horizontally with spatula, for eliminating bubbles or clumps. By a standard grooving tool, a groove was made in the middle of soil sample (Figure 3.8) and the number of impacts needed to close the groove for 13 mm about toward its center was recorded. The same procedure was repeated with higher water contents step by step. Finally the liquid limits were determined by multipoint liquid limit method.

Figure 3.7: Soaking and mixing sample with distilled water

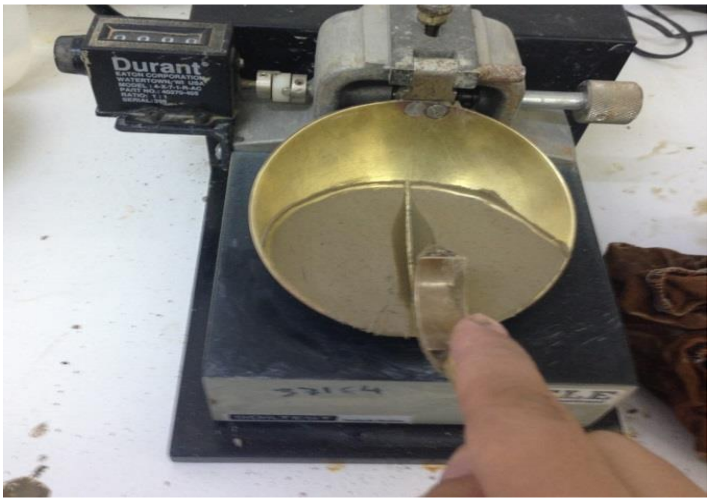


Figure 3.8: A groove was made in the middle of sample

3.9 Plastic Limit

The test was done according to ASTM standard test number D4318-10 for the same sample used for liquid limit test. About 2 g of soil mass was taken in each try and the sample was rubbed on a smooth surface to 3 mm diameter until small cracks were appeared and the water content was obtained using oven drying method.

3.10 Linear Shrinkage

Another method used for measuring the quantity of shrink in soil, was linear shrinkage. In this way, specific amount of undisturbed pulverized soil (about 200 gr) was soaked with water and was reached to its liquid limit. Then using spatula, soil was rubbed in three times inside the special horizontal metal mold (Figure 3.9) and was impacted several times in order to remove all the bubbles [26]. After finishing the last layer, molds were stayed in room temperature for 24 hours, and the day after they were put in oven 40ºC to be shrink until no more evaporation taken place. This procedure was repeated for different percentages of RHA and SF, their combination and also 28 day cured samples for comparing the results of different stabilizer's affects and probably the effect of time for curing. (The samples were not put directly in the oven, preventing the sample to be cleft). At the end of the test the difference of length between the dried sample and the mold was measured (Figure 3.10).

Figure 3.9: Rubbing the soil in linear shrinkage mold

Figure 3.10: Reduction of length of sample in linear shrinkage mold

3.11 Standard Proctor Compaction Test

Standard Proctor compaction test was used to assess the relationship between water content and dry unit weight of samples through the compaction curves. Applying an automatic dynamic compacter with a hammer of 2.5 kg dropping from 305 mm height (Figure 3.11), the mixtures were compacted in standard metal molds with 101 mm diameter in three layers (25 blows on each layer with thickness of 5-8 cm). Then the compacted samples were trimmed, weighed and the water contents were measured (ASTM D2216) with the aim of shaping the relationship of water content and dry density, called the compaction curve. The optimum water contents were determined as the values on the top of compaction curves.


Figure 3.11: Standard compaction mold

3.12 Curing

As mentioned above, the two stabilizers used in this research program were RHA and SF, which both of them are pozzolanic materials react with soil particles in presence of water. Since the RHA is a biological additive, it may need time to indicate its affect. This effect is filling between fractions, reducing swell potential, shrinkage limits, and other hydro-mechanical properties of soil, which can be affected with RHA and SF. So, special condition was prepared for RHA stabilized soil to be cured for 28 days (Figure 3.12). To distinguish same condition for both stabilizers, SF either RHA-SF stabilized soil was also prepared for 28 curing. As depicted in figures, the samples were put above water (in order to keep the sample's moisture) in a special desiccator within a completely closed system (preventing from extra evaporation) under controlled temperature (around 22ºC, room temperature). After this period of time, the samples were removed from the desiccator and all of the experiments were repeated for them.

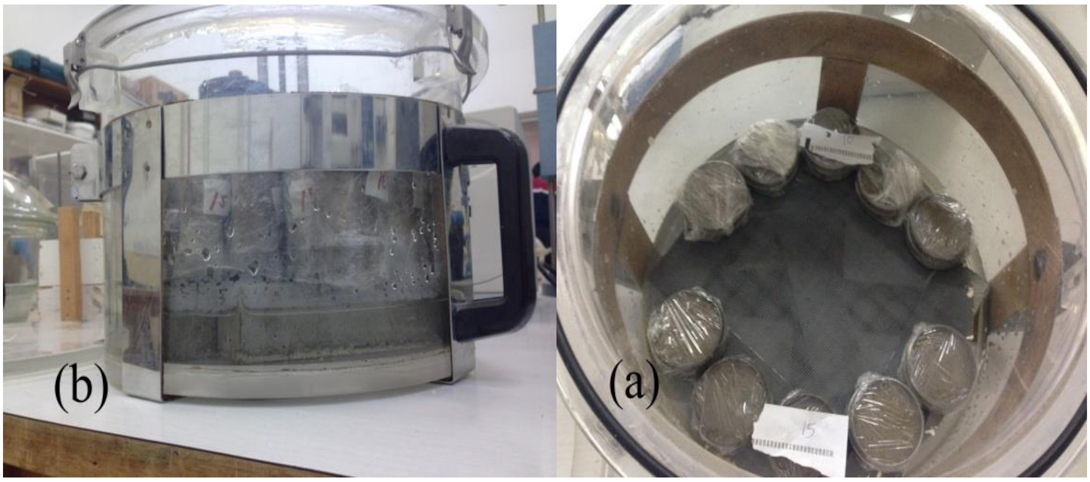


Figure 3.12: (a) Putting the samples in the special desiccator, (b) 28-days cured

3.13 One-dimensional Swell Test

Free swell test was held to monitor the swell potential of each mixture. The samples were compacted at their optimum water contents then the smaller samples in metal rings, 50 mm in diameter and 20 mm in height, were taken (Figure 3.13, 3.14). The same procedure was repeated on samples after curing for 28 days. The samples then left under 7 kPa (Figure 3.15). About 5 mm from the top of rings was left free for swelling. From each mixture a number of same samples were prepared and placed in consolidation cells enclosed by filter paper and porous stone at the top and bottom, to let the water to pass through sample while limiting the sample particles to disperse. The samples were left to swell on consolidation oedometer by filling the cells with distilled water. (The guage readings were recorded at certain time intervals for the first 120 minutes) so the test was followed by taking data every 24 hours till the readings were almost constant, and at that time the test was stopped.

Figure 3.13: Recovering samples from the compaction mold

Figure 3.14: Sample in the metal ring (50 mm diameter and 20 mm height)

Figure 3.15: Samples in oedometer for one-dimensional swell-consolidation testing

3.14 Volumetric Shrinkage

At the end of swelling period, the samples were taken out from water and left in oven at 40ºC to desiccate. Special care was taken not to lose even tiny pieces of soil fragments during the drying process so as not to influence the mass of the sample. The average of diameter and height, and also the mass of each sample (natural soil, 10% RHA, 15% RHA, 20% SF and 10%-10% SF and RHA added samples and their cured ones) were measured daily until the residual water content was reached (Figure 3.18); that is, no further soil water evaporated. The results are shown in Figure 4.9 in Chapter 4. Several relationships were established for shrinkage based on the shrinkage measurements, the most important, is the curve of void ratio versus water content during drying.

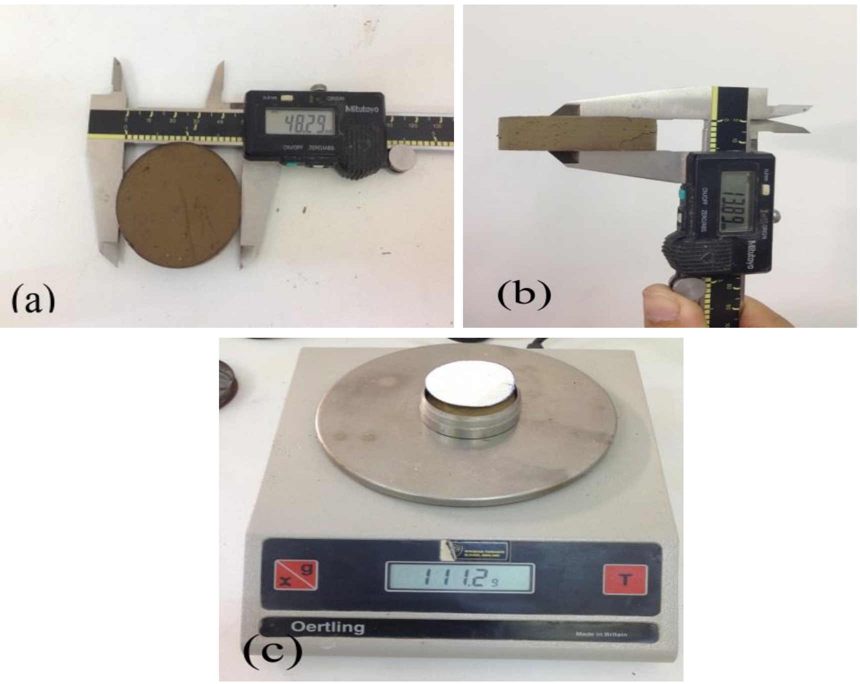


Figure 3.16: Measuring (a) diameter, (b) height and (c) mass of sample

3.15 One-Dimensional Consolidation (ASTM D 2435-96)

Consolidation technique supplies an evaluation of degree and ratio of settlement, while the sample is restricted laterally, allowing vertical drainage under overload, which is applying controlled load. After soil has reached its maximum swell value, loading stage of consolidation experiment was started. The sequence of loading process was based on ΔP/P =1, and each load increment was exerted after 24 hours. This test procedure was repeated for different percentages of SF, RHA, their mixtures and also for 28 day cured ones, and two times for each sample. In the first set of testing the readings were taken by a digital data logger, called MPX 2000, and in the second set of testing, transducers were deformed and autonomous data acquisition unit was used to record and analyze the data by Data System 7 (DS7) software of ELE international Inc. This equipment is shown in Figures 3.17-3.19.

Figure 3.17: DS7 Software

Figure 3.19: Consolidation test with the transducers connected to ADU system

Current Machine & Test Type: cons1 - One Dimensional Consolidation Test BS

Job Number: arc1

Sample Number: arc1

Specimen: A

Current Test Stage: Unloading Stage

Previous Test Stage: Unloading Stage

Load / Unload Stage: 10

Readings Taken: 44

Readings Remaining: 13

Test Running

14-02-19 21/11/13

Compression Gauge: 3.498 mm

ESET NOD32 Antivirus

An error occurred while downloading update files.

Figure 3.5: Displaying the data on the computer

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The first phase of the experimental program consisted of reactivity test on the RHA, and SF to assess their activity, and the physical properties of the selected expansive soil. The second phase includes volume change studies, consisting of swelling, shrinking and compressibility tests on the natural soil and its mixtures with 10% RHA, 15% RHA, 20% SF and 10% RHA+10% SF.

4.2 Reactivity Test

Reactivity of RHA was tested by adding 5 g of material to 200 ml of saturated Ca(OH)2 solution stirred continuously at 40ºC and the pH was measured at frequent time intervals. Figure 4.1 shows the result of pH variation of RHA in the saturated solution of calcium hydroxide.

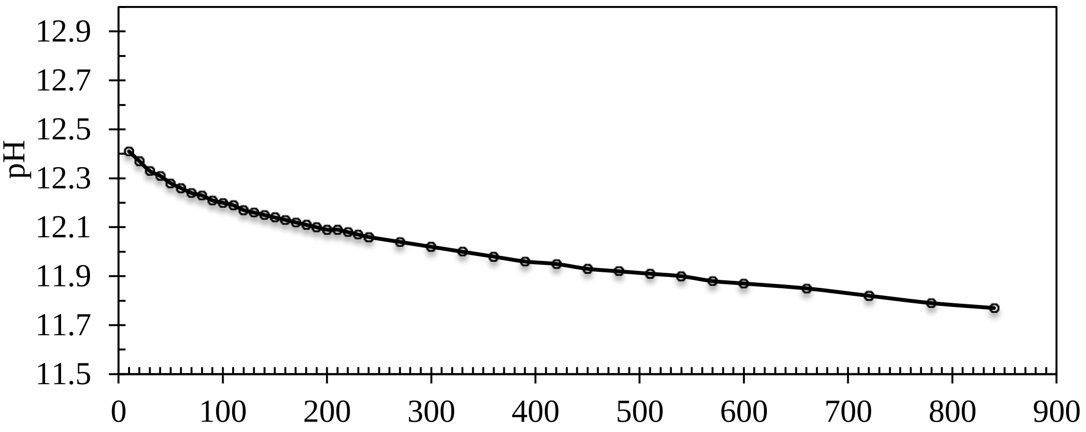


Figure 4.1: pH variation with time

The gradual reduction of the pH value indicates that there was a reaction between the base solution (calcium hydroxide) and the silicic acid. Based on the solubility of amorphous silica at high pH, the pozzolanic activity of rice husk ash can be evaluated by its reaction in the saturated solution of calcium hydroxide. The chemical process within the solution is the dissolution of the amorphous silica from the rice husk ash in the high pH solution followed by the pozzolanic reaction. The chemical reactions can be written as:

$SiO2 + 2H2O \rightarrow 4H+ + SiO4-$

$SiO4- + Ca2+ + 2OH- \rightarrow CaSiO.H2O$

As the ion concentration changes due to these reactions, measurement of electrical conductivity in the solution is a reliable method to evaluate the activity of the material. Unfortunately, in this study the electrical conductivity measurements could not be obtained. However, since a gradual reduction in pH was observed, a similar behavior in EC was also expected which was presented by Pham (2012) shown in Figures 4.2 and 4.3. The figure shows results of reactivity test on different RHA samples. The largest activity was observed for C-RHA, which produces a pH change less than the RHA tested in this study. The largest EC change in Pham (2012) study is also for C-RHA, therefore the EC change in the current work can also be assumed to be larger than this value. As the conductivity and the concentration of the ions is correlated, conductivity reduction reflects the rate of consuming reagents for the reaction; hence, the reactivity of the material is revealed. Therefore it can be concluded that the RHA used in this study is pozzolanic.

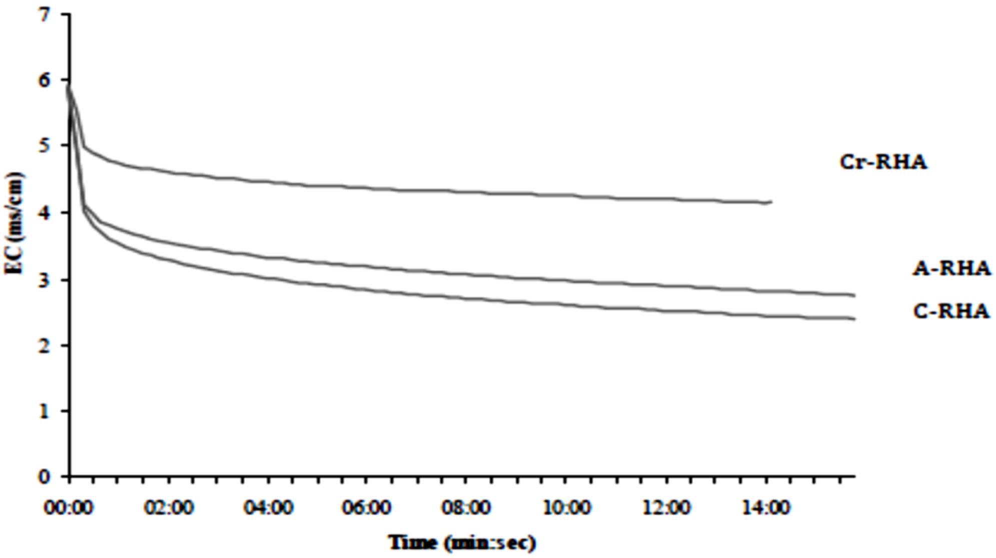


Figure 4.2: EC changes in saturated calcium hydroxide (Pham, 2012)

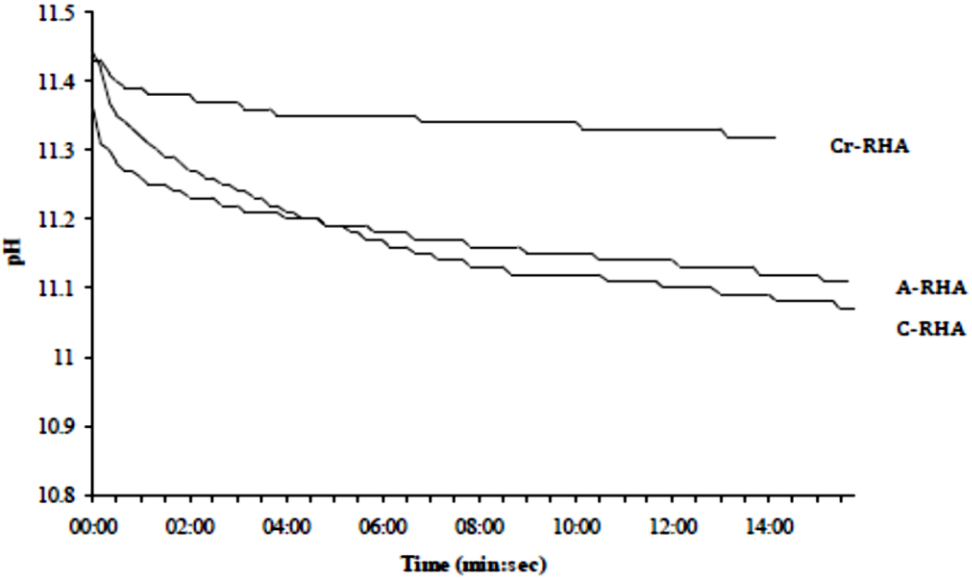


Figure 4.3: pH changes in saturated calcium hydroxide (Pham, 2012)

4.3 Specific Gravity

Specific gravity determination, of a particular type of soil has a main role in estimation of its void ratio. Value of Gs is also linked with shrinkage parameters and hydrometer analysis closely. Therefore, specific gravity was measured carefully according to ASTM standard 854-10 (in 100 ml pycnometer with vacuum pump).

The specific gravities of natural clayey soil, 10%, 15% of RHA and 20% of SF and also 10% RHA and 10% SF added to clayey soil are given in Table 4.1.

Table 4.1: Specific gravities of samples used

	Natural soil	10% RHA	15% RHA	20% SF	10%RHA+10%SF
Gs	2.7	2.6	2.57	2.35	2.38

4.4 Hydrometer Test Results

Figure 4.4 represents the particle size distribution curves of natural clayey soil, and its mixtures with 10%, 15% of RHA and 20% of SF and the mixture of 10% of RHA with 10% of SF. As shown in Figure 4.4, natural soil consists of 54% clay of which 48% are colloids and 46% silt.

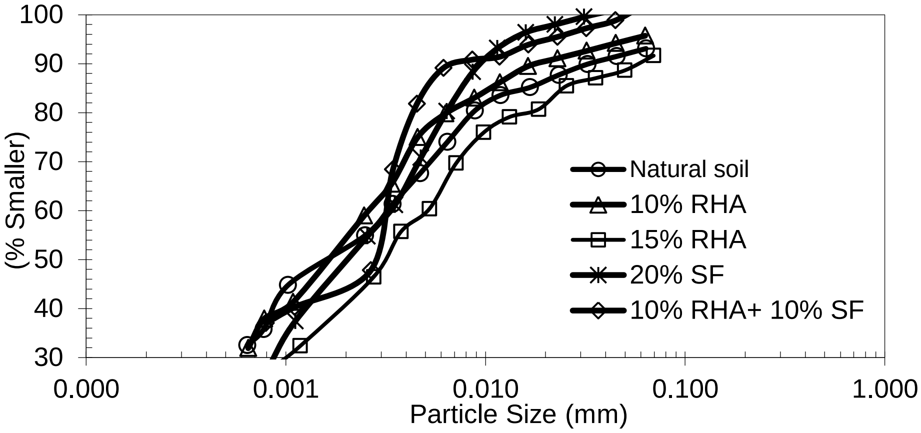


Figure 4.4: Particle size distribution curves of samples used

With the addition of 10% RHA the clay and silt-sized fractions remain the same, yet the colloids reduce to 40% of the clay-sized particles. There is a marked reduction in the clay size fraction from 54% to 41%, of which only 30% are colloids, when 15% RHA is used. Whereas the silt sized fraction increases appreciably from 46% to 59%.

Addition of silica fume alone produces a 50%- 50% fraction of both sizes, and when 10% RHA-10% SF mixture is added the clay fraction reduces while the silt fraction increases notably. These results are summarized in Table 4.2.

Table 4.2: Clay, silt, sand and colloids fractions from hydrometer tests

Particle	N	10% RHA	15% RHA	20% SF	10% RHA-10% SF
% Clay	54	54	41	50	44
% Silt	46	46	59	50	56
% Sand	0	0	0	0	0
Colloids	48	40	30	45	40

4.5 Atterberg Limits

Figure 4.5 displays the plastic limit, liquid limit and the plasticity indices of natural and stabilized soil with different percentages of stabilizers. The plasticity index values indicate a slight change in the plastic behavior of the soil with admixtures, which is also substantiated by the particle size variations discussed in section 4.4. However, the reduction in clay size fraction is not significant enough to reduce the plasticity index. As can be observed from the test results, the 10% RHA and 15% RHA have almost no influence on the Atterberg limits, except for the cured 15% RHA added specimens with a 21% reduction in the plasticity index. A similar behavior is observed for the 10% RHA+10% SF added samples. Overall, even though the additives proved to be pozzolonic in nature, the curing period of 28 days was not sufficient to cause a significant improvement in the plasticity properties of the soil.

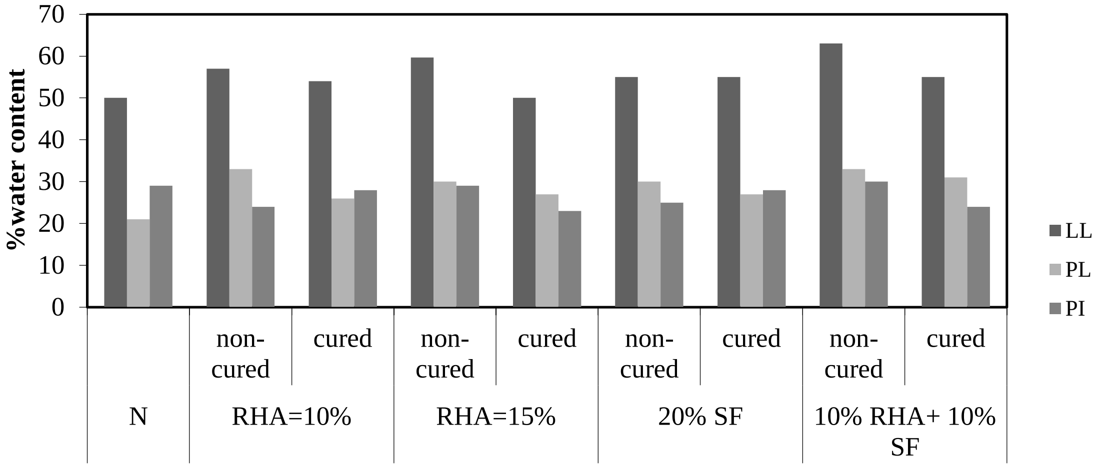


Figure 4.5: Comparison of Atterberg limits in both cured and uncured samples

4.6 Compaction Characteristics

Standard Proctor tests were carried out on natural soil and on its mixtures with RHA and SF in different proportions. The results of the compaction tests performed to assess the optimum water contents and maximum dry densities are given in Figure 4.6. A summary of compaction test results are given in Table 4.3. As can be observed additives caused optimum water content to increase while decreasing the maximum dry density in general.

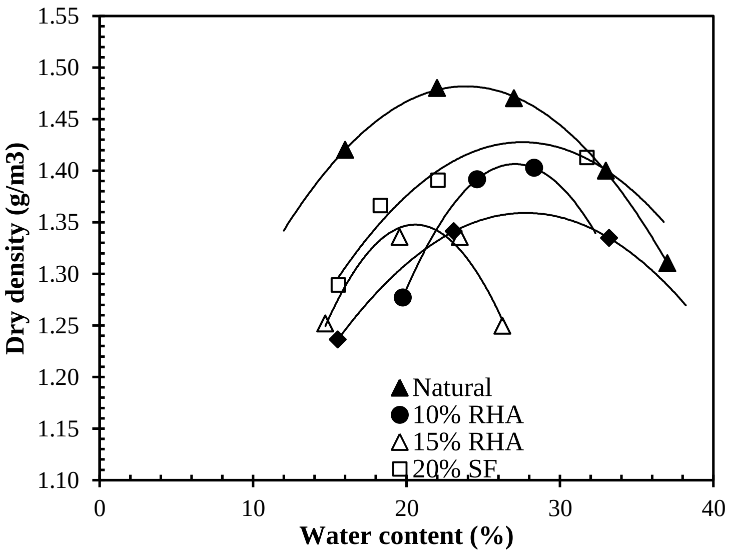


Figure 4.6: compaction curves

Table 4.3: Compaction test results

Sample	Optimum water content (%)	Maximum dry density (g/cm3)
Natural	22	1.48
10% RHA	27	1.41
15% RHA	21	1.35
20% SF	27	1.43
10%RHA-10%SF	28	1.36

4.7 One-dimensional Swell Test Results

One-dimensional swell test results are given as plots of percent swell ($\Delta H/H_0$ x100) versus logarithm of time. The swell curves are presented in Figure 4.7 for specimens with no curing and Figure 4.8 for cured specimens. They are plotted with respect to logarithm of time in order to be able to see the completion of primary swell phase. Primary swell percentage is the main component of the total swell percentage. Total swell is consisted of initial, primary and secondary phases. The secondary swell occurs gradually and usually completes in very long time duration. The rate of secondary swell is the slope of the secondary swell curve.

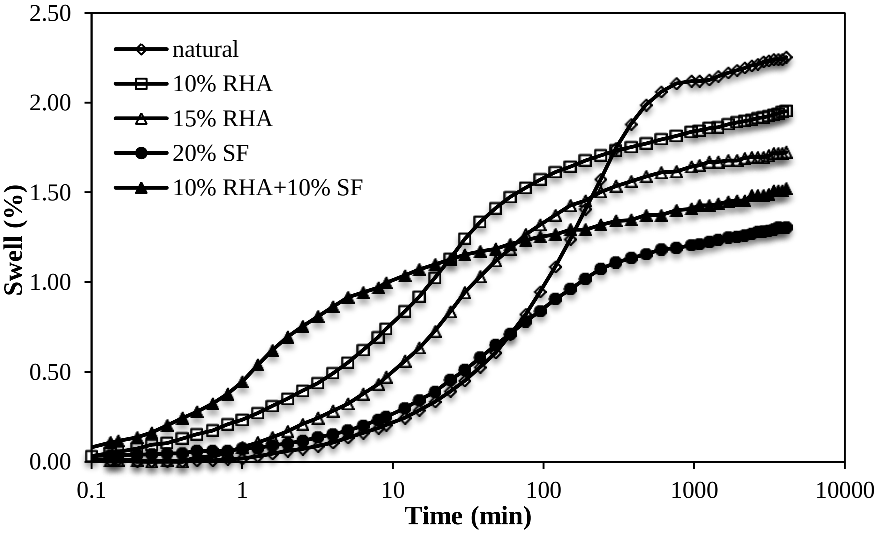


Figure 4.7: Swell-log time curves of natural and stabilized specimens

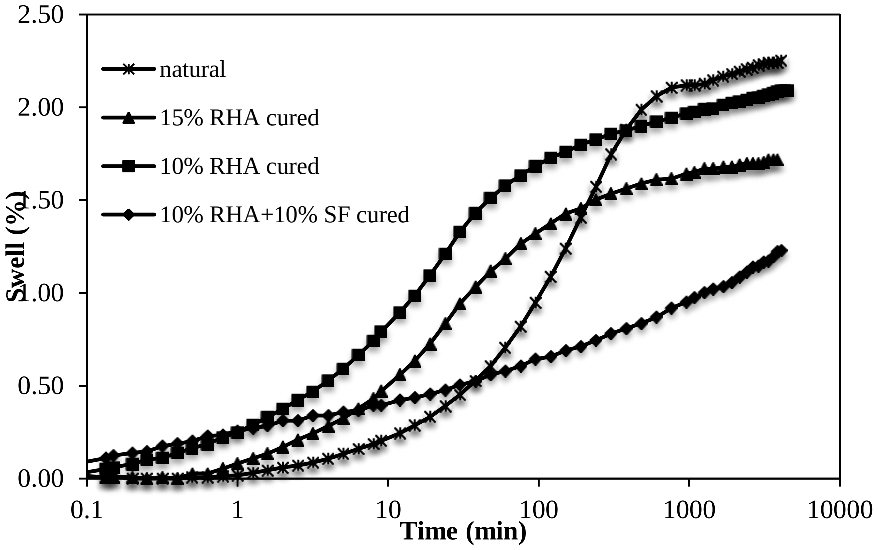


Figure 4.8: Swell-log time curves of natural and cured stabilized specimens.

The swell parameters are summarized in Table 4.4. The initial swell values are the values at the first curvature of the swell plots, which show a tendency of increase and at shorter time intervals (t_{is}) with the inclusion of additives. The main swelling percentage component, the primary swell, however reduces with the effect of the additives while the time of completion reduces. This is the second curvature of the swell-log time curve from which propagates the secondary swell part. This phase proceeds with a low rate and may take a very long time to complete. Overall, the additives reduced the swell potential of the treated expansive soil, the most effective being the 20% SF and 10% RHA+10%SF added non-cured specimens. The test results of the cured specimens with the latter two additives displayed erratic results, thus discarded.

Apparently 10% and 15% RHA have not been effective enough in reducing the swell potential, even after the curing period, whereas, 20%SF and 10%RHA+10%SF have proved to be quite effective, even without curing. Therefore, based on the pozzolanity of the materials and the improvements caused in non-cured state, one could extrapolate the conclusion that the cured specimens would have displayed much more reduction in the swell potentials.

Table 4.4: Swell parameters.

Sample	si (%)	tis (min)	sp (%)	tps (min)	Secondary swell rate
H Natural soil	0.05	5.0	2.05	450	0.286
10% RHA	0.50	0.5	1.60	70	0.241
15% RHA	0.10	0.4	1.60	15	0.158
20% SF	0.06	2.5	1.10	250	0.160
10% RHA 10% SF	0.20	0.5	0.96	5	0.175
10% RHA cured	0.15	0.6	1.75	70	0.230
15% RHA cured	0.02	0.6	1.50	110	0.135
20% SF cured	NA				
10% RHA+10% SF cured	NA				

The swell curves can also be presented as present swell versus time, providing a presentation can emphasizes the effect of different materials.

4.8 Volumetric Shrinkage Test Results

After completion of one-dimensional swell tests, the specimens were dried at 40°C and the diameters and heights were measured at certain time intervals to study the variation of volumetric, axial and diametral strains with time along the shrinkage path. Figure 4.9 shows the top and side views of the desiccated specimens.

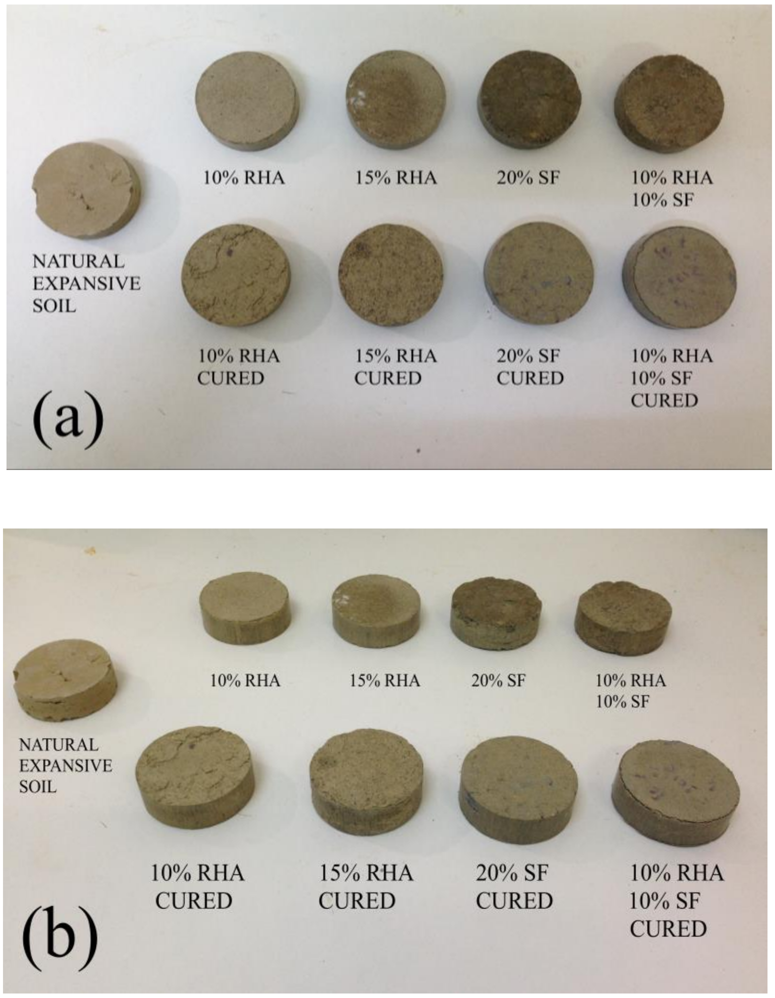


Figure 4.9: Specimens after shrinkage (a) top view, (b) side view

The specimens are observed to have different textures due to types, amounts of additives as well as the effect of curing.

Figures 4.10-4.15 show the shrinkage curves of each specimen before and after curing. The drying starts at a water content parallel to the saturation line and proceeds along this line until a point is reached where the soil dries without any change in overall volume. This is defined as the "shrinkage limit" of the soil. Soil Vision 3.34 software fits a hyperbolic equation to the experimental data given in Equation (3).

$$e_w = a_{sh}[\frac{w^{c_{sh}}}{b_{sh}} + 1]^{(\frac{1}{c_{sh}})} \quad (1)$$

where ,

a_{sh} is the minimum void ratio (e_{min})

b_{sh} is slope of the line of tangency in drying from saturated conditions

c_{sh} is inflection of the shrinkage curve,and w is gravimetric water content

Figure 4.10 shows the shrinkage curve of the natural soil, which shrinked most, and the Figures 4.11-4.15 depict the shrinkage curves of non-cured and cured specimens with different additives. All the shrinkage parameters obtained from SoilVision are summarized in Table 4.5.

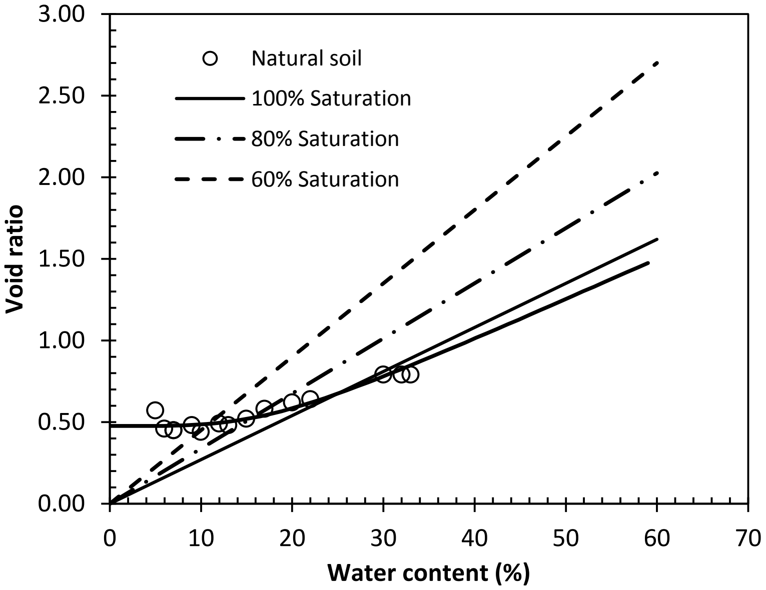


Figure 4.10: Shrinkage curve of natural soil

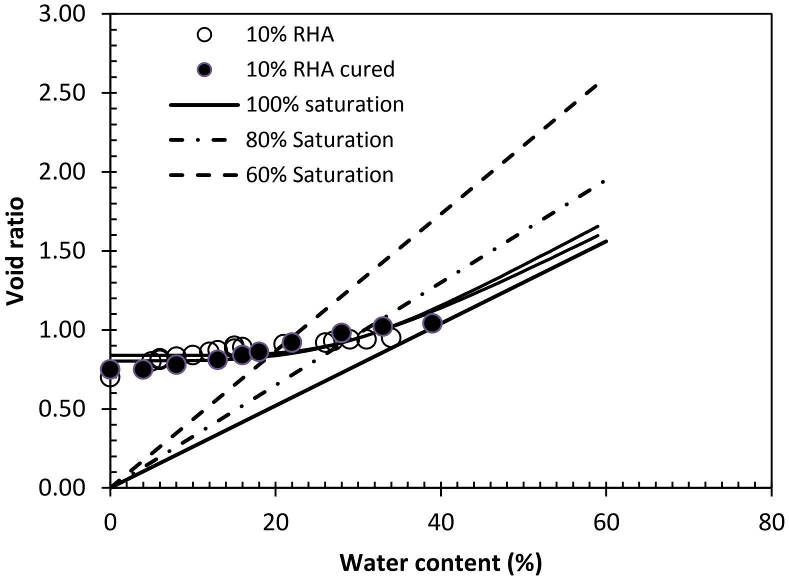


Figure 4.11: Shrinkage curve of 10% RHA non-cured and cured

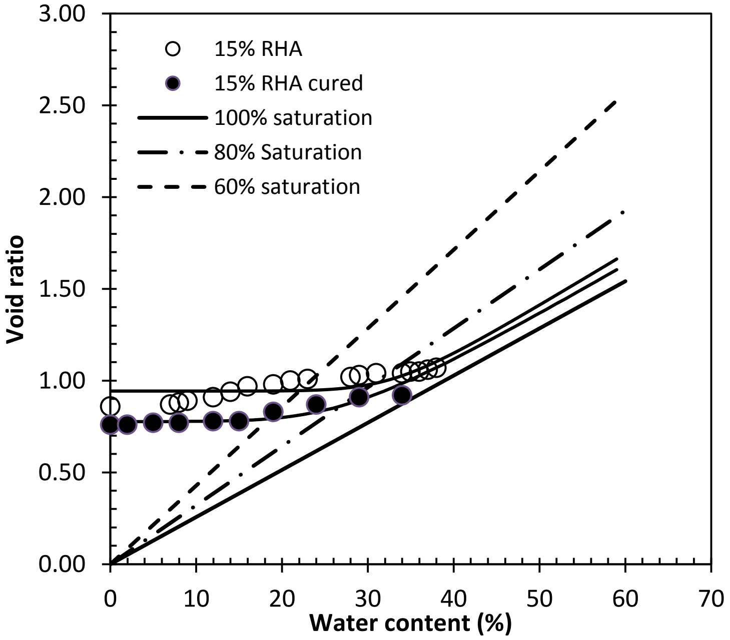


Figure 4.12: Shrinkage curves of 15% RHA added specimens

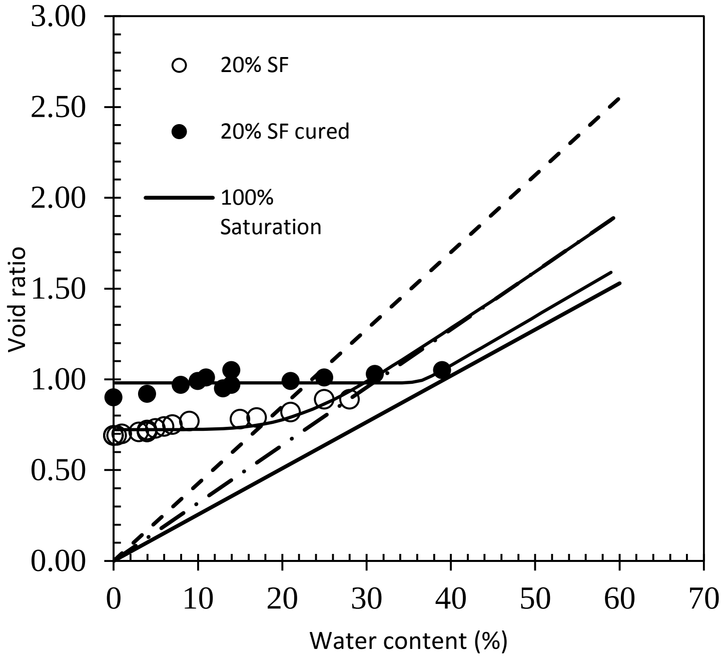


Figure 4.13: Shrinkage curves of 20% SF added specimens

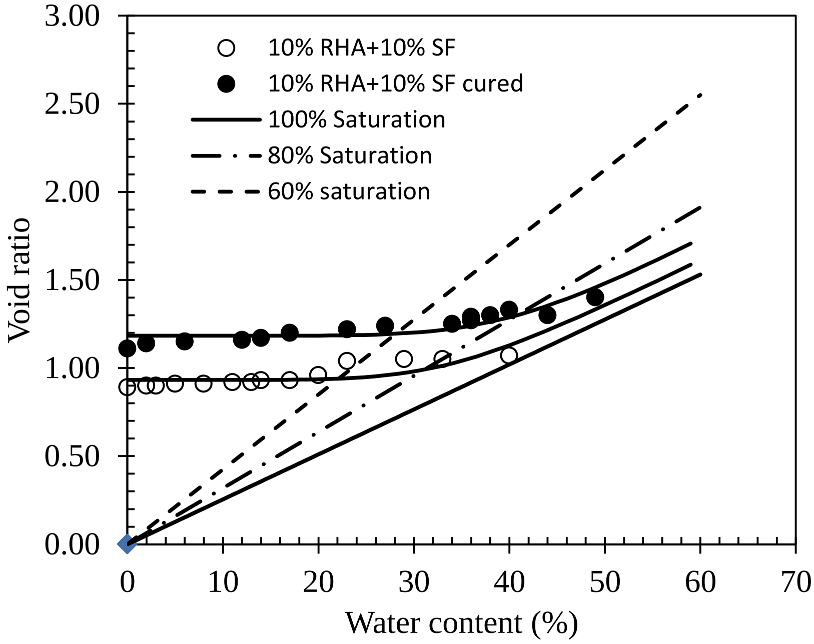


Figure 4.14: Shrinkage curves of 10% RHA-10% SF added specimens

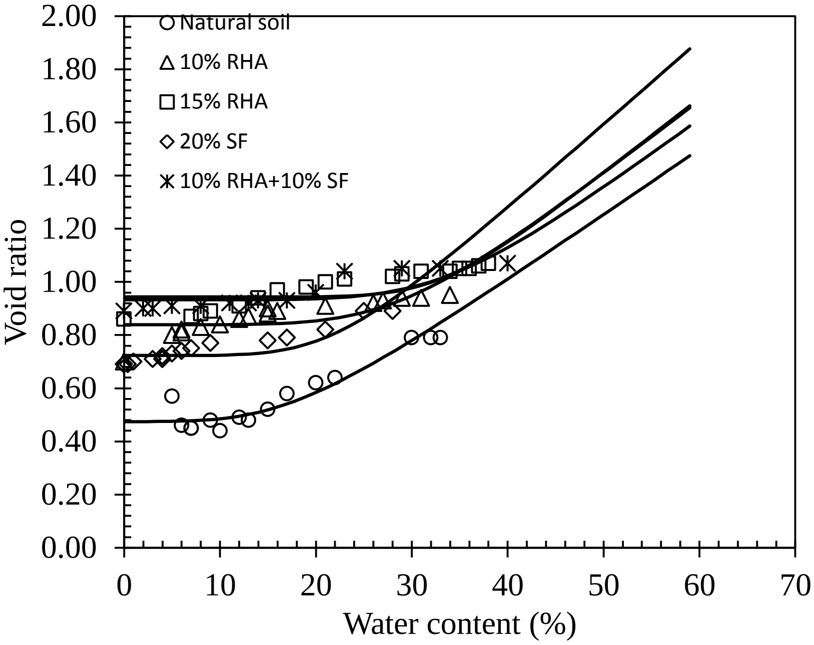


Figure 4.15: Comparison of shrinkage curves of non-cured specimens

Table 4.5: Shrinkage curve fitting parameters from Soil Vision

Sample	a_{sh}	b_{sh}	c_{sh}	Shrinkage Limit
Natural soil	0.47	0.1906367	3.815441	0.19
10% RHA	0.84	0.3002603	5.636816	0.30
15% RHA	0.94	0.334963	8.971935	0.33
20% SF	0.89	0.3144011	5.347806	0.31
10% RHA+10%SF	0.93	0.3486463	6.412794	0.35
10% RHA cured	0.80	0.3014473	4.132655	0.30
15% RHA cured	0.78	0.2872233	5.170688	0.29
20% SF cured	0.98	0.3643373	58.74479	0.36
10%RHA+10%SF cured	1.18	0.4140599	6.826217	0.41

The minimum void ratio and shrinkage parameters are plotted for the natural, treated and cured specimens for better comparison in Figure 4.16. The results of the shrinkage study have clearly revealed that RHA and SF inclusions have reduced the shrinkage potential and moreover, curing has been very effective on the results. The best treatment is concluded to be the 10% RHA+ 10% SF addition which also has the least swell potential.

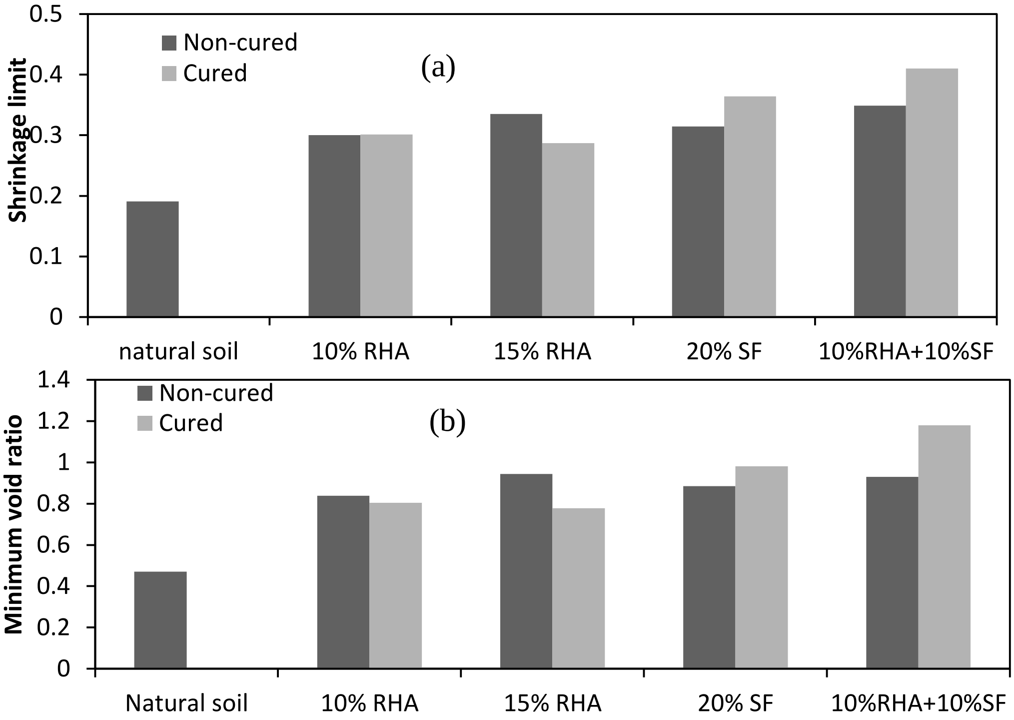


Figure 4.16: Comparison of (a) shrinkage limits (b) minimum void ratios.

Figure 4.17, the axial strain ($\Delta H/H_0$), diametral strain ($\Delta D/D_0$) and volumetric strain ($\Delta V/V_0$) are plotted with respect to time to display the rate of shrinkage. The natural clay is observed to shrink faster, while the treated specimens shrink at a slower rate, mainly in the diametral direction. The volumetric strain reduces by more than 50% when the expansive soil is treated with RHA, SF, and RHA+SF.

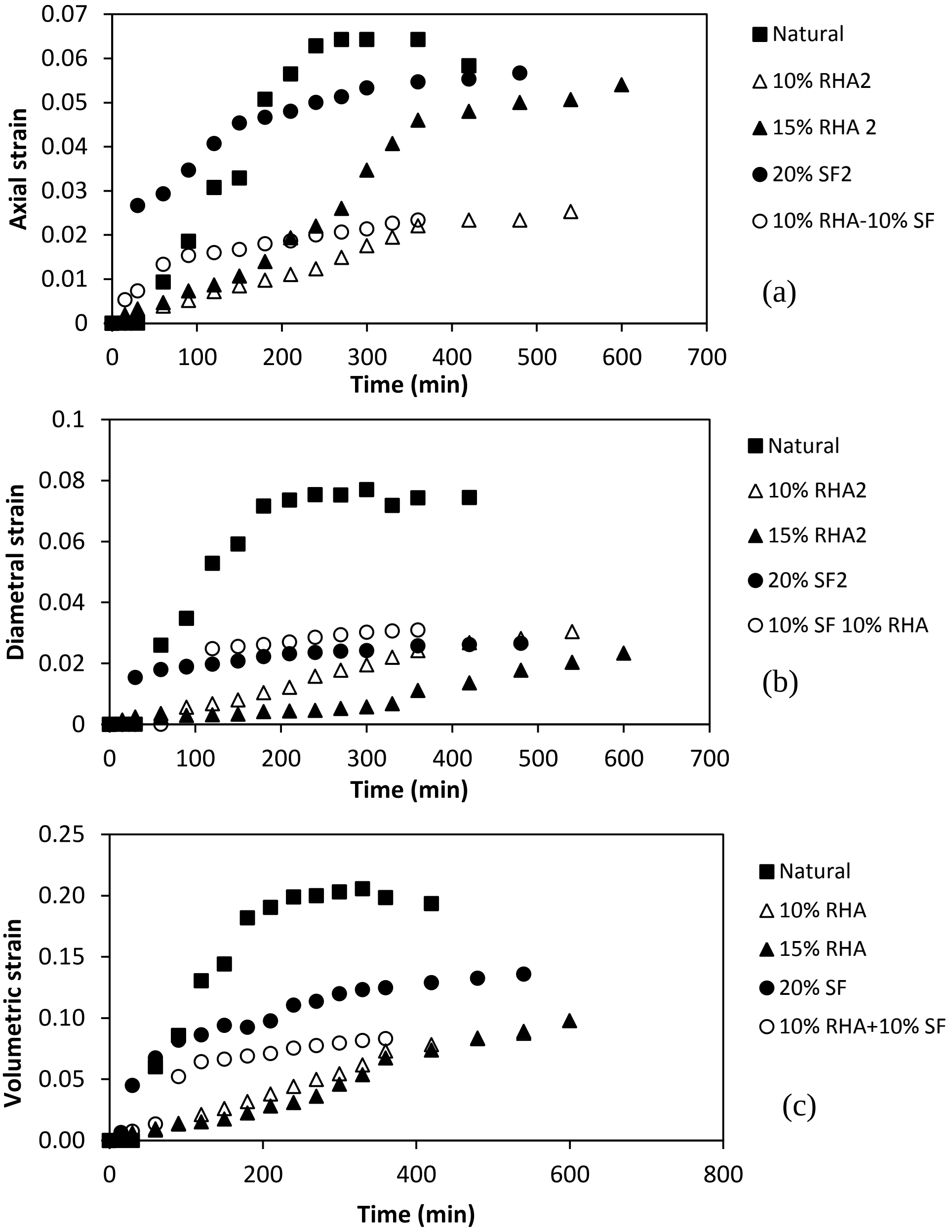


Figure 4.17:Shrinkage strains (a) Axial, (b) Diametral, (c) Volumetric

4.9 One-dimensional Swell-Consolidation Test Results

Results of this test are given as void ratio versus logarithm of effective consolidation pressure in Figure 4.18. The parameters obtained from these curves, are the compression index (Cc), swell index (Cs), pressure (p_s') and preconsolidation pressure (σ_p'), which are shown in Figures 43-46.

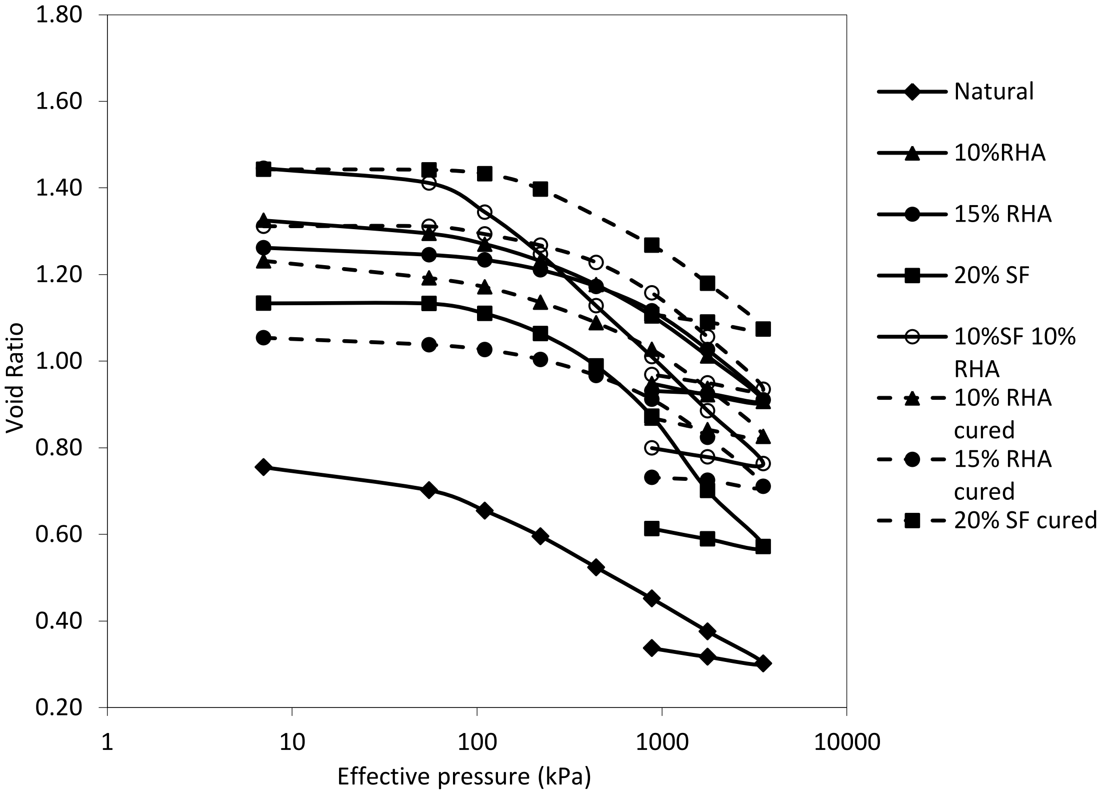


Figure 4.18: Void ratio-log effective consolidation pressure plots at the end of consolidation test.

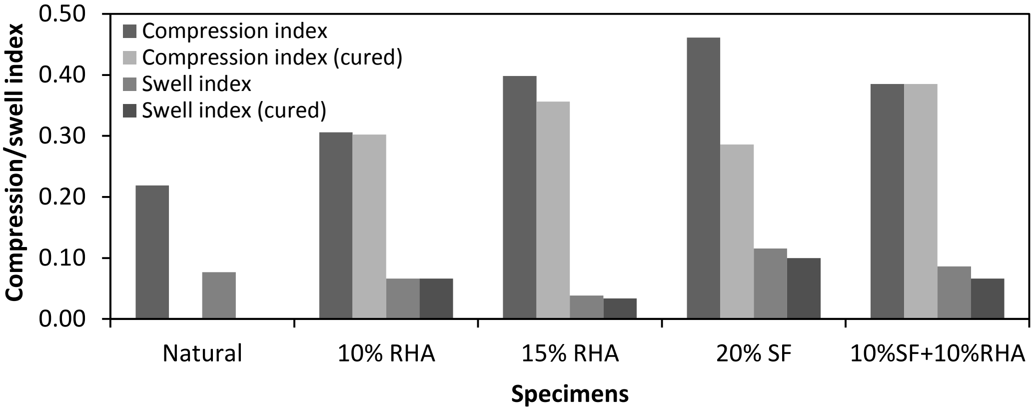


Figure 4.19: Comparison of compression and swell indices.

The compression indices increased with the addition of RHA and SF, which slightly reduced upon curing. Swell indices reduced with RHA but increased with SF giving the best result for RHA+SF specimen. The increase of compression and swell indices can be justified with the corresponding increase in preconsolidation pressures, hence swell pressures. Figures 4.19 and 4.20 show the variation of these pressures for non-cured and cured specimens. The natural sample has equal preconsolidation and swell pressures. 10% RHA and 15% RHA addition increase these values significantly when cured. Preconsolidation pressure in a compacted soil has nothing to do with the time history of specimens, but represents the degree of cementation or bonding created by compaction and further by curing.

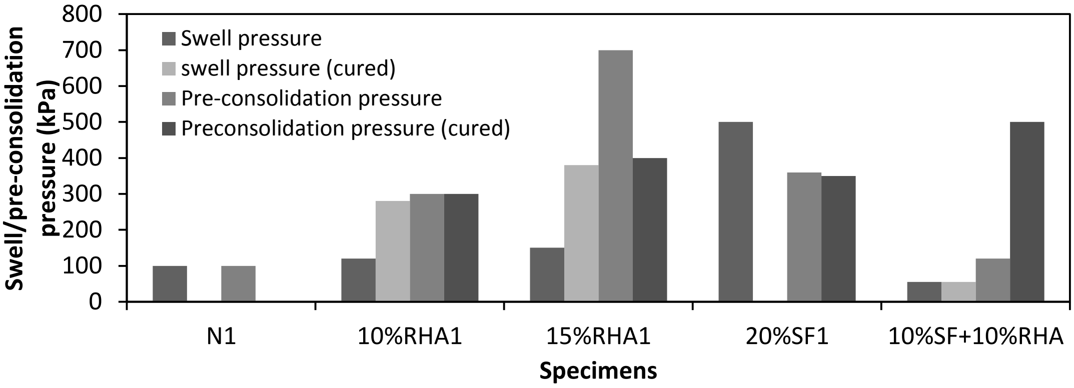


Figure 4.20: Comparison of swell and pre-consolidation pressures.

When soil is treated with SF alone, swell pressure diminishes upon curing. When 10% RHA+ 10% SF is used swell pressure is very low and does not change with curing, whereas preconsolidation, hence the cementation increases with curing.

The increase of compression index is experienced after exceeding the preconsolidation pressure, and since stabilized expansive soil is mainly a surface layer, it will never be subjected to such stresses and rarely be submerged to cause excessive consolidation settlements. The reason for doing consolidation was to determine the swell pressures and the degree of cementation.

4.10 Scanning Electron Microscopy (SEM) Analysis

Figures 4.21-4.23 show the results of the scanning electron micrograph (SEM) images of the natural, 10% RHA mixed with 10%SF non cured and cured ones with a magnification of x1000.

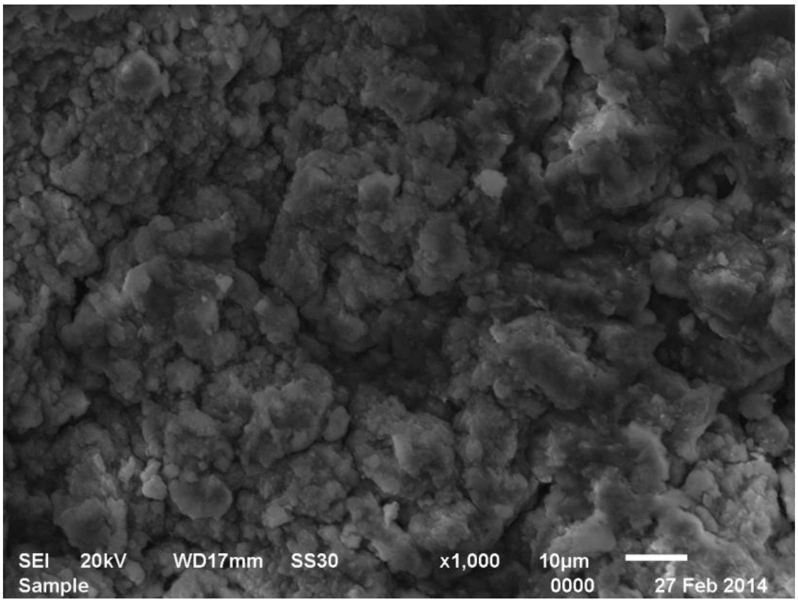


Figure 4.21: SEM image of natural compacted soil

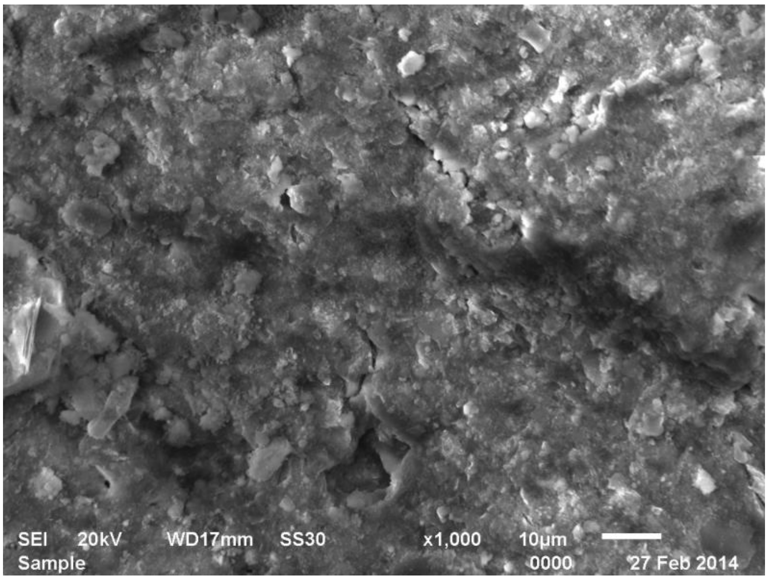


Figure 4.22: SEM image of 10% RHA & 10% SF non-cured sample

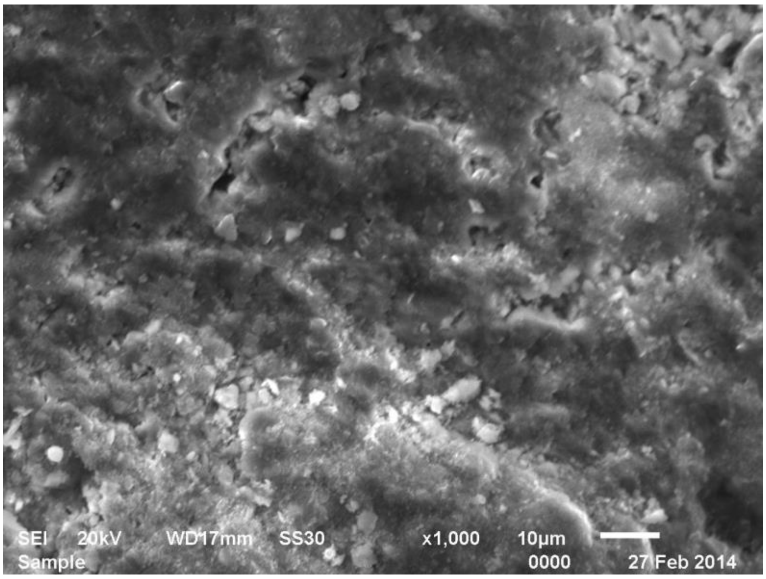


Figure 4.23: SEM image of 10% RHA & 10% SF cured sample

The SEM images reveal the change in structure of the natural specimens by the addition of 10% RHA-10%SF before and after curing. The crumb structure in the natural soil with some flakey smectite minerals disappears in the cured specimen, (Figure 4.23) with RHA and SF firmly bonding the clay particles into a more uniform texture.

Chapter 5

CONCLUSION

This work presents the findings of an experimental study on the possible use of industrial waste products of rice husk ash and silica fume. The results showed that even though the reactivity test and XRF results indicated that the open-air burnt rice husk ash could be sufficiently pozzolanic, it has not been very effective when used in proportions of 10% and 15% by dry mass of the soil and cured for 28 days. To enhance the reactivity of the RHA, silica fume was also incorporated in this study, first by using 20% for comparison reasons, and then in combination with RHA in 10%-10% mix. The latter has showed some improvement yet not significant enough in improving plasticity properties, which has given very erratic results. It has, however improved swelling, shrinkage and pre-consolidation pressure.

The following are the main conclusions derived from this study:

1. Addition of RHA in 10% and 15% by dry mass of natural expansive soil (CH) has not given consistent results in plasticity parameters, yet overall there is a tendency of decrease in the plasticity index with the addition of RHA and SF, mainly in the combination of the two. The highly pozzolanic SF seems to have increased the reactivity of the RHA.
2. The additives have reduced the swell percentage and the rate of swell notably. This implies that the texture and structure of the specimens changed, hence

the air entry of specimens increased, allowing faster movement of water into the specimens.

3. A significant change in the shrinkage parameters has been observed, while the minimum void ratio at the end of shrinkage remained higher, the shrinkage limit increased by the addition of RHA and SF. The best improvement is noticed in the 10% RHA-10% SF mixture added specimen.

As a future study, it is recommended to investigate the effect of other pozzolans to be used in conjunction with RHA and their reactivity using electrical conductivity and pH measurements. Furthermore, durability tests, such as cyclic wetting-drying, elevated temperatures or change in pore water chemistry and their effect on the treated soil should also be studied, incorporating the principles of unsaturated soils, as stabilized compacted soils are unsaturated for prolonged periods.

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