USING WASTE CERAMIC DUST IN STABILIZATION OF CLAY SOILS

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SAYA ABDULLAH SABER YABA: USING WASTE CERAMIC IN STABILIZATION OF CLAY SOILS

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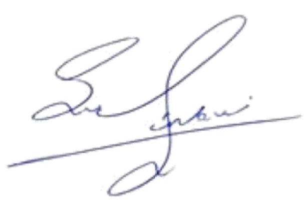

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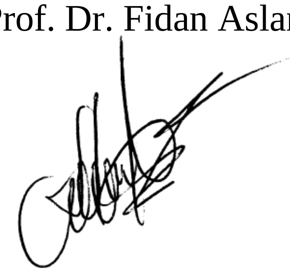

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Around 30% of the global daily produced ceramic tiles go to waste. Ceramic wastes that are sent to the landfills have negative effects on soil, water, and the environment, as they are containing aluminum, silica and iron oxide, leaching into the soil especially in acidic soil aluminum can damage roots and vegetation, waste water may contain insoluble particular matter or heavy metals, and air emissions increase by spreading dust. Using waste ceramic dust in soil stabilization involves better disposal of such waste, in this way while the additional environmental burden and emission is reduced, the usage of natural resources is also minimized. For this purpose, three local clay soil samples from Erbil in North-Iraq were gathered and the effect of the addition of waste ceramic dust on the mechanical properties of these samples was experimentally examined in two different grading sizes. The ceramic dust with particle sizes passing sieve No.40 and sieve No.10, in the proportion of 0, 5, and 10% percentages were used.

The study showed that with an increase in ceramic dust from 0 to 5, and 10%, liquid limit, plastic limit, plasticity index, optimum moisture content of the clay soil decreased. On the other hand maximum dry density, unconfined compressive strength and California bearing ratio increased. The study showed that the addition of No.10 gradation ceramic dust results in better improvement compared to the same amount of ceramic dust in No. 40 size. The current work concludes that soil stabilized with the right type and ratio of ceramic dust could be suitable for a sustainable highway construction subgrade by reducing the design thickness and potentially being more economic.

***Keywords**:* Ceramic waste; soil stabilization; strength; CBR; environmental impact

ÖZET

Dünyada günlük üretilen seramiğin yaklaşık%30'u çöpe gidiyor. Düzenli depolama alanlarına gönderilen seramik atıklar alüminyum, silika ve demir oksit içerdiğinden toprak, su ve çevre üzerinde olumsuz etkilere neden oluyor. Özellikle asidik toprakta alüminyumun toprağa sızması köklere ve bitki örtüsüne zarar verebilir. Atık su çözülmeyen belirli madde veya ağır metaller içerebilir. Tozun yayılmasıyla hava emisyonları artar. Toprak stabilizasyonunda atık seramik tozunun kullanılması, bu tür atıkların daha iyi bertaraf edilmesine yardımcı olur. Bu şekilde, çevresel yük ve emisyon azaltılırken, doğal kaynakların kullanımı da en aza indirilir. Bu amaçla, Kuzey Irak'taki Erbil'den üç yerel killi toprak numunesi toplanmış ve atık seramik tozu ekliyerek bu numunelerin mekanik özellikleri, deneysel olarak iki farklı sınıflandırma boyutunda incelenmiştir. Partikül boyutu 40 ve 10 numaralı elekten geçen, yüzde 0, 5 ve %10 oranlarında seramik tozu kullanılmıştır.

Çalışma, seramik tozunda 0'dan 5'e ve% 10'luk bir artışla, likit limitinin, plastik limitinin, plastisite indeksinin artmasıyla killi toprağın optimum nem içeriğinin azaldığını göstermiştir. Öte yandan maksimum kuru yoğunluk, serbest basınç dayanımı ve California taşıma oranının arttığı gözlemlenmiştir. Çalışma, No. 10 dereceli seramik tozunun eklenmesinin, No.40 boyutundaki aynı miktar seramik tozu ile karşılaştırıldığında daha yüksek iyileşme sağladığını göstermiştir. Mevcut çalışma, doğru tipte ve seramik tozu oranında stabilize edilmiş toprağın, tasarım kalınlığını azaltarak ve daha ekonomik hale getirilerek sürdürülebilir bir otoyol alt tabakasi inşaatı için uygun olabileceği sonucuna varılmasını mümkün kılmıştr.

Anahtar Kelimeler: Seramik atık; zemin iyileştirmesi; zemin mukavemeti; CBR; çevresel etki

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LIST OF ABBREVIATIONS

CD:	Ceramic dust
LL:	Liquid limit
PL:	Plastic limit
PI:	Plasticity index
$\boldsymbol{G_s}$**:**	Specific gravity
SPT:	Standard proctor test
OMC:	Optimum moisture content
MDD:	Maximum dry density
UCS:	Unconfined compressive strength
UCBR:	Unsoaked California bearing ratio
SCBR:	Soaked California bearing ratio
ASTM:	American Society for Testing and Materials
IS:	Indian Standards

CHAPTER 1
INTRODUCTION

1.1 General

In past decades, environmental protection, recycling issues, and waste prevention have taken a leading role in social debates to create sustainable planet growth (Silva et al., 2014). The manufacture of processed and human behaving patterns today produces an ever-rising volume of all kinds of waste. To seek realistic and economic applications for solid wastes, major attempts are being made (Vieira and Monteiro, 2009).

The use of natural resources available is becoming a challenge for environment and society, the substitute materials that are rejected as waste can be used again to conserve our natural resources, such as aggregates necessary for civilization and engineering works constructions to live in a more sustainable environment. In the year 2011-2012 the worldwide production of ceramic tiles was about (11,200 million square meters). China's the biggest ceramic tile producer. They produce about (5,200 million square meters) which is 47% of the world's production of ceramic tile and 39% of the world's use. This value can tell us that tiles have become the most widely used materials. Broken tiles of ceramic and sanitary ware are typically manufactured in altered ways. Some are made in industrial factories after manufacturing due to their flaw or while transporting and using them. Eventually, most of the ceramic waste tiles are generated as a result of demolition and building processes. Ceramic materials have resistance to the force of physical, biological, and chemical deterioration. This property makes them a strong and acceptable alternative for stabilization (Agrawal, 2017).

For us to provide a structure that service its design life, reliable experimental works should be carried out about the soil's engineering behavior at a planned site. If it is found to miss something, then engineering techniques and admixtures can be applied, referred to as soil stabilization, which is the method of strengthening and enhancing soil properties in term of engineering characteristics to reach its standard lifetime, stable and economic. Stabilization has been used in a wide range of civil engineering projects, with the primary objective of increasing its strength, durability, avoid dust amount and erosion and reduce construction cost by using available materials. The use of ceramic waste tiles to enhance the properties of soil is a cost-effective and safe process. In manufacturing units, a large amount of broken ceramic tiles is getting produced each year. Ceramic wastes were then considered to be used as an admixture in fine sand (Panwar and Ameta, 2016).

The use of ceramic is not only to enhance soil properties, it can also solve the problem associated with its disposal. There are many methods in the reusing of ceramic waste. Earlier ceramics were fired-hardened pottery artifacts that came from clay, alone or blended with other ingredients. But later, ceramics were glazed and fired for smooth surfaces and colored surfaces. Ceramic waste or scrub materials are inorganic and harmful materials. Clayey soils have a low bearing capacity for shear and low consistency. Working with such soils is hard since it doesn't have adequate consistency to hold the load on them (Balegh et al., 2020; Saini et al., 2018).

It is calculated that Construction and Demolition waste (C&D) accounts globally for the largest proportion of solid wastes, which is 75%, while ceramic wastes lead the highest percentage of it with 54%. Materials as ceramic include ceramic floor tiles, wall tiles, sanitary ware, and household ceramics. It describes inorganic materials made from nonmetallic compounds then made by firing processes while they might contain some organic materials (Zimbili et al., 2014; Hidalgo et al., 2019).

Manufacture of products is not only aimed to get the more effective use of energy and reduce the environmental pollutant, but it can be beneficial to the sustainable growth of the environment and society. Production of raw materials by industry has significant importance in resource recycling in waste management to reuse the ceramic waste dust in the construction of soil structures. In developed countries, a lot of attentions are paid to waste management and recycling. On the other side, some nations were relatively short of money and recovered their products from being reused. Ceramic industries have become one of the major sources of national income due to the building's explosive growth around the world. The literature survey showed that 30% of the whole world's ceramic industry production goes to industrial waste. A lot of waste ceramic in all kinds of ceramic can be caused during production, sale, storage, and transportation (Shuying et al., 2014).

The worldwide inventory of ceramic waste dust during the final polishing process of ceramic tiles exceeds 22 billion tons (El-Dieb et al., 2018). Owing to the number of ceramic waste tiles produced in the housing industry, stockpiles of ceramic wastes pose environmental concerns. The commonly practiced form of ceramic tile is mostly landfill, this current choice for the disposal of ceramic wastes is causing major environmental problems in contamination of land soil, groundwater, and air. This is largely due to the lack of regulation, lack of expertise, risk avoidance, and standard procedures in using ceramic wastes in the mixtures. Ceramic tiles are mostly made from natural materials containing a high proportion of clay minerals. They undergo a dehydration process and firing at temperatures of 700°C to 1000°C (Cabalar et al., 2017). Its chemical composition differentiates the ceramic waste powder; it contains a high concentration of silica, aluminum oxide, and iron oxide, comprising 89.1% of its whole composition. Nowadays, in a rapidly growing world's population, solid waste landfills will continue to receive larger amounts of solid wastes to satisfy customer needs (Silva et al., 2014).

In acidic soil when pH is lower than 5, Aluminum enters the root tips and it stop root growth of the plant it will cause phytotoxicity if the soil contains high minerals as well (Panda et al., 2009). Nano particles have been regarded as emerging occupational hazards in recent years, exposure to them can occur during different process such as while production, transportation, application and waste recycling. The danger of exposures to aerosol particles depends on the type of origin, the rate of transport of particles and their removal or concentration in the workplace environment (Bessa et al., 2020).

Soft soil foundation poses a major challenge in construction activities to long-term affect the facility's function constructed on them in the base (Shen et al., 2019). So that in this research, clay soils had been used with the low bearing ability and compressive strength, and the stabilization of different clay soils will be carried out with different percentages of ceramic dust. To see the physical property changes and be used as a strong, stable material in highway construction facilities. Also, stress the need for design and improved material to bring new ways for soil stabilization using local soils in economic pattern and provide better functions.

1.2 Objective of the Thesis

- To examine the impact of ceramic waste dust on clay soil properties using Atterberg limits, compaction, unconfined compressive strength, and California bearing ratio as a measurement parameter.
- To determine the effect of required material in soil sample and compare the properties of the treated and untreated clay samples.
- To compare different characteristic and performance of the stabilized soil sample with two different grading sizes of ceramic dust.
- To improve the CBR value for highway subgrades, a smaller design thickness is needed to reduce the total cost and design more economically.

1.3 Scope of the Thesis

The research work is based on a series of experimental testing. The results of the tests are restricted to three clay-soil samples considered in the experiments, which have been combined with two different sizes of ceramic waste dust, sieve No.40 and sieve No.10 particles, by mixing percentages from 0, 5, and 10% to see their properties and performance. One of the important challenges about construction works can be the weakness of clay soils. Therefore, serious procedures need to be discovered to improve the soil's strength and make it strong and ideal for highway basement of subgrades. So for that, ceramic waste can be used as a readymade, inexpensive, and easy to use the material for stabilization.

1.4 Justification of the Thesis

- Economically waste disposal can be done by using ceramic tiles.
- Better environmentally friendly methods in collecting, processing methods than traditional stabilizers.
- In highways to reduce the design thickness of subgrade to more economic value and longer lifetime.
- Lower cost consumption, as ceramic dust is cheaper than traditional stabilizers as lime and cement with chemical agents.

1.5 Outlines of the Thesis

This work consists of five chapters; the first chapter presents a general introduction about the topic and its objective and scope. The second chapter is a literature review and previous studies done in soil stabilization by adding waste materials and waste ceramics. The third chapter describes the materials used in the experiment with the methodology and standards used. The fourth chapter shows all the results and discussions done about each of them. The fifth chapter contains conclusions and recommendations for future works.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Rapid expansion in building sectors and constructing more heavy structures has caused mechanical problems for soil, water, and air pollutions. Instability and high settlement, low shear strength, permeability, high water content, and plasticity are observed in soft soils. Using solid wastes in combination with poor soil for construction to minimize project costs, reduce waste accumulation, and improve longevity is an optimal approach. Waste can be collected as slurry near the manufacturing factories that are exposed to the atmosphere. Some solid wastes are used as admixtures for improving weak soils, such as fly ash, tile dust, and crusher dust. They contain very small fine particles when it is dried. They can cause environmental and air pollution harm (Al-Bared et al., 2018a).

Reusing ceramic waste is a means of solid waste disposal. We can see a rapid growth tendency to use ceramic waste as an aggregate and additives for construction due to the high costs of building materials and saving natural resources. As a result, methods for efficient use of waste materials have been studied for construction and stabilizing (Onakunle et al., 2019)**.** For efficient disposal of waste, it has to depend on the source and waste substance composition, and such compositions can vary greatly. While reusing waste in construction and related operations, their differing composition raises problem unpredictable. So, segregation of waste and using them depending on its form and component would be a safer choice (James and Pandian, 2018).

The best way to bring the infrastructure in place is to upgrade the lower subsoil to hold the construction loads efficiently and resist damages to the structure. Furthermore, the highways and road alignments are restricted, and they carry moving loads continuously due to traffic operations. The solid should have enough strength and do not expand (Rani et al., 2014).

Much solid waste has been used in different civil engineering works such as; glass fibers, palm fiber, biomass ash, quarry dust, fly ash, sawdust, crushed waste ceramic, waste tire ash, crushed waste plastic, crushed waste glass, paper ash, rice husk ash, etc. (Onyelowe et al., 2019). The recent geotechnical engineering trend and building research focus more on searching for inexpensive and locally available materials such as ceramic waste tiles, fly ashes, etc. They then use them as a stabilizer for partial replacement of traditional aggregates (Chittaranjan et al., 2011).

The discharge of waste losses from improper handling in some developed counties has become a big environmental issue. They can be recycled to fulfill different functions, including their use as geo-materials. The researcher has used them to improve soil strength, durability, density while reducing CO^2 gas emission (Shen et al., 2019).

Factory wastes are classified as non-organic solid waste and as a leftover of civil and construction demolition. Red ceramics as bricks and roofing tiles are made from clay materials are a better option for stabilization due to their nature and properties (Vieira and Monteiro, 2009).

The ceramic industry has yet to expand to satisfy better economic growth and the living needs of people. How to apply and reuse the ceramic waste in other construction development is a significant problem in solid waste management and resource recovery (Shuying et al., 2014).

We need more design and modification for multi-scale materials to create new construction developments using locally sourced materials structured in geometric patterns that provide us new functionality (Bajpayee et al., 2020).

Although most researchers referred up to 30%, ceramic dust can be beneficial for weak samples soil stabilization. In the present work, up to 10% ceramic dust was used to initially find out the effect of ceramic dust on strength properties of three different low expansive clays. While there is no ceramic factory in Iraq that might have created a large number of waste tiles daily, many companies bring tiles from outside the country and sell them, in which during the whole process, broken tile wastes is made. On the other hand the demolition of structure results in lots of tile ceramic waste which is not disposed in a regulated manner. Using low amounts of ceramic in subway construction could help the environmental friendly disposal of such waste.

2.2 Expansive Soil

When the foundation is subjected to various types of loads and pressures in soil mechanics, the soil will react and hold the loads according to its strength and property. It is necessary to enhance those soil properties for safety and reach the minimum required safety level (Onyelowe et al., 2019).

Geotechnical engineers have considered that expansive soils are the most challenging and widespread soils. Swelling them creates significant difficulties and damages many buildings and highways, which is so common and difficult to avoid. Even during building, they are challenging to work with and have the very poor bearing capacity and poor strength. Several academic organizations, private companies, highway authorities, and academics are doing intensive work on waste products and environmentally sustainable materials (James and Pandian, 2015a).

To make appropriate soil for construction purposes, many strategies can be applied to improve expansive soils' engineering properties. Damage to various civil engineering structures is based on the occurrence of swell-shrink behavior. Expansive soil, when they are in contact with water, swell significantly, and when water squeezes out, they shrink (Sabat, 2012).

Summayya et al. (2016) Expansive soils experience the action of volume change, and they cause large uplift and upheaval pressure on the building built on them .this expansion is due to the presence of the montmorillonite mineral group. Those minerals are defined by having a large specific area with small scales and high cation exchange power due to their positive ions. Inside expansive soils, clay minerals are found; they can absorb water and expand their volume. More water they absorb causes larger expansion. This shift is enough to force on a building and cause frailer. When dried out, it may also diminish and contribute to dangerous subsidence.

In wide fields all around the world, expansive clays are available. They are marked as problematic soils; they indicate volume changes in the soil at shallow depth and make troubles for the foundations, cracks in the house, and road damage when used without treatment. For instance, in the United Kingdom, the approximate annual expense of such a problem exceeded £150 million and $100 billion in America's the United States (Al-Baidhani and Al-Taie, 2019).

2.3 Clay Soils

Several challenges can be seen due to the clay's low strength characteristic because of the mineral and low ability to withstand loads of the building during its service life. Such poor engineering performance has prompted the researcher to enhance clay soil property, the primary objective of soil stabilization to increase strength and stiffness (Upadhyay and Kaur, 2016).

Clay is a natural material that consists primarily of fine-grain materials having plastic and adhesive properties. Out of any form of soil, clay has the smallest particle size. They contain very small particles that can be seen by an electron microscope. Clay has tiny voids and pores to allow water to be stored and moved through them then contribute to the settlement. It appears to soften and liquefy; this property of clay makes it difficult for building and construction purposes. The clay composition appears to be very compacted. A considerable number of clay particles can be formed in a limited area without having a difference between large soil particles that would also exist (Obianigwe and Ngene, 2018).

Minerals as clays at low water content and high bulk density tend to compress to form rocklike materials. In contrast, at high water content, they can form moldable and pourable pastes for extrusion processes. Smectitic clays are used in bricks when combined with natural binders.

Kaolinite, talc, and pyrophyllite are used to manufacture ceramics, bricks, and tiles (Bajpayee et al., 2020).

Clay contains high organic matter and high moisture content, it is typically sluggish, and its engineering properties are low. The liquid limit of soft clay is lower than the normal water content (Al-Bared et al., 2018a).

Seasonal temperature variations may also cause swell-shrink of clay, the volume change caused by clay affect soil and change soil activities. They change in the amount of bulk soil. Cracks may significantly affect the growth of clay soil structures (Neeladharan et al., 2017).

In the building process, lateritic soils are widely used in many different countries. They have poor bearing capacity and strength due to the high clay concentration in them. Their plasticity can damage the infrastructure and roadway bases or any buildings built on them. If lateritic soil contains a large amount of clay, it cannot be ensured with water and load pressure (Onakunle et al., 2019).

The research's key objective is to improve clay soils by using waste ceramics dust, focusing on the bearing ratio characteristics, the stress of the treated soil samples, and comparing them with untreated samples.

2.4 Clay Mineralogy

Clay minerals are a soil constituent with an effective diameter that is usually less than two microns (0.002 mm) or less in engineering works classifications (Zorluer and Gucek, 2020). Small scales of clay offer particular characteristics to clay minerals as the capacity for cation exchange, plastic behavior, swelling behavior, and low permeability. Clay is very common on the earth's surface so that they appear almost appear in all sedimentary rocks (Obianigwe and Ngene, 2018).

Das (2019), Clay minerals are usually composed of aluminum, magnesium, and iron. The clay minerals' basic crystalline units are: (1) a silicon-oxygen tetrahedron and (2) aluminum or magnesium octahedron. The first crystalline unit of clay mineral is shown in Figure 2.1a; it consists of four oxygen atoms surrounding a silicon atom. Figure 2.1b an octahedral unit consisting of six hydroxyl units surrounding aluminum or a magnesium atom.

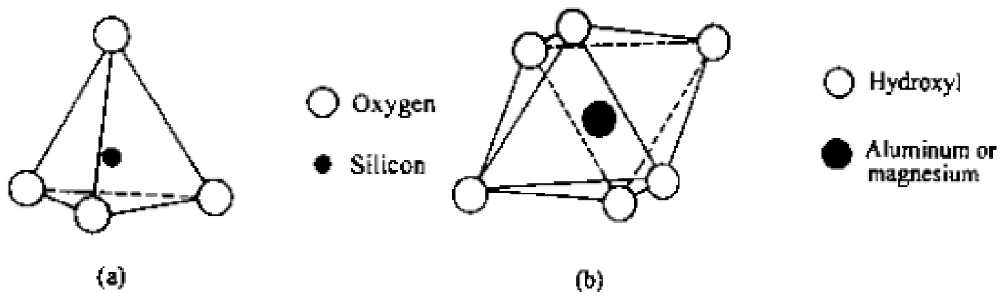


Figure 2.1: (a) Silicon–oxygen tetrahedron unit and (b) Aluminum or magnesium octahedral (Das, 2019)

The tetrahedron units join to form a silica sheet is shown in Figure 2.2a. Note that adjacent tetrahedral share the three oxygen atoms found at the bases of each tetrahedron. The silicon ions have a positive charge, while oxygen atoms have a negative charge. A gibbsite layer shown in Figure 2.2b represents the combination of aluminum octahedral units. Sheets are pointed to brucite if the major metallic atoms are magnesium. When the silica sheets are placed over the octahedral sheets, the oxygen atoms replace the hydroxyls to fulfill their valence bond shown in Figure 2.2c.

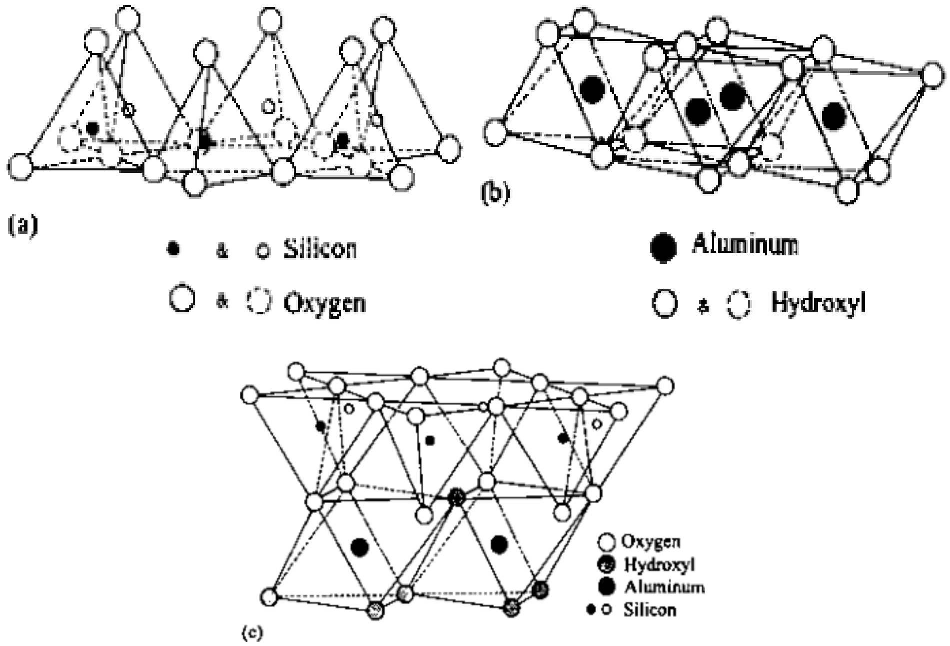


Figure 2.2: (a) Silica sheet, (b) Gibbsite sheet, and (c) Silica–gibbsite sheet (Das, 2019)

Clay minerals are normally amorphous and have a negative charge, largely due to the silicate and aluminum content of hydroxyl ion disassociation. The negative charge causes cations' attraction to the particle surface from the solution, which creates a double layer of surface particle and cation dispersion. Weak cation bonded can be replaced by other strong ones. Inside clay particles, attraction and repulsion force work. A reduction in repulsive force may cause an increase in cation valency or concentration. In cohesive fine soil grains, attractive forces are responsible (Bone et al., 2004).

Clay minerals absorb water for loss heating and create refractory materials at high temperatures. Plasticity characteristic is primarily due to the clay surface preference of water in clay particles. In fine-grain soils, the mineralogical composition is the most important grain property (Obianigwe and Ngene, 2018).

When clay minerals consist of repeating layers of two-layer sheets in a combination of silica sheets with gibbsite sheet or brucite sheets, repetitive layers are bound together via hydrogen bonding and secondary valence forces. The most important clay mineral belonging to this type shown in Figure 2.3 is Kaolinite. Other common clay minerals that fall under this group are serpentine and halloysite.

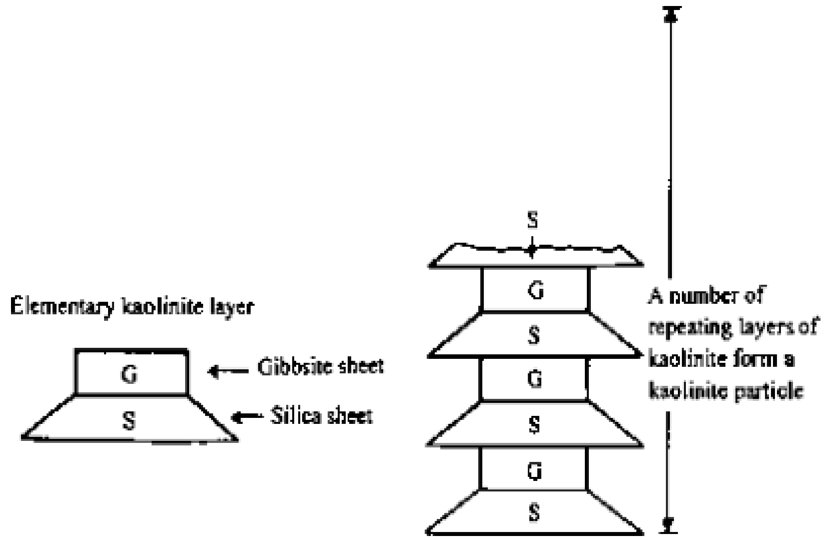


Figure 2.3: Kaolinite mineral structure (Das, 2019)

Minerals such as illite and montmorillonite are the most common clay minerals with three-layer sheets shown in Figure 2.4. They consist of the octahedral sheet in the center with silica sheets at the top and one at the bottom. Repetitive layers of these sheets form the clay minerals. Illite layers are bound to each other by potassium ions. The negative charge for balancing potassium ions is due to the replacement of aluminum for silicon in the tetrahedral sheets. This replacement is described as an isomorphous substitution that happens without modifying the crystalline structure. There is Montmorillonite, which has the same structure as illite. Unlike illite, there are no potassium ions present. It also contains a huge amount of water attracted between the three-sheet layers.

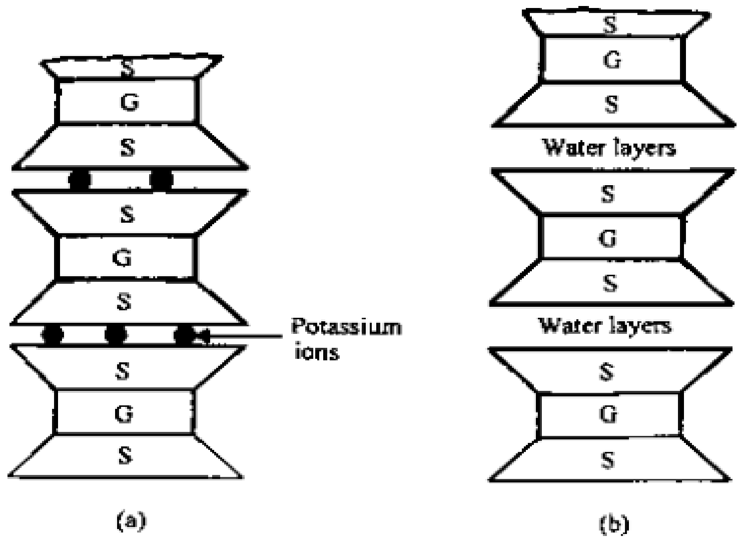


Figure 2.4: Symbolic structures of: (a) illite and (b) montmorillonite (Das, 2019)

A few clay minerals have tubular or fibrous forms that are elongated (45). Aluminum or magnesium can have an aluminum octahedron block, it is contained only aluminum. It is called a gibbsite. In contrast, if it contains only magnesium, it is called brucite .different clay minerals are formed as these sheets stack on with each other with different ion bonding. Using many methods, clay minerals can be identified, such as; X-Ray diffraction, differential thermal analysis, chemical analysis, and electron microscope resolution (Chittaranjan et al., 2011).

2.5 Soil Stabilization

Stabilization can be a useful developing sector for the proper use of waste materials in weak soils. Their efficient use has been demonstrated by several civil, geotechnical engineers (Singh et al., 2014).

Stabilization uses different approaches to change the soil's property and enhance its engineering properties and make them more stable, when it is not sufficient for the building to anticipate purpose and it is necessary to be improved. It can be done by physically mixing the weak soil with stabilizing materials in the form of a homogeneous mix. In the case of a highway, the subgrade is found to be clay soil, and loads will be transferred into the soil in the ground. It typically causes serious problems in civil engineering practices (Canakci et al., 2016).

The modification of stabilized soil indicates that three phases contained in soil are changes, for, i.e., the solid phase is the mineral grains, the liquid phase is the soil's water content, and the gaseous phase that is the voids inside the soil, they are all changed in soil sample stabilized to achieve the desired phase. This is compliant with a given system. The use of stabilizing materials for soil varies according to environmental, economic, and technological aspects. Many ways of Stabilizing soil can be done, such as incorporating additive materials into the soil mix. The method can be either water by bonding soil particles, waterproofing the soil particles, or by mixing both techniques .this additive materials are bounding soil grains, fill the voids and change soil property to the desired degree (Aamir et al., 2019)

One of the waste substances used to enhance clay soils is stabilization using ceramic waste, which is readily usable at separate processing units of building sites (Upadhyay and Kaur, 2016). Still, most researchers haven't yet studied the detailed effects of stabilization on shear strength, consolidation property, stiffness, splitting tensile strength, and hydraulic conductivity of expansive clay soils. Literature is limited to show the impacts of geotechnical properties of stabilized soils, mineralogy, and economic aspects. There is very restricted literature about the behavior of stabilized soil subjected to cyclic loading, using solid wastes in building approach are hardly found in the works (Summayya et al., 2016).

Makusa (2013) Obtained improvement of stabilization can be summarized as; (1) Quality improvement: by reducing swelling and plasticity index while increasing strength and durability with better soil gradation. It can even be used in rainy weather to provide a working base for building activities. (2) Design thickness reduction: The strength and hardness of a soil layer can be increased when using additives to decrease the design thickness of the stable material according to unstabilized ones. Construction thickness might be reduced if the base or subbase course requirement is sufficient (3) Achieve effective control of dust for a safe and healthy working environment (4) Support using waste materials in the construction sector.

2.5.1 Biological soil stabilization

The biological stabilization can be accomplished by forestation or planting. The main purpose of this method is to control erosion. Root patterns such as architectural, physiological, morphological, and biotic play an important role in chemical and physical progress by enabling the soil's structural stability. This approach can be useful for land exposed to water and wind effects not intended for construction. So that from the moment when seeds are planted until the moment it can support them, planting has to be supported by other soil stabilization because they might be moved away through wind or running water (Cabalar et al. 2017).

2.5.2 Mechanical soil stabilization

Mechanical soil stabilization is the oldest type of soil stabilization in nature (Makusa, 2013). It can be achieved through the physical process by altering native soil particles' physical nature to affect its gradation by either induced vibration, compaction or by incorporating other physical properties such as barriers, nailing, solidity. Eventually, dense and well-graded materials can be produced by mixing and compacting a few different grades of two or more soil types. Adding a small number of fine materials such as silts or clays enables binding of the non-cohesive soils, increasing the material's strength. Strong and angular particles of sand and gravel impart internal friction and incompressibility to the mix and can be well stabilized with the addition of clay to fulfill binding properties. Physical and mechanical types of soil stabilization usually include five techniques: compaction, pre-wetting, wetting-drying cycles, reinforcement, and solid wastes.

2.5.3 Chemical soil stabilization

Another major type of soil stabilization is using chemical solutions and slurries (Makusa, 2013). Soil stabilization focuses largely on chemical reactions between pozzolanic material from cementitious stabilizer material and soil minerals that interfere with it chemically and physically and modify its properties to achieve the desired result. Various forms of soil stabilization focus on chemical agents of one kind or another; we can also find formulations that use cement, lime, fly ash, or kiln dust. Much of the reactions obtained are either cementitious or pozzolanic, based on the soil's quality found at the location we're investigating.

2.6 Factors Affecting the Strength of Stabilized Soil

The presence of organic matter, sulfates, sulfides, and carbon dioxide in the stabilized soils may contribute to stabilized materials' undesirable strength, as discussed below; (Makusa, 2013).

1. ***Organic matter**:* The top surface layers of most soil form a large amount of organic matter. In well-drained soils, organic matter may extend to a depth of 1.5 m .that they react with hydration products such as e.g. calcium hydroxide. This results in low pH and affects the hardening of stabilized soils, rendering compacting difficult or impossible.

2. ***Temperature:*** In the field, temperature constantly changes over time. Pozzolanic reactions are susceptible to temperature variation. At low-temperature pozzolanic reactions gets slower, then it will result in lower strength of the mix.

3. ***Sulfates:*** When the calcium-based stabilizer is used in sulfate-rich soils, In the presence of excess moisture, it may cause the stabilized soil to respond and form ettringite or thamausite, the product that produces greater volume than the combined volume of reaction.

4. ***Sulfides:*** Sulfides may be presented in the form of iron pyrites. Oxidation of iron pyrites will create sulphuric acid, which in the presence of calcium carbonate, it may react to form gypsum. Even then, in natural soil, gypsum may also be found.

5. ***Moisture Content:*** Sufficient moisture content is important in stabilizing soil mixes for the hydration process and effective compaction. In soils with high soil-water linkage,

such as clay and organic soils, the hydration process can be slowed due to the absence of moisture content that directly affects the final strength**.**

6. ***Compaction:*** At the same degree of compaction, a stabilized soil has higher maximum dry density than unstabilized soil. optimum moisture content rises with adding more binders in cement stabilized soils, the hydration process takes place automatically when cement reacts with water, it has to be compacted as soon as possible because delay may cause hardening the soil mass. For this extra compaction may be required. Stabilized clay soils are more likely to be affected than other soils due to clays' various plasticity properties. As opposed to cement, there could be certain benefits of delaying compaction for lime-stabilized soils to enable mellowing time and allow the lime to disperse through the soil, thereby creating optimum plasticity.

2.7 Environmental Damage Due to Industrial Wastes and Landfills

The environment we will leave behind with future generations should be sustainable, it impacts the future of the earth today. The use of virgin materials cannot be maintained at a current scale. This reflects on the economic, environmental, and social challenges of human activities. The main aims of waste minimization management are to secure environmental pollution, conserve resources, and secure human health. Other aims include avoid landfill issues in the future, it also demands that any action be environmentally sustainable, economically, and socially secure (Firat et al., 2017).

We must not lose sight of any manufacturing system that can create a by-product and waste products that can harm the environmental system. At many stages in the product's life cycle, such effects can occur, whether during the initial phase, during the production and development phase, during transportation of the materials, or when the material is useless. It is needed to be disposed of by the owner, and As a result, in recent years, there has been increasing public interest with regard to the general issues of waste disposal management and particularly with industrial waste and those wastes from building sectors. The issue has been more acute due to the huge increasing amount of manufacturing and building demolition wastes (Chen and Idusuyi, 2015).

The volume and amount of industrial waste generated worldwide are enormous. Globally, cities produce around 1.3 billion tons of solid waste per year. Assays to the World Bank's 2012 report, it is predicted that this amount will grow to 2.2 billion tones by 2025 (James and Pandian, 2015b). Life Cycle Analysis (LCA) had shown that larger environmental damage and footprint would be caused due to landfilling. It's larger than recycling alternatives or reusing materials. In some European countries, reusing construction and demolition waste has been possible to reuse up to 90% amount (Hidalgo et al., 2019).

Ceramic waste tiles are generated at construction sites. It is commonly disposed of in landfills. Such landfills can influence soil fertility, absorb water and cause damage to vegetation areas and environmental air pollution (Al-Bared et al., 2018b).

The ecological and environmental benefits of waste materials include; (1) landfill disposal of unrecyclable waste by reusing them, (2) reducing g negative effects of wastes on the environment and air pollution, (3) reducing the energy for production and using less natural resources. On the other hand, the alternative material source, transport, and processes, such as fees and landfill management, should be considered for the work (Canakci et al., 2016).

Iraq is estimated to produce 31,000 tons of solid waste every day, with a per capita solid waste exceeding 1.4 kg per day; Baghdad, the capital of Iraq, produces more than 1.5 million tons alone of solid waste each year. In the absence of effective and appropriate methods and places for handling and recycling services, the current way for waste disposal is landfilled with very small concern for human health and the environment (Chabuk et al., 2015).

For the population of 1,118,187, the daily volume of solid waste production in Erbil city was found to be approximately 1.27Kg/capita. Total revenue from recyclable solid waste was $333,488.85 a day in 2016. It has been observed that the city is still lacking in terms of efficient waste treatment technology. Erbil Landfill Site (ELS), situated on the left side of Erbil-Mosul main road about 15km away from Erbil city center, opened in 2001. The site receives more than 2000 tons of municipal solid waste daily (Aziz et al., 2019).

2.8 Ceramic Wastes

In 1980, the American government proposed a superfund bill, and it was pointing to that during the ceramic manufacturing phase, they must deal with any potential waste in a timely and fair manner that was for the more efficient business and production to fix the issue immediately and to be monitored by the government. In Japan, companies pay large attention to ceramic waste management and reprocessing during the manufacturing process because of the lack of space and environmental consciousness and improving their economy and technology. British Ceramic Research Association showed that ceramic waste recycling factories' statics had reached 40%. The main method of reusing ceramic is to remove porcelain and apply new porcelain production. Factories that handle waste ceramic and materials will be in touch with tile factories in this situation, and ceramic technology has archived a favor of ceramic experts, government, and environmental. In Guangdong, the Fengxi Ceramic Research Institute has completed ceramic waste reprocessing and recycling successfully in 2001. They noticed then that ceramic wastes were minimized. Clay minerals are inorganic, non-metallic solids. The old ceramics were artifacts made of clay, cured by fire alone, or combined with other materials. Ceramic was then glazed to produce a smooth and colorful surface. Sanitary and porous ceramics are mainly used in ceramic production. Ceramic tile waste is affordable and not usable material, and we can easily get them from building areas, picking rubble, and near factories via some initial basic processing (Shuying et al., 2014).

The use of ceramic tile waste is safe and cost-effective to enhance soil property and durability. A significant volume of broken tiles of ceramic is created from manufacturing units per year during dressing, polishing, and other processes, but mostly it is produced during dressing and polishing. By using ceramics for stabilizing, the disposal issue of the waste can be solved. Produced wastes can also be used for refilling an excavation. In contrast, the storage of these waste materials may cause problems and spoil out all over the place, affecting the region's aesthetic. The waste of ceramic comes primarily from building industries, and ceramic accounted for about 45% of building and demolition waste. They are not coming only from the construction process, but also from rejected and crushed tiles of the factories. It is stated by numerous researchers from 7-30% of ceramic wastes are being produced during processing in the ceramic tile factories. Such waste accumulates in lands near the factory location, and it can be transported by wind and damage the atmosphere, cause pollution, and create health damage to the individuals (Panwar, 2017).

Ceramic waste is listed as non-recyclable waste material in South Africa. Instead of recycling and reprocessing them, they use them as filling materials. Because there is no guideline and current methodology for using them as stabilizers and the local government may not have enough skills and expertise to reuse the ceramic waste, we can see the same situation in many other countries. Around the world, the new and largest growing industry with better properties relative to natural stone and natural manmade tiles are vitrified tiles for many tiling requirements. They can be avoided for disposal as possible for use in stabilization admixtures (Zimbili et al., 2014).

It is derived from the process when clay mineral is getting dehydrated and subjected to high heat temperature. Depending on the type of ceramic being made, the value is usually more than 1000°C to give necessary mechanical properties and make them useful as aggregate material replacement used in construction (Onakunle et al., 2019).

Ceramic tile manufacturing worldwide is about 8500 million square meters. For instance, in India, the annual production of ceramic reaches approximately 100 million tons, with the production of 600 million square meters approximately (Obianigwe and Ngene, 2018).

Developing cracks and smashes on the new tile surfaces, failures in the building are the key reason for the large volume production of waste tiles at the construction sites. This is attributed to unsafe handling, transporting, casing, and trembling (Al-Bared et al., 2018b). Waste tiles consist mostly of 59.12% silica and 1.60% CaO (Saini et al., 2018).

The silica, aluminum, Iron oxide, and calcium oxide accounts for about 94% of ceramic composition. Due to the high level of aluminosilicate, they can form compounds that are responsible for strengthening (Onyelowe et al., 2019). Ceramic tiles consist of clay minerals derived from earth crust; they are natural minerals such as feldspar used to lower firing temperature and for the shaping process (Rani et al., 2014).

2.9 Experimental Studies

Sabat (2012) the study used waste ceramic materials and mixed it with expansive soil to improve the soil property using California bearing ratio, compaction characteristics, shear strength, and expansive soil swelling parameters. For this purpose, from 0 to 30% of ceramic waste at a 5% rate of increment was used to treat the expansive soil. The experimental result concluded that the liquid limit, plastic limit, plasticity index, swelling pressure, and optimum moisture content decreased as the ceramic contains increased. On the other hand, swelling pressure decreased from 130 to 24 KN/m^2 containing 30% ceramic. Optimum moisture content fell from 20 to 17.6%, and the unconfined compressive strength increased from 55 to 98 KN/m^2. The soaked California bearing ratio value raised by 150%. Cohesion reduced from 18 to 13 KN/m^2. Finally, the use of ceramic waste in the alteration of expansive soil changed the soil's classification from high plasticity CH group to low plasticity CL. He concluded that ceramic dust with efficient stabilization was 30%, which is very economical and worthy for enhancing soil strength for flexible pavement subgrade building.

Rajamannan et al. (2013) studied the impact of addition waste ceramics inside clay soils. His study's findings demonstrated that ceramic wastes could be used as filler materials and concluded from mineralogical, chemical, and morphological that ceramic waste gives better property to the sample without adversely affect by testing water absorption and compressive strength.

Rani et al. (2014) did the study at a rise of 10% on expansive soil combined with ceramic tile wastes of 0 to 30%. The research result showed that liquid limit, plastic limit, optimum moisture content, and swelling pressure decreased. At the same time, the California bearing ratio increased. The treated soil demonstrated optimum improvement from CBR and swelling pressure compared to the untreated sample. It is suggested that up to 20% of tile waste can reinforce an expansive subgrade of flexible pavement, whiling saving in building and construction cost.

Singh et al. (2014) experimented with enhancing locally artificial soil's geotechnical properties by adding fiddle amounts of admixtures such as fly ash, sand, and tile waste. Due to the treated samples, a substantial improvement in the California bearing ratio value was noticed compared to the untreated sample. The finding showed that the best ideal mix for CBR and compaction characteristics are (soil-sand, 70:30, soil-sand-flyash, 63:27:9, soil-sand-flyash-tile waste, 63:27:10:9) respectively.

Chen and Idusuyi (2015) studied the influence of ceramic waste powder on expansive soil's index engineering property. From the experiment results were obtained as the ceramic dust was increased from 0 to 30%, the maximum dry density began to rise from 15 to 18 KN/m^3.the optimum moisture content started to increase due to the substitution of ceramic dust particles having a high specific gravity of 2.82. In contrast, the soil sample had a low specific gravity of 1.9, with them Liquid limit, plastic limit, plasticity index, and swelling pressure decreased. At the same time, California bearing ratio (CBR), maximum dry density (MDD), and Unconfined compressive strength (UCS) have improved. From the X-Ray diffraction analysis, it was concluded that the sample of shrink-swell soil had a high content of montmorillonite that is responsible for this expansion. When 30% of ceramic dust was used, the soaked CBR value rise by 150% compared to the original, untreated sample. His results were almost the same as Ashkaya (2012) mentioned. The optimum value of used ceramic dust is 30% from the economic and management usage of them as a stabilizer in flexible subgrade construction.

James and Pandian (2015a) investigated micro-ceramic dust's impact on lime stabilized expansive soil. The test analysis of soil plasticity and swelling indexes found that ceramic dust enhanced the soil plasticity and property characteristics. Simultaneously, an incensement of about 20% of the soaked California bearing ratio (SCBR) was noticed. The optimal amount percentage of polyvinyl waste was about 30%.

James and Pandian (2018b) studied the effect of ceramic waste dust on swell-shrink and plasticity behavior of stabilized lime soil. They used two amounts of lime content with four distinct amounts of ceramic dust. Work included a power sample UCC power sample mixtures of the soil of lime and press powder. An additional amount of ceramic due to lime stabilized soil was obvious to minimize swell-shrink and plasticity amount. The impact of ceramic dust was seen to be prevented better at lower lime content. The aims of the study were, first, to enhance soil characteristics using waste materials. Second, improve soil hardness property using various ceramic specks of dust. Third, strength calculations with regular proctor test and unconfined compressive strength and how they affect the soil. Forth, reduce soil plasticity to achieve more stable soil.

Michael et al. (2016) study the action of expansive clay stabilized with solid wastes. He focused on the effect of such waste on the engineering properties of the new mix. Various materials have been used, such as ceramic dust, copper slag, sawdust, brick dust, polyvinyl waste, red mud, and fly ash. Test such as CBR, compaction, and Atterberg limits was performed. He revealed that brick and almost all industrial waste have their improvement to the weak soil; also, they are available at low cost.

Upadhyay and Kaur (2016) used soil stabilization using ceramic waste. It was seen that the soil's ceramic waste decreased California bearing ratio liquid limit, plastic limit, and the plasticity index of the soil. When ceramic percentage increases, the overall dry density achieved at some optimum ceramic content declines below optimum ceramic waste content. We can see in their result as the percentage of ceramic dust increases, the California bearing ratio of the mix increases, the free swell starts decreasing, and the optimum moisture content of the soil sample decreases compared to the origin untreated soil sample.

Onakunle et al. (2019) stabilized lateritic soil with waste ceramic dust additive, and the samples were mixed with ceramic dust in 5% incremental rate from 0 to 30|%. he concluded that with the ceramic amount up to 30%, the liquid limit, plastic limit, plasticity index, and optimum moisture content decreased. On the other hand, maximum dry density and California bearing ratio for both soaked and unsoaked samples increased for the same ceramic amount. He recommended up to 30% ceramic dust from economy and strength standpoints can be utilized for soil stabilization. He also referred that a major part of the environment can be sustained over time, and waste tiles will benefit highways and road constructions with better California bearing ratio values.

In their work, Aamir et al. (2019) applied alum sludge (AS) to the soil with a water treatment plant waste product as a stabilizer to achieve higher soil strength. Considering the pozzolanic properties of alum, it was used as a binder to stabilize the soil with the addition amounts of 2, 4, 6, 8, and 10% of dry soil by weight. Tests conducted were particle size analysis, Atterberg limit, modified proctor compaction, and California bearing ratio (CBR). The California bearing ratio of the stabilized soil was substantially increased from 6.53 to 16.86% at the optimum level of an 8% addition of alum sludge. Also, the technique of artificial neural networks (ANNs) was used to evaluate the relations between physical properties of the soil and CBR values; it revealed that at 8% alum sludge, the maximum values were recorded for MDD, OMC, and PI. This research would aim to provide an environmentally sustainable soil stabilization mechanism and a waste management solution.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Introduction

The research was done to see how the effects of waste ceramic dust will act on clay soil properties using ceramic dust in two different sizes with three clay samples. Those three samples were locally collected in different sites having different properties. The investigation was done in three stages. The first stage is carried out on an untreated sample. The second stage is carried out by adding the finer size of ceramic to the samples. The last step is carried out by using the coarser size of ceramic dust in the samples. Comparing the results can provide a clear vision of the effect of ceramic dust on clay soil property.

3.2 Materials

3.2.1 Soil samples location

The clay soil samples used in the experiment were three disturbed samples that have been collected in Erbil-north Iraq after removing 50 cm of the soil surface. For each sample about 100 Kg weight was put into plastic bags, the first sample named S1 is taken from BSV1 near Kawrgosk about 30 min away from Erbil city center, the second sample S2 is from Sarta5 near Darashakran, and finally, the third sample S3 is taken from Sarta6 near Darashakran**.**

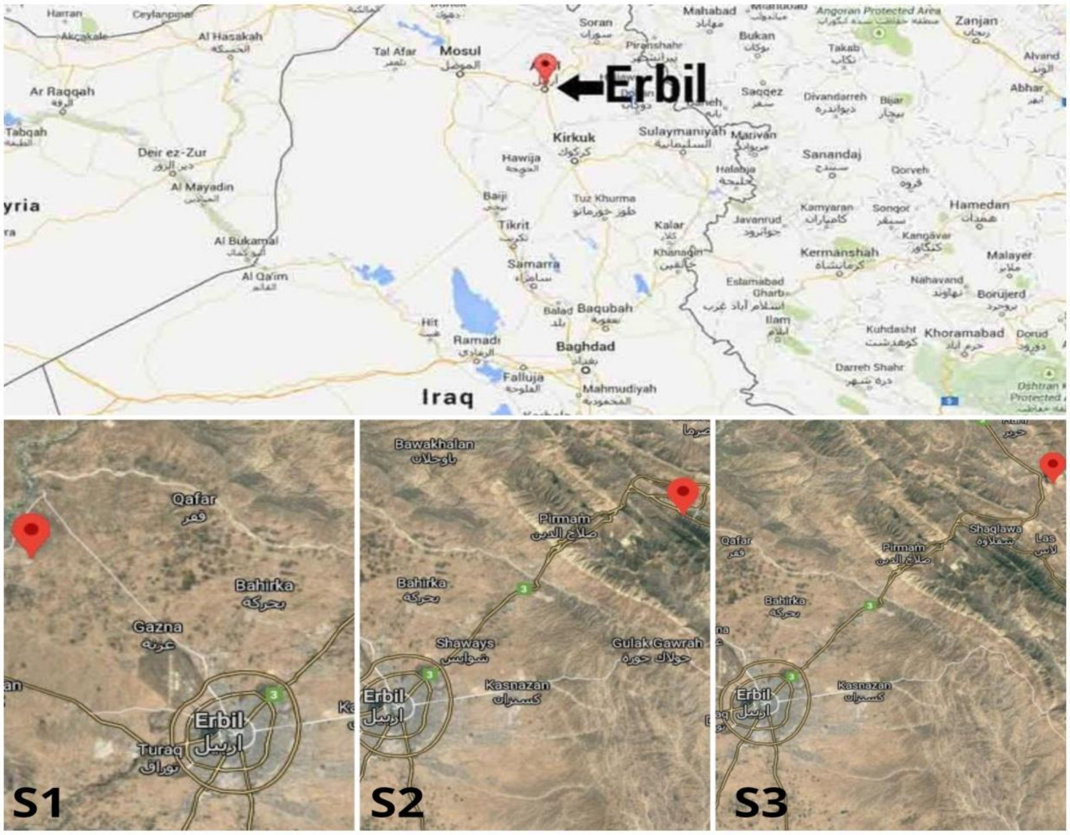


Figure 3.1: Location of the study area within the districts of Erbil-Iraq
(S1 36°20'53''N 43°48'54''E , S2 36°23'48''N 44°19'44''E , S3 36°24'21''N 44°20'07''E)

3.2.2 Ceramic waste

The ceramic waste was collected from the wastes of a company in Erbil-Iraq about 25-26 Kg from broken waste tiles were put into a plastic bag, after collecting and cleaning them by brush to avoid other contaminating minerals they have been crushed by hammer into small pieces, then it has been put in a Los-Angeles abrasion test machine to make it further smaller. After that, the waste has been taken out from the device and sieved through sieve No.40 and sieve No.10.

3.3 Methodology

After collecting the samples, the three clay soils were oven-dried for two days at about 60°C temperature to avoid any alteration or change in the soil composition that could affect its sample properties. Some of them were crushed into smaller pieces to be ready for the mix. To analyze the effects of ceramic dust on clay soil engineering properties, test methods were carried out according to the American Society for Testing and Materials (ASTM) and Indian Standard (IS), as shown in Table 3.1.

Table 3.1: Used experiment and their codes

Experiment Name	Experiment Code
Specific gravity	IS:2720:P3
Hydrometer and grain size distribution	ASTM D422
Atterberg limits	ASTM D4318
Standard proctor compaction test	ASTM D698
Unconfined compressive strength	ASTM D2166
California bearing ratio	ASTM D1883

3.3.1 Specific gravity IS: 2720: Part 3

The experiment method is associated with calculating the specific gravity of soils used to assess the saturation and unit weight of moist soils. Unit weights are required for pressure, settlement, and stability problems in soil mechanics. For both the clay soils and ceramic dust, the specific gravity test had been done according to (Indian standard methods of test for soils, 2002).

Using two density bottles of 50 ml capacity, a water-bath held at a constant temperature of 27°C, A vacuum desiccator with 200-250 mm diameter. A Drying oven capable of holding a temperature of 105 to 110°C, Balance, a vacuum outlet such as a useful filter pump or a vacuum pump. A spatula has a blade 150 mm long and 3 mm wide; the blade shall be thin enough to slip through the density bottle's neck.

Then the procedure starts after drying the density bottles and cooling them in desiccators, and weighed. Using about 50gm oven-dried sample at 60-70°C to avoid reaction of the containing materials in clay soil passing sieve no.10 (2mm), after taking the empty weight of the density bottle, weight of density bottle and dried soil, weight of density bottle and fully saturated soil and finally the weight of density bottle and water calculation can then be done. The sample shall be moved to the density container directly from the desiccators in which it has been cooled. Enough air-free purified water shall be applied such that the soil in the bottle is only covered. The container containing the soil and the water, but without the stopper, must be put in the vacuum desiccators. Precautions are needed during this process to ensure that the air contained in the soil does not bubble to avoid the loss of tiny drops in suspension through the container's mouth. The vacuum shall be removed, and the lid of the desiccators shall be separated. The substance in the bottle is gently stirred with the spatula, or the bottle is vibrated. Until withdrawing the spatula from the bottle, the soil particles stuck to the blade must be wiped away with a few drops of air-free liquid. Therefore the lid of the desiccators is removed, and the desiccator is emptied again. The process shall be repeated until no further air develops from the soil.

When there is a significant drop in the solvent's volume, the stopper shall be withdrawn, and the bottle and the stopper shall be replaced with additional liquid. The stoppered bottle is then removed from the water, cleaned dry, and measured. The method is replicated. If the bottle still isn't full, the bottle shall be withdrawn from the water, cleaned dry, and measured. Two determinations of the specific gravity of the same soil sample shall be made according to equation 3.1.

$$\mathrm{Gs}=\frac{(m2-m1)}{(m4-m1)-(m3-m2)} \tag{3.1}$$

Where

G_s is the specific gravity of soil.

m_1 is the mass of the density bottle.

m_2 is the mass of density bottle and dry soil.

m_3 is the mass of density bottle, dry soil, and water.

m_4 is the mass density bottle and water.

After the calculations have been done, we can see the specific gravity values of the sample and ceramic dust in Table 3.2.

Table 3.2: Specific gravity of soil sample and ceramic dust

Sample Name	Specific gravity
S1	2.68
S2	2.68
S3	2.69
Ceramic dust	2.63

3.3.2 Hydrometer analysis test ASTM D422

The test is conducted to assess the proportion of different grain sizes in the soil sample. The hydrometer system is being used to determine the distribution of finer soil particles. Hydrometer test affects the soil engineering characteristics and is needed for soil classification. The equipment used for the test is a sedimentation tube, 151H hydrometer, mixer, thermometer controlling cylinder, beaker, and stopwatch (American society for testing and materials, 2007)**.**

About 200-250 g dried soil was prepared for three samples and left in water for 24 hr at 100°C, then sieve no.200 have been used to pass them through and wash the sample with running water then putting the remaining particles in a cub and leave it for 24 hr at 60-70°C. For finding the dry weight, the oven-dried sample had been recorded. Then about 50gm of sample is brought, which passes sieve no.200, considered fine soil. The dispersing agent sodium hexametaphosphate then prepared about (40 gm/Liter) solution, both sample and the dispersing agent started to mix about 5 minutes until it becomes slurry and leave it for 24 hr, the soil is mixed then with distilled water and put in a 1000 ml cylinder to take the readings at specific times close the open end of the cylinder with a blocker and protect it with the palms of your hand and start shaking the control cylinder in just such a manner that the contents are completely mixed for one minute. The cylinder was inverted nearly 30 times during the minute.

Place the hydrometer and thermometer in the control cylinder and note the zero adjustments and temperature, respectively. Place the cylinders down and report the time. Free the cylinder from the stopper. After one minute, place the hydrometer slowly and deliberately for the first reading. Reading is achieved by reviewing the surface of the meniscus produced by the extension and the hydrometer stem. The hydrometer is progressively extracted and returned to the control cylinder. Turn it very carefully in the control cylinder to eliminate any contaminants that could have adhered to it. Start taking hydrometer readings after 2 and 5, 8, 15, 30, 60 minutes, and 24 hours.

(a) Oven-dried clay samples (b) Filled hydrometer cylinder

Figure 3.2: Hydrometer test for obtained soil samples S1, S2 and S3

For the data analysis, calculate the equivalent particle diameter by using equation 3.2,

$$D = K\sqrt{\frac{L}{T}} \tag{3.2}$$

Where

D is equivalent particle diameter in mm.

T is time recording during readings in minutes.

Note; the effective length (L) and constant (K) values were taken according to Table 2, And Table 3 from ASTM standard test code D422.

Percent of finer can be calculated according to equation 3.3 below;

$$P = R_c \times \frac{a}{W_s} \tag{3.3}$$

Where

P is the percentage of soil in suspension.

R_c is corrected hydrometer reading (R_c=R_{actual} –zero correction+CT).

W_s is the weight of the soil sample in grams.

Note; Temperature Correction Factors CT and a value correction Factors 'a' for unit weight of solids are from Table 3.3 and Table 3.4, respectively.

Table 3.3: Temperature correction factors CT

Temperature C	factor CT
20	0.00
21	+0.20
22	+0.40
23	+0.70
24	+1.00
25	+1.30
26	+1.65
27	+2.00
28	+2.50
29	+3.05
30	+3.80

Table 3.4: Correction factors for unit weight of soil solids

Unit weight of soil solids (g/cm^3)	Correction factor a
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.04

Finally, the adjusted percent of fines are calculated by Equation 3.4.

$$Pa=P \times \frac{F200}{100} \tag{3.4}$$

Where

F200 = % finer of #200 sieve as a percent

Table 3.5: percentages of passing for obtained samples

Sieve	Percent Passing		
	S1	**S2**	**S3**
0.075	93	86	89
0.04	86	83	85
0.03	76	79	80
0.02	70	71	73
0.01	64	63	65
0.007	57	54	55
0.004	52	50	51
0.002	46	43	45
0.001	42	38	40

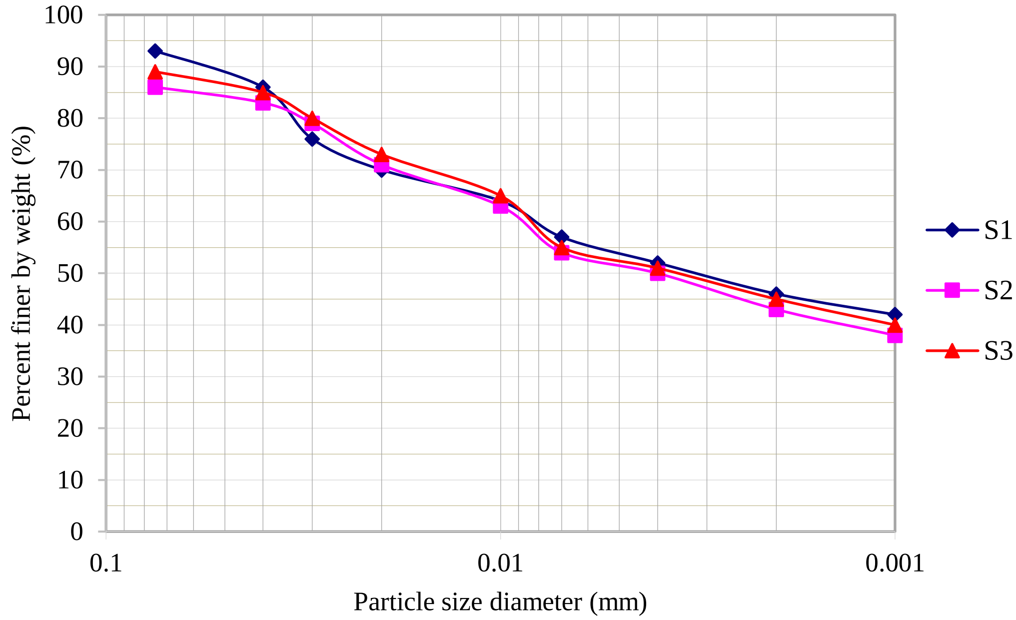


Fig 3.3: Particle size distribution curve for the obtained clay samples

In figure 3.3, we can see that the three soil samples, in general, contain around 46, 43, and 45% clay, and the rest is silt.

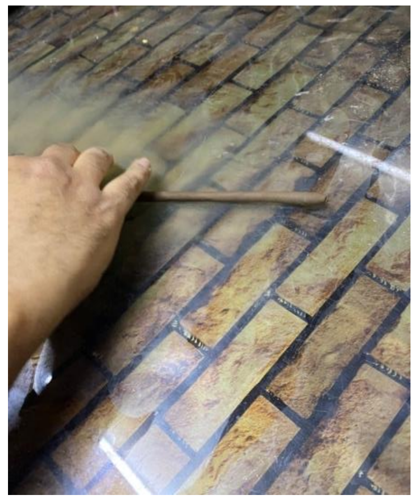
3.3.3 Atterberg limits ASTM D4318

The test is performed to determine the liquid limit, plastic limit, plasticity index, and gradation distribution of a fine-grained soil. Cohesive materials get stickier until it acts like a liquid at this point it is known as a liquid limit, the water content that changes a soil texture from dry granular material to moldable plastic material is known as the plastic limit, the range between the plastic limit and the liquid limit is defined as the plasticity index. The Atterberg limits are based on the soil's moisture content (American society for testing and materials, 2010).

For this Casagrande device, a flat grooving tool with gage, moisture cans, balance, spatula, wash bottle filled with distilled water, drying oven. To do the test, three samples of clay, each about 500 g dried soil samples at 60-70°C for 24 hours passing sieve no.40, have been used for the untreated clays and clays contaminating ceramic dust. It was done for clay samples at the first stage without containing ceramic dust and then samples containing 5% ceramic dust, 10% ceramic dust passing sieve no.40. By adding water with each trial, the sample was mixed, then put sample to Casagrande and press the soil to remove air pockets and stretch it to a depth of around 10 mm at its lowest point. The soil paste shape was nearly at a horizontal surface. The grooving tool was precisely used to carve a smooth straight groove down the middle of the cup. Begin apparatus turns at a rate of approximately two drops per second and counts the number of drops (N) for the liquid limit. For each sample cans were prepared and weighted, a small sample was cut and put inside the cans by spatula from edge to edge and weight it, but the can and soil sample into the oven for 100-110°C for 24 hr for calculation of water content.

While for each sample, about 20-30 g was extracted for the plastic limit test. The plastic limit (PL) is the water content, in percent, at which the soil can no longer be deformed by rounding into 3.2 mm. threads of diameter until crumbling. Once the soil is mixed with water until the soil has stability, it can be rolled without sticking to the palms. The mass was rolled in between palm and fingertips and the glass tray. Hand pressure was used to roll the mass onto a uniform thread. The gathered pieces of the crumbled thread together and put the soil in a moisture tub. The average water content used to calculate the plastic limit, PL. the check should be done to see if the variation in water content is larger than the appropriate range between two samples, 2.6%. Then Calculation was done for the plasticity index (PI=LL-PL).

(a) Liquid limit test



(b) Plastic limit test

Figure 3.4: Atterberg limit test procedures

For finding the expansion index for the obtained samples, it can be calculated according to equation 3.5 (Abbas and Rashid, 2017**)**.

$$EI=1.8 \times PI \tag{3.5}$$

In Table 3.6, the expansion potential has been classified from very low to very high values depending on the plasticity index according to ASTM D4829 (American society for testing and materials, 2011). The expansion result for the soil samples are shown in Table 3.7

Table 3.6: Expansion potential depending on the plasticity index

Expansion Index (EI)	Expansion potential
0-20	Very low
21-50	Low
51-90	Medium
91-130	High
$> \mathbf{130}$	Very High

Table 3.7: The expansion potential for the soil samples depending on their plasticity index and expansion index

Samples with Ceramic dust %	Plasticity Index (PI)	Expansion Index(EI)	Expansion Potential
S1-0%	20.62	37.12	Low
S2-0%	21.10	37.98	Low
S3-0%	21.35	38.43	Low
S1-5%	21.27	38.29	Low
S2-5%	21.56	38.81	Low
S3-5%	21.53	38.75	Low
S1-10%	19.51	35.12	Low
S2-10%	21.39	38.50	Low
S3-10%	21.24	38.23	Low

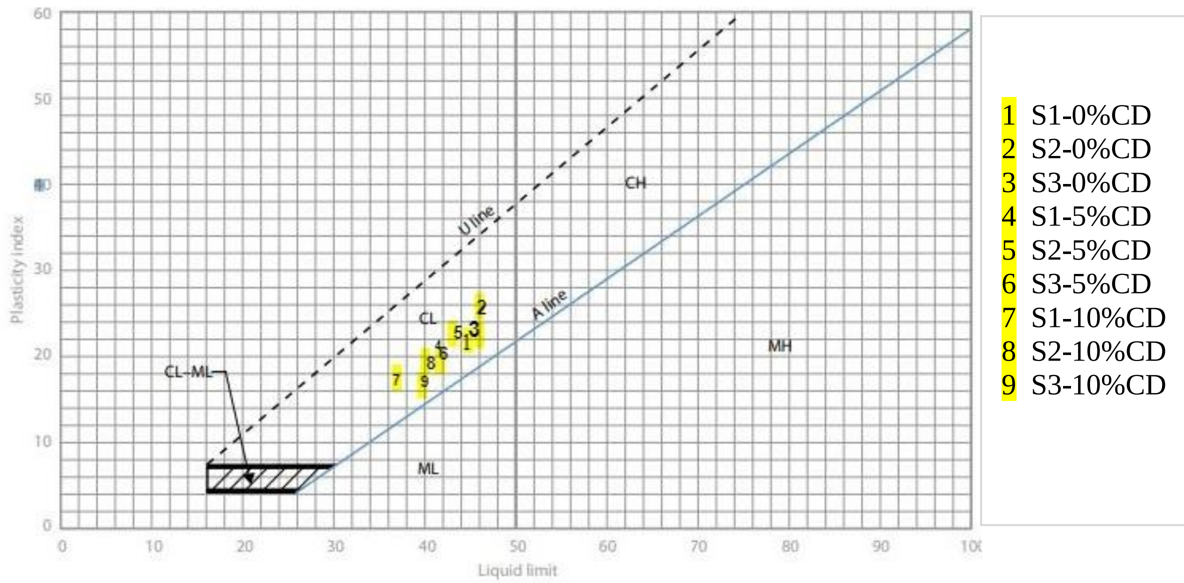


Figure 3.5: Plasticity chart for obtained clay samples

In Figure 3.5, the soil sample classification can be seen according to USCS classification depending on their liquid limit and plasticity index, according to that the three soil samples are classified under the CL group category**.**

3.3.4 Standard proctor compaction test ASTM D698

Compaction is widely used to allow engineering soil to sustain mechanical and subsequence loading without collapse. Through mechanical methods, spaces between soil particles can be reduced in treated soils.

This experimental test is conducted to determine the interaction between the moisture content and the soil's dry density for a given compacting effort. Most engineering properties, such as strength, stiffness, shrinkage resistance, and soil impermeability, can increase soil density. In the typical proctor test, the soil is compacted by a 5.5 lb hammer dropping one foot away into a soil-filled mold. The mold used in the test has a height of 115 mm, a width of 100 mm. It is then loaded with three equivalent layers of dirt, and each layer is exposed to 25 drops of the hammer (American society for testing and materials, 2012).

In this research, for each oven-dried sample, they were put at 60-70°C for two days. About 5000g soil passing sieve No.4 is taken and been mixed with every two different sizes of ceramic dust with various amount of water adding to the mix starting with 500 ml mostly that accounts for 10% water content, totally (15) samples were prepared for compaction test. We let them for a while, and then compact the mold in 3 layers, every 25 blows in a dynamic free falling hammer from 12 in the distance, the weight of the mold filled with the compacted soil was recorded. A sample was taken to calculate optimum water, which is the water content that results in the greatest density for a specified compaction effort, and put it in the oven for 24 hr at 100-110°C. For each sample, four trials were done and been calculated for optimum values. The soil should fill the cylinder, and the last compacted layer must extend slightly above the collar joint. The soil sample was removed from the mold using a mechanical extruder

After calculating moisture content and wet density, maximum dry density can be calculated for the mix. Using four trails of different amounts of water for each sample, MDD and OMC can be found in the graph using the following equations 3.6, 3.7, and 3.8.

$$\text{Moisture content} = \frac{W_{water}}{W_{Dry\ sample}} \times 100 \tag{3.6}$$

$$\rho_{Wet} = \frac{W_{wet\,sample}}{V_{mold}} \tag{3.7}$$

$$\rho_{Dry} = \frac{\rho_{Wet}}{(1+\frac{water\ content}{100})} \tag{3.8}$$

Where

ρ_{Wet} is wet density in g/cm^3.

ρ_{Dry} is the dry density of the soil.

3.3.5 Unconfined compressive strength ASTM D2166

This test method involves assessing the unconfined compressive strength of the cohesion soil in an unchanged, remodeled, or reconstituted state using a strain-controlled application of the axial load. The method gives an estimated value for the strength of coherent soils in terms of overall stress. This helps geotechnical engineer for long-term efficiency and treated soil behavior (American society for testing and materials, 2012).

For the test about 5000g dried clay sample at 60-70°C for two days, Specimens having a minimum diameter of 30 mm and cohesive characteristics that pass sieve no.4 is taken and get well mixed with their optimum water content then put in compaction mold and compact it by three layers each 25 blow by a dynamic compactor falling hammer, the total samples for unconfined test prepared were (15) samples with and without ceramic dust. After compaction, the sample was cut out from the extruder having the dimension of (height 7.66 cm, diameter 3.80 cm) and put the samples inside the loading unit so that it is focused on the rim. Then properly change the loading mechanism so that the upper plate is in contact with the specimen. The initial reading of the electronic deformation unit was reported into the sheets. The machine used for this test had providing ring number 5540/2.5 KN and factor of 2.74, rate of strain is 1.25mm as shown in Figure 3.6, start the machine and apply the load to produce stress from top and strain at a rate of 1⁄2 to 2%/min in the below record the frailer, when the stress decreases or get repeated three times, Record load, deformation, and time values at appropriate intervals to determine the shape of the stress-strain curve (usually 10 to 15 points are sufficient). after the loading completed a representative sample was trimmed for water content calculation, and it has been put in the oven at 100-110°C for 24 hr, and then ultimate load for each mix has been calculated, for finding strain e equation 3.9 was used,

$$\varepsilon = \Delta L / L_i \tag{3.9}$$

Where:

ε is the axial strain

ΔL is length change of specimen as read from deformation indicator or computed from the electronic device, mm.

L_i is the initial length of the test specimen, mm.

The average cross-sectional area calculated, Ac, for a given sample according to the applied load of Equation 3.10, as follows

$$A_C = \frac{A_i}{1-\frac{\varepsilon}{100}} \quad (3.10)$$

Where

A_C is corrected area cm^2.

A_i is the initial average cross-sectional area of the specimen, cm^2.

ε is an axial strain for the given load, expressed as a percent.

The compressive stress σc, to three significant figures or nearest one kPa [0.01 ton/ft^2], for a given applied load were found according to equation 3.11.

$$\sigma = \frac{P}{A} \text{ kPa} \quad (3.11)$$

Where

P is given applied load, kN

A is the corresponding average cross-sectional area, mm^2

(a) Unconfined compressive machine

(b) Failed samples of S1, S2 and S3

Figure 3.6: Unconfined compressive strength test

3.3.6 Unsoaked California bearing ratio ASTM D1883

This test procedure involves measuring the CBR (California Bearing Ratio) for subgrade pavement, subbase, and base components of laboratory compacted samples. The test method is primarily intended, though not limited to evaluating the strength of coherent materials having a maximum particle size of less than 3⁄4 in (19 mm) in length (American society for testing and materials, 2016).

It is a characteristic strength function of soil to assess the mechanical strength of the soil by penetration. When an axial load is placed on treated and untreated soil samples, their axial strains are tracked. It can be done in two situations, soaked and unsoaked bearing ratios by penetration of 2.5mm and 5.00 mm (Zorluer and Gucek, 2020).

To find the soaked CBR value, the samples must be soaked in water for at least four days before the test, which needs more time that will affect causing a rise in construction cost and pause it than the method of unsoaked CBR, this delay in calculating the soaked CBR can be eliminated by doing the unsoaked test and then convert it into soaked ones for this, many researchers have suggested a different empirical relationship to correlate CBR with various soil variables (Lakshmi et al., 2016).

In this research total (15) unsoaked samples were prepared for each sample 3 molds about 5000g each at their optimums were mixed and compacted in 5 layers. The specimens were compacted through three different compacting attempts to obtain unit weights above and below the desired unit weight. We wanted the CBR value for soil at95 % of the maximum dry unit so that the specimens were prepared and compacted using the first mold compacted each layer with ten blows, the second mold five layers each 25 blows, and the third mold with five layers each 56 blows. Then the samples were put inside the CBR machine to be penetrated by a cylindrical rod. Before beginning the penetration, we position the penetration piston with the smallest possible load, but not more than 10 lb in any situation (44 N). Set the pressure and penetration gages to 0. This initial load is needed to ensure a suitable placement of the piston and is assumed to be zero when deciding the load penetration relationship. Anchor the strain gauge to the load measurement unit, if possible; in no case, tie it to the support bars of the testing system. A surcharge of weights was imposed on the specimen necessary to achieve a loading rate equal to the base material's weight. There is no particular weight of the pavement, so we used 4.54 kg of weight. And start penetration, the first stage in top of the sample after record the reading and penetration in 10cm, the test has been stopped. The sample was removed and put in the machine again in a different direction and start to load in the bottom directions until it penetrates 10cm, then stopped the readings and removed the mold. We were taking a representative sample for water content and dry density calculations. The plunger of the CBR system had an area of 19.35 Kg/cm^2. We calculated the CBR values at 2.5 and 5 mm penetration such that the highest value of four CBR values is selected for any prepared mold. The effects of stress (load) versus depth of penetration are plotted to evaluate the CBR for each specimen. The CBR at the defined density is calculated by the CBR graph versus the device's dry weight. The volume of the mold was (2357.76cm^3). The calculation for γdry and UCBR were done according to the following equations (3.12), equation (3.13), and equation (3.14)

$$\text{Water content}=\frac{Water\ weight}{W\ dry\ soil} \qquad (3.12)$$

$$\gamma_{dry}=\frac{\frac{Msoil}{Volume}}{1+\frac{water\ content}{100}} \qquad (3.13)$$

$$CBR\%_{\text{2.5 and 5mm}} = \frac{dial\ gauge\ readings}{Plunger\ Area} \times \frac{100}{Standard\ pressures} \quad (3.14)$$

Where

γ_{dry} is dry mass of soil as compact.

V is the volume of the mold.

(a) Compaction machine

(b) CBR Loading machine

(c) Sample S1 after 10cm penetration

Figure 3.7: California bearing ratio test process

CHAPTER 4
RESULTS AND DISCUSSION

Many different additives and methods have been applied to improve clay properties. In this study, ceramic dust has been used in two different particle sizes by 0, 5, and 10% for three types of soils. Results of the tests used on obtained soils will be shown and discussed in this chapter.

4.1 Specific Gravity

For the specific gravity test, the IS method was applied for untreated clay samples and ceramic dust. Many researchers have identified the fundamental gravity of ceramic waste to range between 2.27 to 2.82 (Panwar, 2017). In this study, the specific gravity of ceramic dust was found to be 2.63. Depending on the percentage of ceramic and untreated clay with their calculated specific gravity, each mix's specific gravity was found according to the empirical equation (4.1) (Iravanian, 2008). Results for the specific gravity of all the mix are shown in Table 4.1.

$$Gs_{mix} = \frac{100}{\frac{Soil\%}{Gs_{soil}} + \frac{Ceramic\ Dust\%}{Gs_{ceramic\ dust}}} \tag{4.1}$$

Where

Gs_{mix} is the specific gravity of the mix.

Gs_{soil} is the specific gravity of the soil.

$Gs_{ceramic\ dust}$ is the specific gravity of ceramic dust.

$Soil\%$ is the percentage of soil in the total weight of the mixture.

$Ceramic\ Dust\%$ is the percentage of ceramic dust in the total weight of the mixture.

Table 4.1: Specific gravity result for clay soil with different proportion of ceramic dust

Sample	CD%	Gs ceramic dust	Gs mix
S1		2.63	2.68
S2	0%	2.63	2.68
S3		2.63	2.69
S1		2.63	2.677
S2	5%	2.63	2.677
S3		2.63	2.687
S1		2.63	2.675
S2	10%	2.63	2.675
S3		2.63	2.684

By observing Table 4.1, it can be seen that for the S1 sample, after adding 5% of ceramic dust, the specific gravity slightly decreased from 2.68 to 2.677, while by adding 10% ceramic change the value became 2.675. For the S2 sample, specific gravity was found to be the same as for S1 calculated. For S3, the specific gravity is 2.69, and by adding 5% of ceramic dust, it was decreased to 2.687, while in 10% ceramic dust mix, the value became 2.684. The specific gravity test result showed that adding ceramic dust to the calculated specific gravity of the obtained soils was slightly reduced. This could be due to the high specific gravity of clay soils.

4.2 Atterberg limits

For the Atterberg limit test, the ASTM D4318 method was applied for the obtained soil with the different amounts of ceramic dust; results are shown for all untreated samples and stabilized samples with ceramic dust in Table 4.2.

Table 4.2: Results for Atterberg limits with different amounts of ceramic dust

Sample	CD%	Soil class	Atterberg limits		
			LL	**PL**	**PI**
S1		CL	43.8	23.1	20.6
S2	0%	CL	46.5	25.4	21.1
S3		CL	45.6	24.2	21.4
S1		CL	42.0	20.7	21.3
S2	5%	CL	44.0	22.4	21.6
S3		CL	42.4	20.9	21.5
S1		CL	37.9	18.4	19.5
S2	10%	CL	41.8	20.4	21.4
S3		CL	40.4	19.2	21.2

From Table 4.2, it can be seen that for an untreated sample of clays they have a higher liquid limit and plastic limit values. At the same time, 5% of ceramic dust passing sieve No.40 was added to the mix, the liquid limit and plastic limit started to decrease, by additional adding of ceramic dust, the liquid limit and plastic limit values decreased more slightly, that means the lean clay with high plasticity have been changed to a lower plasticity clay without a change in soil classification category.

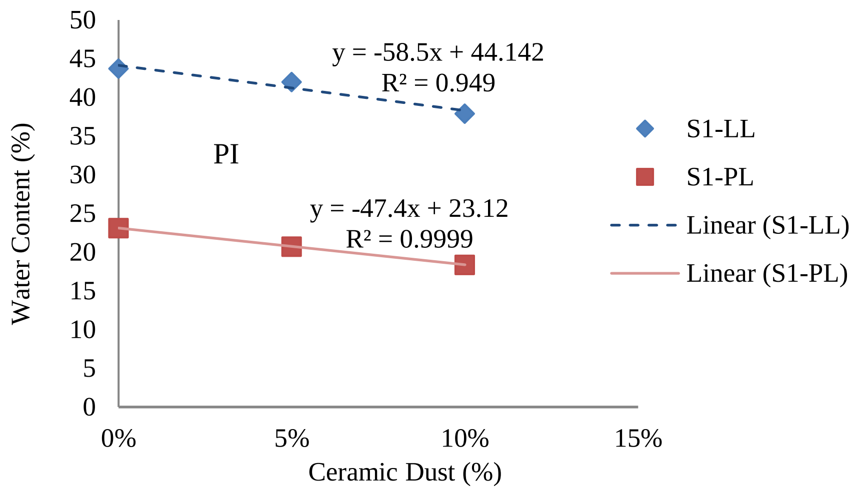


Figure 4.1: Liquid limit, plastic limit, and plasticity index for sample S1

According to the test results shown for sample S1 in Figure 4.1, we can see that with adding ceramic waste dust passing sieve no.40 from 0 to 5%, the liquid limit (LL) decreased slightly from 43.75 to 42%, Plastic limit (PL) decreased from 23.13 to 20.73% and plasticity index(PI) increased from 20.62 to 21.27%. By adding 10% ceramic dust, the LL, PL, and PI were decreased to 37.9, 18.39, and 19.51%, respectively. According to (Onakunle et al., 2019**)**, the plasticity index value significantly reduced from 19.51% for untreated soil to 12.3% when clay contained 30% ceramic dust. The value was a significant indicator that moved the clay soil from high plasticity to medium plasticity.

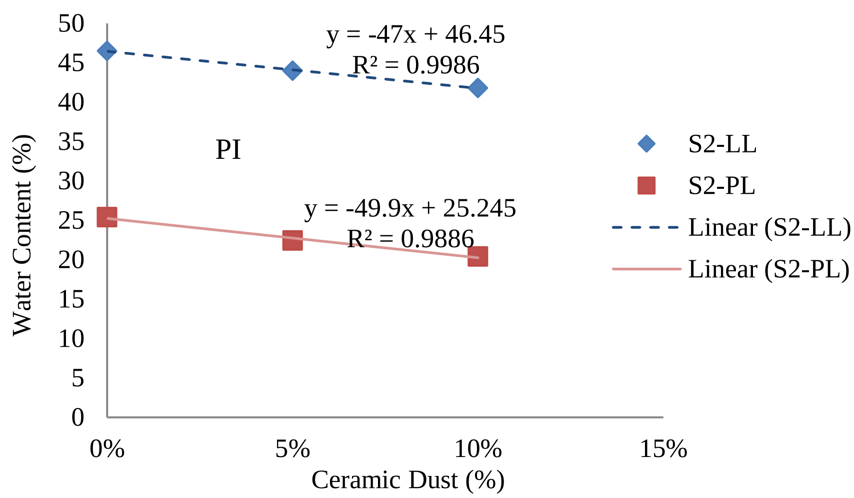


Figure 4.2: Liquid limit, plastic limit, and plasticity index for sample S2

For the second sample, S2, the results are shown in Figure 4.2. The LL value decreased from 46.5 to 44%, PL decreased from 25.4 to 22.44%, and PI slightly increased from 21.1 to 21.56% by adding 5% ceramic dust. While when 10% of ceramic specks of dust were added to the sample, the LL and PL decreased to 41.8 and 20.41%, respectively, and there was a slight increase in PI value to 21.39%.

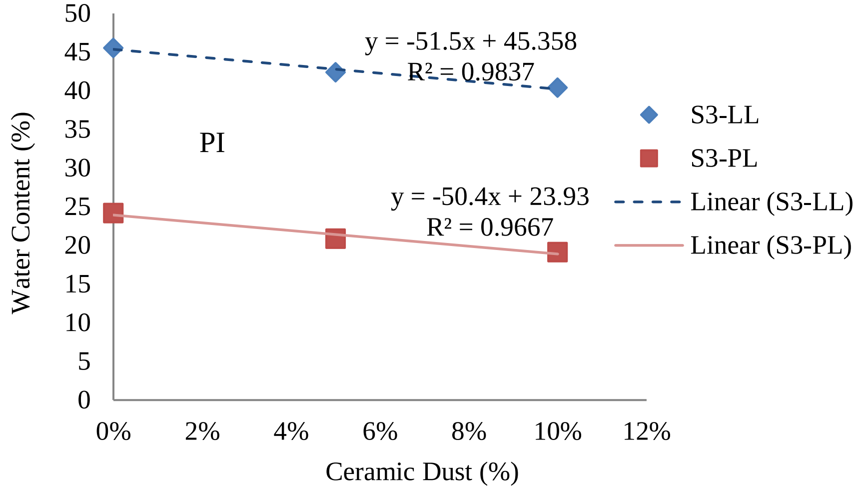


Figure 4.3: Liquid limit, plastic limit, and plasticity index for sample S3

For the third sample, S3, the LL, PL, and PL for untreated clay were recorded as 45.55, 24.2, and 21.35%, respectively, as shown in Figure 4.3. After adding 5% ceramic dust, LL and PL's values decreased to 42.4, 19.16%, respectively, and PI increased to 21.53%. On the other hand, in a sample containing 10% ceramic dust, the LL, PL, and PI decreased to 40.4, 19.16, and 21.24%, respectively. The reduction in Atterberg limits is mostly due to the replacement of soil grains by ceramic dust grains (Cabalar et al., 2017).

4.3 Standard Proctor compaction

For compaction, the standard proctor compaction method ASTM D698 was used for the obtained sample to find the values of optimum water content (OMC) and maximum dry density (MDD) of each sample prepared from the curve of dry density versus water content percentage. The test results are shown and compared according to the different ceramic amount and two different ceramic sizes in Table 4.3.

Table 4.3: Results of standard proctor compaction for obtained sample

Sample	CD%	Size of ceramic	Standard proctor compaction	
			MDD (g/cm^3)	OMC %
S1			1.832	16.15
S2	0	0	1.774	13.84
S3			1.920	14.16
S1			1.881	13.23
S2	5%	#40 (0.425mm)	1.815	12.22
S3			1.951	12.89
S1			1.919	11.13
S2	10%	#40 (0.425mm)	1.875	11.35
S3			1.992	10.63
S1			1.897	12.56
S2	5%	#10 (2mm)	1.891	11.87
S3			1.971	12.25
S1			1.952	10.52
S2	10%	#10 (2mm)	1.938	10.23
S3			2.025	9.96

Table 4.3 shows that untreated clay samples have less dry density than samples containing 5% ceramic dust while their water content is much higher than the samples containing 5% ceramic. On the other hand, samples contain 10% ceramic dust has a higher dry density than untreated and clay containing 5% ceramic dust. Also, the water content is less.

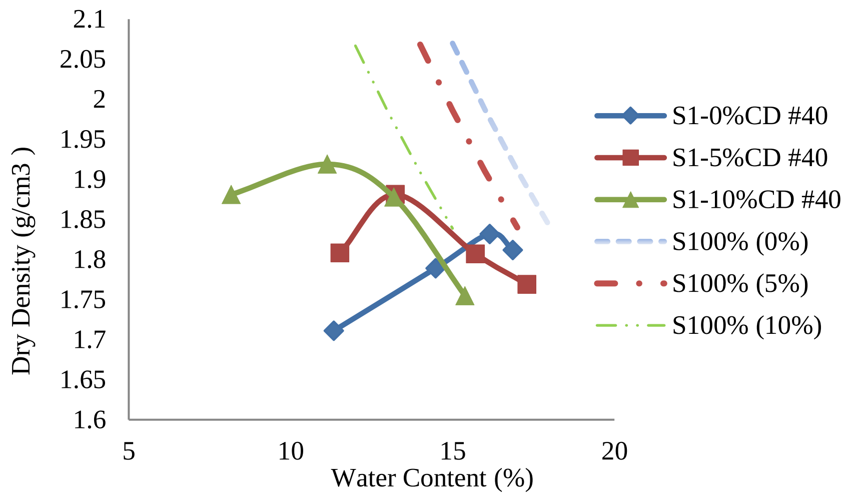


Figure 4.4: Standard compaction curve for S1 with different amount of ceramic dust in finer size of ceramic grains #40 (0.425mm)

For the finer ceramic size passing sieve no.40, results are shown in Figure 4.4 for S1, and it can be seen that for untreated clay sample S1 it has an MDD and OMC of 1.832(g/cm^3) and 16.15%, respectively. when 5% ceramic dust is added to the mix, the values of MDD have increased to 1.881(g/cm^3) due to the replacement of ceramic dust particles, OMC decreased to 13.23% due to the reduction in attraction for water molecules. on the other hand, 10% of ceramic dust increased the MDD to 1.897 (g/cm^3) and decreased OMC furthermore to 12.56%.

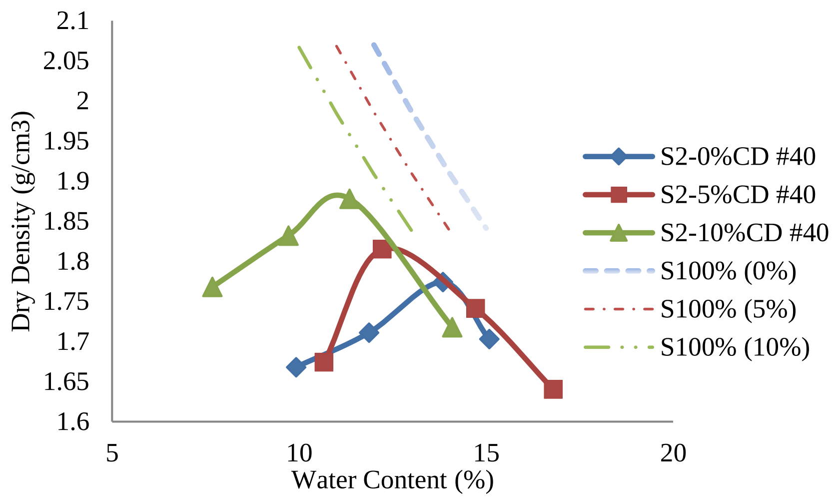


Figure 4.5: Standard compaction curve for S2 with different amount of ceramic dust in finer size of ceramic grains #40 (0.425mm)

For the same ceramic size sieve no.40, in Figure 4.5 for S2, it is shown that for untreated clay S2 having MDD and OMC of 1.774 (g/cm^3)and 13.84%, respectively. And when 5% of ceramic dust is added to the mix, the values of MDD have increased to 1.815 (g/cm^3) and OMC decreased to 12.22%. on the other hand, 10% of ceramic dust increased the MDD to 1.875 (g/cm^3) and again decreased OMC furthermore to 11.35%. The 100% saturation line can also be seen for each curve with 0, 5, and 10% ceramic dust, which is very close to each other.

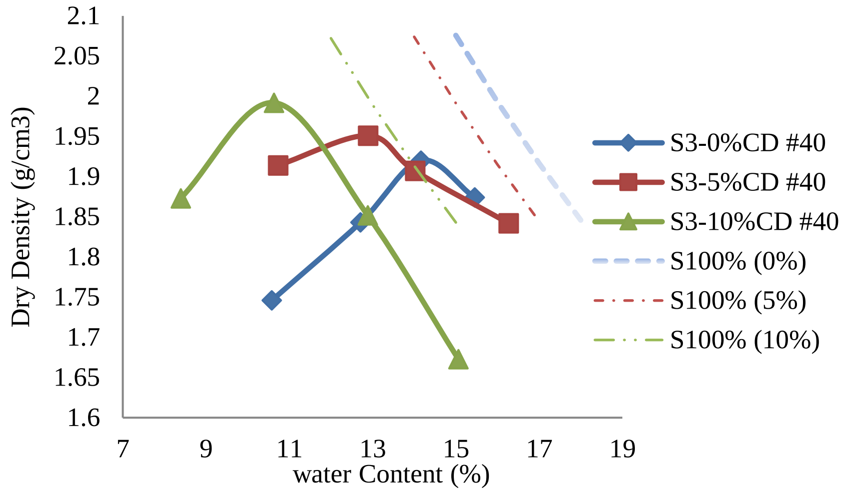


Figure 4.6: Standard compaction curve for S3 with different amounts of ceramic dust in finer size of ceramic grains #40 (0.425mm).

In Figure 4.6 for S3, it is shown that untreated clay S3 has MDD and OMC of 1.920 (g/cm^3)and 14.16 %, respectively. And when 5% of ceramic dust is added to the mix, the values of M.D.D have increased as it was for S1 and S2 to 1.951 (g/cm^3) and OMC decreased to 12.89%. on the other side, 10% ceramic dust increased the MDD to 1.992 (g/cm^3) and again decreased OMC furthermore to 10.63%.

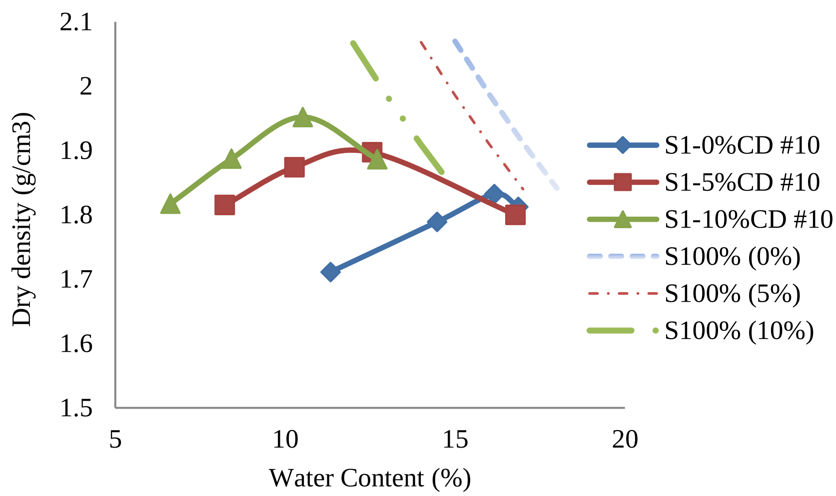


Figure 4.7: Standard compaction curve for S1 with different amount of ceramic dust in coarser size of ceramic grains #10 (2mm)

About the coarser ceramic size passing sieve no.10, in Figure 4.7 for S1, it can be seen that for untreated clay sample S1 it has an MDD and OMC of 1.832 (g/cm^3)and 16.15%, respectively, as mentioned in table 4.3. when 5% ceramic dust is added to the mix, the values of MDD has increased to 1.897 (g/cm^3) and OMC decreased to 12.56%, which is a better result. on the other hand, 10% ceramic dust increased the MDD to 1.952 (g/cm^3) and decreased OMC furthermore to 10.52%.

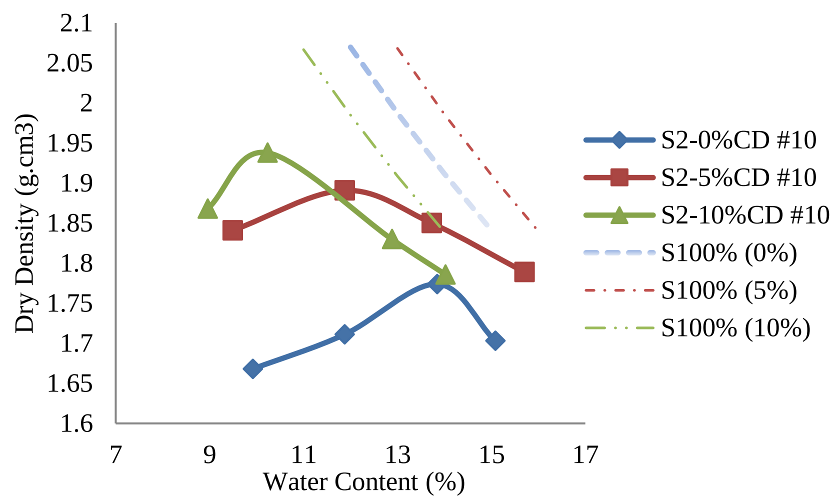


Figure 4.8: Standard compaction curve for S2 with different amount of ceramic dust in coarser size of ceramic grains #10 (2mm)

For the same coarser ceramic size passing sieve no.10, for S2 shown in Figure 4.8, it is shown that the untreated clay sample S2 has an MDD and OMC of 1.774 (g/cm^3)and 13.84%, respectively. when 5% ceramic dust is added to the mix, the values of MDD has increased to 1.891 (g/cm^3) and OMC decreased to 11.87%, which is a better result. on the other hand, 10% ceramic dust increased the MDD to 1.938 (g/cm^3) and decreased OMC furthermore to 10.23%.

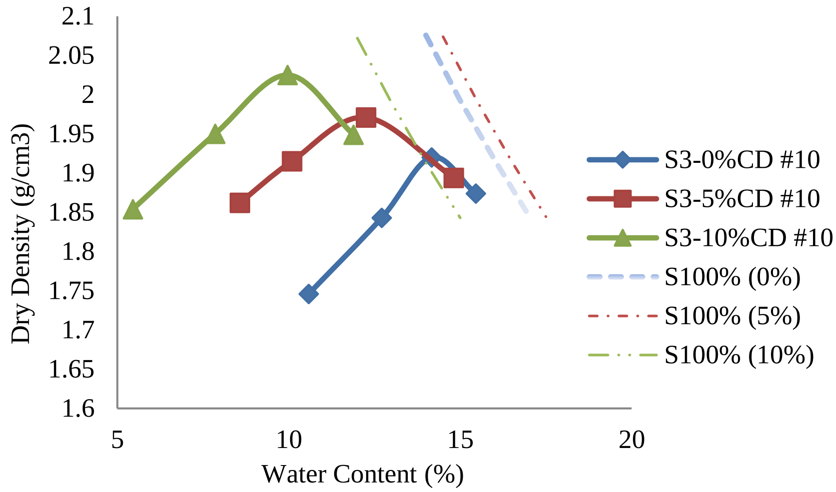


Figure 4.9: Standard compaction curve for S3 with different amount of ceramic dust in the coarser size of ceramic grains #10 (2mm)

Figure 4.9 shows the result for S3, and it is shown that untreated clay has an MDD and OMC of 1.920 (g/cm^3)and 14.16%, respectively. when 5% ceramic dust is added to the mix, the values of MDD has increased to 1.971 (g/cm^3) and OMC decreased to 12.25%, which is a better result. on the other hand, 10% ceramic dust increased the MDD to 2.025 (g/cm^3) and decreased OMC furthermore to 9.96%.

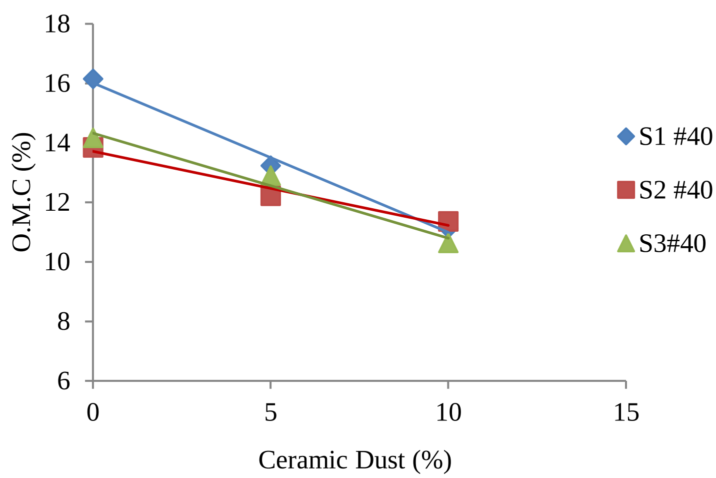


Figure 4.10: The optimum water content with different amount of ceramic dust in finer size of ceramic #40 for samples (S1, S2, and S3)

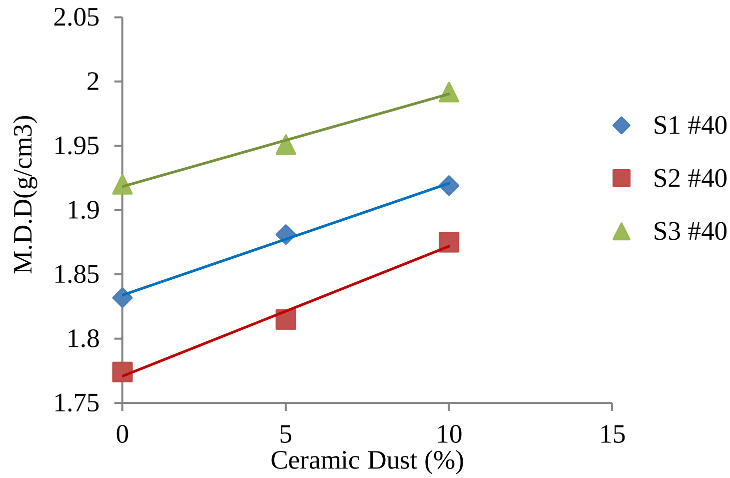


Figure 4.11: The optimum moisture content with different amount of ceramic dust in finer size of ceramic #40 for samples (S1, S2, and S3)

The OMC values versus ceramic dust amounts for obtained samples with the finer size of ceramic dust (#40) are shown in Figure 4.10, in S1 the untreated sample had an OMC of 16.15%, after adding 5% ceramic dust, the value decreased by 18% to become 13.23%.while for 10% ceramic dust the result decreased by 31%, and it became 11.13%. For S2, the O.M.C was calculated to be 13.84%, and by adding 5% ceramic dust, it also decreased by 11.71% and became 12.22%. On the other hand, it decreased furthermore by about 18% in 10% ceramic dust to become 11.35%. In the third curve for S3 sample OMC decreased from 14.16% to 12.89, so about 8.96% decreased. While after adding 10%, the value decreased by 24.93% and became 10.63. In the study of Onakunle et al. (2019), OMC decreased when ceramic dust was added until 30% due to the heavier weight of ceramic particles.

The MDD values versus ceramic dust amounts for obtained samples are shown in Figure 4.11, the initial MDD for S1 was 1.832 g/$cm^3$and after adding 5% ceramic dust, the value increased by 2.67% to become 1.881g/cm^3.While for 10% ceramic dust, the result increased by 4.75%, and it became 1.919. For S2, the OMC was calculated to be 1.774 g/cm^3 and by adding 5% ceramic dust, it also increased by 2.31% and became 1.815 g/cm^3. On the other hand, it increased furthermore by 5.69% in 10% ceramic dust to became 1.875 g/cm^3. At last, for S3, MDD increased from 1.92 to 1.951, so about 1.61% increased and after adding 10%, the value increased by 3.75% and became 1.992 g/cm^3.

So that by adding more ceramic dust from 0, 5 to 10%, the decreasing percentages for OMC while increasing percentages for MDD can be a good point to give better property to the clay soil by having lower water content and higher maximum dry density comparing to the untreated clay samples, these changes are caused due to the ceramic dust particles that they have been fired at high temperatures. Hence, they give better strength to the mixture.

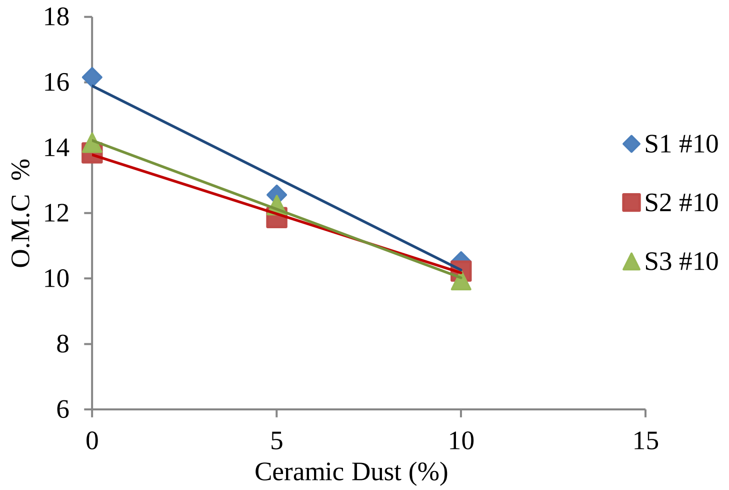


Figure 4.12: The optimum water content with different amount of ceramic dust in coarser size of ceramic #10 for sample (S1, S2, and S3)

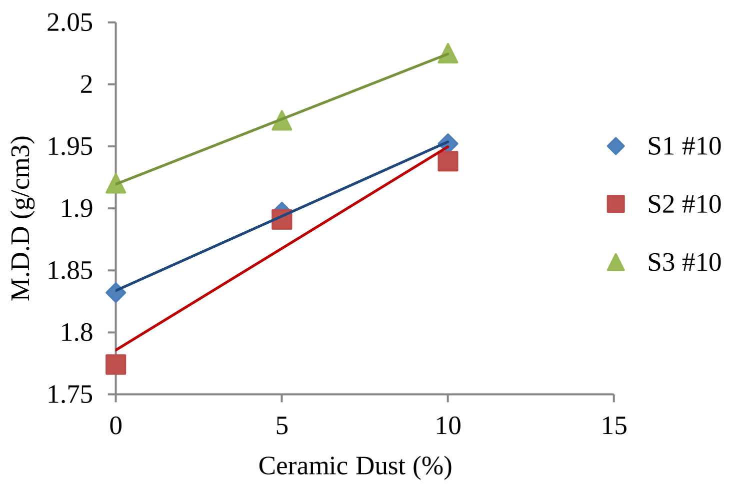


Figure 4.13: The optimum water content with different amount of ceramic dust in coarser size of ceramic #10 for sample (S1, S2, and S3)

For the coarser size of ceramic dust (#10), The OMC values versus ceramic dust amounts for obtained samples are shown in Figure 4.12. For S1, the untreated clay had an OMC of 16.15%, after adding 5% ceramic dust, the value decreased by 22.22% to become 12.56%.while for 10%, ceramic dust decreased by 34.86%, and it became 10.52%. The OMC for S2 was calculated to be 13.84%, and by adding 5% ceramic dust, it decreased by 14.23% and became 11.87%. On the other hand, it decreased furthermore by 26.08% in 10% ceramic dust to become 10.23%. The third curve about S3 O.M.C was decreased from 14.16% to 12.25, so about 13.49% decreased. While after adding 10%, the value decreased by 29.66% and became 9.96. For all the additions the reduction happened in a linear manner.

For the coarser size of ceramic dust (No. 10), the MDD values versus ceramic dust amounts for obtained samples are shown in Figure 4.13, the initial MDD for S1 was 1.832 g/cm^3, after adding 5% ceramic dust, the value increased by 3.55% to become 1.897 g/cm^3. On the other hand, for 10% ceramic dust, the result increased by 6.55%, and it became 1.952 g/cm^3. For S2, the OMC was calculated to be 1.774 g/cm^3 and by adding 5% ceramic dust, it also increased by 6.59% and became 1.891 g/cm^3. It increased furthermore by 9.24% in 10% ceramic dust to become 1.938 g/cm^3. At last, for S3, MDD increased from 1.92 g/cm^3 to 1.971 g/cm^3 so about 2.66% increased, after adding 10%, the value increased by 5.47% and became 2.025 g/cm^3.

Table 4.4: Linear constant for obtained soil samples

	Optimum moisture content			**Maximum dry density**		
Soil	**a**	**b**	$\boldsymbol{R^2}$	**a**	**B**	$\boldsymbol{R^2}$
S1 #40	-0.502	16.013	0.991	0.0087	1.8338	0.9947
S2 #40	-0.249	13.715	0.971	0.0101	1.7708	0.9883
S3 #40	-0.353	14.325	0.975	0.0072	1.9183	0.9936
S1 #10	-0.563	15.892	0.975	0.012	1.8337	0.9977
S2 #10	-0.361	13.785	0.997	0.0164	1.7857	0.9427
S3 #10	-0.42	14.223	0.997	0.0105	1.9195	0.9997

In table 4.4, it can be seen that in general, all proportion yield good and acceptable R^2values for OMC and MDD for S1, S2, and S3 with the finer size of ceramic dust the better fitting can be seen in MDD that yields better values comparing to the OMC values and R^2.in coarser size of ceramic dust in S1 and S3 for MDD has better values and fitting than OMC, while in S2 MDD showed slight reduction and better values could be seen in its OMC compared to its MDD. This variation can be due to the different sizes and mineralogy of the mix.

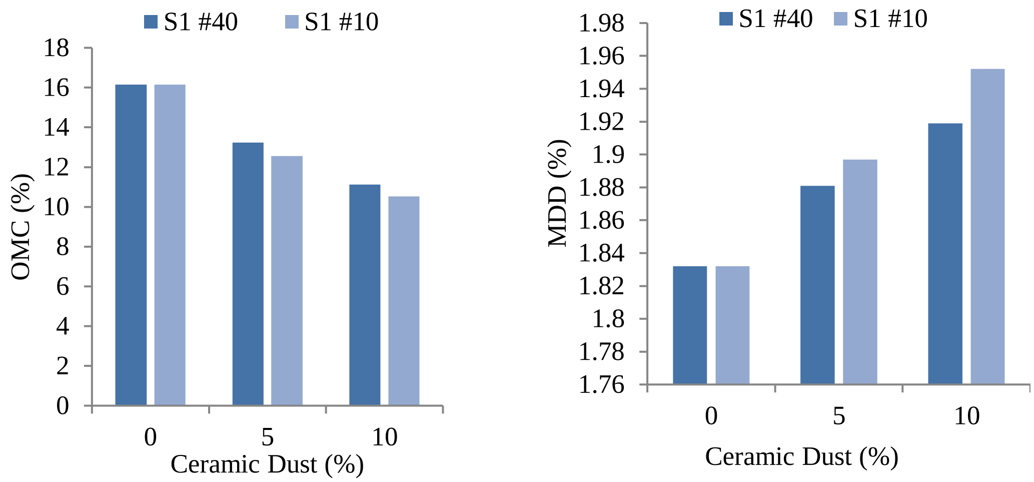


Figure 4.14: (a) The optimum water content versus the different amounts of ceramic dust in both sizes of ceramic for sample (S1) ;(b) Maximum dry density versus the amount of ceramic dust for both sizes of ceramic for sample (S1)

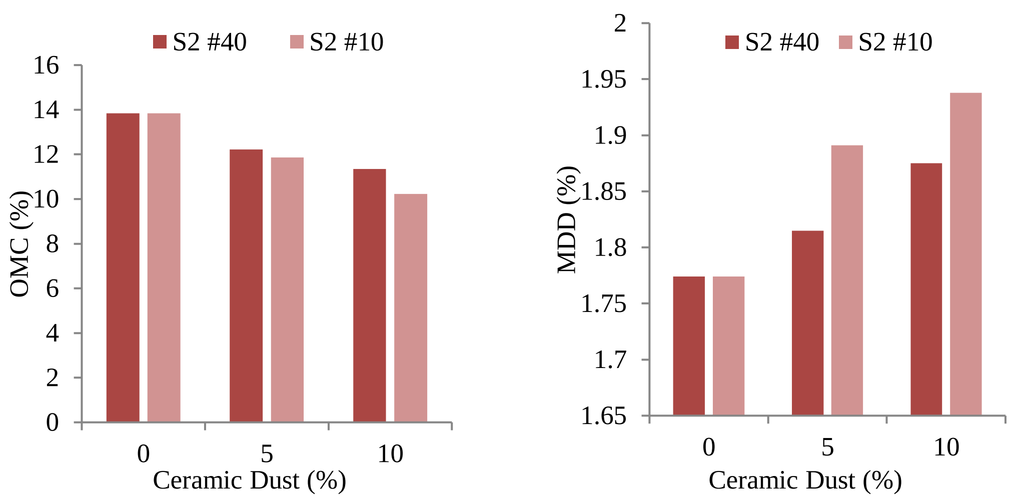


Figure 4.15:(a) The optimum water content versus the different amounts of ceramic dust in both sizes of ceramic for sample (S2);(b) Maximum dry density versus the amount of ceramic dust for both sizes of ceramic for sample(S2)

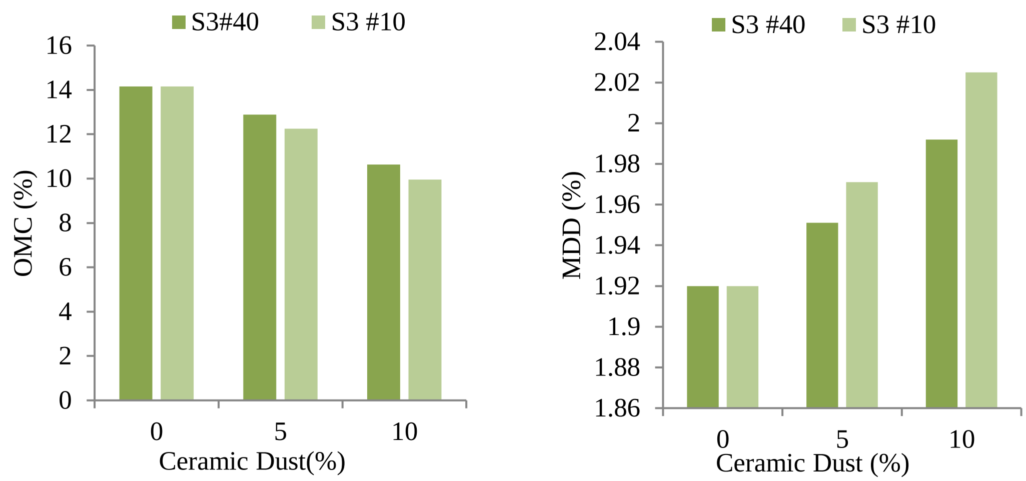


Figure 4.16:(a) the optimum water content versus the different amounts of ceramic dust in both sizes of ceramic for sample (S3);(b) maximum dry density versus the amount of ceramic dust for both sizes of ceramic for sample(S3)

Both ceramic sizes showed to give better optimums comparing to the untreated clay sample, while the coarser size of ceramic dust which is sieve no.10 showed less water content results and higher dry density values compared to the mixtures with the finer size of ceramic dust for samples S1, S2 and S3 as shown in the figure 4.14, 4.15 and 4.16, for sample S1, S2 and S3 respectively, this can be due to the gradation of the particles as they contain larger particles. With a smaller total surface area, water absorption can be lowered. On the other side, after compaction, it will give a higher dry density at lower water content than the finer size of ceramic dust.

4.4 Unconfined compressive strength

For unconfined compressive strength, the method of ASTM D2166 was applied to determine the approximate compressive strength for obtained clay samples, it was done on three types of clay soil, for untreated samples and mixed samples with ceramic dust in the proportion of 0, 5, and 10% according to two different sizes of ceramic waste dust, they were compacted with their optimum water content and dry density for comparing the results and calculate the compressive strength**.** It can be seen in Table 4.5 the results for unconfined compressive strength with and without ceramic dust for all the mixtures. It has been noticed from the results that with adding ceramic dust to the untreated clay, the strain value starts to increase to a higher value. By adding 10% more ceramic the stress increases higher than untreated and 5% ceramic dusts.

Table 4.5: Results of unconfined compressive strength for obtained samples

Sample	CD%	Size of ceramic	Unconfined compressive strength	
			Strain €	**Stress σ (kPa)**
S1	0	0	0.0975	237.781
S2			0.0997	267.662
S3			0.0821	241.840
S1	5%	#40 (0.425mm)	0.0902	262.798
S2			0.0764	292.470
S3			0.0731	271.099
S1	10%	#40 (0.425mm)	0.0899	290.371
S2			0.0810	312.084
S3			0.0871	291.287
S1	5%	#10 (2mm)	0.0886	290.788
S2			0.0811	317.637
S3			0.0858	297.229
S1	10%	#10 (2mm)	0.0907	311.001
S2			0.0764	332.660
S3			0.0734	304.621

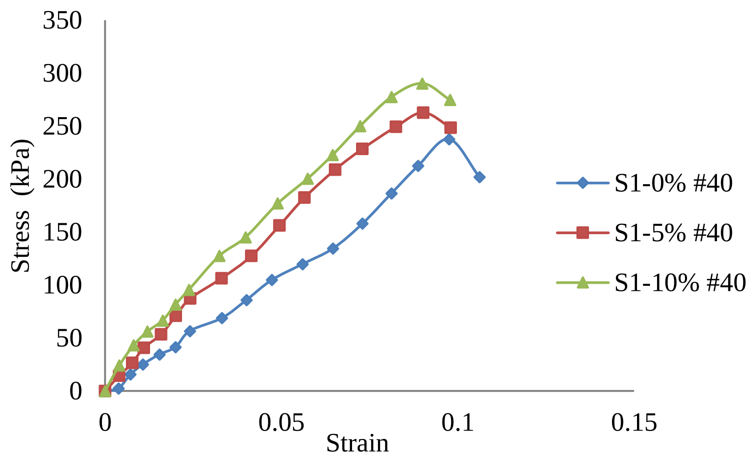


Figure 4.17: Stress versus strain based on unconfined compressive strength for S1 with the finer size of ceramic dust (#40)

The unconfined compressive strength for the S1 sample without containing ceramic dust has a value of 237.781kPa. In contrast, the result for the same clay sample containing 5% ceramic dust in the finer size (#40) increased to 262.798 kPa as shown in Figure 4.17, with the addition of ceramic dust to 10% result increased to 290.371kPa. Sabat (2012**)** concluded that as ceramic percentages increase, MDD starts to increase. As a result, the UCS follows the increasing values comparing with the untreated soil.

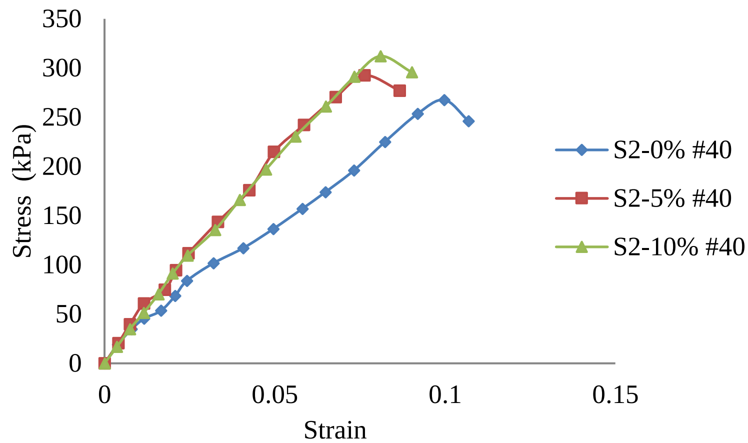


Figure 4.18: Stress versus strain based on unconfined compressive strength for S2 with the finer size of ceramic dust (#40)

For soil sample S2, as shown in Figure 4.18, the unconfined compressive strength without containing ceramic dust was 267.662 kPa. In comparison, soil samples containing a 5% finer size of ceramic dust (#40) increased to 292.47 kPa, with the addition of ceramic dust to 10% result increased to 312.084 kPa.

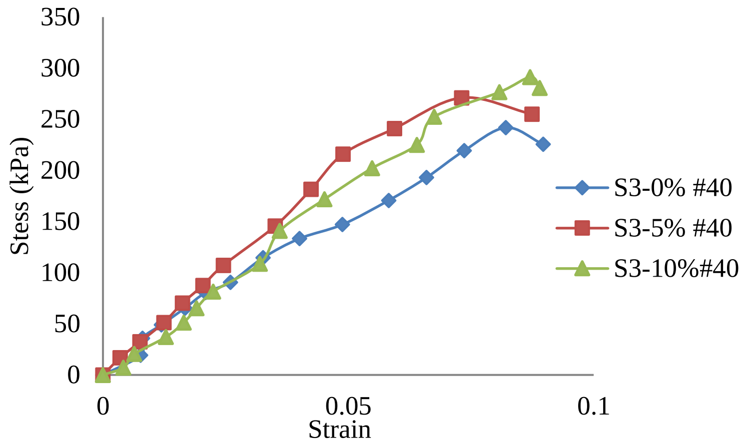


Figure 4.19: Stress versus strain based on unconfined compressive strength for S3 with the finer size of ceramic dust (#40)

For sample S3 as shown in Figure 4.19, the unconfined compressive strength without containing ceramic dust was 241.84 kPa. In contrast, soil sample containing 5% finer size of ceramic dust (#40) increased to 271.1kPa, with the addition of ceramic dust to 10% result increased to 291.29 kPa.

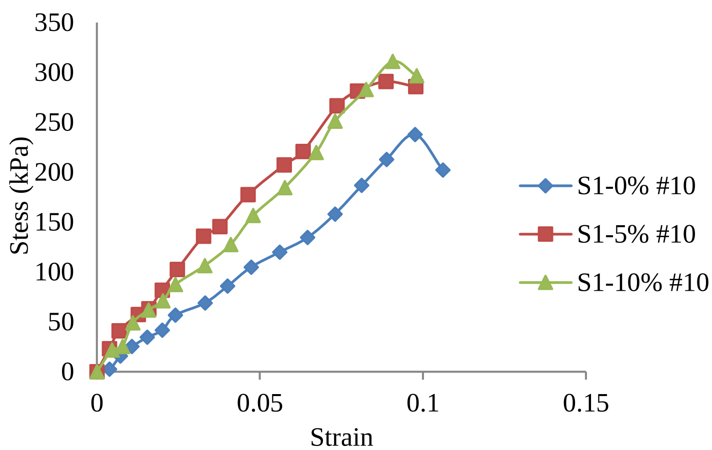


Figure 4.20: Stress versus strain based on unconfined compressive strength for S1 with coarser size of ceramic dust (#10)

Figure 4.20 the unconfined compressive strength for sample S1 value increased from 237.78 to 290.79 kPa when ceramic dust increased from 0 to 5%. While besides 10% of ceramic dust, the value increased to 311kPa.

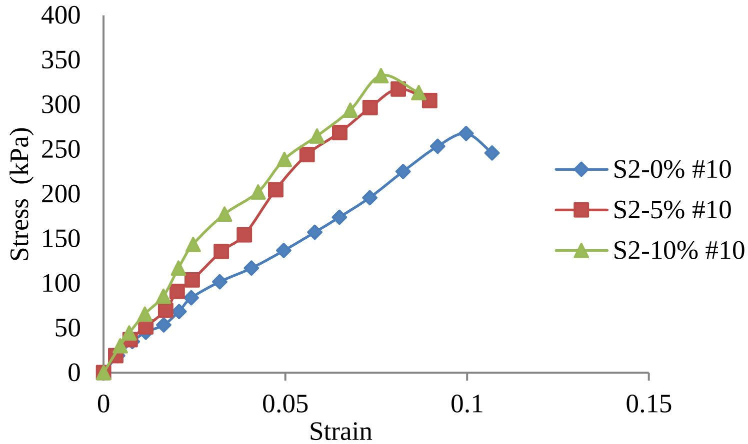


Figure 4.21: Stress versus strain based on unconfined compressive strength for S2 with the coarse size of ceramic dust (#10)

For S2, results are shown in Figure 4.19. When ceramic dust increased from 0 to 5%, the unconfined compressive strength value increased from 267.66 kPa to 317.64 kPa, while also of 10% ceramic dust, the value increased to 332.66 kPa.

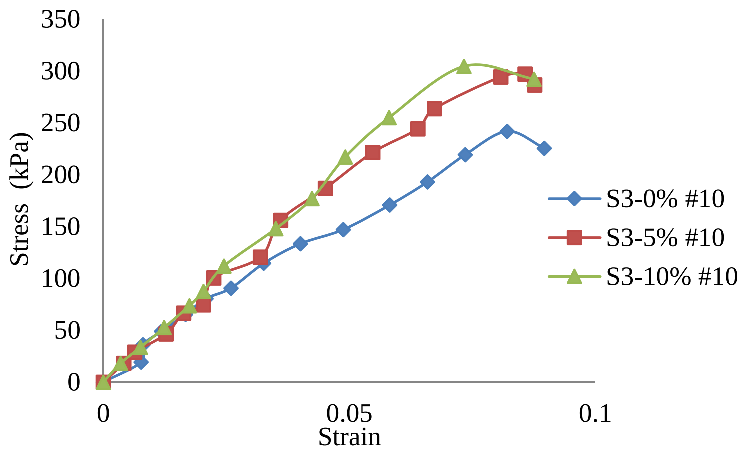


Figure 4.22: Stress versus strain based on unconfined compressive strength for S3 with coarser size of ceramic dust (#10)

Figure 4.22 results are shown for S3 with the coarser size of ceramic dust (#10) when ceramic dust increased from 0 to 5%, and the unconfined compressive strength value increased from 241.84 kPa to 297.23 kPa while also of 10% ceramic dust the value increased to 304.62 kPa.

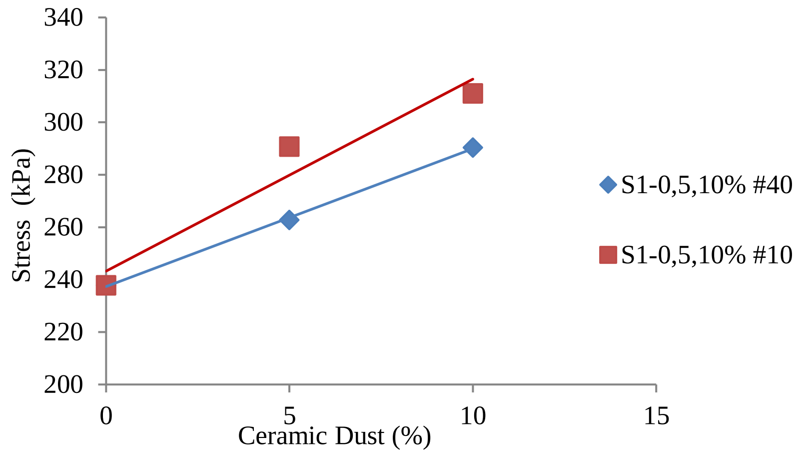


Figure 4.23: Stress versus the different amounts of ceramic dust for the S1 sample with both ceramic dust sizes

The stress values versus ceramic dust amounts for S1 sample without and with both ceramic dust sizes are shown in Figure 4.23. with the finer ceramic dust, the stress was 237.78kPa, and after adding 5% ceramic dust, the value increased by 10.52% to become 262.8 kPa, While for 10% ceramic dust, the result increased by 22.12%, and it became 290.37kPa. With the coarser size of ceramic dust, the stress was 237.78kPa, and after adding 5% ceramic dust, the value increased by 22.29% to become 290.78 kPa for 10% ceramic dust, the result increased by 30.79%, and it became 311 kPa.

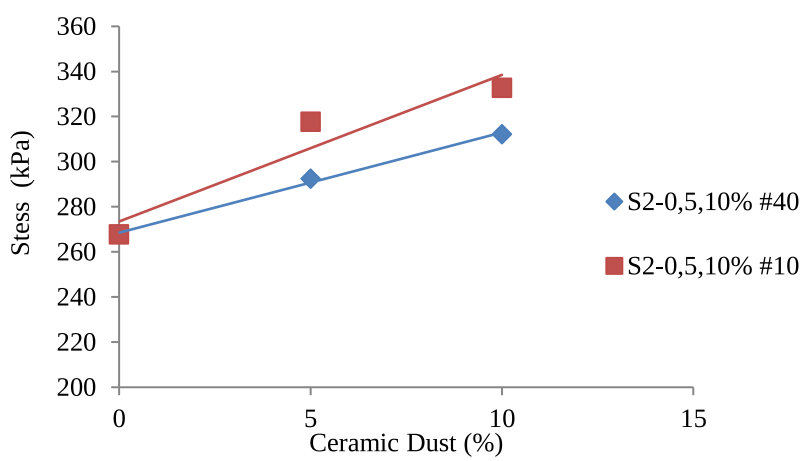


Figure 4.24: Stress versus the different amounts of ceramic dust for the S2 sample with both ceramic dust sizes

For S2 and finer ceramic size, the stress was 267.66 kPa, and by adding 5% ceramic dust, it also increased by 9.27% and became 292.47 kPa. On the other hand, it increased furthermore by 16.6% in 10% ceramic dust to became 312.08 kPa. For the coarser ceramic size, the initial stress was 267.66 kPa. Adding 5% ceramic dust increased it by 18.67% to 317.64 kPa, further addition of 10% ceramic dust increased the value by 24.28% to become 332.66 kPa, as shown in Figure 4.24.

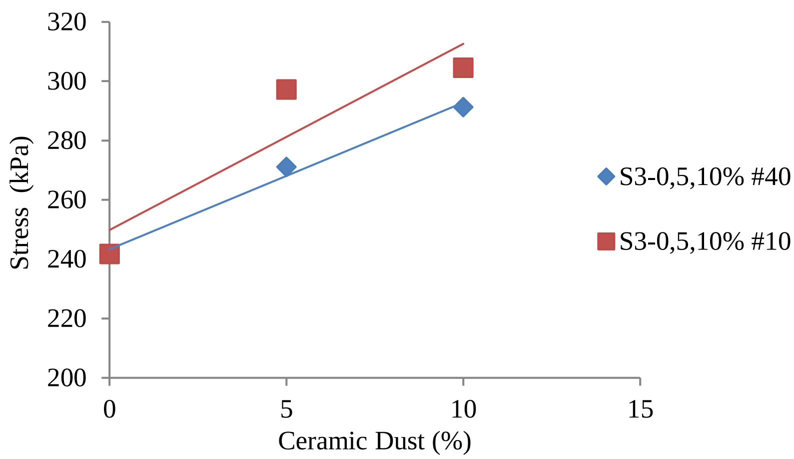


Figure 4.25: Stress versus the different amounts of ceramic dust for S3 sample with both ceramic dust sizes

For S3 and finer ceramic size, the stress increased from 241.84 kPa to 271.1 by adding 0 to 5% finer size of ceramic dust by 12.1%. On the other hand, it increased furthermore by 20.45% in 10% ceramic dust to become 291.29. For the coarser ceramic size, the initial stress was 241.84 kPa. Adding 5% ceramic dust increased it by 22.90% to become 297.23 kPa while adding 10% ceramic dust increased the value by 25.96% to 304.62kPa, as shown in Figure 4.25.

4.5 Unsoaked California bearing ratio

Method of ASTM D1883 was applied for California bearing ratio for unsoaked (UCBR) sample to determine the subgrade strength used in road and pavement. We applied the method for the obtained clay samples, it was done as the previous tests on three types of clay soil, for untreated samples and mixed samples with ceramic dust in the proportion of 0,5 and 10% according to two different sizes of ceramic waste dust, before CBR test, they were compacted in their optimum water content and optimum dry density.

Table 4.6 shows unsoaked California bearing ratio results with and without ceramic dust for all the mixtures. It has been noticed from the results that with adding ceramic dust to the untreated clay, the UCBR value starts to increase to a higher value. Also, by adding 10% ceramic dust, the UCBR increases higher for both ceramic dust sizes. In comparison, the coarser size gives a higher UCBR value due to the gradation of the ceramic dust in the mix.

Table 4.6: Results of unsoaked California bearing ratio for obtained samples

Sample	CD%	Size of ceramic	UCBR
S1	0	0	11.1
S2			15.0
S3			11.8
S1	5%	#40 (0.425mm)	15.6
S2			20.0
S3			16.0
S1	10%	#40 (0.425mm)	24.5
S2			26.7
S3			25.0
S1	5%	#10 (2mm)	18.4
S2			22.2
S3			19.2
S1	10%	#10 (2mm)	27.1
S2			30.1
S3			26.9

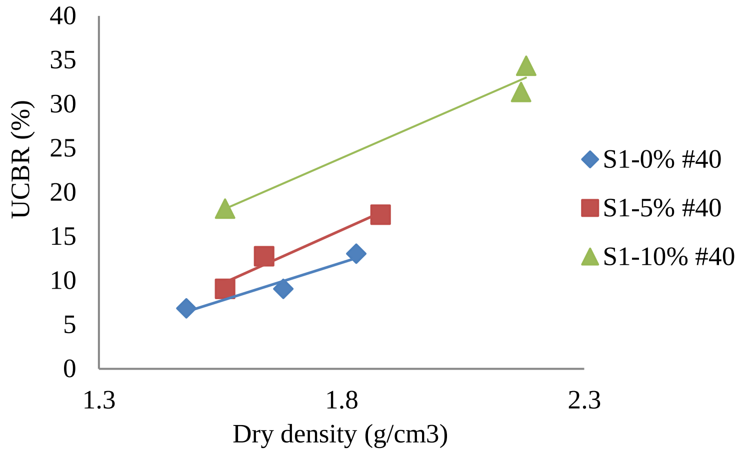


Figure 4.26: Dry density versus unsoaked California bearing ratio for S1 sample with finer size of ceramic dust (#40)

For S1 sample result are shown in Figure 4.26 with the finer size of ceramic dust(#40), for untreated clay sample it had UCBR values as 6.85,9.06 and 13.05% respectively, when 5% ceramic dust added to the mix by total weight the values increased to 9.08,12.76 and 17.46% respectively. Simultaneously, UCBR values increased and reached 18.16, 31.38, and 34.37% when ceramic dust amount increased from 0 to 10%.

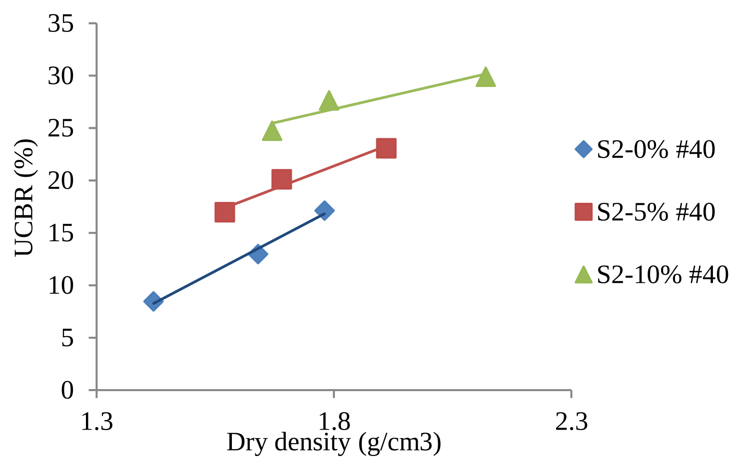


Figure 4.27: Dry density versus unsoaked California bearing ratio for S2 sample with finer size of ceramic dust (#40)

Figure 4.27 results are shown for S2 with the finer size of ceramic dust (#40), for untreated clay sample UCBR values were calculated as 8.47, 12.98, and 17.14%, respectively. When 5% ceramic dust was added to the mix by total weight the values increased to 16.97, 20.11 and 23.07%. On the other hand, UCBR values increased to 24.76, 27.67, and 29.91%, respectively, when the amount of ceramic dust increased to 10%.

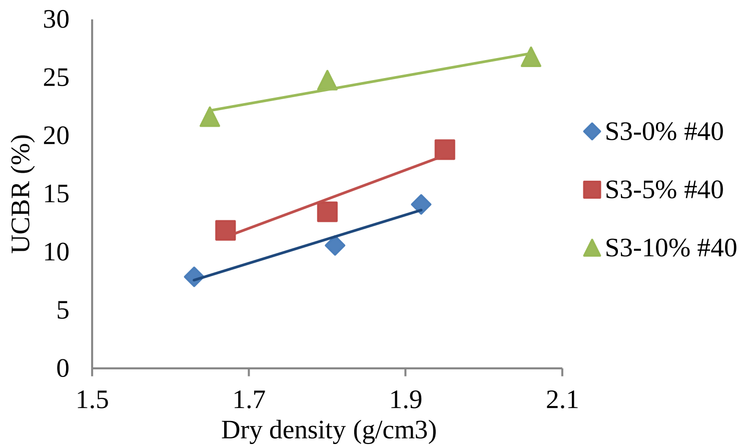


Figure 4.28: Dry density versus unsoaked California bearing ratio for S3 sample with finer size of ceramic dust (#40)

For the S3 sample, results are shown in Figure 4.28, with the finer size of ceramic dust (#40), for untreated clay sample values of UCBR were calculated to be 7.87, 10.56, and 14.08%, respectively. When 5% of ceramic dust was added to the mix, the values increased to 11.87, 13.45 and 18.81%. Values of UCBR increased to 21.64, 24.77, and 26.78%, respectively, when ceramic dust amount increased to 10%.

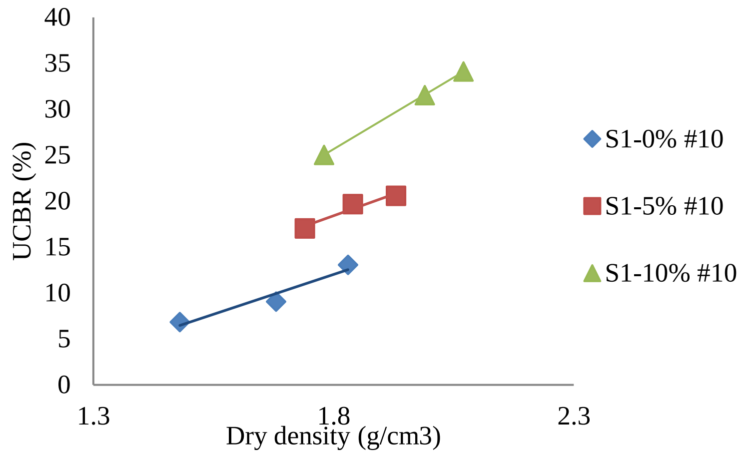


Figure 4.29: Dry density versus unsoaked California bearing ratio for S1 sample with coarser size of ceramic dust (#10)

The S1 sample, with the coarser size of ceramic dust (#10) result, is shown in Figure 4.29, for untreated clay sample values were 6.85, 9.05, and 13.05%, respectively. While 5% ceramic dust was added to the mix, the values increased to 17.05, 19.66, and 20.58%. Values of UCBR increased to 25.05, 31.54, and 34.12% when ceramic dust amount increased from 0 to 10%.

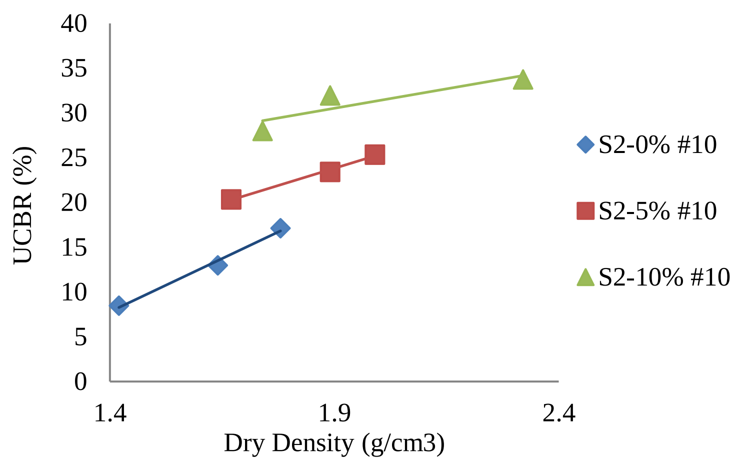


Figure 4.30: Dry density versus unsoaked California bearing ratio for S2 sample with coarser size of ceramic dust (#10)

In the coarser size of ceramic dust (#10), results are shown in Figure 4.30. For S2, for untreated clay samples, UCBR values were calculated as 8.47, 12.98 17.14%, respectively. When 5% ceramic dust was added to the mix by total weight, the values increased to 20.36, 23.41, and 25.37%, respectively. While UCBR values increased to 27.99, 31.97, and 33.77%, respectively, the amount of ceramic dust increased from 0 to 10%.

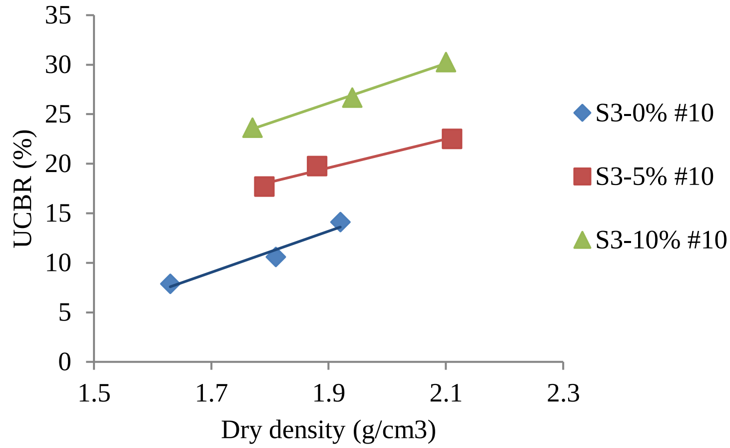


Figure 4.31: Dry density versus unsoaked California bearing ratio for S3 sample with coarser size of ceramic dust (#10)

Finally, the S3 sample results are shown in Figure 4.31, with the finer size of ceramic dust (#40), for untreated clay sample values of UCBR were calculated to be 7.87, 10.56, and 14.08%, respectively. When 5% of ceramic dust was added to the mix, the values increased to 17.67, 19.75, and 22.51%. On the other hand, values of UCBR increased to 23.64, 26.66, and 30.26%, respectively, when ceramic dust amount increased to 10%.

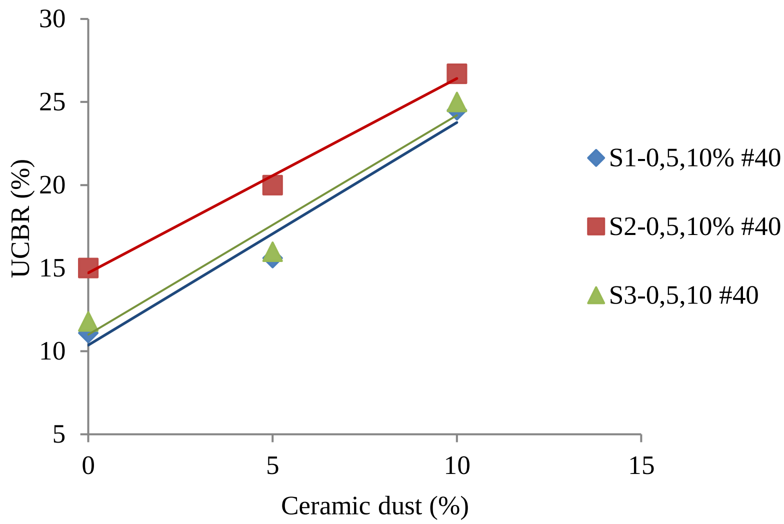


Figure 4.32: Amount of ceramic dust unsoaked California bearing ratio for obtained samples with finer size of ceramic dust (#40)

Unsoaked California bearing ratio values versus ceramic dust amounts for S1 sample without and with finer ceramic dust size shown in Figure 4.32, with the finer size of ceramic dust the value was 11.1%, and by after adding 5% ceramic dust the value increased by 40.54% to become 15.6%.While for 10% of ceramic dust, the result increased by 120.72%, and it became 24.5%. For the S2 sample, UCBR was 15%, after adding 5% ceramic dust, the value increased by 33.33% to 20%, on the other hand, for 10% ceramic dust, the result increased by 78%, and it became 26.9%. In sample S3, for initial UCBR value was 11.8%, adding 5% ceramic dust increased by 35.59% to become 16%. Simultaneously, the addition of 10% of ceramic dust increased the result of 111.86% to 25%. There was a 150% increase in soaked CBR of treated soil with 30% ceramic dust compared to untreated soil samples, which is aligned with Sabat (2012)'s work.

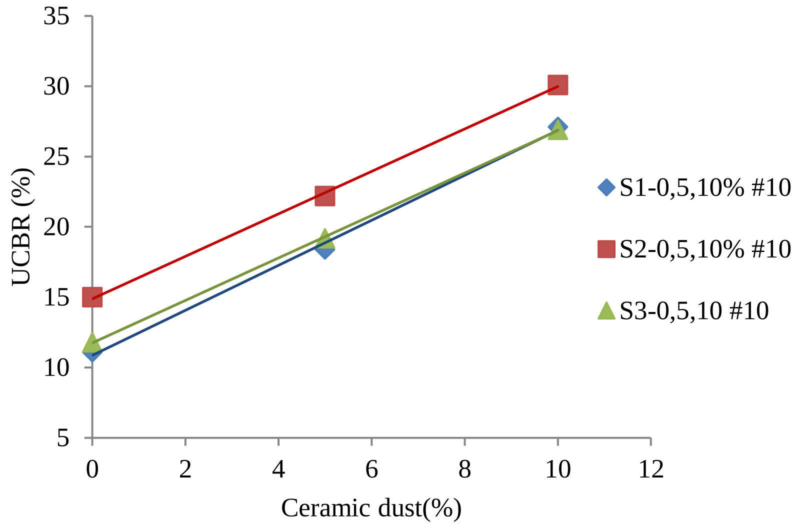


Figure 4.33: Amount of ceramic dust unsoaked California bearing ratio for obtained samples with coarser size of ceramic dust (#10)

Figure 4.33 unsoaked California bearing ratio values versus ceramic dust amounts with the coarser size of ceramic dust (#10) for the S1 sample was 11.1%. After adding 5% ceramic dust, the value increased by 65.77% to become 18.4%. While for 10% of ceramic dust, the result increased by 144.14% to become 27.1%. For the S2 sample, UCBR was 15%, after adding 5% ceramic dust, the value increased by 48% to 22.2%, on the other hand, for 10% ceramic dust, the result increased by 100.67%, and it became 30.1%. In sample S3, for initial UCBR value was 11.8%, adding 5% ceramic dust increased by 62.71% to become 19.2%. Simultaneously, the addition of 10% of ceramic dust increased the result of 127.91% to become 26.9%.

From Figure 4.32 and 4.33, if we compare the slopes for both ceramic dust sizes, we can see that the UCBR values for S1, S2, and S3 with the finer size of ceramic sieve no.40 having slopes of 1.3, 1.17, and 1.32, respectively. While in the coarser size of ceramic dust no.10 slopes were higher, and there are 26%, 34%, and 19% increment respectively in slopes comparing to the finer size and values are 1.6, 1.51, and 1.51. So that the coarser size of ceramic caused slight, rapid increment comparing to the finer size of ceramic dust.

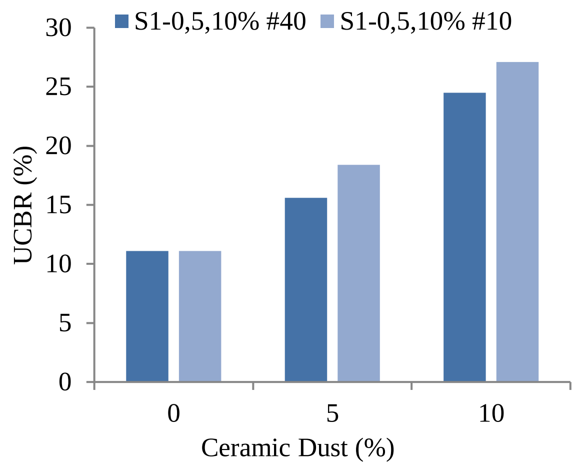


Figure 4.34: Unsoaked California bearing ratio versus the different amount of ceramic dust in both size of ceramic for sample (S1)

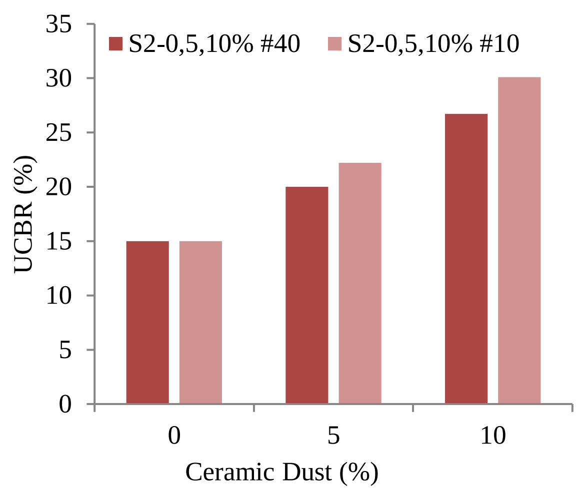


Figure 4.35: Unsoaked California bearing ratio versus the different amount of ceramic dust in both size of ceramic for sample (S2)

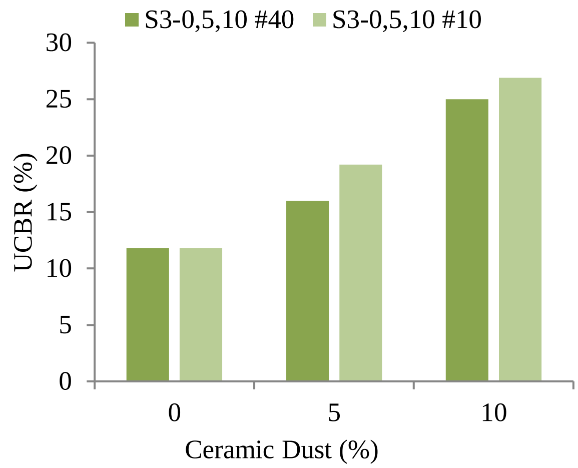


Figure 4.36: Unsoaked California bearing ratio versus the different amount of ceramic dust in both size of ceramic for sample (S3)

Figure 4.34, 4.35, and 4.36 show that both ceramic dust sizes have increased unsoaked California bearing ratio values compared to untreated soil. At the same time, the coarser size of ceramic had slightly higher UCBR values. The UCBR incensement with different amount of ceramic dust and sizes could be due to the several reasons that the stabilized clay has, such as higher stiffness due to high ceramic grain stiffness, less plasticity, more friction and interlocking between clay and ceramic dust particles. The coarser size of ceramic has a lower surface area and lower water absorption capacity in the mixture.

The soil samples can be used as subgrades for flexible pavement, and this subgrade soil provides protection for the above structure build on it. Subgrade efficiency will affect the design of the pavement its lifespan. Prepared subgrade thickness is usually up to 12 inches (Schaefer et al., 2017).

Osouli (2017) did the unsoaked CBR value for calculating the soaked CBR. He used some correction factors for plasticity index, percent passing No.200, and dust ratio, while Lakshmi et al. (2016) conducted CBR on CL type of soil with the soaked and unsoaked condition. They found that the minimum value for CBR reduction from unsoaked to soaked was 86%. This is due to the presence of water that in soaked CBR water helps the plunger penetrate easier at lower time duration. The minimum value of 86% was used to predict the soaked CBR values for obtained samples and then comparing them to the standard, as shown in Table 4.7. Sign (√) refers to that sample is accepted to be used according to the standard. In contrast (×) sign, the sample cannot be used according to the standard mentioned. A comparison between ASTM and BS standards is given in Table 4.7.

Table 4.7: Predicted Soaked California bearing ratio for obtained samples and standards (ASTM D1883, BS 1377)

Sample	CD%	Size of ceramic	Soaked CBR %	ASTM Standard For CL Soil CBR Limit (1-15%)	BS Standard For CL soil CBR Limit (3-4%)
S1	0	0	1.6	√	×
S2			2.1	√	×
S3			1.7	√	×
S1	5%	#40 (0.425mm)	2.2	√	×
S2			2.8	√	×
S3			2.2	√	×
S1	10%	#40 (0.425mm)	3.4	√	√
S2			3.7	√	√
S3			3.5	√	√
S1	5%	#10 (2mm)	2.6	√	×
S2			3.1	√	√
S3			2.7	√	×
S1	10%	#10 (2mm)	3.8	√	√
S2			4.2	√	√
S3			3.8	√	√

In table 4.7, it is shown that the untreated samples S1, S2, and S3 having CBR values of (1.6, 2.1, and 1.7%), by comparing them according to the (Table 1/ Section 6E/ Subgrade Design and Construction), for a clay soil having a LL>40 and PI>10, the CBR values between 1 to 15 can be suitable for highway subgrade application with very poor rating according to (Table2/Section 6E/Subgrade Design and Construction). While after adding 10% ceramic dust of finer size, CBR values increased and reached (3.4, 3.7, and 3.5%) which is an acceptable and improved value. On the other hand, by adding 10% of the ceramic coarser size, the CBR values increased higher values to reach (3.8, 4.2, and 3.8%). Therefore we can see the coarser size of ceramic gives a higher CBR value that can lead to a much better rating in ASTM standards, less thickness design, and less cost by using a higher CBR value.

According to British Standard (BS1377, 2016), for a CL type of soil, the predicted suitable value for CBR is about 3 to 4%. Due to this, the untreated samples cannot be used for subgrade, and the soil can be accepted to use after it gets to be stabilized by contains 10% of ceramic dust in both sizes to improve the value. In contrast, the coarser size has a better CBR value due to their larger particles having better gradation.

Finally we can conclude that up to 10% amount of coarser size of ceramic dust had shown improved properties in increasing compaction, unconfined compression and CBR values, with reducing the samples plasticity and water content. About the CBR results despite the improvement, it seems that higher percentages of ceramic dust will get a better grading result, when we compare our CBR values with ASTM standard we can see that it improved to higher CBR values at the same group of rating, due to some reasons the study has not been used larger percentage of ceramic dust because of the study area , that there is not a factory for production of ceramic dust and the number of waste ceramic tiles in Erbil city have not been calculated by any researcher, so that up to 30% ceramic will be hardly affordable for a long highway project.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Industrial wastes can be used effectively for soil stabilization. Different types of industrial waste materials are suitable for various soil types, and they provide multiple degrees of enhancement. Ceramic waste, which represents a higher percentage of building debris worldwide, can be used in road construction, reducing waste's environmental impact. In this investigation, a series of laboratory tests were performed on three clay samples with two different ceramic sizes, in the proportion of 0, 5, and 10% by weight. Tests were done to observe the effects of ceramic waste dust on the liquid limit, plastic limit, plasticity index, MDD, OMC, UCS, unsoaked CBR of clayey soil. The research findings mostly showed that the clayey soil's engineering properties had improved considerably due to stabilizing with ceramic dust. The following conclusions can be drawn based on the findings and discussions of the study.

1. By addition of ceramic dust to soil, the research aims to solve the ceramic wastes' disposal, which if not managed wisely, can create serious threat to the environment and human health. Effective control of dust can be achieved by usage of ceramic dust in soil stabilization.
2. By addition of ceramic dust from 0 to 10% LL decreased by (13, 10, and 11%) for S1, S2, and S3, respectively. At the same time, PL decreased by (20, 19, and 20%) for S1, S2, and S3.
3. The MDD of the sample S1, S2, and S3 increased with adding ceramic waste dust from 0 to 10%. While OMC of the sample S1, S2 and S3 were decreasing, so the compaction parameters were improved by the addition of both sizes of CD. Comparing both sizes of ceramic dust, MDD was increased, and OMC was decreased using the coarser size of ceramic dust compared to the finer size.
4. The UCS increases with the increase in the percentage of the addition of ceramic dust in both sizes of ceramic, in the finer size about (22, 16, and 20%) were increased for

S1, S2, and S3 sample respectively. Simultaneously, the coarser size showed more improvement and higher strength due to larger particles and a higher dry density, the change percentages were (30, 24, and 25 %) for S1, S2, and S3 samples, respectively.

5. The unsoaked CBR goes on increasing with the increase in the percentage of the addition of ceramic dust. There is (120, 78, and 111%) increase in CBR value for S1, S2, and S3, respectively, with finer size of the ceramic addition. The coarser size of ceramic unsoaked CBR was increased more with (144, 100, and 127%) for S1, S2, and S3, respectively. When 10% of ceramic dust was added, this may significantly decrease highway pavement design thickness.
6. Addition of about 10% of ceramic dust can be useful in soil stabilization and help reduce environmental pollution by using waste materials and reducing usage of available natural resources. By using more ceramic dust better results may be achieved, but as there's not a ceramic tile factory in Iraq so the amount of waste could not be enough for using them in higher percentages and for a long highway construction subgrades. Though for smaller projects it could be researched.
7. The use of solid waste in soil stabilization improves the soil's geotechnical properties. The soil samples can be used as subgrade for highways with smaller design thickness by achieving a higher CBR value than the untreated sample.

5.2 Recommendations

The following recommendations are forwarded based on the results of this study:

- More investigations should be performed to find the best quantity of ceramic dust to increase clay soil strength.
- Different ceramic industries and government agencies should be aware of this possible soil stabilizing content and encourage its uniform production and use.
- Stabilizing soils with cement, lime, and ceramic powder waste together with various soil forms and observing the impacts.

- It is proposed from the study that cost analysis, sustainability consideration, and potential comparisons between unstabilized and stabilized roads should be carried out with considerable accuracy.

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APPENDIX 1

Plagiarism and Ethical Rules Contract Form

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APPENDIX 2

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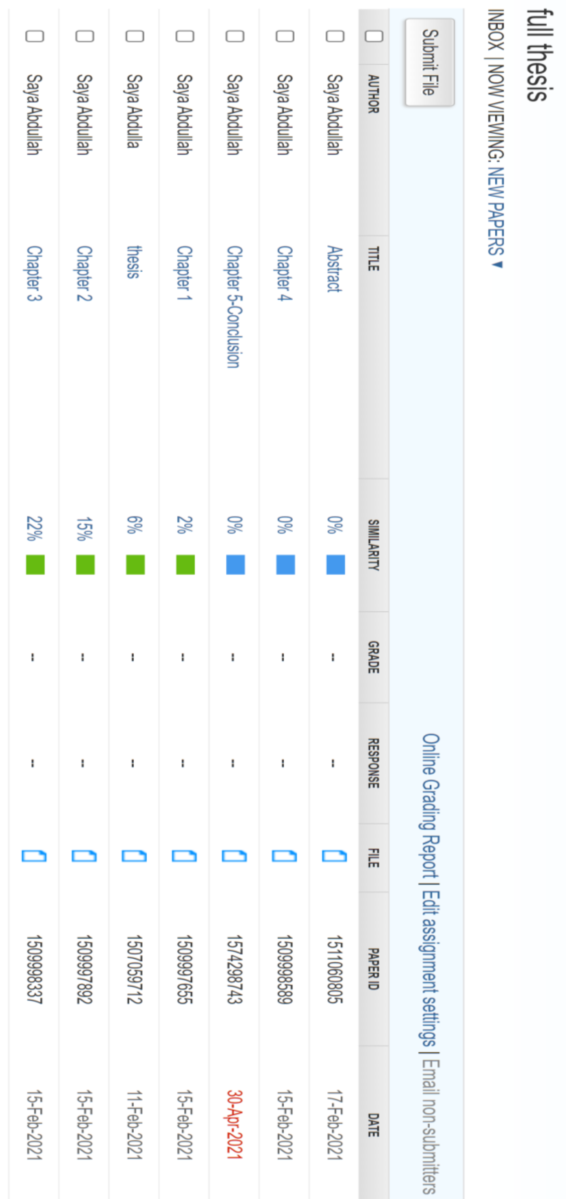

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