DECEMBER 20

M.Sc. in Civil Engineering

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UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

USING SEWAGE SLUDGE ASH AND STONE POWDER IN SOIL STABILIZATION AND CONCRETE MIXTURES

M.Sc. THESIS

IN

CIVIL ENGINEERING

BY

MAIS ABDULRAZZAQ IBRAHIM

DECEMBER 2017

Using Sewage Sludge Ash and Stone Powder in Soil Stabilization and Concrete Mixtures

M.Sc. Thesis

in

Civil Engineering

University of Gaziantep

Supervisor

Prof. Dr. Ali Fırat ÇABALAR

by

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December 2017

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: Using sewage Sludge Ash and Stone Powder in Soil Stabilization and concrete mixtures.

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Exam date: 07.12.2017

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Mais Abdulrazzaq IBRAHIM

ABSTRACT

USING SEWAGE SLUDGE ASH AND STONE POWDER IN SOIL STABILIZATION AND CONCRETE MIXTURES

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December 2017
79 pages

In this study, two different types of wastes (Sewage Sludge Ash SSA and Stone Powder SP) were used as a stabilizer to improve some geotechnical properties of silty soil and as alternatives of cement and sand in concrete mixtures. Five different ratios (in weight percentage: 0%, 5%, 10%, 15%, and 20%) of SSA and SP admixtures are mixed with cohesive soil to make soil samples. Also the materials used with four different ratios (0%, 10%, 20%, and 30% in weight) in 1:2:4 (cement: sand: gravel) concrete mixtures. In order to understand the influences of admixtures on the soil properties, tests of Atterbeg limits, compaction, unconfined compressive strength, fall cone, laboratory vane shear, and primary swell were performed on those samples. Another test of compressive strength was performed to 28-days cured concrete samples. The study shows that the unconfined compressive strength of specimens with the SSA addition was improved and with the SP addition was reduced; furthermore the undrained shear strength obtained from fall cone and laboratory vane shear tests was increased in both SSA and SP addition. The strength of concrete samples contained SSA and SP was adversely affected with increasing the SSA and SP ratios in the mixtures. This suggests that SSA and SP have many potential applications in the field of geotechnical engineering and can used to reduce the cost of non-structural application such as road pavement, walkways, and floor works.

Keywords: soil stabilization, silt, sewage sludge ash, stone powder, undrained shear strength.

ÖZET

TOPRAK ÇAMUR KÜVESİ VE TAŞ TOZU ZEMİNİN STABİLİZASYONUNDA VE BETON KARIŞIMLARINDA KULLANILMASI

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Aralık 2017
79 sayfa

Bu çalışmada iki farklı atık türü (kanalizasyon atık külü SSA ve taş tozu SP) siltli zeminin bazı geoteknik özelliklerini geliştirmek için bir stabilizatör olarak ve beton karışımlarında çimento ve kum alternatifleri olarak kullanılmıştır. SSA ve SP katkılarının beş farklı karışım oranlarında (ağırlık yüzdesi olarak:%0, %5, %10, %15 ve %20) zemin numuneleri yapmak için kohezyonlu zemin ile karıştırılmıştır. Ayrıca, malzemeler 1: 2: 4 (çimento: kum: çakıl) beton karışımlarında dört farklı oranda (ağırlıkça %0, %10, %20 ve %30) karıştırılmıştır. Katkıların zemin özellikleri üzerindeki etkilerini anlamak için, bu numuneler üzerinde Atterbeg limitleri testleri, kompaksiyon, serbest basınç dayanımı, düşen koni penetrasyon, laboratuvar kanatlı sonda, serbest şişme deneyleri gerçekleştirilmiştir. Basınç dayanımının bir başka testi basınç testi 28 günlük kürlenmiş beton numunelerine gerçekleştirilmiştir. Çalışma SSA ilaveleri ile örneklerin serbest basınç dayanımının iyileştiğini ve SP ilavesi ile azaltıldığını göstermektedir; Ayrıca düşen koni penetrasyon ve laboratuvar kanatlı sonda testlerinden elde edilen drenajsız kayma mukavemeti hem SSA hem de SP ilavesinde artmıştır. SSA ve SP içeren beton numunelerinin mukavemeti, karışımlardaki SSA ve SP oranlarının artması ile olumsuz etkilenmiştir. Bu, SSA ve SP'nin geoteknik mühendisliği alanında birçok potansiyel uygulamasının bulunduğunu ve yol döşeme, yürüyüş yolları ve döşeme işleri gibi yapısal olmayan uygulamaların maliyetini düşürmek için kullanılabileceğini göstermektedir.

Anhtar kelimeler: zemin stabilizasyonu, silt, kanalizasyon atık külü, taş tozu, drenajsız kayma mukavemeti.

To My

Father and mother, which they spend their life for me and give the support to reach this level from the knowledge

ACKNOWLEDGEMENTS

First of all, praise be to my God, the Cherisher and the Sustainer of the World. A thesis work is a product of collective efforts and able guidance. A work has a life and spirits of its own. I believe that no work can achieve its ultimate objectives without proper guidance and support from others. I wish to express my heartiest thanks to my respected guides **Prof. Dr. Ali Fırat ÇABALAR**, Department of Civil Engineering, University of Gaziantep - Turkey, who devoted their valuable time and provided enthusiastic guidance, advice and continuous encouragement, which were the constant source of inspiration for the completion of this thesis work.

I cannot forget to recall with my heartiest feelings, the never-ending heartfelt stream of caring and blessings of **my Father** and **my Mother**, to support me with everything from my early childhood till reach higher education, They were always denying themselves for supporting and pushing me to every success.

Finally, I wish to record my heartfelt gratitude and indebtedness to all of my friends, I appreciate them for the kind of support that they have extended to me.

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CHAPTER 1

INTRODUCTION

1.1 General

In general, rising quality of life and the development of the industrial revolution have had a negative effect on the urban environment. Many cities are now grappling with the high volume of wastes, methodology of mechanical disposing, and the reducing of wastes impact on local and global environment.

In this study, two types of wastes (sewage sludge ash and stone powder) were performed to test their possibility to change into fruitful materials such as clayey soil stabilizers and partial alternatives to the fine contents of normal strength concrete. These materials can be classified as hazardous materials to the environment as well as the human health.

Soil stabilization is the mean of changing the geotechnical engineering properties of a weak soil to meet the required specifications. The stabilization of the soil has basically involved the enhancing of the strength, improvement of the volumetric behavior, and increasing the bearing capacity. Soil stabilization with wastes has not only improved the geotechnical properties but also has adopted to be a useful method from the economic and environmental point. Recently, more researches had been carried out in utilizing the wastes in soil stabilization methods (Jafari and Esna-ashari, 2012). Another more studies had been carried out on using the wastes in ground improvement of different projects like road pavements and highway (Kamie et al., 2007; Ugai and Ahmed, 2009; Ahmed et al., 2010, 2011, Khoury and Zaman, 2007, Karakus, 2011).

Other methods for recycling the waste, such as utilizing the wastes as additives materials in manufacturing industrial bricks, ceramic tiles, glasses, and concrete (Joan, 2012; Saboys, 2007; Acchar 2006; Erol, 2008; Chatveera, 2011).

Due to the accumulation of the wastes in large quantities day by day especially the sewage sludge ash in Gaziantep city, Turkey, there is a need for reconsidering of “WASTES” to analyze and utilize to become “WEALTH”. These materials have been subjected to several laboratory tests during this study to achieve useful materials to be used in ground improvement and as construction materials.

1.2 Problem statement

The clayey soil can be considered as a problematic soil and need an extra support from the geotechnical engineers to allow the embankment and structural foundation to successfully establish over it (Coduto 1999).

The clayey soil behavior is inversely related to the rise of water, its develop plasticity with limited amount of water (Grim, 1953; Das and Sobhan, 2013). The clayey soil performance very good at the optimum water content, when the amount of water rises above the optimum point the strength and the stiffness decrease noticeability (Dhakal, 2012). Moreover, the clay particles has the tendency to swell more than the soil with larger particle size which can be the cause of damage the structure of the soil, such as embankment, pavement, or harms the foundation structure. To deal with problem, some solid waste materials can be added to enhance the strength of the subgrade layer as well as enhance the sub base layer for pavement. The use of the wastes in improving the soil properties will also provide better conditions to construct foundation upon weak soils with saving cost and energy.

1.3 Objectives

The main objective of this study is to enhance the geotechnical engineering properties of the clayey soil by an economic, innovative, and easy method by adding the sewage sludge ash and the stone powder as these materials can easily available and supplied from the municipality of Gaziantep city. On the other hand, there is a necessary need to find benefit recycling methods in few cost and high quality.

Recycling waste is necessary to both natural environment and humans. Recycling minimizes the need for raw materials and producing energy as great amounts of energy are used when making products from raw materials. One needs to know the importance of recycling at the same time being earth friendly can help our planet a better place to live in.

1.4 Outline

This study contains five chapters. Chapter 1 presents the background and the objectives that this study carrying of for. Chapter 2 involves some researches histories which are relevant to current research under the name of literature review. The materials characteristics and properties and the methods that carried out during the experimental work are all included in chapter 3. Chapter 4 deals with the results and discussions that obtained from the laboratory tests. Finally, chapter 5 includes the conclusions gained from the various tests on this study.

CHAPTER 2
LITERATURE REVIEW

2.1 General

The effects of sewage sludge ash and the stone powder wastes on the stabilization of the clayey soil and concrete were studied in few articles since this type of recycling was developed in the last few years. Limited references on the types of recycling that related to our study are listed dawn in this chapter

2.2 Waste sludge in soil stabilization

Deng-Fong; (2006) had mixed the soft cohesive soil with five different percentages of SSA/hydrate lime (0%, 2%, 4%, 8%, and 16%) of weight. The results indicate that the UCS increased by 3-7 times higher than that of the untreated soil. The swelling behaviors were reduced, and the shear strength also increased, the 95% CBR value of soil were close to high bearing capacity when the SSA/hydrate lime added to the untreated soil which is improve the soil and change its condition from poor to good condition.

Lin et al. (2008) had used the SSA with the hydrate lime to enhance the properties and strength of cohesive soil. The results showed that the UCS, the shear strength, friction angle, and the swelling behavior were improved the geotechnical properties of soft cohesive soil.

Li Chen and Deng-Fong Lin (2008); studied the adding of incinerated sewage sludge ash (ISSA) mixed with cement in 4:1 ratio for using as soft, cohesive, subgrade soil stabilizer. In this study they used five ratios of ISSA/cement (0%, 2%, 4%, 8%, and 16% in weight). In order to understand these five admixtures properties and its effects on the soil; tests of pH value, compaction, triaxial compression, UCS, Atterberg limit, and CBR were applied to the samples. The tests results shows that the unconfined compressive strength increased by approximately 3-7 times than that of the untreated soil, the swelling behavior was reduced by 10-60%, and the CBR values were improved by 30 times than the untreated soil. The pH value increased with the increasing of ISSA/cement ratio, but during and after the curing age which is 28 days, the pH value deceased. This is due to the calcium saturation principle of pH values. The study shows that the ISSA contain 9% calcium and the cement 62%. The calcium gradually decreased during the stabilization operation causing the reduction in pH values. The final results of the pH value indicate that the pH value of 2% ISSA/cement mixture was less than that of the untreated soil at 28 days. The Atterberg limits tests results indicated noticeably decreasing in plasticity indices for the five specimens after 3 days curing. However, as the curing time increased the plasticity index decreased, this is because of the un-reacting ISSA/cement is obtaining moisture from air. The unconfined compressive strength has been increased between 2 and 4 times than the untreated soil at 3 days curing. The increasing of the strength continues with the increasing of the curing time. The triaxial test was carried out by loading the specimens to an effecting pressure of 25 and 50 kpa, for the untreated soil, when the stress reaches its maximum, the strain is about 10% when the ISSA/cement mixtures adding to the soil, the shear failure of the samples is close to brittle failure. The minimum strain for the samples is seen where the maximum stress are observed. In result the maximum shear strengths are obtained for the samples that containing 8% and 16% of ISSA/cement.

Gullu and Girisken (2013) made a practical study about the treatment of fine grained soil by the sewage sludge for stabilization aims. The study had been carried out on different samples with different proportions of sludge (0, 5, 10, 20, 30, 40, 50, 60, 70 and 80 %) of dry weight of the mixtures. Different mechanical tests had carried out to understand the behavior of the soil after adding the sludge as a stabilizer. The results indicated that the unconfined compressive strength increases with the increase of sludge, the CBR values shows that the sludge had the ability to improve the soil to good rating especially at 50% sludge dosage, the friction angle clearly enhanced at most of the sludge dosage, also the shear-stain responses promise to develop ductility behavior due to the sludge adding. The compaction test of the mixtures of soil with different proportions of sludge from 5 to 80% was performed by the moisture content versus density curves. The increasing of sludge dosage resulted in a decrease in the maximum dry unit weight and an increase in the optimum moisture content. However, the higher dry density values, the higher quality stabilization. This is achieved at the optimum moisture content. The shear-strain behavior of soil with sludge was performed in the direct shear test by applying three normal stresses (55, 95, and 150 kpa). Under the higher normal stress, the high shear stress obtained, because of the bonding between the soil and sludge particles are enhanced. The horizontal stress is calculated by the ratio of (horizontal displacement/specimen length). The ductility can also be recorded by the failure strain. The samples reached their failure shear stress at the horizontal stress of 5-7%. This is useful to know that the addition of sludge imparting more ductility to untreated soil. The performance of the soil with sludge mixtures after the UCS test showed that the UCS increases with the increasing of sludge dosage which is mean that the sludge classify as a soil conditioner agent for improving the fine-grained soil.

Haun-Lin and Deng-Fong Lin (2012) investigated the stabilization of the cohesive soil by replacing 15% of clay with SSA and cement at a ratio of 3:1. Nano-Al_2O_3 was then added to the treated soil with 1-3% of weight. The treated soil tested in terms of compaction, UCS, CBR, and swelling potential. The UCS with CBR results indicated a great improvement. The swelling potential was effectively reduced. The conclusion of this study was that the %15 SSA and cement had the ability to stabilize the cohesive soil.

Al-joulani (2012) studied the effects of the stone powder with lime on the fine soils by adding 10-30% of stone powder and lime by the dry weight of soil. The effects on compaction, CBR, and direct shear were tested. The addition of 30% stone powder and lime improved the CBR ratio, increased the friction angle, and reduces the cohesion.

2.3 Waste sludge in road pavement

Leda et al. (2013) had used 10% weight of SSA to improve the road base layers. They start by stabilizing the soil to get the required standard properties. Then the SSA has been added to this soil and subjected to the mechanical tests. The results showed that the soil that treated with the sludge is effective for usage in highway construction.

Ingunza, Pereira, and Junior (2014) tested a three different mixture of soil-cement-sludge ash, which are content of 3, 6, and 9% cement and 5, 10, 20, and 30% sludge ash. The results showed increase in the strength for all the different mixtures but the largest strength observed for the 20% sludge ash mixture, which is 26% more than the mixture without sludge ash. Compaction test expressed in this study in term of evaluating the compaction effects on the maximum dry weight and the optimum moisture content, the results showed that the maximum dry unit weight increases with increasing the cement content for the same compaction energy. The optimum water content decreases with increasing cement content; also for given cement content; the optimum water content decreases with increasing the compact energy and the dry unit weight increases and the optimum moisture content decreases, as excepted.

2.4 Waste sludge in brick manufacturing

Berman and Alleman (1984) had produce a type of brick called biobrick which is a mixture of sludge with clay and shale. They used the content of sludge 15-25% to produce the biobrick. The properties of the resulting brick had the same of that the regular brick in term of look, feel, and smell.

Tay (1987) mixed the clay with 40% dried ash and 50% sludge ash to make bricks. The compressive strength of the 0% sludge is 87.2 N/mm^2, decreasing to 37.9 N/mm^2 for 40% dried sludge and 96.4 N/mm^2 for 50% sludge ash.

Tay et al. (2002) had develop a noval brick by using sludge ash with maximum percentage of 50% mixing with clay. The result was that the brick containing 10% of sludge ash have nearly the same strength of the normal brick.

Cusido et al. (2003) utilized the sewage sludge and forest debris to produce bricks. The produced brick is lighter in weight than the normal brick, sound and thermal insulation is higher than the clay-bricks.

Liew et al. (2004) used the sewage treatment plant as a raw material in a clay brick production. The bricks were manufactured by adding sludge ash for 10 to 40% by dry weight. The texture and finishing of the surface of the sludge-clay bricks were rather poor. The chemical and physical properties of bricks contain 40% sludge were capable of meeting the standard properties, the bricks with more than 30% sludge were not recommended because they were brittle and easily broken. Therefore this sludge-clay bricks are suitable only for using as common bricks which are usually not exposed to view because of its poor surface finishing.

Joan and Lazaro (2012) had made a study about the effect of environmental on the bricks that made from the sewage sludge such as leach ability and toxicity. The result showed that the use of 5-25% of sludge in weight or even more doesn’t show any effect on the user health and also the environmental.

Bilgin (2011) investigated the possibility of making bricks with waste marble dust by different proportions from 0% to 80% by the dry weight. The produced brick sintered at three different temperature, 900, 1000, and 1100℃. The physical, chemical, and mechanical strength of the manufactured marble dust brick indicated positive results in addition to reducing the cost of bricks production.

2.5 Waste sludge as artificial aggregate

Bhatty and Reid (1989) investigated the use of sludge ash aggregate in cement mortar but the results were adversely affected the strength of the mortar.

Yip and Tay (1990) used the sludge incinerated in a brick-firing kiln at 1050℃ in the production of lightweight aggregates. The results indicated that the sludge ash aggregates characterized by low thermal conductivity and high fire resistance which made them suitable for using in fire protection and thermal insulation of concrete.

Tay et al. (2002) produced a paste from dried sludge and clay were pulverized both separately to fine size and mixed with water, then exposure to high temperature. The quality of this produced aggregate had been measured by evaluate the compressive strength of the concrete that made by this aggregate which is ranged between 31-38.5 N/mm^2 when comparing with the concrete made with granite which is 38 N/mm^2 strength.

Chou et al. (2006) produced lightweight concrete by using the sewage sludge ash mixed with clay, and had found that the mixture with 20-30% of SSA is the more adequate for lightweight aggregate.

Shane et al. (2008) attempted to develop a construction product with low-energy that basically uses the ISSA. Result of the test performed on the product shows an increasing in the reactivity and workability when compared with conventional products.

Fang-chih chang (2009) mixed the fine-powdered stone sludge with waste silt in different particle size at a mix proportion of 35:50 to produce the artificial aggregate. This aggregate subjected to a vibratory compaction of 33.3 Hz and cured for 28 days. The compressive strength tested of the 28 days artificial aggregate to be about 29.4 MPa.

2.6 Waste sludge as cement-like material and foamed concrete

Tay and show (1991) studied the properties of cement made from sludge ash. As a comparison between the chemical composition of the sludge cement and of the ordinary Portland cement, they had almost the same amount of Si and the Al in the sludge ash is about three times that in the cement. The limiting values are to be regarded as valid for the production of cement for general works. Physical properties of the sludge cement indicated that the sludge cement to be rated sound, the specific gravity were 3.33. The bulk density was 685 kg/m^3, a high water demand since the result of the consistency test was 82%, and the sludge cement is found to be quick-setting. The strength of the sludge cement mortar cubes that are air cured is adequate for general masonry work since the 7-days and 28-days compressive strength are 5.93 N/mm^2 and 6.28 N/mm^2 respectively, and that of masonry cement are 3.45 N/mm^2 at 7-days and 6.21 N/mm^2 at 28-days according to ASTM C91 Standard Specification for masonry work.

Manzo et al. (2004) had used 15 and 30% of SSA by weight in mortar, and had tested the compressive strength of the mixture. The results indicated that mortar of 15% SSA has similar compressive strength to that of the normal mortar.

Halliday, Dyer and Dhir (2012) had found that the adding of SSA in different percentages to the concrete reduce the strength and the workability of the concrete, and the reduction increase with the increasing of SSA content. But when replacing the fine aggregate of the foamed concrete with 50% and 100% by SSA show that there was increasing in the strength and reduced the thermal conductivity of the foamed concrete because of the porous nature of SSA. Also they found that the replacement of cement with SSA will affect the compressive strength negatively.

When 10% of SSA was used, the strength reduced by 4 and 8% at 28 days curing and the reduction recorded by 6% at 56 days curing. The reduction continued with increasing whenever the SSA content increased, for 20% SSA the reduction was 23-29%, for 30% SSA it has reached to 40-55% at 28 days curing.

2.7 Waste sludge in ceramic and glass manufacturing

Suzuki et al. (1997) had prepared ceramic samples by mixing the SSA with limestone, as the SSA texture is being as fine dust, it can be adding directly to other ceramics components. The resulting sample that contain 50% SSA showed that its strength, acid resistance and water absorption is nearly the same as the normal ceramic.

Ferreira et al. (2003) had tested the ceramic that containing sludge ash in term of leaching property. The result appeared minimum diffusion values of heavy metals.

Park et al. (2003) studied the glass-ceramics that contain the sewage sludge which is coming from the incineration of fly ash at 760℃ for 1h. The microstructure of the nucleated specimen at the heating region of 1050-1200℃ resulted in two phases; anorthite and diopside. These phases had changed with the changing of the temperature, for example; the specimen that heated at 1050℃ for 2 h consisted of diopside with minor proportion of anorthite. The specimens heated at 1105℃ were mainly composited of anorthite. In this study the glass-ceramic that containing large amounts of diopside (1150℃/2h) had better chemical and physical properties than that contained anorthite (1150℃/3h) because of the interlocking microstructure of diopside crystals.

Montero et al. (2009) studied the effects of adding the sewage sludge ash and marble on the ceramics properties. This materials were added to the clay in various proportions for making the ceramic, giving up a different products of ceramic, having different technology behavior and different mineralogical composition. Investigation of the properties of the product in term of linear contraction, strength, and water absorption indicated that the adding of the sludge can easily react on the clay and providing better sintering of original powders.

Joan and Cecilia (2011) had used the sewage sludge to produce a lightweight clay ceramics. The resulting ceramic indicate that it had lower thermal conductivity.

Martnez-Garcia et al (2012) had replaced the clay used in ceramic by the sewage sludge at different percentages. The mechanical properties had been tested for the products, giving up that the product containing 5% sludge has good properties such as water absorption, strength and water suction.

2.8 Concrete mixture with wastes sludge

Tay (1987) examined the use of the sludge ash as filler in concrete mixtures by blending it with cement. Results of shrinkage, segregation, and water absorption of concrete includes more than 40% of sludge were not recommended. Workability of the concrete decreased with the increasing of sludge amounts also the setting times of the concrete with sludge were longer than the original concrete. The compressive strength of concrete cubes including sludge ash blended cement decreased at all aging times with the increasing of sludge percentages. The 28-days compressive strength of concrete cubes that contain 10% sludge is about the same as the control strength. The remarkable decreasing was recorded for the concrete with 40% sludge ash blended cement; the strength fell by about 50%. The results from this study indicated that the sludge ash could be used as a small partial replacement of cement in concrete mixtures.

Tay and Show (1991) had found that the mixing of sludge with clay to produce lightweight aggregate. Tests were carried out on this aggregate as well as the concrete contain this aggregate to examine the properties in term of specific gravity, water absorption, compressive strength, bulk density, and porosity. The results indicated that the clay-blended sludge could be used to produce lightweight aggregate.

Tay and Show (1991) studied the use of clay-blended sludge in lightweight aggregate concrete production. The process of this study was by dewatering the sludge collected from the sewage treatment, mixing with clay and firing in a brick-making kiln at 1050°C_1080°C. The produced ash was then graded to the required aggregate sizes. Table 5 shows the physical properties of the clay-blended sludge coarse aggregate produced. As the clay composition increases from 10-40%, the practical density, bulk density, and 10% fines of the aggregate record an increasing trend. On the other hand, porosity, water absorption, and specific gravity of the aggregate decrease as the clay amount increases by 10-40%. The compressive strength at 28-days of the concrete made by clay-blended sludge aggregate increased with the increasing of clay from 10% to 40% for all mixes. As a result from this study, the clay-blended sludge is a potential material for the production of lightweight aggregate concrete for structural use.

Yaque et al. (2004) had tested the durability of the concrete that contain sludge in its mixture. This showed that the durability of concrete with sludge has similar to that of reference concrete.

Valls et al. (2005) had used the sewage sludge as fine sand by various percent from 0-10%. This indicates that there was a reduction in the compressive strength and also the use of more than 10% sludge caused a delaying in the setting time and the other mechanical properties of the concrete were significantly reduced.

Table 2.1 Physical properties of clay-blended sludge aggregate.

Clay (% by weight)	Ten percent fines (KN)	Particle density (g/cm3)	Bulk density (kg/cm3)	Specific gravity	Water absorption (%)	Porosity (%)
10	12.5	1.46	622	2.82	6.58	48.2
20	14.2	1.85	636	2.80	6.55	33.9
30	16.6	2.29	651	2.79	6.45	17.9
40	17.6	2.56	660	2.77	6.01	7.6

Mahzuz (2011) studied the use of stone powder as an alternative of sand in concrete mix and mortar. In that study, the stone powder concrete gained a compressive strength 15% higher than that of concrete with normal sand, the highest strength of mortar with stone powder reached to 33.02 MPa.

Ali and Hashmi (2014) tested the 28-days compressive strength of concrete cubes that its cement partially replaced with marble dust and its sand with stone dust. The result of the cube that contains 10% marble stone and 20% stone dust recorded an increase of about 15.23% in compressive strength.

Valeria et al. (2010) investigated the 28-days compressive strength of the concrete that substituted of sand by waste marble stone. The concrete provided compressive strength higher that of the control concrete mixture.

Sakalkale et al. (2014) studied the effect of marble dust stone by replacing with sand for about 50% by the dry weight on the compressive strength of concrete. The result shows that there is about 10.72% increase in compressive strength.

Birinci et al (2007) tested the compressive strength of the concrete after replacing 50% of sand with marble dust and limestone dust. The compressive strength of the marble sand concrete was better than that of limestone concrete.

Demirel (2010) investigated the effect of using the waste marble dust sand replacement at particular proportions. The compressive strength of the concrete showed an enhancing.

The wastes studied in this research create large scale environmental problems and pollution. The dispose of sewage sludge and stone powder in ground improvement as well as in normal strength concretes as alternatives of fine concrete materials has many environmental benefits, in term of enhancing the quality and improving the engineering properties as well as reducing the cost of both ground improvement and concrete production. However, little has been known about the utilization of sewage sludge ash and stone powder in soil stabilization. Thus, this study concentrated on the utilizing of the wastes, by preliminary laboratory tests, in the process of clayey soil stabilization and replacing fine aggregate of concrete with sewage sludge ash and stone powder.

CHAPTER 3
MATERIALS AND EXPERIMENTAL METHODOLOGY

3.1 Introduction

This chapter represents all the laboratory tests which carried out to achieve the objectives of this study. All the soil and concrete samples had been prepared in accordance with the standards of the American Society of Testing and Materials (ASTM). During the laboratory tests, the sewage sludge ash SSA and the stone powder (SP) considered as additives and alternatives for clayey soil and normal concrete, respectively. The SSA and SP were chosen for the purpose of recycling them in effectively and useful manner because of their availability in large quantities. All the tests were carried out on the untreated soil and the stabilized soil with various selected ratios that listed in Table 3.1

Table 3.1 Soil-admixture ratios that have been tested during the experimental study.

Materials	Mixing ratios (% in weight)				
SSA	0	5	10	15	20
SP	0	5	10	15	20
SSA+SP	0	10	20	30	40

3.2 Purpose

The common methods of recycling wastes materials are by disposing to landfills. Reuse the wastes or converting them into useful materials is most desirable. The main purpose of this study is to investigate the effects of SSA and SP on the mechanical soil properties by testing the Atterberg limits, compaction behavior, fall cone, vane shear, unconfined compressive strength, and the swelling potential. Also the test of compression has been carried out for the concrete samples included the SSA and SP inside their mixtures.

3.3 Materials

In this section, the properties and characteristics of the untreated soil and the additives were studied and analyzed.

3.3.1 Silty soil

The soil used to treat in this study was collected from Gaziantep University campus. Its color was found to be dark brown as shown in Figure 3.1. Table 3.2 showing some engineering properties that were obtained during the laboratory tests performed to the soil. The Atterberg limit test was carried out in accordance with ASTM D4318-2000 standards in order to evaluate the liquid limit (LL), plastic limit (PL), and the plasticity index (PI). The soil classified according to ASTM D2487-2000 and AASHTO as ML and A-1-a, respectively. The particle size distribution of the soil is showing in Figure 3.2. The modified compaction test was performed to calculate the optimum moisture content (OMC) and the maximum dry density (γ_{dmax}) in accordance with ASTM D1557-98-2000.

The pictures obtained from the scanning electron micrograph (SEM) show that the clay particles is semi-spherical and has some porous in its microstructure as in Figure 3.3. Also the analysis of the clay by the energy dispersive x-ray (EDX) represented the chemical compositions of the material, Table 3.3 and Figure 3.4

Table 3.2 Some engineering propertied of the untreated soil

Properties of untreated soil	Results
Liquid limit (LL) %	34.5
Plastic limit (PL) %	27.95
Plasticity index (PI) %	6.55
Classification (USCS)	ML
Classification (AASHTO)	A-1-a
Maximum dry density (γ_{dmax}) g/cm^3	1.65
Optimum moisture content (OMC) %	17.58
Unconfined compressive strength (UCS) kPa	400
Swelling potential %	1.2

Table 3.3 Chemical composition of the untreated soil (in weight %)

Elements	C	O	Mg	Al	Si	K	Ca	Fe
Untreated soil	8.062	53.1	1.197	9.465	15.948	1.041	7.028	3.379

Figure 3.1 The soil used during the experimental study.

Figure 3.2 Particle size distributions of the soil.

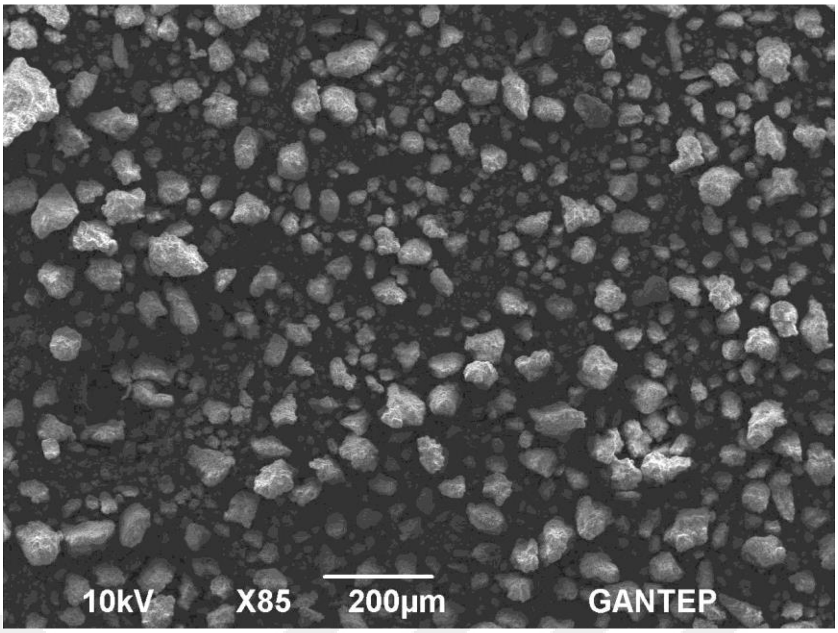

Figure 3.3 SEM picture of the soil.

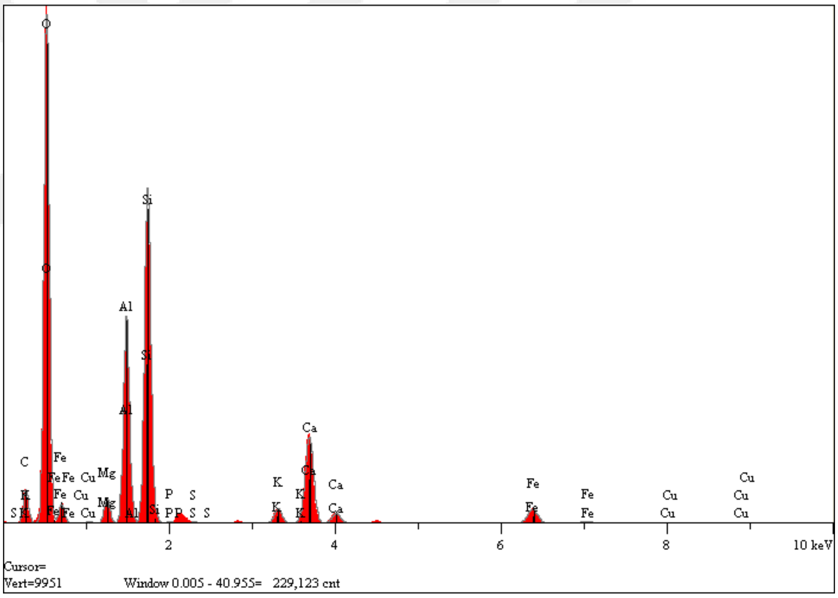

Figure 3.4 EDX analysis of the soil.

3.3.2 Sewage Sludge Ash (SSA)

The sewage sludge ash collected by the municipality of Gaziantep, Turkey. It had been dried and rounded to pass through sieve #1 before using in the laboratory tests. The SSA classified as a hazardous waste since it produces in large quantities a day. Hence, the methods of disposing it became very necessary. The materials has gray color as shown in Figure 3.5 and its chemical composition analyzed in Table 3.4 and

Figure 3.6 which are obtained from the EDX analysis test. Figure 3.7 shows the microstructure of the SSA form the SEM picture test.

Table 3.4 Chemical composition of the sewage sludge ash (in weight %)

Elements	Fe	Al	Si	Mg	Ca	O	C	Na	K
SSA	1.446	8.38	15.29	1.035	9.682	49.748	8.719	1.295	1.518

Figure 3.5 The Sewage Sludge Ash (SSA).

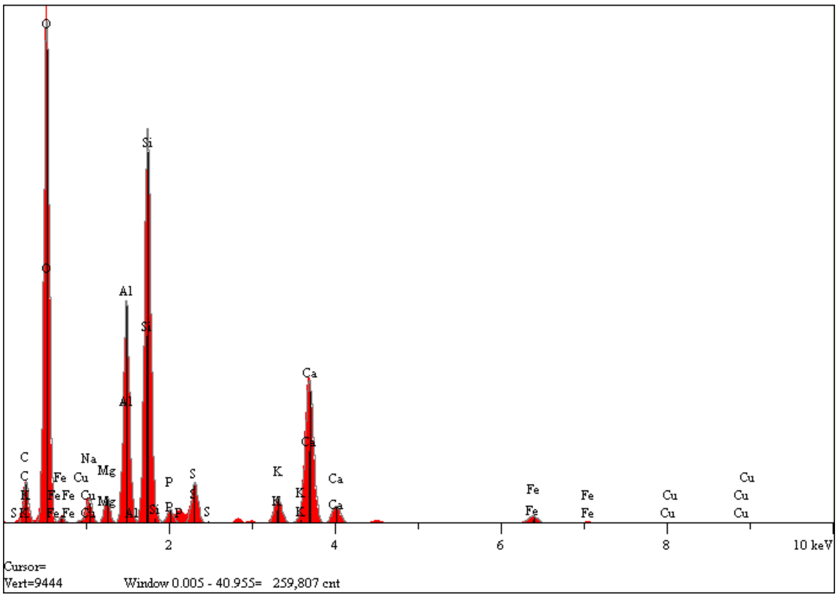

Figure 3.6 EDX analysis of sewage sludge ash (SSA).

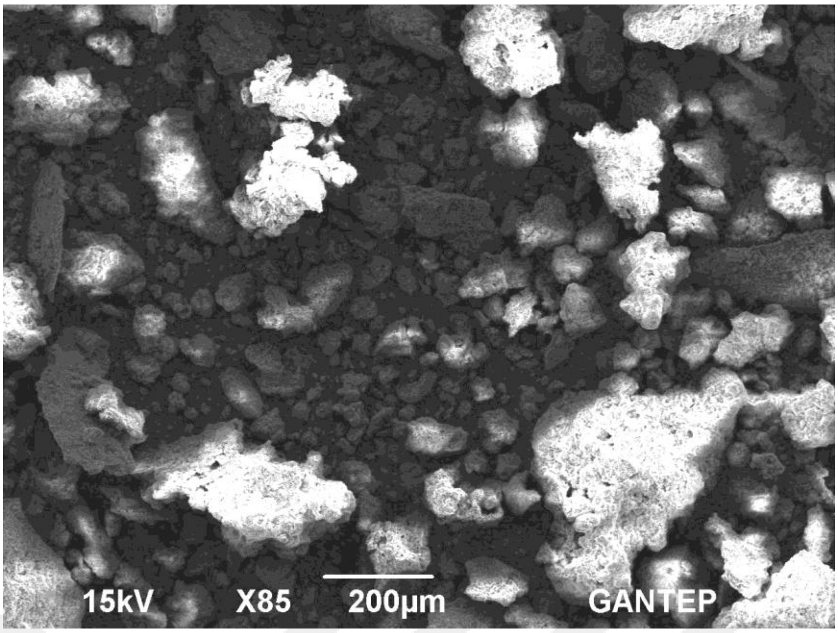

Figure 3.7 SEM picture of sewage sludge ash (SSA).

3.3.3 Stone powder (SP)

The stone powder is a white powder Figure 3.8 collected from the crushed stone in Gaziantep city, Turkey. The chemical composition and the image of its microstructure are showing in Table 3.5, Figure 3.9, and Figure 3.10, respectively.

Table 3.5 Chemical composition of the stone powder (in weight %)

Elements	Fe	Al	Si	Mg	Ca	O	C	Na	K
SP	0.172	0.513	0.634	0.243	29.34	54.648	13.403	0.15	0.02

Figure 3.8 The Stone Powder (SP).

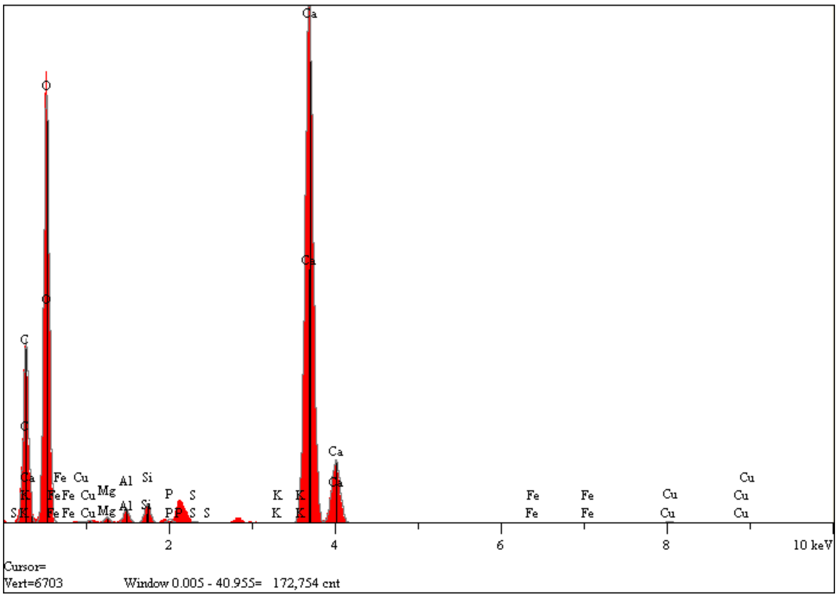

Figure 3.9 EDX analysis of the stone powder (SP).

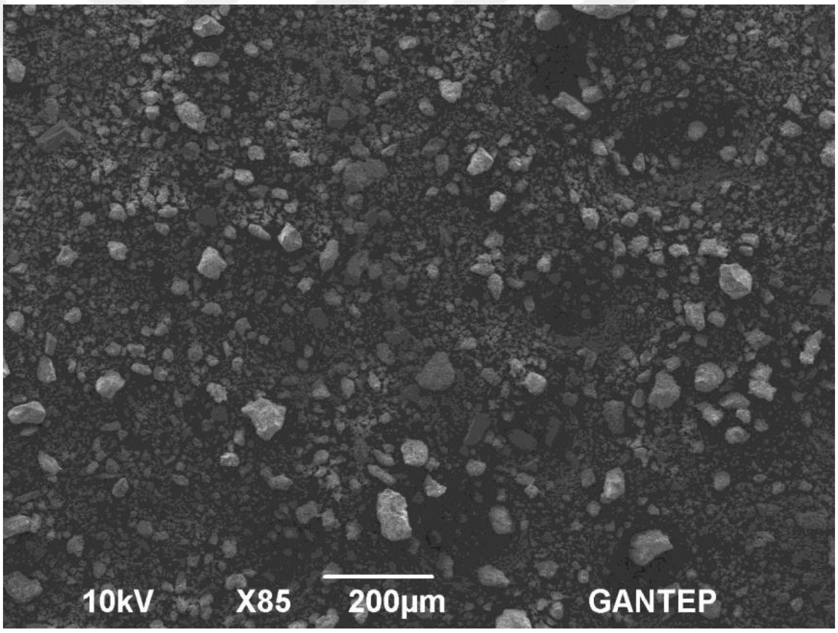

Figure 3.10 SEM picture of the stone powder (SP).

3.3.4 Concrete

The coarse materials used in concrete mixture were delivered from the same source. Figure 3.11 shows the volumetric gradient of the gravel and sand materials. The fine materials of the concrete included a Portland cement (type 32.5R), sewage sludge ash (SSA), and stone powder (SP). The amount of water used was 35% by weight of fine materials in each mixture.

Figure 3.11 The particle size distribution of sand and gravel.

3.4 Grain size distribution

According to ASTM C325-2007 standards, the sieve analysis had been carried out using 1 kg dry soil. The sieves were arranged in a set according to the sieve opening diameter from top to bottom; 2, 1, 0.600, 0.425, 0.300, 0.150, and 0.075 mm; respectively as shown in Figure 3.12. The dried soil was then placed in the first top sieve and shacked for 10 minutes. The remained soil in each sieve has then been weighted.

Figure 3.12 Sieving set.

3.5 Sample preparation

All the laboratory samples were prepared by bending the SSA and SP with the silt that passed from sieve #200 (0.075 mm) at same four ratios; 5%, 10%, 15%, and 20% by the dry weight for each SSA and SP in addition of another four mixes of both SSA and SP together at 10%, 15%, 20%, and 30% by the dry weight. Each sample was mixed at the optimum water content and the maximum dry weight according to the standard test procedures. Regardless the dimensions and the metal made of the mould of each test that carried out during the experimental study, all the specimens prepared to be smooth and flat in surface and perpendicular to the sample length.

3.6 Experimental methodology

3.6.1 Atterberg limits test

This test was performed to evaluate the liquid limit (LL), plastic limit (PL), and the plasticity index (PI) for each soil admixture ratio in accordance with ASTM D4318 test specifications;

1) Liquid limit (LL): a sample of about 100 gm. dried soil with different amounts of the stabilizers were prepared to test the liquid limit by Casagrande device shown in Figure 3.13. The sample first mixed with water to obtain a uniform paste. Each sample was repeated 4 times at 4 different water contents. At the first trial, the paste should have a consistency that makes it needs 35 to 40 drops of cup to cause closed of standard groove for sufficient length. The sample replaced in the marked brass with a flat surface by using knife-edge. A groove will then make in the specimen by using a special grooving tool. The test must be repeated to get a groove closing between 10 and 40 blows. When the groove closed at a distant of 12mm, number of blows that achieved this groove closing recorded and a wet sample must be taken from the closing area and placed in a pre-weighted cup to be balanced and dried for 24 hours. The water content will then calculated after 24 hours, the number of blows was drawn against the water content. The liquid limit is the water content at the 25 blows gained from the graph.

2) Plastic limit (PL): the same mixed soil-admixture that prepared for the liquid limit finding had been taken and placed on a flat plate then rolled by hand fingers at a rate of 80-90 strokes per minute to make a thread of about 3mm in diameter. The plastic limit is the water content at which the soil threads cracks at 3mm in diameter. If the thread diameter becomes less than 3mm without cracks, its mean that the water content is larger than the plastic limit. Reduce the water content by repeating the kneading of soil and rolling it again into thread. When the soil threads cracked into several pieces, these pieces had been collected into a ball and re-rolled again into a thread. These steps were repeated until the soil could no longer roll into a thread. The cracked pieces were placed into pre-weighted containers and its weight was recorded before it was placed in oven for 24 hours to calculate the water content. The average of two water contents was calculated as the plastic limit of the mixture.

3) Plasticity index (PI): is the difference between the liquid limit and the plastic limit, it is the state in which the soil still has a plastic behavior between the non-plastic and viscous fluid states.

Figure 3.13 Casagrande device used during the experimental study.

3.6.2 Compaction (modified proctor) test

The compaction method defined as the method of re-arranging the soil particle by reducing the internal air void by impacting an external energy. The modified proctor test was carried out on the all previously mentioned proportions in accordance with ASTM D1557-2000 standards, as shown in Figure 3.14. The dry soil with the admixture was first mixed in a large pan, the weight of soil mix with the compaction mould and its base were weighted with an electronic balance. The water then added to the dry mix gradually with an interval of 3% by the dry weight and blended carefully until the mix became uniform in color and texture. The mix placed in the compaction mould with five equal layers, each layer compacted with 31 blows by the special designed proctor hammer; as described by (Cabalar et al., 2014) at a rate not exceed 1.5 seconds per blow, it was ensured that the hammer covered all the surface during the impacting. It was also ensured that the last layer thickness must be above the top end of the mould and extended through the collar. After finishing the compaction of five layers, the collar carefully separated from the mould and the extended layer trimmed off by a spatula. The weight of the mould with still the soil inside was then recorded. To measure the water content, specimen from top, middle, and bottom of the compacted soil was then placed in the oven containers to be dried for 24 hours.

The dry density can be calculated by:

(3.1)

Where;

γ_d is the dry density (gm/cm^3);

γ_m is the moist density (gm/cm^3); and

w_c is the water content (%).

Figure 3.14 Compaction apparatus used during the experimental study

3.6.3 Unconfined compressive strength test (UCS)

The samples prepared for the unconfined compressive strength test according to ASTM D2166-2000 in the same procedure of that of compaction test, the amount of water used adopted the optimum water content obtained from the compaction test for each single mixture. A cylindrical sample of 50mm in diameter and 100mm in height was compacted at five layers, removed from the mould, and the placed into the standard unconfined compressive device as shown in Figure 3.15. The load applied axially with an axial strain rate of 0.5-2% per minute. The both gages had been set on zero reading, thereafter, the compression machine had been tuned on and the readings took at a deformation interval of 0.20 mm. when the specimen reached its maximum point of deformation, the device stopped, Figure 3.16 shows the sample before and after the compression. The unconfined compressive strength for each sample was then plotted against the stain which calculated by the following equation;

(3.2)

Where;

ε is the axial strain;

Δl is the deformation in length (mm); and

L_o is the initial length of sample (mm).

The unconfined compressive strength was then calculated by the equation;

(3.3)

Where;

q_u is the unconfined compressive strength (kpa);

p is the axial load (KN); and

A is the cross-sectional area of the specimen which can be calculated by;

(3.4)

Where is the initial area of the sample before deformation (mm^2).

Figure 3.15 Unconfined compressive strength device.

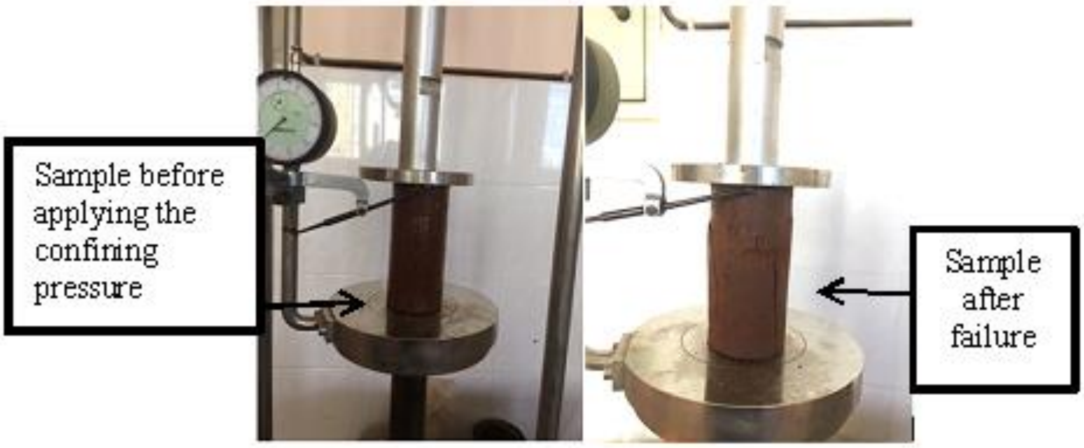

Figure 3.16 The unconfined compressive strength sample before and after applying the load.

3.6.4 Fall cone test (FCT)

The fall cone test carried out according to BS1377 standards. ELLE fall cone apparatus Figure 3.17 used during this test to obtain the liquid limit and the undrained shear strength for the untreated and treated soils. The machine has its own cup with 55 mm in diameter and 40 mm in depth. The cone is a stainless steel metal, its weight with the attached pin together is 80 gr and its angle is 30º Figure 3.18. The same procedures were carried out for all the samples. About 80 gr dry mass of soil and the fixed amounts of additives were mixed manually in dry condition in a plastic bag to get a homogeneous mix; initial amount of water has then been added to the dry mix to start the test. The mix was then replaced in the cup of the fall cone device taking into account the discharge of the air voids by compacting the mould including the soil on a flat surface. Then the surface of the sample has been smoothed and adjusted to be leveled. The procedure started by moving the cone dawn manually to make it just touches the sample surface in the middle point. The cone released to penetrate the sample by press and hold 5 s the bottom which responsible for moving the cone. The penetration value was then recorded from the dial gage connecting with the apparatus. Finally, a small quantity was taken from each sample to calculate the water content after drying to 24 hr. The steps have been repeated five times with different water content for each sample.

The various penetration values have been plotted against the water contents. The most acceptant way for measuring the liquid limit, is to be considered as the water content at 20mm cone penetration.

The undraind shear strength were then calculating by equation 3.5

(3.5)

Where,

s_u = Undraind shear strength (kpa);

k = constant depend on the cone angle (0.85 for 30º angle) (Wood 1985);

m = the cone mass = 80 (gr);

g = the gravity acceleration (N); and

d = the penetration depth (mm).

Figure 3.17 The fall cone apparatus used during the experimental study

Figure 3.18 The stainless steel penetration cone

3.6.5 Laboratory vane shear test (LVT)

Similar to fall cone and the unconfined compressive strength tests, the vane shear test is developed to measure the undraind shear strength of the soil in accordance with ASTM D 4648-94. The apparatus of the laboratory vane shear test is shown in Figure 3.19, it is basically consists of four-blade located vertically with right angles between the blade and the other Figure 3.20, the height of the vane is equal to twice of its diameter.

The samples prepared the way that of the samples tested in the fall cone test. The sample sheared by inserting the Torvane; which is the device that has blades at its end and a calibrated scale on the top Figure 3.21; manually through the sample to a desired test depth and rotate the Torvane at a rate of 1 to 1.5º per second. The vane has kept the rotation to determine the torsional force that causes the sample to fail. The maximum torque reading was recording from the calibrated scale and the converted to the undrained shear strength by using equation 3.6;

(3.6)

Where;

Su = the undrained shear stress (kpa);

T= the maximum torque required to shear the sample (KN-m); and

K= is a constant depending on the dimensions of the vane which can be calculated by equation 3.7;

(3.7)

Where: D is the diameter of the vane (m); and

H is the height of vane (m).

Figure 3.19 Laboratory vane shear device used during the experimental study.

Figure 3.20 The blades of laboratory vane shear device used during the experimental study

Figure 3.21 Calibrated scale of vane shear device used during the experimental study

3.6.6. Expansion index (Primary swell) test

This test has been carried out to determine the expansion potential of a soil in accordance with ASTM D 4829-95, 2000 test specification. The expansion potential was the used to classify the soil according to Table 3.6, (Day, Robert W., soil testing manual), as it has very low, low, medium, high, or very high expansion potential.

Test procedures were first the preparation of the soil specimens of untreated and the treated sample with the fixed ratios of additives. Each sample was mixed at it maximum dry density and optimum moisture content conditions. The soil sample was then compacted in a ring of 50 mm in diameter and 20 mm in height as shown in Figure 3.22. The compaction machine is shown in Figure 3.23. After compaction, the ring mould included the soil sample was then placed in a surrounding container with dry and clean porous plates above and under the ring sample. This container with the sample was then placed in the center of the consolidometer device, Figure 3.24. A vertical pressure of 6.9 kpa has been applied on the soil sample. Initial dial reading was recording within the first 10 minutes of applying the pressure. The container was then filled with water and allowed to swell for 24 h. The primary swell is the considered to be 10% of the expansion index which is calculated by equation 3.8

(3.8)

Where;

EI = the expansion index;

h_f= final reading (height) of the specimen at the end of 24 h of swelling; and

h_i = initial reading (height) of the specimen.

Table 3.6 Typical soil properties based on expansion potential

Expansion potential	Very low	low	medium	high	Very high
Expansion index (%)	0-20	21-50	51-90	91-130	>130

Figure 3.22 The sample to be tested for the primary swelling ratio

Figure 3.23 CBR devices for compaction the sample of the primary swelling test used during the experimental study

Figure 3.24 Consolidometer apparatus used during the experimental study

3.6.7 Compressive strength of concrete

Cylindrical samples of 100 mm in diameter and 200 mm in height were prepared for test the compressive strength of concrete in accordance to the test specifications of ASTM C 39. The samples were mixed on the basis of replacing the cement and sand with different ratios of sewage sludge and stone powder, the concrete mixtures are listed in Tables 3.7 and 3.8. Three samples were prepared for each mixture. The quantities of the control concrete mix 1:2:4 are shown in Table 3.9. The mixing was done by a revolving mixer at approximately 3-5 minutes to reach the uniform consistency of concrete. The mixtures were then pushed into the oiled cylindrical plastic moulds in three layers with compacting each layer to remove the entrapped air. The samples kept in the moulds in the laboratory at a temperature of 30±5°C for 24 h Figure 3.25. The next day, the samples was remoulded and cured up in a water basin for 28 days, Figure 3.26. The cylinders were tested in the compression machine Figure 3.27, by applying a vertical load perpendicular to the direction of casting at a rate of 1.5 MPa/s up until the specimen gets fail. The maximum load and stress at which the sample fails were recorded.

Table 3.7 Mixing ratios used for the preparation of SSA concrete

(Cement + SSA) : sand : Gravel	Cement : (sand + SSA) : Gravel
(1+0) : 2 : 4	1 : (2 + 0) : 4
(0.9 + 0.1) : 2 : 4	1 : (1.8 + 0.2) : 4
(0.8 + 0.2) : 2 : 4	1 : (1.6 + 0.4) : 4
(0.7 + 0.3) : 2 : 4	1 : (1.4 + 0.6) : 4

Table 3.8 Mixing ratios used for the preparation of SP concrete

(Cement + SP) : sand : Gravel	Cement : (sand + SP) : Gravel
(1+0) : 2 : 4	1 : (2 + 0) : 4
(0.9 + 0.1) : 2 : 4	1 : (1.8 + 0.2) : 4
(0.8 + 0.2) : 2 : 4	1 : (1.6 + 0.4) : 4
(0.7 + 0.3) : 2 : 4	1 : (1.4 + 0.6) : 4

Table 3.9 Mix proportions of one mixing ratio for SSA concrete

sample	Cement (kg)	SSA (kg)	Sand (kg)	Gravel (kg)	Water (lt)	w/c
Control	1.4	0	3.57	7.19	0.56	0.40
%10 SSA with cement	1.26	0.14	3.57	7.19	0.56	0.40
%20 SSA with cement	1.12	0.28	3.57	7.19	0.56	0.40
%30 SSA with cement	0.98	0.42	3.57	7.19	0.56	0.40
%10 SSA with sand	1.4	0.35	3.21	7.19	0.87	0.50
%20 SSA with sand	1.4	0.72	2.85	7.19	1.27	0.60
%30 SSA with sand	1.4	1.07	2.5	7.19	1.60	0.65

Table 3.10 Mix proportions of one mixing ratio for SP concrete

sample	Cement (kg)	SP (kg)	Sand (kg)	Gravel (kg)	Water (lt)	w/c
Control	1.4	0	3.57	7.19	0.56	0.40
%10 SSA with cement	1.26	0.14	3.57	7.19	0.56	0.40
%20 SSA with cement	1.12	0.28	3.57	7.19	0.56	0.40
%30 SSA with cement	0.98	0.42	3.57	7.19	0.56	0.40
%10 SSA with sand	1.4	0.35	3.21	7.19	0.87	0.5
%20 SSA with sand	1.4	0.72	2.85	7.19	1.27	0.6
%30 SSA with sand	1.4	1.07	2.5	7.19	1.60	0.65

Figure 3.25 The concrete samples during the setting time.

Figure 3.26 Curing of the concrete samples.

Figure 3.27 Compression machine used during the experimental study .

CHAPTER 4
RESULTS AND DISSCUSION

This chapter deals with the analysis and discussion of all the data obtained during the laboratory experimental work.

4.1 Atterberg limits test

This test was carried out to obtain the liquid limit (LL), plastic limit (PL), and the plasticity index (PI) of the untreated and treated soil samples. Table 4.1 as well as the subsequent Figures 4.1 to 4.9 shows the variation in Atterberg limits of the raw soil and all the stabilized mixtures.

The LL and PL were increased with the increasing of SSA ratio; the untreated soil has a liquid limit and plastic limit of 34.50% and 27.95%, respectively. While at the %20 SSA admixture, the liquid limit and the plastic limit are 41.00 and 39.24, respectively Figure 4.1 and 4.2. Figure 4.3 shows the reduction in the plasticity index with increasing of the SSA ratio.

In the case of SP stabilizer, the liquid limit and the plasticity index increased with the increasing the SP amount, but the plastic limit decreases.

Finally, when SSA and SP added together to the raw silt soil, the liquid limit and the plastic limit had been increased by about 17.85% and 18.93%, respectively.

The variation in the Atterberg limits attributes to the property of flocculation and agglomeration of the silt. This phenomenon affects the soil mixture by increasing its mixing water. Therefore, the need of the soil-additives mixes for water increased, as the amount of SSA and SP increased and because of that the ability of these materials to absorb the water is higher that the siltey soil.

Table 4.1 Effect of SSA and SP wastes addition on the consistency limits

Materials	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI (%)
Silt	34.50	27.95	6.55
Silt + %5SSA	35.40	28.60	6.80
Silt + %10SSA	36.30	30.84	5.46
Silt + %15SSA	38.70	35.94	2.76
Silt + %20SSA	41.00	39.24	1.76
Silt + %5SP	35.50	28.57	6.93
Silt + %10SP	36.10	21.95	14.15
Silt +%15SP	36.60	20.51	16.09
Silt + %20SP	38.00	22.87	15.13
Silt + %5SSA + %5SP	35.60	33.34	2.26
Silt + %10SSA + %10SP	37.10	31.87	5.23
Silt + %15SSA + %15SP	40.60	34.12	6.78
Silt + %20SSA + %20SP	42.00	34.48	7.52

Figure 4.1 Variation of liquid limit with addition of sewage sludge ash

Figure 4.2 Effect of addition of sewage sludge ash (SSA) on the plastic limit

Figure 4.3 Effect of addition of sewage sludge ash (SSA) on the plasticity index

Figure 4.4 Variation of liquid limit with addition of stone powder (SP).

Figure 4.5 Effect of addition of stone powder (SP) on the plastic limit.

Figure 4.6 Effect of addition of stone powder (SP) on the plasticity index.

Figure 4.7 Variation of liquid limit with addition of sewage sludge ash (SSA)and stone powder (SP).

Figure 4.8 Effect of addition of sewage sludge ash (SSA) and stone powder (SP) on the plastic limit.

Figure 4.9 Effect of addition of sewage sludge ash (SSA) and stone powder (SP) on the plasticity index.

4.2 Modified proctor compaction test

The test was performed to study the variation in optimum moisture content and the dry density after and before the treated of soil with SSA and SP. Figure 4.10, 4.11, and 4.12 show the compaction behavior of soil with SSA, SP, and SSA/SP admixtures, respectively. It can be seen the optimum moisture content of the SSA and SSA/SP soil mixtures increased from 17.58% for the zero additives to 23.47% for the %20SSA admixture and 24.79% for the %20SSA+%20SP admixture. The adding of SP does not have much effect on the optimum moisture content and the dry density, the results were very close to that of the untreated soil.

The increasing of the optimum moisture content refers to the replacement of silt particles with SSA. The SSA has a rough surface and its ability to absorb the water higher the silt. Therefore, the optimum moisture content increased.

The maximum dry density reduced by about 8.48% gradually by adding the SSA at different amounts from 0% to 20%. Also it was decreased by %10 at %20SSA+%20SP. The reason of this behavior returns to the fact of that the SSA increases the need of water, the amount of absorbed water obstructed the soil particles to close to each other and therefore the density reduced as it can be seen in Figures 4.13 to 4.18.

These results agree with that obtained by Gullu, (2016) which indicated a gradual increasing in the optimum moisture content from 19% to 37% for the sewage sludge dosage of 10 % and 80%, respectively. While the maximum dry density decreased after adding 10% of the sewage sludge water.

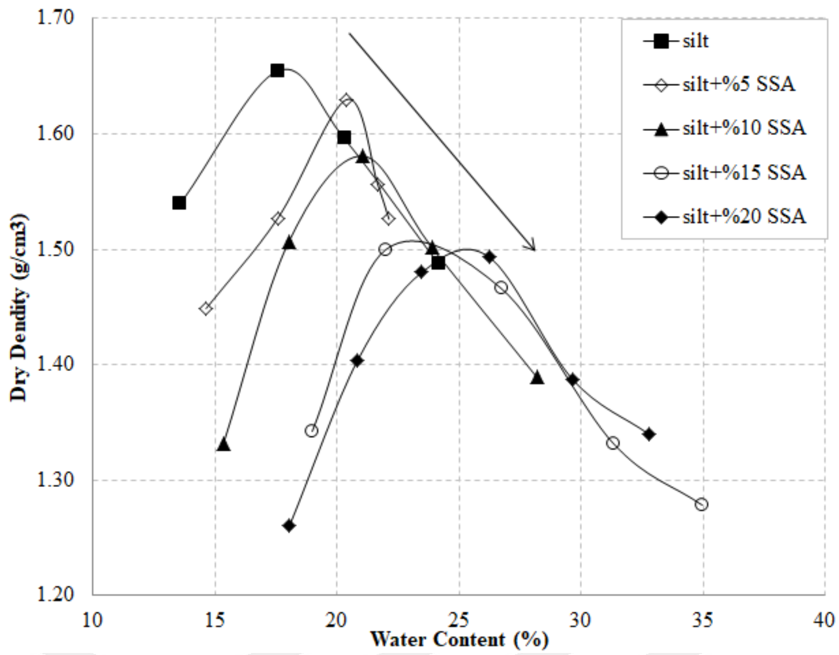

Figure 4.10 Effect of addition of sewage sludge ash (SSA) on density-moisture content relationship.

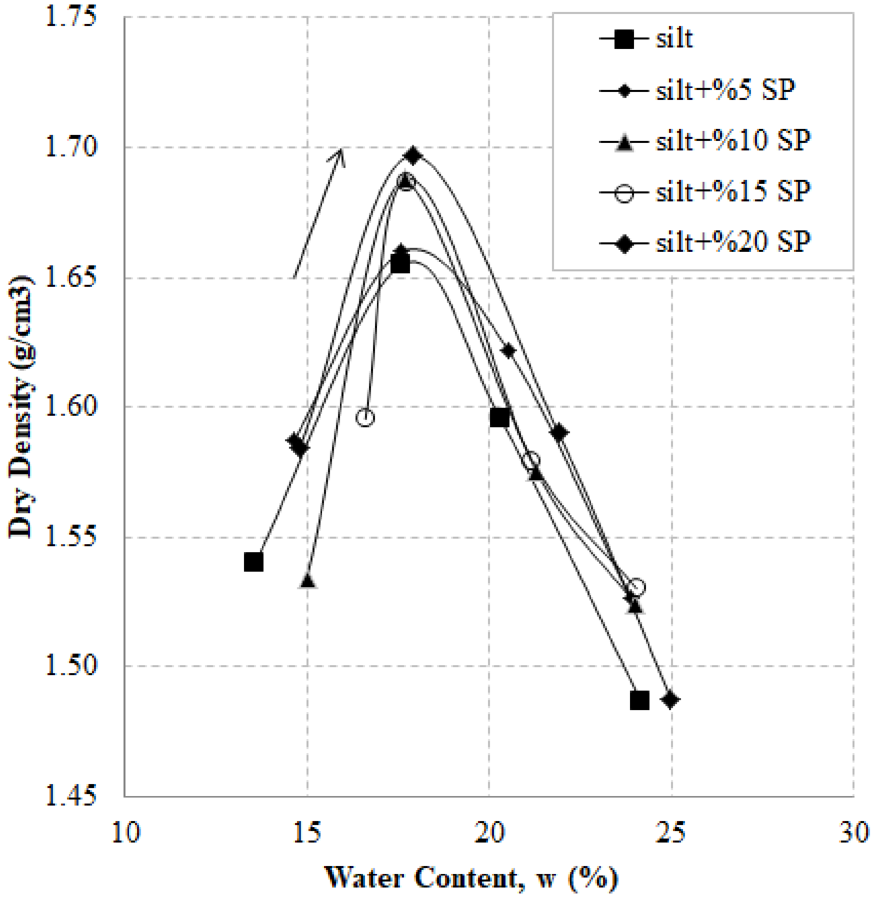

Figure 4.11 Effect of addition of stone powder (SP) on density-moisture content relationship.

Figure 4.12 Effect of addition of sewage sludge ash (SSA) and stone powder (SP) on density-moisture content relationship.

Figure 4.13 Influence of sewage sludge ash (SSA) on soil moisture content.

Figure 4.14 Influence of sewage sludge ash (SSA) on soil dry density.

Figure 4.15 Influence of stone powder (SP) on soil moisture content.

Figure 4.16 Influence of stone powder (SP) on soil dry density.

Figure 4.17 Influence of sewage sludge ash (SSA) and stone powder (SP) on soil moisture content.

Figure 4.18 Influence of sewage sludge ash (SSA) and stone powder (SP) on soil dry density.

4.3 Unconfined compressive strength (UCS) test

The untreated soil as well as the treated soil samples with different additions of SSA and SP was prepared to test the unconfined compressive strength of each mixture. The test has been performed immediately as the samples prepared, mixed, and compacted to their OMC and $\gamma_{dmax.}$ The results of all the mixtures are shown in Figures 4.19, 20, and 21. The results indicated that the adding of SSA works on increasing the UCS gradually as the amount of SSA increased from 0 to 15% by the dry weight, the strength of the 20% SSA fell slightly but still higher than the strength of the raw silty soil. The peak strength has been achieved in %15SSA-soil mixture. From Figure 4.20, it can be seen clearly the strength of the SP admixture decreased. It can also be noticed that the soil tends to behave more ductile with adding the SP waste. The ductility means that the ability of the soil to deform under tensile stress without rapture, or the ability of soil to resist plastic deformation. It can be evaluated as the strain at which the material gets fail in the test. Figure 4.20, shows the strength behavior of the soil by adding SSA and SP admixtures together, the results indicated that the better strength recorded at the mixture that contains %15 of each SSA and SP. When the amount of mixtures increased to %20, the strength was close to the raw clay strength, but the sample transforms to react as a brittle as it fails with low plastic deformation.

In general, the ductility and the brittleness do not affect the strength of the materials, but the material with high ductility is more desirable in engineering classification. The energy absorption for each mix ratio was the calculated by the area under the stress strain curve to the yield point which is also called toughness. Figures 4.22, 4.23, and 4.24 show the differences in energy absorption by adding different additives ratio.

The increase in strength in SSA-soil mixtures refers to the replacing of silt particles by SSA which is work on increasing the bond between the soil particles and reduces the segregation behavior in clay matrix. On the other hand, the addition of SP reduced the strength because the SP particles have no cohesion behavior unlike the silt particles, in result; it decreased the bond among the soil particles.

The reduction in the unconfined compressive strength has disagreement with tsiltyhe results obtained by (Roohbakhshan, 2013) whom studied the effects of the lime and the stone powder on the unconfined compressive strength behavior of the silty soil. The results showed an increasing in the strength with increasing the amount of lime and stone powder.

Figure 4.19 Effect of sewage sludge ash (SSA) on the unconfined compressive strength.

Figure 4.20 Effect of stone powder (SP) on the unconfined compressive strength.

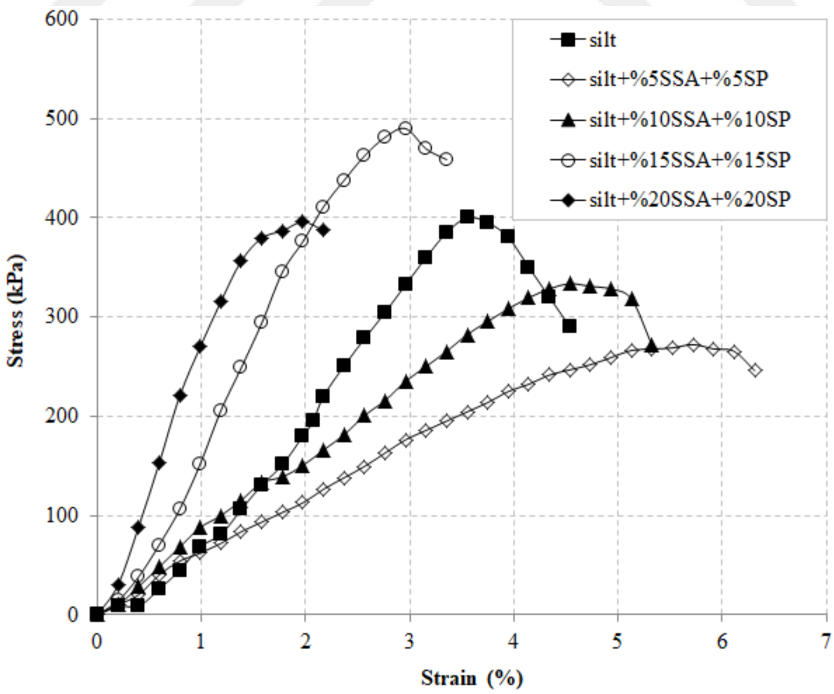

Figure 4.21 Effect of sewage sludge ash (SSA) and stone powder (SP) on the unconfined compressive strength.

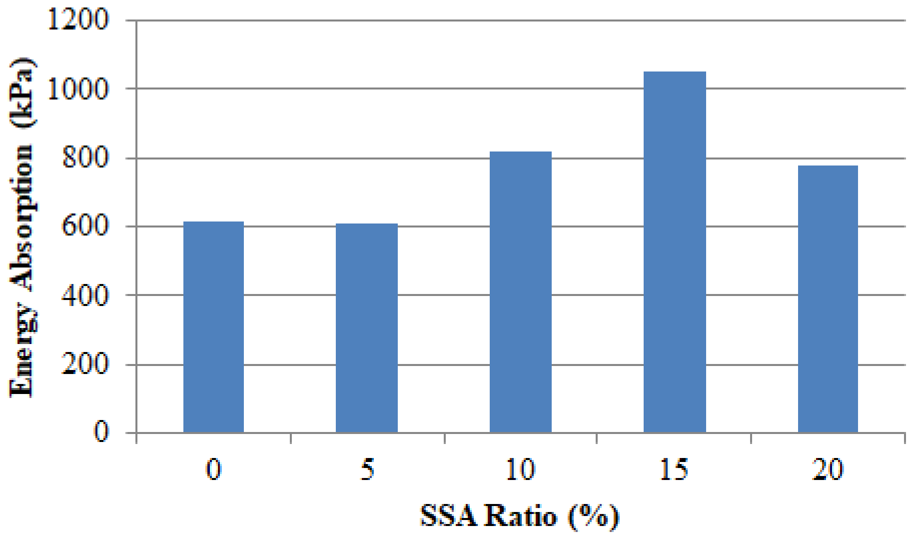

Figure 4.22 Effect of sewage sludge ash (SSA) on the energy absorption of soil.

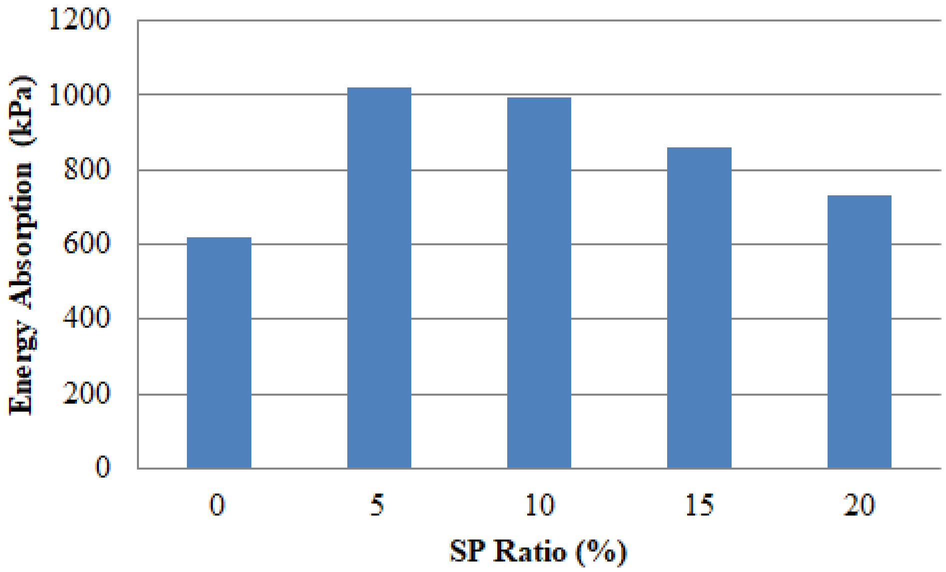

Figure 4.23 Effect of stone powder (SP) on the energy absorption of soil.

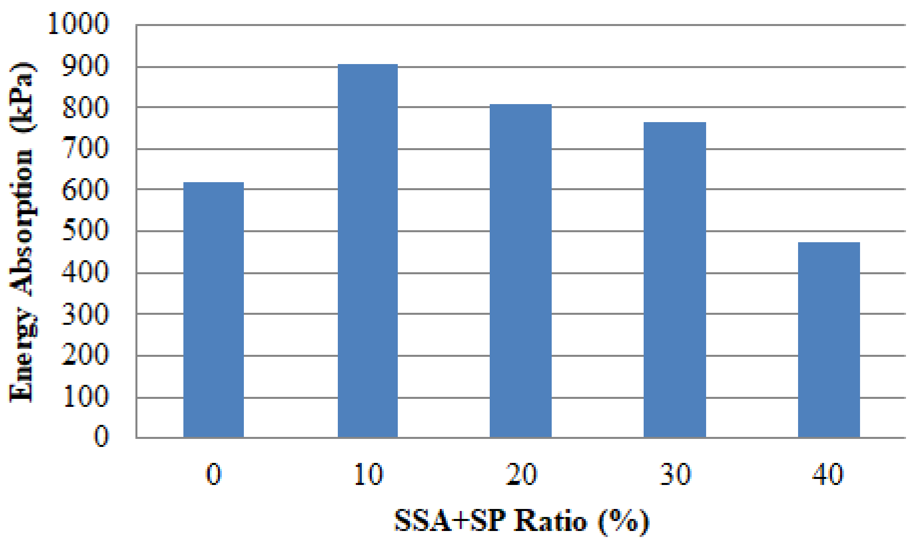

Figure 4.24 Effect of sewage sludge ash (SSA) and stone powder (SP) on the energy absorption of soil.

4.4 Fall cone test (FCT)

Fall cone test had been performed to evaluate the liquid limits and the undrained shear strength of the untreated and treated soil. The liquid limits data obtained during the test and compared with that obtained from the Atterberg limits test Table 4.2.

The results indicated that the liquid limits increased by increasing the SSA and SP with different ratios same as what were resulted during the Casgrande test. Figures 4.26, 4.27, and 4.28, represent the relationship of the cone depth penetration against the variation of water content. The water content of the sample at the 20 mm penetration was considered as the liquid limit of the sample. It can be seen that the penetration depth of the cone decreased with the decreasing of water content of each single mixture, also the water content of the stabilized soil is greater than that of the untreated soil at all the treatment stages of SSA, SP, and SSA/SP admixtures.

The undrained shear strength has been calculated by equation 3.5, the results plotted against the water content for each sample in Figures 4.29, 4.30, and 4.31, it can be seen that the undrained shear strength increased as the amounts of additives increased, in the same time, the strength decreases as the water content increase. The relationship between the undrained shear strength and the water content can be considered as a linear model using the obtained data as follows:

(4.1)

Where;

w = water content:

m = the slope of the curve;

s_u= the undrained shear strength (kpa); and

c = the intercept of the curve.

The parameters m, c, and the correlation coefficient R^2, for the above linear relation were calculated and recorded in Table 4.3, based on the data obtained, the results indicated the undrained shear can be evaluated by the linear model in equation 4.1 since the correlation between the results and the actual data is very good as the correlation coefficient is very close to 1.

The main influential factors affecting the undrained shear strength are the cohesion and internal friction angle of the soil particles which are directly related with the soil water content. In this test, it can be seen that the SSA and SP particles reduced the silt fractions due to the flocculation and agglomeration effect. The SSA and SP particles caused a formation by increase the friction strength of the soil particles. The results obtained from this test do not match the results of the fall cone test on silt-sand mixtures by (Cabalar et al., 2015) which indicated a reduction in the liquid limit with increasing the sand amount to silt mixtures.

Table 4.2 Tests Results of liquid limits determined by fall cone and Casgrande

Materials	Liquid limits	
	Fall cone	**Casagrande**
Silt	31.00	34.50
Silt + %5SSA	35.90	35.40
Silt + %10SSA	39.00	36.30
Silt + %15 SSA	41.20	38.70
Silt + %20 SSA	43.00	41.00
Silt + %5SP	33.00	35.50
Silt + % 10SP	36.50	36.10
Silt + %15SP	38.00	36.60
Silt + %20SP	40.00	38.00
Silt + %5SSA + %5SP	36.20	35.60
Silt + %10SSA + %10SP	39.80	37.10
Silt + %15SSA +%15SP	42.00	40.90
Silt + %20SSA + %20SP	44.70	42.00

Table 4.3 Determination of parameters in linear $w = ms_{u(FCT)} + c$ model

Materials	***m***	***c***	R^2
Silt	-0.523	28.98	0.969
Silt+%5 SSA	-0.702	32.65	0.966
Silt+%10 SSA	-0.745	35.97	0.931
Silt+%15 SSA	-0.550	39.50	0.927
Silt+%20 SSA	-0.551	41.64	0.927
Silt+%5 SP	-0.71	31.55	0.888
Silt+%10 SP	-0.793	34.54	0.990
Silt+%15 SP	-0.803	38.42	0.989
Silt+%20 SP	-0.808	40.65	0.968
Silt+%5 SSA+5%SP	-0.432	34.77	0.941
Silt+%10SSA+%10SP	-0.390	36.90	0.858
Silt+%15SSA+%15SP	-0.486	40.25	0.902
Silt+%20SSA+%20SP	-0.458	43.55	0.988

Figure 4.25 Relationship between cone penetration depth and water content at different ratios of sewage sludge ash (SSA).

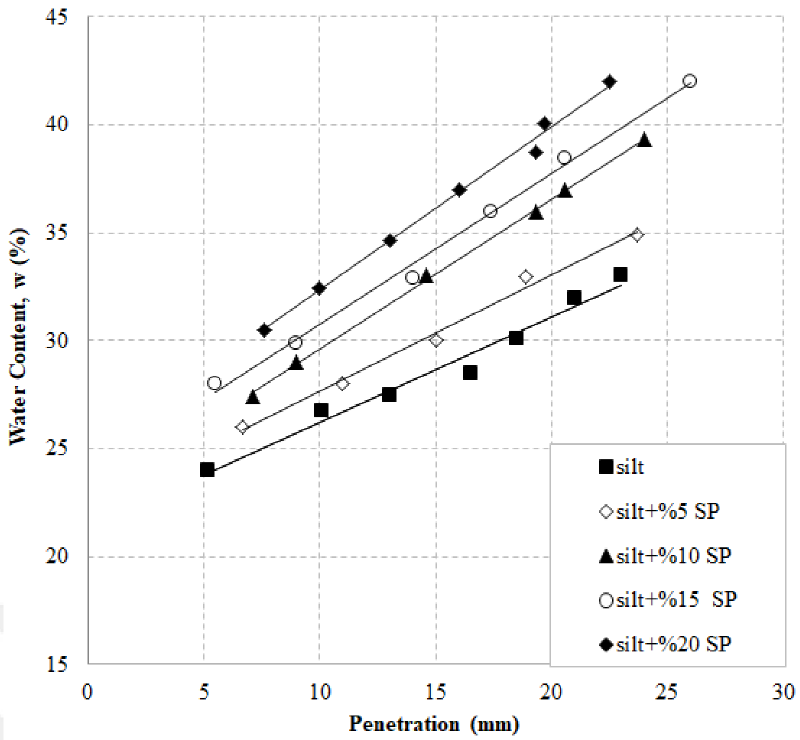

Figure 4.26 Relationship between cone penetration depth and water content at different ratios of stone powder (SP).

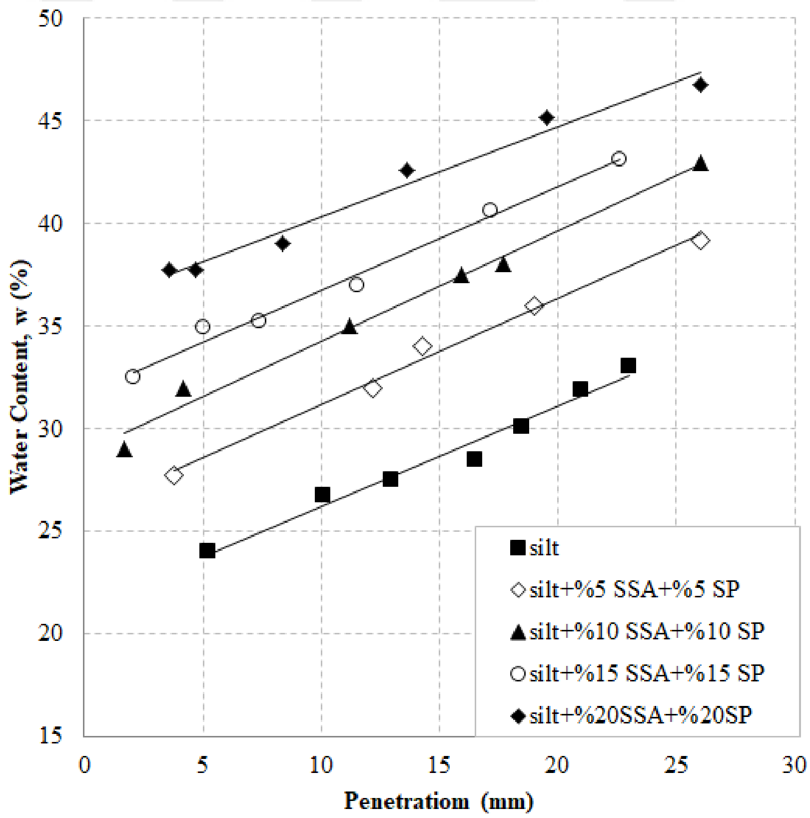

Figure 4.27 Relationship between cone penetration depth and water content at different ratios of sewage sludge ash (SSA) and stone powder (SP).

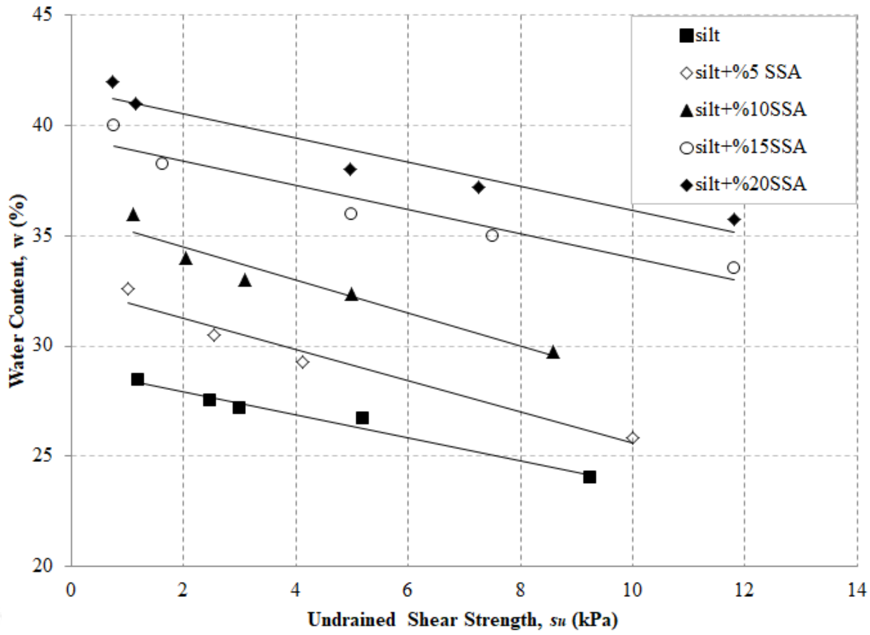

Figure 4.28 Variation of undrained shear strength from fall cone test with addition of sewage sludge ash (SSA).

Figure 4.29 Variation of undrained shear strength from fall cone test with addition of stone powder (SP).

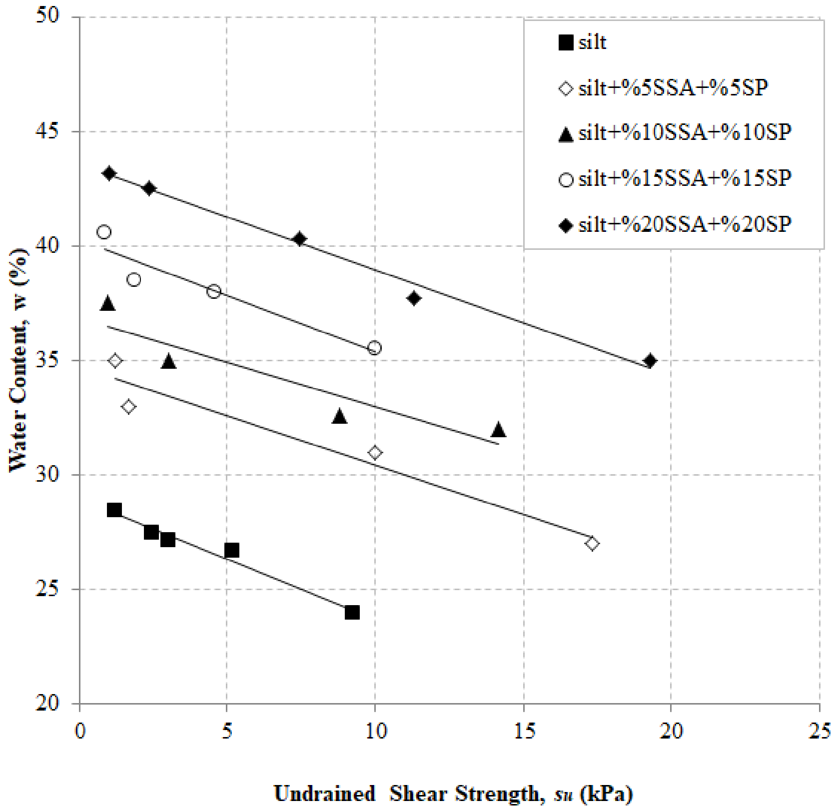

Figure 4.30 Variation of undrained shear strength from fall cone test with addition of sewage sludge ash (SSA) and stone powder (SP).

4.5 Laboratory vane shear test (LVT)

The test was performed to calculate the undrained shear strength and to compare with that obtained from the fall cone test.

The undrained shear strength calculated by equation 3.6, the data obtained were then plotted against the water content and presented in Figures 4.32, 4.33, and 4.34. As the strength obtained from the fall cone test, the strength form vane shear test increased with the amount of additives. For each mixture, the strength increased by reducing the water content. The undrained shear strength affected basically with the cohesion and internal friction angle, which the both are related with their water content.

It can be realized that the relation between the undrained shear strength and the water content is also linear and can be described as follows:

(4.2)

The parameters m, c, and R^2 of the linear relation of strength and water content are listed in Table 4.4. The correlation coefficient as it can be seen, is very close to 1 which is mean that this linear relation is very satisfactory to use for calculating the undrained shear strength.

Figure 4.35, 4.36, and 4.37 showing the comparison between the undrained shear strength obtained from both fall cone and laboratory vane shear tests. It can be seen that the case of adding the SP the results seems to be near to each other at different water contents and admixture ratios, the addition of both SSA and SP results are almost similar at the mixtures of high water content and trend to be different at low water contents.

Table 4.4 Determination of parameters in linear $w=ms_{u(LVT)}+c$ model

materials	***m***	***c***	***R^2***
Silt	-0.351	30.36	0.957
Silt+%5 SSA	-0.613	37.69	0.988
Silt+%10 SSA	-0.529	40.79	0.991
Silt+%15 SSA	-0.367	42.19	0.995
Silt+%20 SSA	-0.343	43.45	0.988
Silt+%5 SP	-0.378	33.19	0.968
Silt+%10 SP	-0.333	35.38	0.974
Silt+%15 SP	-0.396	37.84	0.988
Silt+%20 SP	-0.401	39.57	0.957
Silt+%5 SSA+5%SP	-0.409	37.10	0.987
Silt+%10SSA+%10SP	-0.303	38.56	0.969
Silt+%15SSA+%15SP	-0.290	41.14	0.986
Silt+%20SSA+%20SP	-0.278	44.27	0.993

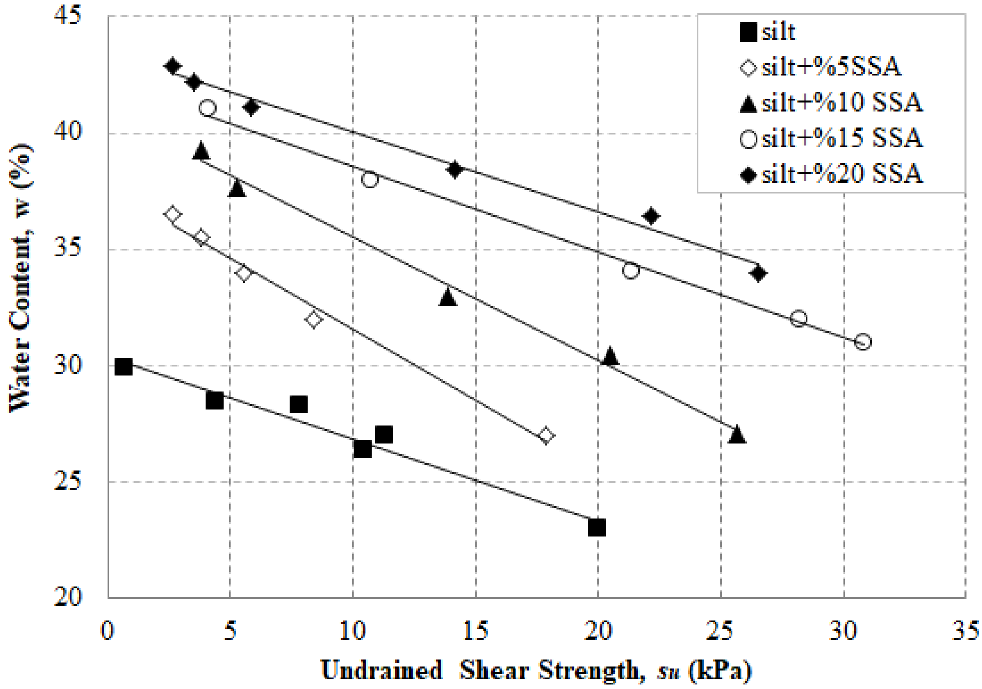

Figure 4.31 Variation of undrained shear strength from laboratory vane shear test with addition of sewage sludge ash (SSA).

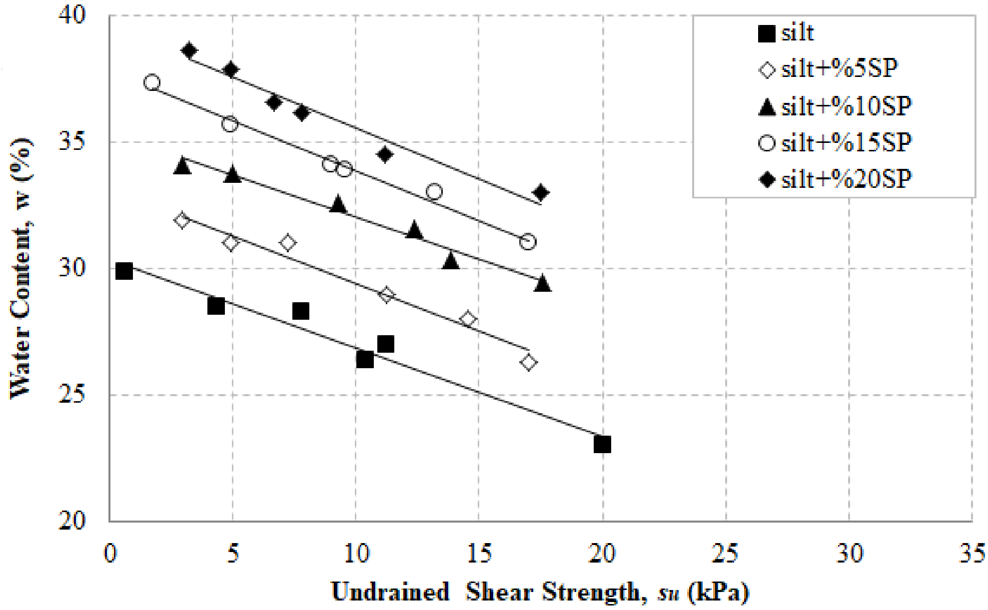

Figure 4.32 Variation of undrained shear strength from laboratory vane shear test with addition of stone powder(SP).

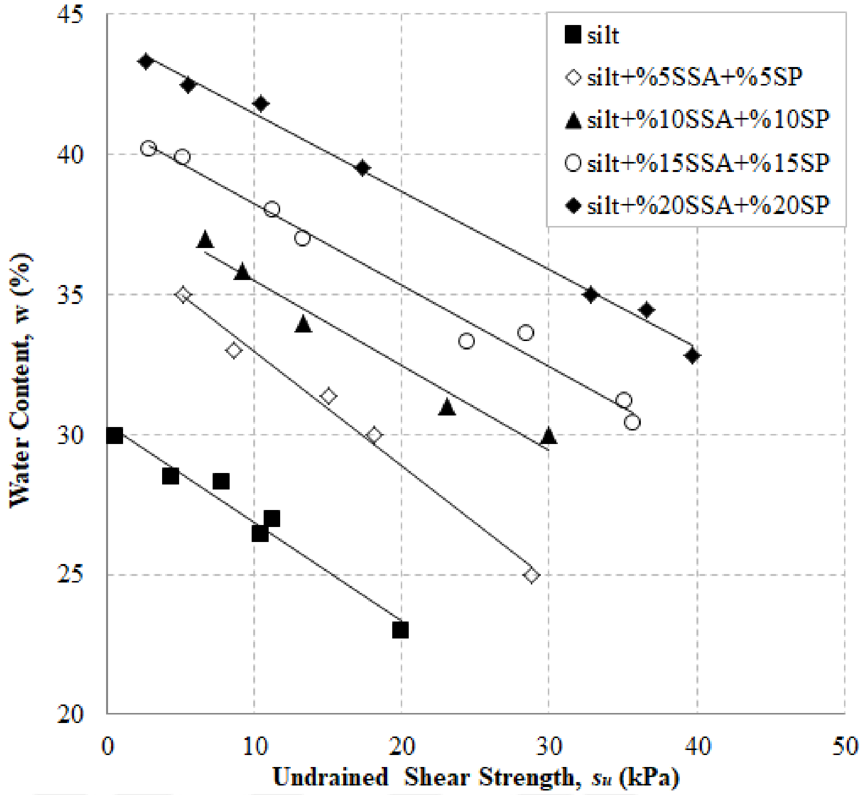

Figure 4.33 Variation of undrained shear strength from laboratory vane shear test with addition of sewage sludge ash (SSA) and stone powder (SP).

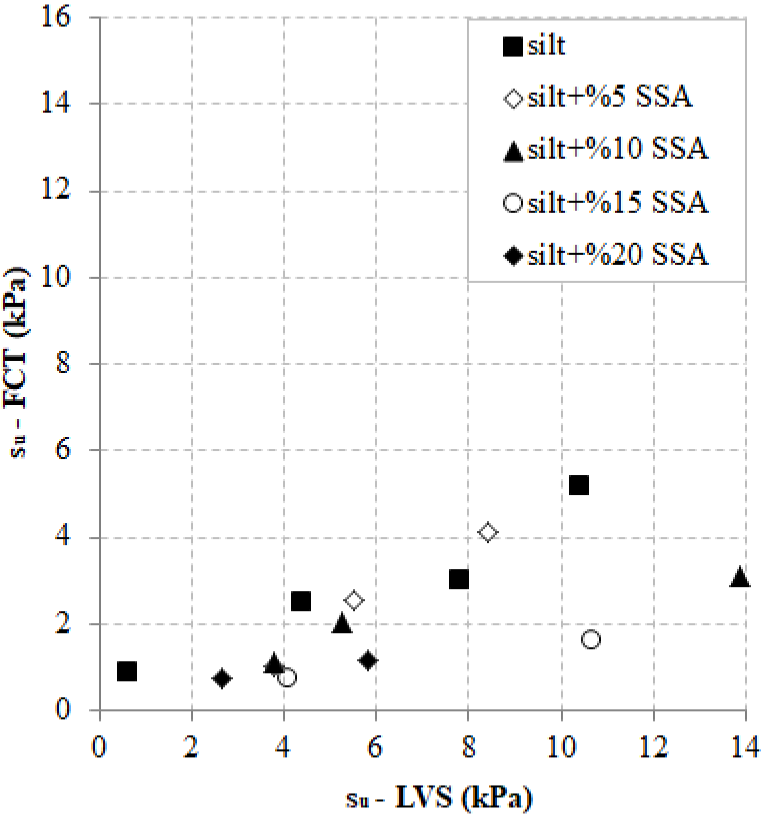

Figure 4.34 Comparison of the undrained shear strength at adding sewage sludge ash (SP).

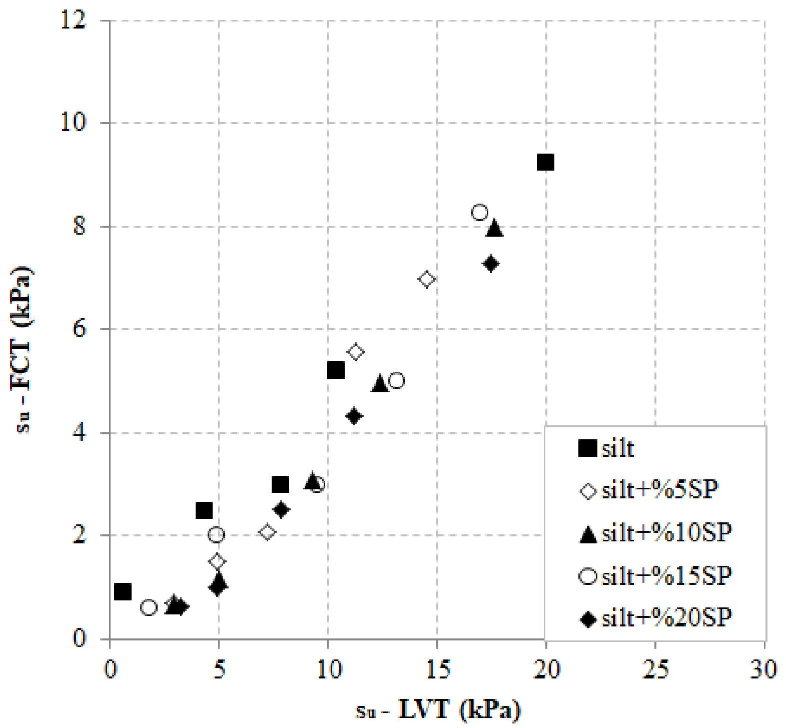

Figure 4.35 Comparison of the undrained shear strength at adding stone powder (SP).

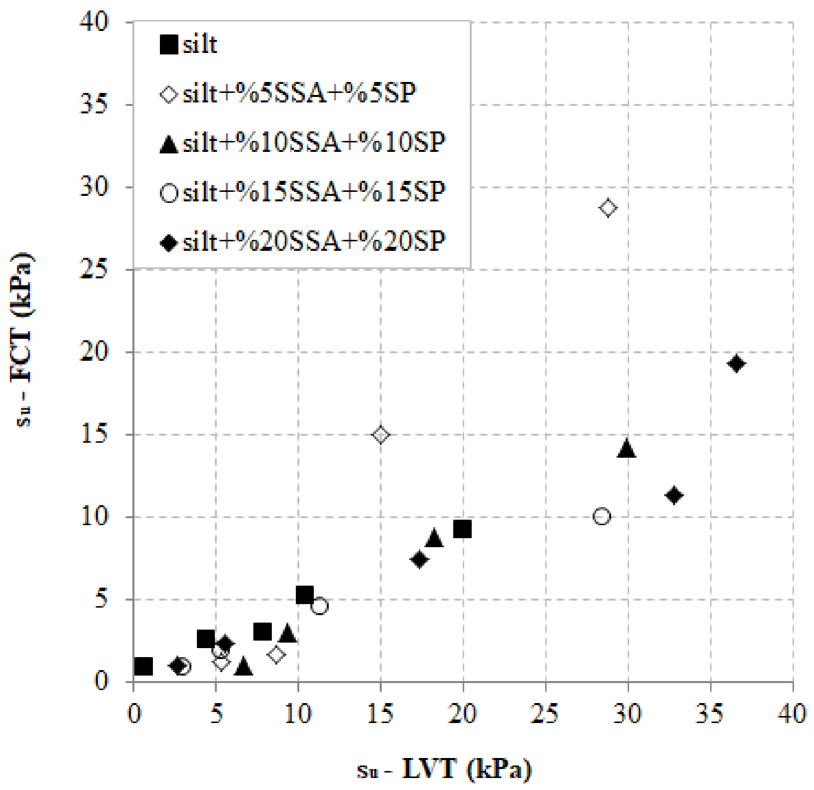

Figure 4.36 Comparison of the undrained shear strength at adding sewage sludge ash (SSA) and stone powder (SP).

4.6 Expansion index (Primary swell) test

The test was carried out to determine the properties of soil, before and after the treatment, in term of its expansion potential.

The data obtained from this test had been calculated by equation 3.8 to find the expansion index (primary swell). Figure 4.38 shows the primary swell for each mixture studied during the experimental work. It can be seen that the expansion index reduced at all the stages. The reduction was about 20_60% with the adding of SSA in different ratios from 0% to 20%, about 25% reduction by adding 20% SP, and 33-75% reduction in case of adding both SSA and SP.

According to Table 3.6, the soil has transformed from high expansion potential soil to medium and low expansion potential with adding SSA and SSA/SP admixtures, respectively. The SP admixture has almost no effect on the expansion property of the soil.

In general, the more fine particles soil, the more expansive soil. The soil used in the study is classified as fine soil size that is passed sieve #200. This is the cause of the high expansion potential property as well as it's prove why the SP has not been significantly affected the expansion potential because it is finer than the silt particles of the soil used.

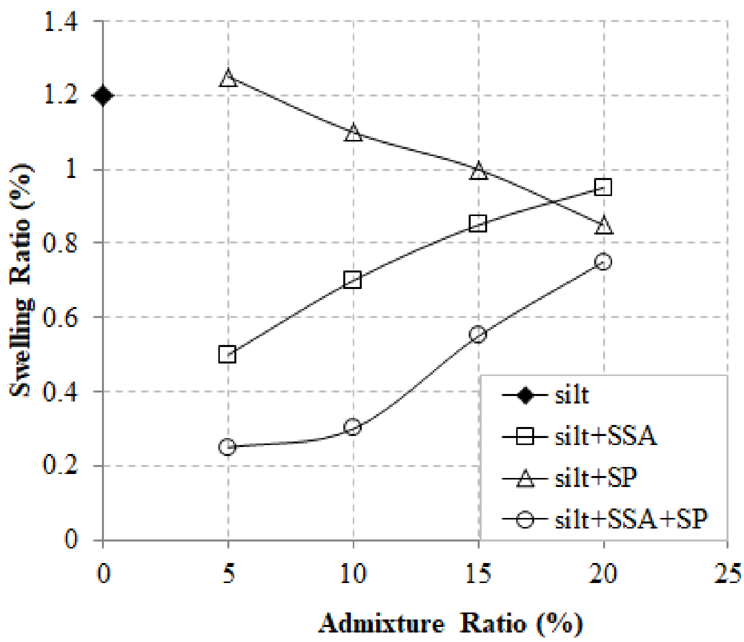

Figure 4.37 The primary swell index at different ratios of additives.

4.7 Compressive strength of concrete

The compressive strength of the concrete with SSA and SP shows poor performance at the whole proportions of wastes used as alternatives with cement and sand as presented in Table. In general, the chemical elements that affected the pozzolanic reactions are Si, Al, and Fe. Due to the small percentage of the mentioned elements appeared in SSA and SP as presented in Tables, the wastes cannot be considered as good pozzolanic materials with the requirements in ASTM C 618 (1991). It can be seen from Table 4.5, the 28-days compressive strength of the control concrete is higher than the all other mixtures that replaced with SSA and SP. Furthermore, as the fineness modulus of the SSA and SP are less than that of sand, the concrete shows poor strength. With coarser particle, concrete showing higher strength. The SSA/SP concrete could be recommended for the general works where no high strength required such as floor screed and mortar.

The sewage sludge ash and the stone powder have generally no economic value as well as in the same time have a negative impact on the environment and public health. So the utilizing of these wastes in medium grade concrete and mortar will minimize the cost as well as reduce the bad impact of wastes. Figures 4.39, 4.40, 4.41, and 4.42 presented the influence of 28-days compressive strength of concrete with different ratios of wastes replacing with sand and cement.

Table 4.5 Comparison of 28-days compressive strength (kPa) of concrete cylinder (200mm*100mm) with replaced sand with SSA

Mix ratio cement: (sand : SSA) : Gravel	**28-days stress (kPa)**			**Mean (kPa)**
1 : 2: 0 : 4	21.25	21.9	22.25	21.8
1 : (1.8 : 0.2) : 4	16.24	16.87	16.03	16.38
1 : (1.6 : 0.4) : 4	14.59	14.79	14.89	14.75
1 : (1.4 : 0.6) : 4	11.63	11.47	11.85	11.65

Table 4.6 Comparison of 28-days compressive strength of concrete cylinder (200mm*100mm) with replaced cement with SSA

Mix ratio (cement : SSA) : sand : Gravel	**28-days stress (kPa)**			**Mean (kPa)**
(1 : 0) : 2 : 4	21.25	21.9	22.25	21.8
(0.9 : 0.1) : 2 : 4	17.25	17.87	16.89	17.34
(0.8 : 0.2) : 2 : 4	15.66	16.8	17.01	16.49
(0.7 : 0.3) : 2 : 4	12.34	11.69	12.5	12.18

Table 4.7 Comparison of 28-days compressive strength of concrete cylinder (200mm*100mm) with replaced sand with SP

Mix ratio cement : (sand: SP) : Gravel	**28-days stress (kPa)**			**Mean (kPa)**
1 : 2: 0 : 4	21.25	21.9	22.25	21.80
1 : (1.8 : 0.2) : 4	14.15	13.89	14.98	14.34
1 : (1.6 : 0.4) : 4	13.58	15.99	14.88	14.82
1 : (1.4 : 0.6) : 4	13.55	13.87	12.99	13.47

Table 4.8 Comparison of 28-days compressive strength of concrete cylinder (200mm*100mm) with replaced cement with SP

Mix ratio (cement : SP) : sand : Gravel	**28-days stress (kPa)**			**Mean (kPa)**
(1 : 0) : 2 : 4	21.25	21.9	22.25	21.8
(0.9 : 0.1) : 2 : 4	16.09	17.09	15.71	16.30
(0.8 : 0.2) : 2 : 4	14.05	15.92	14.21	14.73
(0.7 : 0.3) : 2 : 4	14.01	13.58	12.87	13.49

Figure 4.38 Compressive strength of concrete cylinder with cement replaced by sewage sludge ash (SSA) at different ratios.

Figure 4.39 Compressive strength of concrete cylinder with sand replaced by sewage sludge ash (SSA) at different ratios.

Figure 4.40 Compressive strength of concrete cylinder with cement replaced by stone powder (SP) at different ratios.

Figure 4.41 Compressive strength of concrete cylinder with sand replaced by stone powder (SP) at different ratios.

CHAPTER 5
CONCLUSIONS

5.1 General

This chapter presents the summary of the experimental works and an attempt to conclude the major the advantages and disadvantages of recycling the sewage sludge ash and the stone powder in soil stabilization method also as an alternative of cement and sand in un-reinforced concrete. These methods will save the construction costs as well as reduce the environmental and human health risks.

5.2 Conclusions

The following conclusions are listed down based on the experimental work:

1. Liquid limits had been increased by increasing SSA, SP, and SSA/SP admixture with different amount (%5, %10, %15, and %20) by dry weight. The plastic limits had been increased by adding SSA and SSA/SP admixtures, the adding of SP has almost no effect on the plasticity index of the soil. The plasticity index increased by adding SSA, reduced by adding SP and SSA/SP.
2. The adding of SSA and SSA/SP affected the compaction behavior of the soil by decreasing the maximum dry density and increasing the optimum moisture content. SP admixture has a very little effect on the compaction behavior.
3. The unconfined compressive strength increased by 10% and %20 for the soil sample that contain %15 SSA and %30 SSA/SP by the dry weight, respectively. Adding of SP reduced the unconfined compressive strength by %25 lower than the untreated soil.
4. The fall cone test results of the silt treated with different proportions of SSA and SP showed an increase in liquid limit and undrained shear strength.
5. Also the results of obtained from the laboratory vane shear test indicated an increase in the undrained shear strength of the various treatment stages with SSA and SP.

6. The primary swell index for the treated soil with SSA, SP, and SSA/SP reduced by about 20_60%, 25%, and 33_70% by adding SSA, SP, and SSA/SP, respectively.

7. Finally, the replacing of sand and cement by the SSA and SP showed poor compression strength, delay in setting time, and shrinkage behavior in the high proportion of sand and cement replaced. The utilizing of wastes as alternatives in concrete will benefit for the use of concrete in the non-structural applications like walk ways and pavement.

8. Depending on the results, the sewage sludge ash could be considered as a good silty soil stabilizer. This method will solve a large part of disposal problems. On the economic side, it is considered free of charge and easily available.

5.3 Recommendations

Some possible scopes recommended for future studies as follow:

1. Using the SSA in combination with cement in soil stabilization.
2. All the samples were tested immediately for the unconfined compressive strength test; different samples may be test after curing ages of 7, 14, and 28 days to investigate more accurate results.
3. Utilizing more than %20 of SSA to study the effects of the larger amounts on soil mechanical properties.

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