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IMPROVING GEOTECHNICAL PROPERTIES OF SILTY SAND BY USING XANTHAN GUM AND WASTE BRICK

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IN

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BY

RABİA DUYMAZ

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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.

Rabia DUYMAZ

ABSTRACT

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This study presents change the engineering properties of silty sand altered by the addition of xanthan gum and brick which is a waste material. The samples were prepared by mixing silty sand at various proportions by dry weight of xanthan gum biopolymer (0, 0.5, 1, 3%) and dry weight of waste brick (%10), and then tested at the end of different curing times (0, 7, 28, and 56 days). To understand the effect of waste material and biopolymer on silty sand, a series of laboratory tests carried out such as specific gravity test, Atterberg limit test, fall cone test, vane shear test, compaction test, falling head permeability test, California bearing ratio (CBR), oedometer test (consolidation), unconfined compression test (UCS). According to the results of all experiments it was determined that the best efficiency would be obtained when 0.5% XG was added to a mixture of silty sand and 10% waste brick for soil improvement.

Key Words: Silty Sand, Xanthan gum, Biopolymer, Improvement, Waste Brick

ÖZET

KSATAN SAKIZI VE ATIK TUĞLA KULLANILARAK SİLTLİ KUMUN GEOTEKNİK ÖZELLİKLERİNİN GELİŞTİRİLMESİ

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Bu çalışma, siltli kumun mühendislik özelliklerinin ksantan sakızı ve atık bir malzeme olan tuğla ilavesiyle değişimini sunmaktadır. Numuneler, siltli kumun ağırlıkça çeşitli oranlarda ksantan sakızı biyopolimeri (%0, 0.5, 1, 3) ve atık tuğla ağırlığı (%10) ile karıştırılmasıyla hazırlanmış ve daha sonra farklı kür sürelerinin (0, 7, 28 ve 56 gün) sonunda test edilmiştir. Atık malzeme ve biyopolimerin siltli kum üzerindeki etkisini anlamak için özgül ağırlık testi, Atterberg limit testi, düşme konisi testi, kanatlı kesme testi, standart kompaksiyon testi, düşen seviyeli permeabilite testi, Kaliforniya taşıma oranı (CBR), oedometre testi (konsolidasyon), serbest basınç deneyi (UCS) gibi laboratuvar testleri gerçekleştirilmiştir. Tüm deneylerin sonuçlarına göre, zemin iyileştirmesi için siltli kum ve %10 atık tuğla karışımına %0,5 XG eklendiğinde en iyi verimin elde edileceği belirlenmiştir.

Anahtar Kelimeler: Siltli Kum, Ksantan sakızı, Biyopolimer, İyileştirme, AtıkTuğla

''Dedicated to my family''

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LIST OF SYMBOLS AND ABBREVIATIONS

Cc	Compression Index
Cr	Recompression Index
Cv	Coefficient of Consolidation
C and D	Construction and Demolition Material
CBR	California Bearing Ratio
G_s	Spesific Gravity
LL	Liquid Limit (%)
MDD	Maximum Dry Density (gr/cm^3)
OMC	Optimum Moisture Content (%)
PI	Plasticity Index (%)
PL	Plastic Limit (%)
SEM	Scanning Electron Microscope
SM	Silty Sand
UCS	Unconfined Compression Test
USCS	Unified Soil Classification System
W_{opt}	Optimum Water Content (%)
XG	Xanthan Gum
γ_{drymax}	Maximum Dry Unit Weight (kN/m^3)

CHAPTER 1
INTRODUCTION

1.1 General

Since almost all engineering structures such as buildings, roads, railways, bridges and dams will be built on the ground, so that examining the soil behavior have a great importance for civil engineers. However, not all soils are suitable for construction. This situation requires improvement of the ground. Mainly, soil improvement is the temporary or permanent alteration of soils engineering properties by various methods. Soil works and soil improvement date back to ancient times. The oldest geological map, thought to date back to between 1814 and 1821, was discovered in ancient Egypt Agaiby et al. (2013) and it is also known that the Romans also carried out soil improvement works. There are some textbooks about soil improvement written already in the 18th and 19th centuries Flodin & Broms (1981).

The change in civilizations, the increase in the world population and the development of living standards has caused develop in construction with number of engineering problems. Among these problems, the most fundamental problem affecting the geotechnical field is the engineering characteristics of the soil. Nowadays, soils engineering properties and the suitability for construction can be determined much better than past. In the studies, unsuitable soils can be identified together with their causes. Geotechnical engineers have come up with various ideas for use on soils that are not suitable for construction such as mechanical improvements such as vibro compaction, vacuum consolidation, ground freezing. In addition to mechanical improvements, improvements were also made by adding some materials to the soil. In the past, the popular binding materials were lime and cement. The waste materials that are still popular and common today are recycled construction and demolition waste materials and lime, which has been frequently used from past to present. However, over time, it has been observed that the usage of cement and lime improvement materials can be harmful for the environment. And also, because of these improvements are insufficient and cannot always be implemented, and also for environmental, economic reasons new methods have also started to experiment over time. Engineers which are doing geotechnical studies worldwide have turned to utilizing different waste materials to reduce carbon emissions and also biopolymers to avoid affecting the biological balance lately.

1.2 Research Aim

In this study, interactions of silty sand (SM) with biopolymer Xanthan gum (0, 0.5, 1, 3%), waste brick (10%) and their mixtures were investigated. The engineering properties of these materials were investigated with various geotechnical laboratory experiments.

1.3 Outline of the Thesis

This thesis is made up of 5 chapters. In Chapter 1, Introduction gives information about the purposes and the originality of the thesis. Chapter 2 gives information in the literature on biopolymers and waste materials. In Chapter 3, the materials and the methods used in this study are introduced. In Chapter 4 the test results are given with the interpretation of these test results as well their comparison with results in the literature. In chapter 5 gives summary of the results of the thesis study.

CHAPTER 2
LITERATURE REVIEW

2.1 Ground Improvement

Soil improvement has been a critical issue for civil engineering from past to present. Various ground improvement methods have come until present day which are undergone some changes from civilizations as old as the Egyptian and Roman civilizations. These methods are generally mechanical soil improvement methods such as vertical drains, vibro compaction, stone columns, dynamic compaction, grouting, preloading, (Singh et al., 2017).

Vertical drains has been used for soft soil since the 1920s Goldberg and Palmatier (2013). Singh et al. (2017) mentioned that there are two types vertical drains ; sand drain and wick drain. Basack and Bhattacharya (2011) investigated effects of vertical drains on soft soils. Vertical drains quicken the consolidation of soft soil. It is one of the preferred methods for improving soft soils with low hydraulic conductivity and low shear strength, as it accelerates construction and shortens the implementation period of the project. Chai et al. (2013) found out that vertical drains increase the mass hydraulic conductivity of the soil.

Another method is vibro compaction. Berner (1998) ascertained that vibro compaction the sand fill showed an increase in both strength and stiffness of soil. Compaction of the sand particles resulted in a denser arrangement settlement of the ground. Debats et al. (2003) observed that after the column installation, large pore pressures were formed in the clay soil around the column, and the horizontal effective stress increased significantly while the vertical effective stress increased. In the long term, uniform settlement occurs and a significant increase in mean effective stresses was observed. Also they observed clayey soil stiffness modulus improvement. Singh et al. (2017) found out vibro compaction make loose soil more dense. Zayyat et al. (2005) mention the bearing capacity of soil was significantly improved. Geogrids provides uniformly distribution gravity loads on the stone columns. Also, bearing capacity and settlement characteristics of soil were improved. It has provided a significant reduction in construction cost and duration.

Stone columns are another improving method. Mokhtari and Kalantar (2012) mention that stone columns increase load carrying capacity and decrease settlement significantly. Due to its granular and freely draining structure, consolidation settlement is accelerated but reduces post-construction settlement. According to Mohanty and Samanta (2015), axial stress and stiffness of the entire soil improved after using stone columns. Ali et al. (2010) pointed out that smaller diameter columns more useful and durable than large diameter columns for soil improvement. Cooper and Rose (1999) found out stone columns increases shear strength of the soil. The stone columns met the necessary short-term stability for construction. Stone columns allow construction and commissioning quickly.

Kodikara et al. (2018) mention that compaction increases soil strength and bearing capacity, at the same time reduces compressibility and permeability. Compacted soils showed have higher stiffness and shear and tensile strengths.

Sayehvand and Kalantari (2012) refer that grouting method increases shear strength of soil. This method prevents liquefaction as it causes the soil to become denser. Jet columns contribute bearing support and lessen settlement. Wang et al. (2020) found out when grout are inserted into the soil, a swift increase in the excess pore water pressure occurs in the enclosing soil.

Chu et al. (2000) mention that when the vacuum preloading method is applied to soil, lateral displacement should be contemplate. Vacuum preloading can reduce surcharge height of embankments on soft clay soil to avoid any failure. According to Dhowian (2017), preloading has been found practical and suitable to improve the soil features. Laboratory consolidation tests found to be sufficient to similar the field preloading method. Consolidation test results found out nearly equal to the settlement directly measured in the field. Lei et al. (2020) studied conventional vacuum preloading (CVP) method and air booster vacuum preloading (AVP). mentioned that AVP method showed greater surface settlement, water discharge and dissipation of pore-water pressure than CVP method. Study showed that AVP method decrease the water content and increase the shear strength. Also, AVP method provided denser microstructure. They stated that the strengthening effect of the AVP method was more effective than the CVP method. Wu et al. (2021) found out that the cone, sleeve resistance, density, compression modulus, cohesion, and internal friction angle greatly increased while water content, void ratio, and compression coefficient were quite decreased.

2.2 Biopolymers

Biopolymers are one of the popular soil improvements method recently because of they are totally eco-friendly. As far as we know, no adverse effects of biopolymers on living life and the environment have been reported so far. Biopolymers are polymers that are produced by or derived from living organisms, such as plants, microorganisms or animals.

Fatehi et al. (2021), classified and analyzed most of the biopolymers in a review article. According to this article, plant- based biopolymers are produced from plants or agrarian waste materials. These biopolymers are guar gum, lignin, agar gum, beta-glucan, sodium alginate and carrageenan. Guar gum which is obtained from guar plant and it is a polysaccharide which include two sugars galactose and mannose. Guar gum is more cost-effective because it is produced in large quantities. Guar gum has large hydroxyl groups, therefore forms hydrogel bonds between soil particles and hydrogen ions. Lignin, is one of the most abundant polymers through world. Lignin has phenolicnature and it is a natural glue. Thanks to its natural structure, non-toxicity, environmentally friendly and cheap due to its easy availability, making it an alternative to traditional stabilizers. Lignin contributes to a more stable soil as it fills the gaps between soil particles. Agar gum, another plant-derived biopolymer, is a thermogelatin polysaccharide derived from macro algae, which is red marine algae. Not all agar gum exhibits the same properties, the properties vary depending on the seaweed from which the agar gum is produced. Agar gum has long molecular structure and low ionic inclination that's why direct interactions with soil particles and agar gum is difficult. Agar gums surround soil particles and fill the gaps. Beta-glucan is another plant-based biopolymer. Beta-glucan found in cellulose in plants and in the cell walls of yeasts. Beta-glucan can form hydrogen bonds easily due to its the carboxyl (COO-) and hydroxyl which is on its edge. This causes the biopolymer to retain more water. In conclusion, the pores between soil particles fill more and the volume of soil expands. Sodium alginate is a salt with an alginic acid product and it is an anionic polysaccharide. It is obtained from marine brown algae cell walls generally. Alginate is soluble in water and creates a gum as a result of its interaction with water molecules. Due to its eco-friendliness, low cost and low toxicity, alginate has become one of the preferred bio-materials for soil improvement. Alginate is a substance that can be affected by the acidity and basicity of the soil. A decrease in viscosity has been observed when the pH value of the medium decreased. Carrageenan is other plant-derived biopolymer, which is a linear polysaccharide get from red seaweeds. Carrageenan is water soluble and an anionic biopolymer. Carrageenan can be affected with both pH and temperature. When the temperature increases and the pH decreases, it is expected that reduction in the stability of carrageenan.

Secondly, Fatehi et al. (2021) referred about biopolymers which are animal-derived. These are animal sourced biopolymers which are chitin and chitosan, casein. Chitin and chitosan extracted from shellfish such as shells of shrimps. Chitosan can soluble in water and it tends to interact with negatively charged surfaces. Chitosan consist of D-glucosamie and N-acetyl-D glucosamine. After dissolution in acetic acid, chitosan becomes cationic due to the amino groups positive charges. By this means, chitosan interacts with negatively charged clay particles. Casein is one of the protein biopolymer and it behaves negative at pH of 6.6. High-quality casein is derived from skim milk and is the best casein to use in soil improvement works. However, protein-based biopolymers show limited hydrophilic properties and less trend water absorption than other polymers.

Lastly, Fatehi et al. (2021) mentioned about microorganism-based biopolymers which are gellan gum, polylysine, dextran and xanthan gum. Microorganism-based biopolymers are derived from bacterial and microbial fermentation; they are a renewable resource. One of the microorganism- based biopolymer is gellan gum. Sphingomonas elodea bacterias fermentation produces gellan gum. Gellan gum has high molecular weight biopolymer and thermogelatin anionic polysaccharide. When temperature higher than 90°C, gellan gum can soluble in water. Later on when the temperature is lowered, it forms a gel. Studies shows that this biopolymer shows stable behavior at low pH and high temperatures. Also, this biopolymer can form high-quality gels remarkably. All these features of gellan gum makes it suitable additive for soil improvement. Polylysine is another microorganism- based biopolymer. Polylysine is bacterial fermentation product commonly in the strains in the genus Streptomyces. It has both hydrophobic and hydrophilic features. ε-polylysine positive charges can interact with negatively charged surfaces such as fine clay. Dextran has complicated branched glucan. Dextran gets from sucrose by particular lactic-acid bacteria. Dextran can soluble in the water and its solubility was not affected by pH. Dextran solutions shows Newtonian fluid feature. Dextran has microbial production process for usage in geotechnical application. Leuconostoc mesenteroides bacteria was used to produce dextran in fine sand reduce the surface erosion rate. Xanthan gum (XG) is used in various sectors such as in mainly cosmetics industry, food industry; and also oil, paper, paint, pharmaceuticals and also textile industries as a thickening, gelling, or suspending agent, and as a flocculent as well for viscosity control. Due to these properties, the suitability of its use in soil improvement has been the subject of research by engineers recently.

Chang et al. (2015) observed an increase in the strength of coarse-grained soils treated with xanthan gum due to the xanthan matrix created on the soil surface and in the soil voids. They also noticed that while this matrix increases the soil stiffness, increases its fragility. In fine-grained soils such as clay, xanthan gum increases strength by forming hydrogen or electrostatic bonds with soil particles and xanthan monomers. Thanks to these bonds, soils that are well graded, strengthening is maximized. In this study, they decided optimum Xanthan gum concentration approximately 1–1.5%. Also, they noticed that Xanthan gum's strengthening effect dependent on four factors, these are type of soil, Xanthan gum content, moisture content and mixing method (dry and wet mixing).

Soldo and Miletić (2019) studied different types of soil and analyzed the compressive strength of silty sand with and without XG and they have seen that the compressive strength of silty sand which is treated with Xanthan gum remarkably higher than silty sand without XG. According to study, the compressive strength increased about %180 after applying XG. Based on this result, they found that sands with a certain amount of fine particles interact better with XG and give better results. They also mentioned that the shear strength of silty sand treated with XG increased. According to conclusion of their study, they suggested two ways to apply XG for soil stabilization. One of them is mixing XG mechanically in gradually with soil and then add water to the soil-XG mixture for soil surface. Another suggestion is firstly dissolving XG in water and then add this solution to soil for deeper soil improvement.

Sujatha and Saisree (2019) studied the effects of guar gum on silty sand. In their study, they found that as the amount of guar gum in the mixture with the soil increased, the liquid and plastic limits of the soil increased and also shrinkage limit. They observed that as guar gum was added to the soil, the dry unit weight increased and the optimum moisture content decreased. They mention that the reason for this is that the gum reduces the friction between the particles in the soil matrix. The addition of guar gum showed a significant reduction in the permeability of the soil. They found that guar gum provides the soil with high shearing resistance. Smaller void ranges and the strong hydrogen bonds contributes higher unconfined compressive strength when soil treat with guar gum. In the study, it was observed that the curing time increased the strength of the soil as well as when the amount of guar gum increased. It was also observed that durability increased with increasing guar gum content.

Zhang et al. (2018) researched some engineering properties of lignin to low-plastic silt. In the study, they observed that as the amount of lignin increased, undrained shear strength also increased. They found that this is due to the fact that lignin binds the soil particles to each other better and forms cementing materials. Also, Lignin's chemical formation of had a noticeable effect on the Atterberg limits of the stabilized silty soil.

Fatehi et al. (2018) studied engineering properties of casein which is a protein-based biopolymer and sodium caseinate salt which is production of sodium hydroxide is added to casein, on poorly graded sand. Both increase in sodium caseinate and casein, increased the compressive strength of soil samples. Casein treated samples compressive strength was appreciably grown until 7 days. After 14 days of curing, it was observed that the compressive strength reached the maximum level and increasing process sustained stable up to 28 days. It was observed that soil treated with sodium caseinate needed more time to achieve maximum compressive strength compared to soil treated with casein. For both biopolymers, it had observed that the compressive strength increased when the temperature increased up to 60°C. They found that casein and sodium caseinate interacted productively with the soil and formed more resistant bonds most effectively at 120°C. Both biopolymers were found to increase the shear strength parameters of the soil. The casein treated soil has increased friction angle than sodium caseinate treated soil samples. When casein and sodium caseinate biopolymer increase, CBR value increased. Sand samples which is treated with sodium caseinate has shown greater strength than which is treated with casein.

Ayeldeen et al. (2017) researched effects of guar gum and xanthan gum on collapsible soil. When both xanthan and guar gum increased, maximum dry density of soil reduced. According to study wet mix method is more effective than dry mix method for reducing the collapsible potential. Both biopolymers reduced friction angle of soil but increased cohesion.

Cabalar et al. (2017) studied effects of xanthan gum to sand. Study showed that higher XG amount decrease void ratio and permeability in sand. In addition, the consolidation test, showed that higher xanthan gum content decrease soil’s compressibility under load and its expansion after release or compression. This study also showed that UCS values increased proportionally with XG value and curing time. In addition, the authors observed that as xanthan gum was added to the soil, the compressibility decreased noteworthy and the stiffness increased noticeably.

Singh and Das (2020) researched effects of xanthan gum to high plastic silt. The study showed that the liquid limit value decreased as the amount of XG increased, but the plastic limit value increased continuously. It was also observed that the shrinkage limit increased with increasing XG content. With the increase in XG content, MDD gradually decreased and OMC increased in light compaction. However, they observed the opposite effects in heavy compaction. Results of UCS in this study showed that XG increased the soil strength. They also found that the swelling pressure decreased as the XG content increased. As a result of the experiments, they found that the XG addition to the soil increased the compressibility index moderately. They found that while the XG amount in the soil increases, the soil's permeability decreases. They also investigated effect of XG added to the soil on freezing/thawing. They found that the moisture and weight loss of soils containing XG was less than those without XG. Joga and Varaprasad (2019) investigated the improvement of the engineering properties of clay by XG. They observed that maximum dry density value decreased when amount of XG increased. In UCS experiment, they observed an increase in the strength of the clay mixed with XG during the curing period up to 28 days. However, they found that the strength did not increase as much in the later curing periods (90 days). In their direct shear test, they observed that the cohesion value of the samples increased significantly with the curing time, but the same was not the case for the internal friction angle values. They found that the compressibility of XG treated soils improved with the extension of the curing time.

Hamza et al. (2022) investigated the effect of XG on the engineering properties of fat clay. According to study increase in XG amount in soil increase liquid limit and plastic limit. Maximum dry density was also found to increase with increasing XG. Study showed pore fluid viscosity increases with an increase with XG. They also found that UCS and CBR values increased with the amount of XG in the soil and curing time. They stated that even a small amount of XG significantly increased the strength of the samples with a long curing time. They observed that the stabilization of the soil improved slightly over time with the addition of XG.

2.3 Waste Materials

Since the 1960s, the rapid development of industrialization, the misuse of natural resources worldwide and population growth have accelerated the accumulation of atmospheric CO_2 concentration Bauer et al. (2013); Hossain (2022).Studies have shown that the accumulation of CO_2 in the atmosphere is currently 400 ppm, which is dangerous for human health Hossain (2022); Li et al. (2016).Considering this situation in terms of geotechnical engineering production of new materials for soil improvement also cause carbon emissions worldwide. In addition, wastes generated from old buildings, industry and many other sources pose a great threat to the environment due to disposal problems. Limestone or lime is best known, a common and classic waste and additive.

Pastor et al. (2019) studied waste limestone powder effects on medium-low plasticity clay. In the study, a decrease in liquid limit and plasticity index was observed when limestone powder was added to the soil but plastic limit kept almost constant. It was observed that the swelling decreased in the soil to which limestone powder was added, but the UCS value increased with increasing limestone powder amount. It was also stated that the void ratio, Cc and Cs values decreased with the increase in the amount of limestone powder.

Reddy et al. (2018) researched waste limestone powder effects on black cotton soil. Similarly, to Pastor, he found that limestone powder reduced the swelling of the soil. He observed that the maximum dry density of black cotton soil increases up to a certain lime powder content and then decreases. He also found that up to a certain limestone dust content, the optimum moisture content decreases, but as the limestone dust content continues to increment, the optimum moisture content increases. Sharma and Sharma (2021) mixed rice husk ash (agriculture waste) and construction demolition waste (broken cemented floor)are mixed in changing amounts in clayey soil alone and together with lime. By mixing these materials in certain ratios, he studied their engineering properties. He observed that OMC and MDD increased in the mixture of clay and rice husk ash. OMC and MDD decreased in the mixture of clay and construction demolition waste. OMC increased, MDD decreased in the mixture of clay and lime. OMC increased, MDD decreased in the mixture of clay, lime and rice husk ash and mixture of clay, lime and construction demolition waste and mixture of Clay: RHA: CDW: lime mixture. UCS tests for all mixtures showed that the strength of the samples increased. CBR results showed that mixture of clay and lime obtains the highest CBR value followed by mixture of clay, rice husk ash, lime and construction demolition waste; mixture of clay, construction demolition waste and lime; mixture of clay, lime, rice husk ash; mixture of clay, construction demolition material and clay, rice husk ash mixture.

Abbey et al. (2020) studied how changed mechanical properties and microstructure of clay soil when it mixed with by-product cementitious materials, polypropylene and glass fiber. They observed an increase in UCS when the polypropylene, glass fiber and cement content in the soil mix was increased. They observed that the compressive strengths of soils containing less cement increased at higher curing temperatures.

Butt et al. (2016) studied geotechnical effects of saw dust ash (SDA) which is waste of wood, on clayey soil. They observed increases in liquid limit and plastic limit with increasing saw dust ash content in the soil. They stated that this was due to the high water absorption of saw dust ash. They found that the maximum dry density decreased with increasing saw dust ash content in soil, but the optimum moisture content increased up to a certain saw dust ash content and then decreased. It was reported in this study that the CBR values of the soil mixed with saw dust ash improved significantly. They stated that the strength values of the soil mixed with saw dust ash increased up to a certain saw dust ash ratio, then it decreased strength of soil at higher ratios due to the low strength of saw dust ash.

Qu and Zhu (2021) mixed palm fiber with clayey soil. The palm fiber has been obtained from the palm trees. They found that the compressive strength of clay soil and ductility of soil increases with the length and fiber content of palm fiber up to a certain point. They also found that palm fiber increased the energy absorption capacity of clay soil. In the experiment conducted in this study, it was found that the palm fiber made the fracture tendency of the soil ductile and formed a single diagonal shear plane, at the same time, the fracture formed multiple cracks and bulging occurred in the middle of the sample. It was observed that ductility increased with the addition of palm fiber to the soil.

Akbulut et al. (2007) used scrap tire rubber, polyethylene, and polypropylene fibers to improve clay soil. It was found that when scrap tire rubber fibers were mixed with clay, UCS values increased up to a point but then decreased. An increase in the UCS values of the clay samples mixed with both polyethylene and polypropylene fibers was observed. Soil's damping ratio and shear modulus increased with tire rubber, polyethylene and polypropylene fibers. In addition, it was determined in this study that both the length and the content of synthetic fibers are important for soil improvement. Salehi et al. (2021) examined effect of crushed stone waste and cement and their combination on silty sand. When crushed stone was added to silty sand, an increase in MDD and a decrease in OMC were observed. When cement was added, it was observed that it increased OMC to a certain extent, but did not affect MDD very much. In the study, it was observed that the pH values of mixture of silty sand and cement increased as the cement content increased. It was observed that the soil's CBR values increased when increase in crushed stone waste or cement content at a definite curing time. It was also found that CBR values improved with increasing curing time. It was observed that the UCS value increased while increasing in cement in the soil. However, in the mixture of waste stone and soil, the UCS value increased up to a certain waste stone ratio and then started to decrease lightly. They performed a freeze-thaw test to check the strength of the samples. As a result of this test, they found that the CBR values of the soils mixed with cement were affected more than the soil samples mixed with crushed stone. They also observed a decrease in the UCS values of the samples used in this experiment for both mixtures.

Al-Baidhani and Al-Taie (2020) investigated effect of recycled crushed ceramic rubble (RCCR) on the expansive soil. Study showed that mixture of expansive soil and recycled crushed ceramic rubble reduced the liquid limit, plastic limit, and plasticity index. It was also determined that the plastic limit decreased as the recycled crushed ceramic rubble ratio in the mixture increased. Also, it was found that the maximum dry density increased when recycled crushed ceramic rubble was added to the soil. It was observed that OMC decreased when recycled crushed ceramic rubble was added to the soil. It was stated that this was due to the ceramic fragments reducing the moisture holding capacity of the soil. Recycled crushed ceramic rubble increases specific gravity, maximum dry unit weight and soil strength but decreases swelling. When recycled crushed ceramic rubble added to soil plasticity and compaction properties improved.

Al-Bared et al. (2018) examined geotechnical effects of recycled ceramic crushed tiles (RCT) on soft soil. In this study two sizes waste material were used. Both sizes of waste material were improved compaction and MDD and strength of soil improved significantly.

Poon and Chan (2006) studied the effect of recycled concrete aggregates and crushed clay bricks on the soil when used as sub-base material. They noted that crushed clay brick is much weaker than recycled concrete and clean soil. They stated that the strength of recycled concrete aggregate and crushed clay brick decreased after soaking. They found that the optimum moisture content increased when coarse-grained clay bricks were added to the soil, crushed clay brick particles decreased the maximum dry density due to the effect of high water absorption and low particle density. The experiments showed that the soil mix mixed with fine recycled concrete aggregate was more sensitive to changes in moisture than the soil mixes containing finely crushed clay bricks. They found that soil containing smaller clay brick grains had less sharp moisture-dry density curves. It was observed that CBR values decreased as the brick ratio in the soil increased.

Arulrajah et al. (2013) investigated C and D materials(recycled concrete aggregate, crushed brick, waste rock, reclaimed asphalt pavement, and fine recycled glass)'s geotechnical and geoenvironmental properties on the soil. They found that water absorption decreased as the grain diameter increased for all materials. In the experiments, they found that waste rock had the highest MDD and fine recycled glass had the lowest value. The experiments showed that waste rock has the lowest OMC and waste brick has the highest OMC among the waste materials. Study showed that by the whole of waste materials, mixture of soil with recycled concrete aggregate and crushed brick had the lowest permeability and highest permeability had shown mixture of waste rock, reclaimed asphalt pavement and fine recycled glass. The study showed that recycled concrete aggregate, waste rock and fine recycled glass are more resistant to abrasion than recycled concrete aggregate and crushed brick. They found that recycled concrete aggregate, crushed brick and waste rock were affected by increasing the target moisture content and density level.

Rahman et al. (2014) studied the geotechnical properties of recycled construction and demolition waste materials (crushed brick, recycled concrete aggregate and reclaimed asphalt pavement) to evaluate their appropriateness as pipe backfill materials. They observed that the specific gravity of reclaimed asphalt pavement was lower than recycled concrete aggregate and crushed brick. Waste materials specific gravity showed that they can be considered good quality aggregates for engineering applications. The study showed that the specific gravity of coarse grain sizes of all waste materials was slightly higher than that of fine grain sizes. They also observed that the water absorption capacity of coarse particle size was lower than that of fine particle size for all wastes. In the study, it was observed that hydraulic conductivity was low for recycled concrete aggregate and crushed brick but high for reclaimed asphalt pavement. They found that the crushed waste brick and recycled concrete aggregate were well interlocked with the soil during compaction. They found that recycled concrete aggregate has more resistance to abrasion than crushed brick and reclaimed asphalt pavement. It was determined that reclaimed asphalt pavement had the lowest OMC and crushed brick had the highest OMC in the waste materials tested. They found that while the shear strength of recycled concrete aggregate was higher than crushed waste brick, reclaimed asphalt pavement had the lowest shear strength among all waste materials. The study also showed that the strain percentages for crushed waste brick, reclaimed asphalt pavement and recycled concrete aggregate materials increased with the rise in confining effective stress. According to the study, these waste materials can be categorized as non-hazardous waste.

Durga and Prasad (2017) used waste brick and lime to improve the engineering properties of the black cotton soils. In the study, they found that the CBR value increases as waste brick dust and lime separately or together were added to the soil. In their study, they observed that lime increased the CBR value more than waste brick. They also stated that the decrease in OMC and the increase in MDD were higher in the samples mixed with lime compared to the samples mixed with waste brick.

Cabalar et al. (2019) investigated the effects of dragged asphalt, crushed waste brick and crushed waste concrete paving slab on the swelling of clay. The study showed that the liquid limit and plastic index values of the soil decreased when mixed with each waste material. They found that the swelling values obtained from the consolidation test were higher than the CBR values. They concluded that this may be due to the different dimensions of the samples and the surcharge load applied vertically. They also thought that the particle size of the wastes they used for the experiments might have caused this situation. They obtained the best results in both the oedometer and CBR tests on the mixture of soil and dragged asphalt pieces and the worst results on mixture of soil and waste brick. Since dragged asphalt and crushed concrete paving slab have a higher specific gravity than waste crushed brick, they had to be mixed with clay in smaller quantities. They figured out that this resulted in more clay in the oedometer cell than dragged asphalt and crushed concrete paving slab, so these mixtures swelled more than the waste crushed brick and soil mixtures.

Al-Obaydi et al. (2022) examined engineering effect of dragged asphalt, crushed waste brick, crushed waste concrete on soil. In their experiments, they observed that dragged asphalt significantly reduced the optimum moisture content of the soil, while waste crushed brick and crushed concrete did not change it much. They stated that waste crushed brick and crushed concrete can also absorb water, but not as much as clay. They determined that except for waste crushed bricks, other wastes increased the maximum dry unit weight of the soil. In general, they found that the addition of construction waste to clay soil increased the strength of the soil. They found that crushed concrete waste increased strength and stress the most, followed by dragged asphalt and waste crushed brick, respectively. The CBR experiments showed that if the thickness of the layers of the soil mixed with waste materials is increased, the strength values will also increase.

Sharma and Shrivastava (2022) researched the shear strength properties of recycled construction and demolition (C and D) materials mixtures with soil. The CBR results showed that recycled concrete aggregate has the highest shear strength followed by crushed brick and reclaimed asphalt pavement. Also CBR results showed that recycled concrete aggregate and crushed brick are good quality materials for pavement sub-bases but reclaimed asphalt pavement does not suitable for usage in subbases. Additionally, crushed brick showed lower shear strengths than other materials.

Leite et al. (2011) investigated the usability of recycled construction waste(mixture of ceramic, concrete blocks, mortar, reinforced concrete, steel, plastic, asbestos cement and wood) in pavement applications. It was observed that the water absorption of soils mixed with materials with high porosity such as bricks and tiles increased. They also found that cementitious materials have frequently cubic particles, while less porous ceramic materials have usually flat particles. Compaction was found to affect the grain size of the waste material. They observed that the particles break during the compression process and that this breakage increases with the increase in energy. Additionally, they found that this fracturing changed the grain shape classification of the waste materials. They observed a slight decrease in the permanent deformation of the sample compressed at higher energy at the same stress level. They also stated that the everlasting deformation of the waste material depends on the stress level.

Getaneh (2020) investigated the engineering effects of gypsum and crushed waste brick mixed with soil. They used certain proportions of gypsum and waste bricks together in the same soil mixture. At the end of the study, they found that combined use of gypsum and waste brick reduced the liquid limit, plastic limit and plastic index values of the soil. They also found that the combined use of gypsum and waste brick increased the OMC value of the soil but decreased the MDD. They also observed that the mixture of gypsum and waste brick increased the CBR value of the soil but decreased the swelling.

Melbouci (2009) study showed that crushed brick decrease dry density. They also observed that the CBR values of the soil decreased with the addition of waste bricks. They explained the reason for this as the increase in pore water pressure due to the imbibition of waste brick. They found that the highest shear strength when small grained bricks in dry state were added to the soil and observed that the deformation of the samples was very low. They found that the friction angle increased and cohesion decreased with the addition of brick particles to the soil.

Arulrajah et al. (2011) examined engineering effects of waste brick to improve the soil. Study mentioned if moisture content increased, shear strength of the crushed brick reduced. Study showed that water absorption of large grained waste bricks is less than that of fine grained bricks. They found that the hydraulic conductivity value of the waste brick fragments was very low, moreover stated that the brick particles had relatively fewer elongated aggregates, which increased the workability of soil.

Blayi et al. (2020) investigated the changes in the soils engineering properties waste brick at different ratios of added to high plasticity clay. In the study, they observed a decrease in liquid limit, plastic limit, plasticity index, and linear shrinkage as the proportion of waste brick added to the soil increases up to a certain point. They found that MDD increased with the increase in the amount of waste bricks added to the soil, but OMC decreased. They also found that swelling and permeability decreased with the addition of waste bricks to the soil. They determined that the strength of the soil increased with the addition of waste bricks, but the energy absorption capacity of the soil decreased and the ductility of the soil decreased. Due to the decrease in the ductility of the samples, they have shown transition from ductile fracture to brittle fracture. Study showed that as the amount of waste bricks added to the soil increased, the CBR values and friction resistance of the samples increased.

CHAPTER 3
MATERIALS AND EXPERIMENTAL METHODOLOGY

3.1 Materials

3.1.1. Soil

Soil was residual soil that is mainly disturbed in Gaziantep University Campus. Table 3.1 shows the main geotechnical properties of this soil. It is classified as silty sand (SM) according to the Unified Soil Classification System (USCS). The grain size distribution of the sample silty sand can be seen in Figure 3.7 and SEM pictures shown in Figure 3.2.

Table 3.1. Main geotechnical properties of the soil used in this study

Soil Properties	Value
% Gravel	12,19
% Sand	50,60
% Silt	26,79
% Clay	10,42
Liquid Limit	29,348
Plastic Limit	22,830
Plasticity Index	6,518
Gs	2,68
Optimum Moisture Content, %	18,5
Maximum Dry Density, kN/m^3	17,2

Figure 3.1. Photo of silty sand

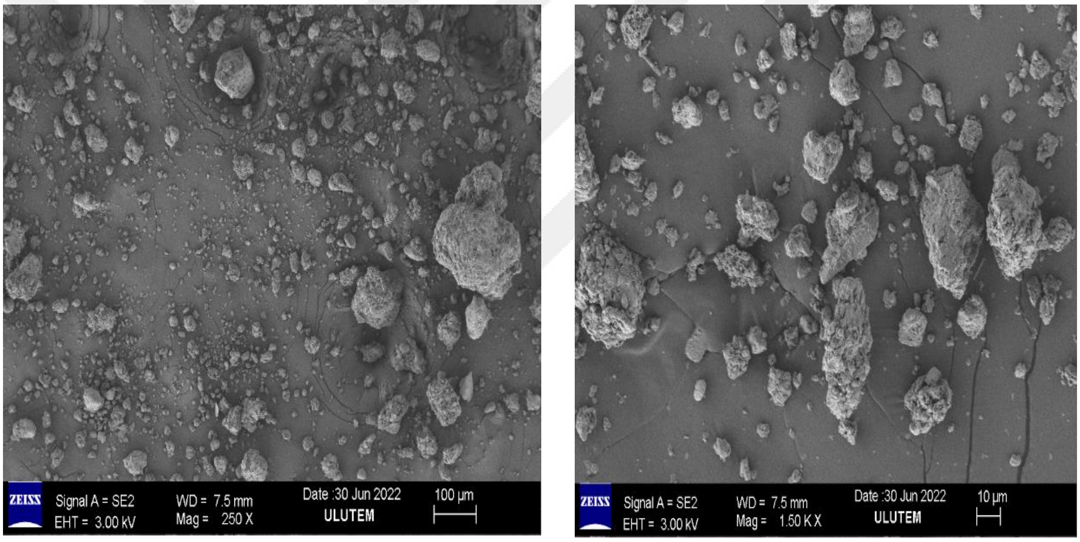


Figure 3.2. SEM pictures of silty sand

3.1.2. Waste Brick

Waste brick was obtained from the ruins of the former student dormitory located on the Gaziantep University Campus. It was determined that the bricks consisted entirely clay by performed sieve analysis and hydrometer analysis. Specific gravity of brick found 2,67. It was determined that the bricks consisted entirely clay by performed sieve analysis and hydrometer analysis. Large brick pieces were broke into smaller pieces by hammer and sieved according to the experiments to be carried out. Even small pieces often had angular geometry, as the bricks were broken by hand (by hammer). The grain size distribution of the sample waste brick can be seen in Figure 3.7 and SEM pictures shown in Figure 3.4.

Figure 3.3. Photo of waste brick before and after breaking for experiments

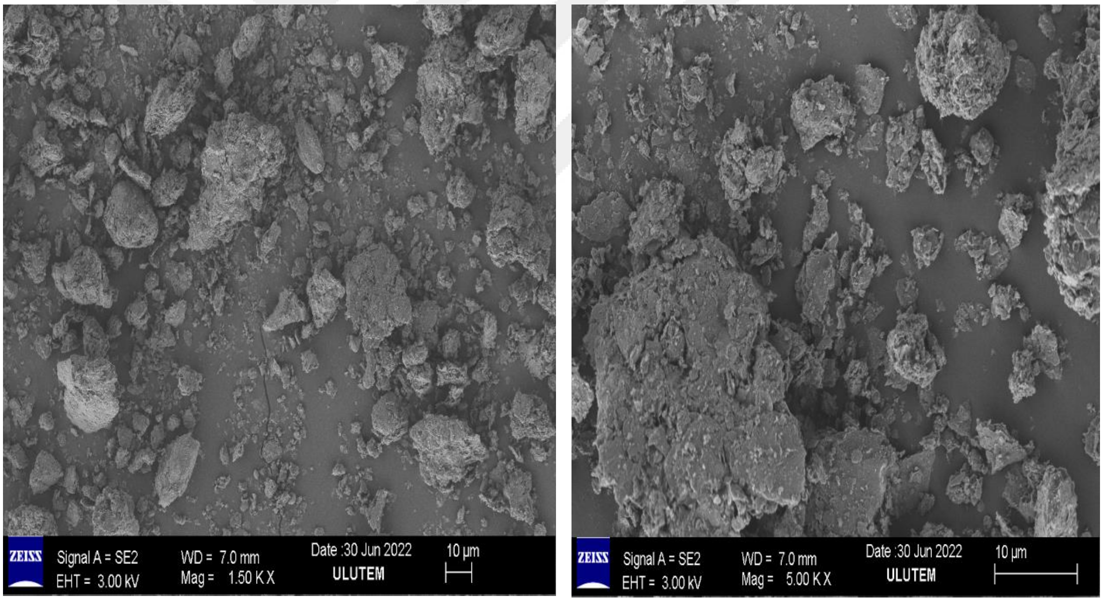


Figure 3.4. SEM pictures of Waste Brick

3.1.3. Xanthan Gum

Xanthan gum ($C_{35}H_{49}O_{29}$) is a polysaccharide which the result of glucose-sucrose fermentation made by the Xanthomonas campestris. Xanthomonas campestris is anaerobic and microaerophilic bacteria so that it can be produce in the laboratory with an optimum growth temperature of about 25–30°C and with an optimal pH between 6 - 8 easily. Xanthan gum shows high stability under a wide range of temperatures and pH (Chang et al. (2015)). Usage of a small amount of xanthan gum increase in the viscosity of a liquid noteworthy (Latifi et al. (2017)). The SEM pictures shown in Figure 3.6.

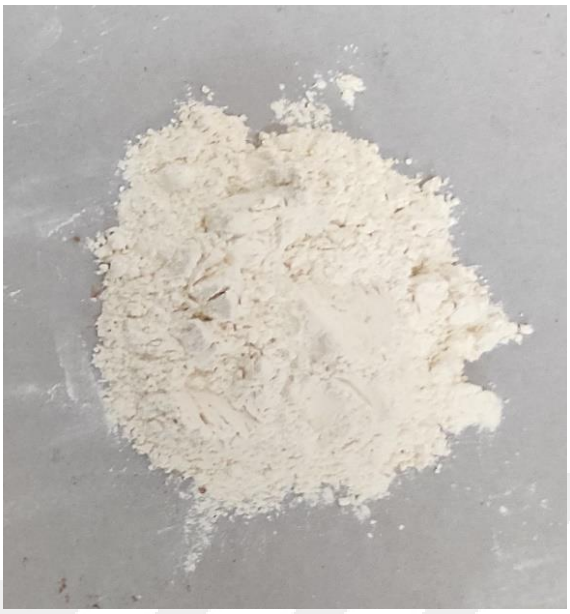


Figure 3.5. Photo of Xanthan gum

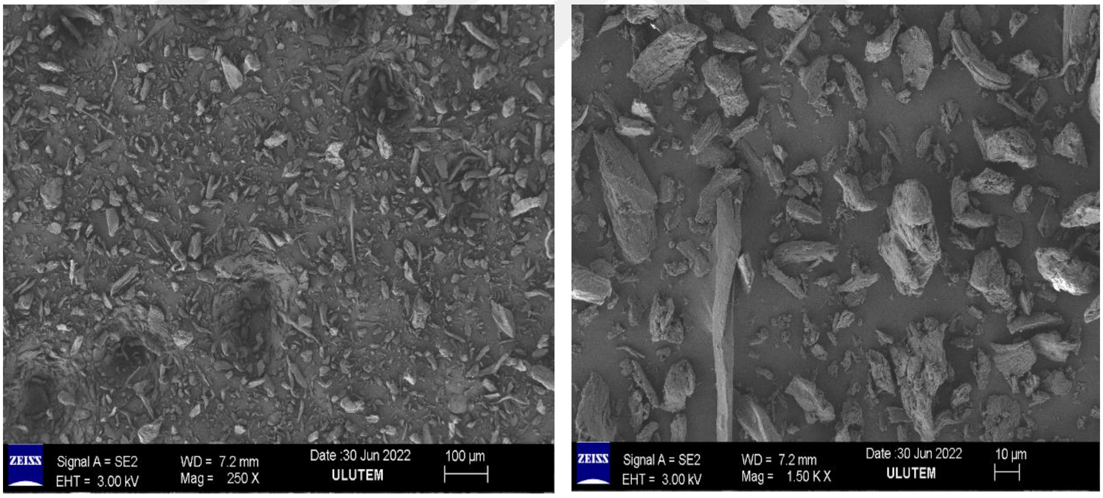


Figure 3.6. SEM pictures of Xanthan gum

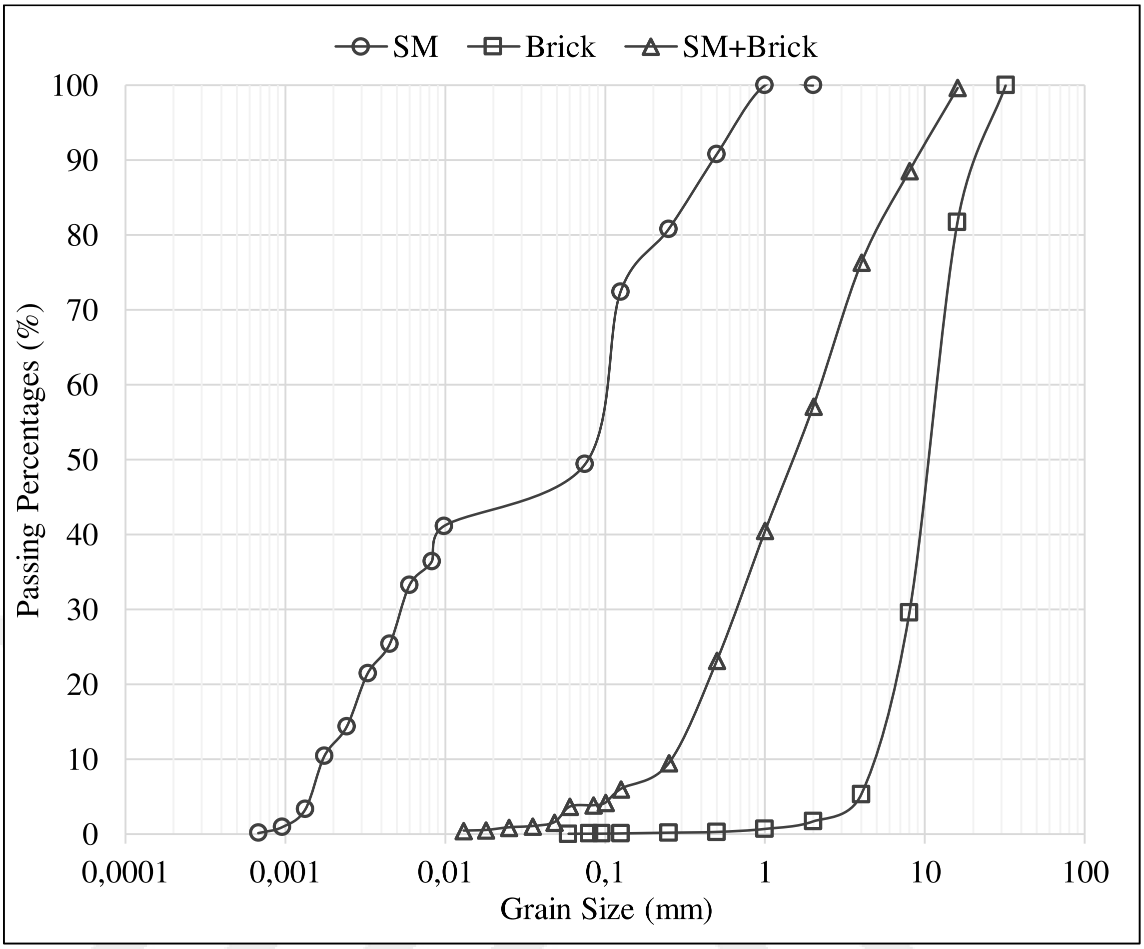


Figure 3.7. Grain size distribution curve

3.2. Sample Preparation

For experiments, the soil below the 1 mm sieve was used and large waste brick pieces were broken into smaller pieces by hammer the size of the waste brick was sieved to be one tenth of the diameter of the container to be used in the experiment according to the experiment to be performed. In the experiments, the soil and waste brick kept in the oven for 24 hours was used to ensure the water content. During the preparation of the samples, 0.5, 1 and 3% XG and %10 waste material (Cabalar et al., 2016) was added to the soil and dry mixing was performed.

Figure 3.8. Apparatus and scale used to mix materials

3.3. Experimental Methodology

For these study some of laboratory tests have done. These are particle-size analysis, hydrometer test, specific gravity test, Atterberg limits test, fall cone test, vane shear test, compaction test, falling head permeability test, California bearing ratio (CBR), oedometer test (consolidation), unconfined compression test (UCS).

3.3.1. Particle-Size Analysis and Hydrometer Test

Particle-size analysis and Hydrometer test have carried out according to ASTM D422-63 (2007). For particle-size analysis clearly weighted soil is prepared. Then, the weights of the completely clean sieves and pan are weighed and noted. The sieves are arranged in order with the one with the largest aperture at the top and the one with the smallest aperture at the bottom. Soil is poured from the top onto the sieves and the sieve shaker is operated for 15 minutes. The sieves with retained soil on them are then weighed again and noted. The particle size curve is then generated by making the calculations specified in the standard. The hydrometer test is performed to determine the proportion of smaller particles such as clay in this soil sample. 50 grams of the remaining soil in the pan is taken. The ground and 1 liter of water are mixed almost homogeneously by shaking up and down in a glass measuring cylinder. Then the cylinder is placed on a flat and solid surface. The hydrometer is dropped into the cylinder. Measurements are taken at certain time intervals. The hydrometer is cleaned and dried before each reading. After the last reading is taken, the processes specified in the standard are performed and the table formed forms the fine-grained part of the sieve analysis.

Figure 3.9. Sieve with sieve shaker and hydrometer

3.3.2. Specific Gravity

Specific gravity test has carried out according to ASTM D792-20 (2020). Firstly, empty pycnometer with its cap is weighed. Then about 200 grams of soil is placed in the pycnometer and weighed with cap. The pycnometer with the soil is then completely filled with water. The soil and water are thoroughly mixed and then the air inside the pycnometer is vacuumed, then weighed. The pycnometer is then drained and cleaned. Lastly, only water filled into the clean pycnometer and weigh it. The weights which is noted before are used in the formula in the standard to find the specific gravity.

Figure 3.10. Pycnometer and vacuum

3.3.3. Atterberg Limits

Atterberg limits was performed according to ASTM D 4318-00 (2000). For determining to liquid limit Casagrande cup method is used. The soil and water mix until homogenous. Then, the soil paste is placed in the Casagrande cup and a groove is made at the center of paste. Starting from low water content, the experiment continues towards high water content. The number of blows for each test is written down and the small amount of sample is placed in the oven for water content. Then the graph of the number of strokes and water content is plotted. The water content corresponding to 25 strokes in the graph indicates the liquid limit of the soil. The Plastic limit test is performed rolling mixture of soil and water by hand on a non-porous surface. Plastic limit is the water content at which soil just crumbles when it is meticulously rolled out to a diameter of 3 mm. If the soil crumbles at diameter smaller than 3 mm means that the soil is too wet. If the soil crumbles at a diameter greater than 3 mm then this means the soil is drier than the plastic limit.

Figure 3.11. Casagrande cup

3.3.4. Fall Cone Test

Fall cone test have carried out according to ASTM D 4318-00 (2000). The soil sample was prepared to completely fill the container in which the experiment would be performed. The best method for this process is to calculate the volume of the container and determine the amount of soil to be placed in it accordingly. After that, starting from low water content, the amount of water added to the soil was increased after each experiment. The homogeneously mixed soil and water were placed in the container so that there was no gap and the surface was smooth. After the tip of the cone has barely touched the surface of the soil, the button was pressed for five seconds. Then the penetration value for that water content was read some soil was placed in the oven to calculate the net amount of water.

Figure 3.12. Fall cone apparatus

3.3.5. Vane Shear Test

Vane shear test was performed according to ASTM D 4648 (2000).Soil was prepared to fill the container completely. The best method for this was to calculate the volume of the container and accordingly determine the amount of soil to be put into it. Then, starting from low water content, the amount of water added to the soil was increased after each experiment. Lower vane slowly mid into the soil and rotate vane at a rate of approximately 6° per minute (0.1° per sec). The experiment was repeated three times for each soil sample, the first reading and the last reading are noted for calculations. Shear strength calculation were made by averaging the readings.

Figure 3.13. The laboratory vane shear apparatus

3.3.6. Compaction Test

Compaction test have carried out according to ASTM 698-07 (2007). Approximately 5 kg of soil sample was weighed. Clean and dry the mold and the base plate was weighed. The soil sample was divided into three equal parts. One third of the soil was placed in the mold and the entire surface is compacted uniformly with 25 strokes of the hammer. The same procedure was done for the other two layers. Collar was removed and excess soil was cut down above the mold with straight edge. The mold filled with soil was weighed and a sample was taken for water content. Starting from low water content, the amount of water added to the soil was increased after each experiment and at least five experiments were performed to plot a graph and the peak of the graph indicates the optimum moisture content.

Figure 3.14. Compaction test apparatus

3.3.7. Falling Head Permeability Test

Falling head permeability test was performed according to TS EN ISO 17892-11 (2014). Soil sample was prepared at the optimum water content determined by the compaction test and placed in the mold to be used for the permeability test by compaction. Firstly, the sample was saturated by using water. Then three different diameter pipes which are 0.4 cm, 0.5 cm and 1.2 cm were selected for the start of the experiment. Water was supplied to the chosen pipe up to the specified height. How much the water in the pipe decreases over a period of time was noted. This procedure was carried out sequentially for three selected pipes of different diameters. The permeability coefficient was planned to calculated with the data obtained.

Figure 3.15. Falling head permeability test

3.3.8. California Bearing Ratio (CBR)

California bearing ratio (CBR) have carried out according to ASTM D1883-21 (2021). For this study unsoaked CBR test have been done. Sample was prepared at the optimum water content determined by the compaction test for each mixture. Soil was compacted in five equal layers and each layer was should be given 56 blows by 4.89 kg rammer with drop of 450 mm height for heavy compaction. Collar was removed and excess soil was cut down above the mold with straight edge. The mold filled with soil was weighed. After weighing the compacted soil, put the filter paper disc on the base plate. Turn upside down the mold with the compacted soil and clamp the base plate and place a perforated disc. A dial gauge was placed on the molds and the molds are left for 96 hours and the final readings are taken. The mold was weighed again. The mold was then placed in the CBR machine and the load-penetration graph was obtained. CBR % measured at 2.5 mm and 5 mm is important and whichever of these values is greater is accepted as the CBR % of that sample.

Figure 3.16. California bearing ratio (CBR) test apparatus

Figure 3.17. CBR samples

3.3.9. Oedometer Test (Consolidation)

Oedometer test (consolidation) was performed according to ASTM D2435/D2435M-11 (2020). Sample was prepared at the optimum water content determined by the compaction test for each mixture 75 mm diameter and 19 mm thick, confined in a circular metal ring and sandwich in between porous stones. Vertical static load accretions were applied at regular time intervals (e.g. 12, 24, 48 hrs.). The load was doubled with each increment up to the required maximum (e.g. 25, 50, 100, 200, 400, 800 kPa). With a porous stone both top and bottom the soil sample the drainage will be two-way. During each load stage dial gage readings were noted for every time interval. After 24 hours the loads were unloaded as respectively they loaded and let the sample to swell. After which the sample was removed and a sample was taken for water content. This test determines the coefficient of consolidation (cv).

Figure 3.18. Oedometer (consolidation) test apparatus and setup

3.3.10. Unconfined Compression Test (UCS)

Unconfined compression test (UCS) have carried out according to ASTM D2166−00 (2000). Sample was prepared at the optimum water content determined by the compaction test for each mixture. Two-part splinted mold which has 44 mm diameter and 100 mm height was used to prepare to UCS samples. A special designed hammer was used for this test. This hammer was designed considering the required compression energy in accordance with the standard and the number of blows was determined accordingly. Accordingly, it was determined that when the sample was compressed 31 times with the designed hammer, energy equal to the energy applied in the standard UCS was generated and the sample was compressed equally (Cabalar et al. (2018)).

Figure 3.19. Unconfined compression test (UCS) apparatus and setup

After the samples were prepared, they were removed from the mold and kept at room temperature and in the open air during required times. (0, 7, 28 and 56 days) and then tested.

Figure 3.20. Unconfined compression tester during UCS sample testing

3.3.11. Direct Shear Test

Direct shear test was performed according to ASTM D3080/D3080M –11, (2004). Direct shear tests were performed standard direct shear equipment which have digital dial gauges. Sampler which has 60 mm x 60 mm inner dimensions which are also the inner dimensions of shear box, was used. The thickness of box is about 50 mm while thickness of sample has prepared 25 mm. Sample was prepared at the optimum water content determined by the compaction test for each mixture. All samples were compacted in the same way with the direct shear mold at stationary speed. All samples were tested under three different normal stresses which are 0.7, 28 and 55 kPa and a 1.0 mm/min rate of displacement. Horizontal and vertical displacement, also shear force values during the shearing were noted at definite time intervals.

Figure 3.21. Direct shear test

CHAPTER 4
EXPERIMENTAL RESULTS AND DISCUSSION

The influence of xanthan gum biopolymer and waste brick treatment on the characteristics of silty sand (SM) has been studied with different laboratory tests.

4.1. Fall Cone Test

The fall cone test results clearly showed that there was not much change in the liquid limit when only waste brick was added to the soil (from 31,365 to 31,434) but the addition of XG significantly increased the liquid limit as seen in Figure 4.1 and Figure 4.2 (from 31,365 to 44,580). As Al-Obaydi et al. (2022) pointed out brick has less absorption activity. In addition, as can be seen in Figure 4.3, the shear strength values of only waste brick were added almost the same with soil (from 2,36 kPa to 3,88), while an increase in shear strength was observed as XG was added to mix (from 3,88 kPa to 5,93 kPa).

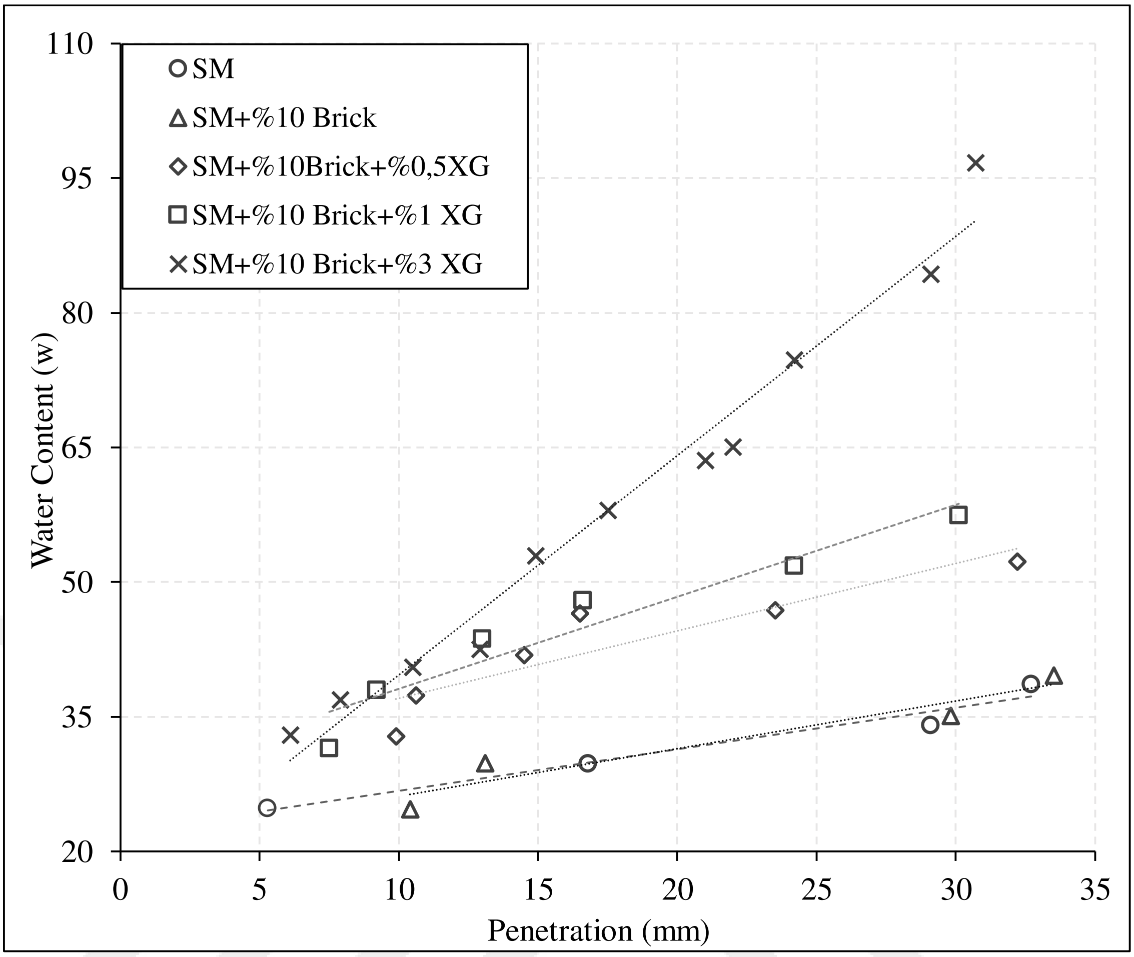


Figure 4.1. Penetration-water content

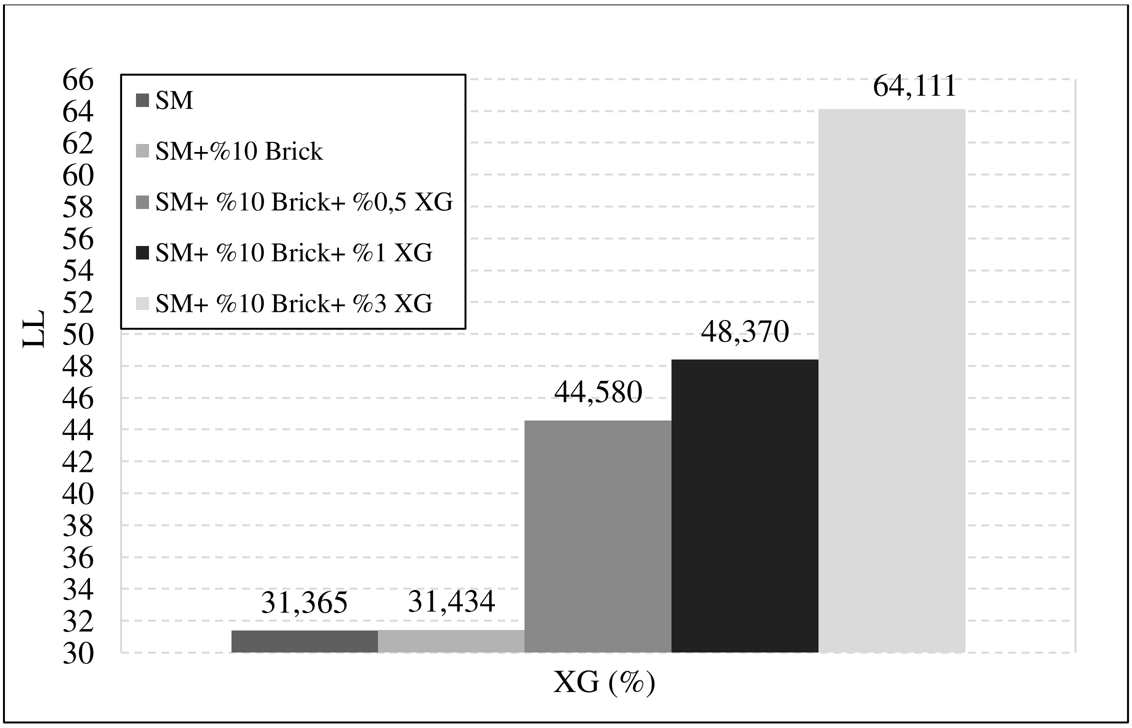


Figure 4.2. Liquid limit-XG ratio

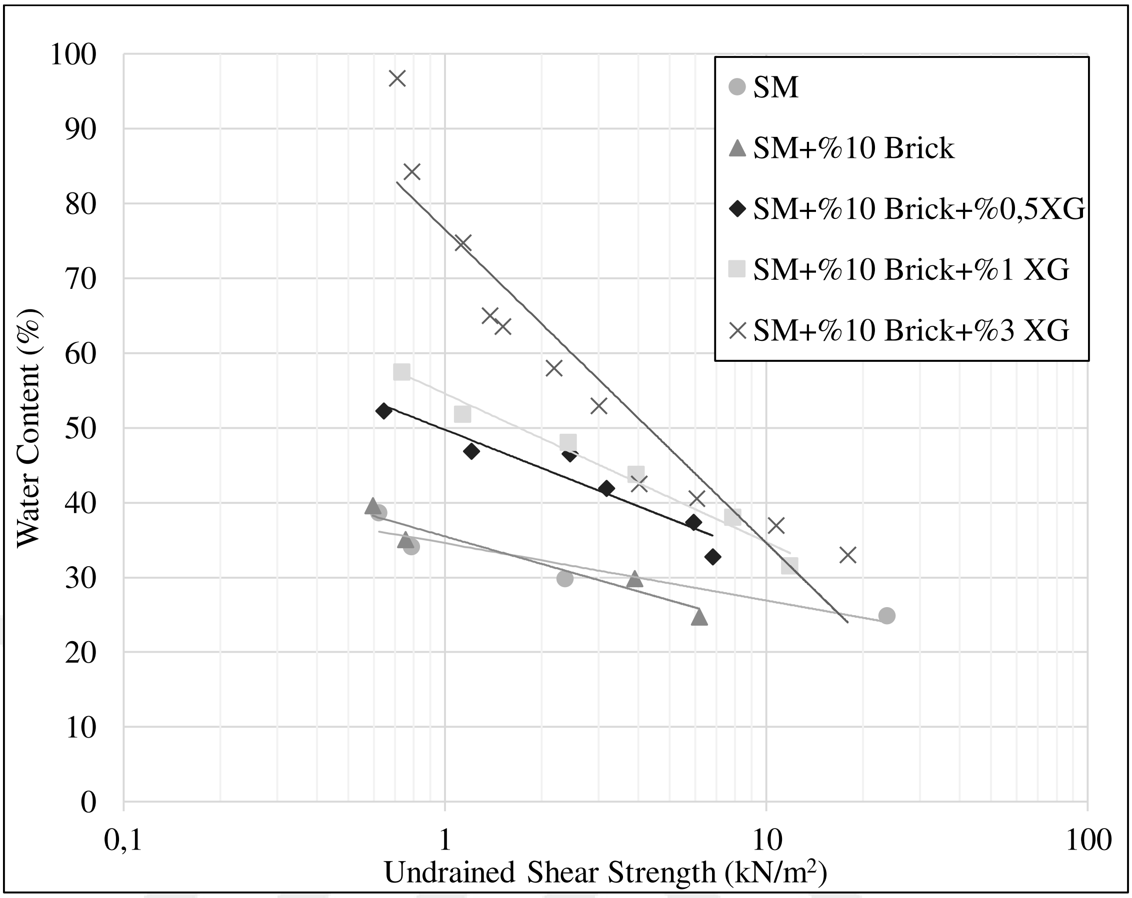


Figure 4.3. Undrained shear strength-water content

4.2. Vane Shear Test

The vane shear test showed higher values than the fall cone test at the same water contents. In the vane shear test, while XG was increasing and the water content remained constant shear strength increased (from 6,285 kPa to 10,422 kPa) because the soil showed more resist as shown in Figure 4.4. Additionally, it was observed that as the water ratio increased for each mixture, the shear strength decreased.

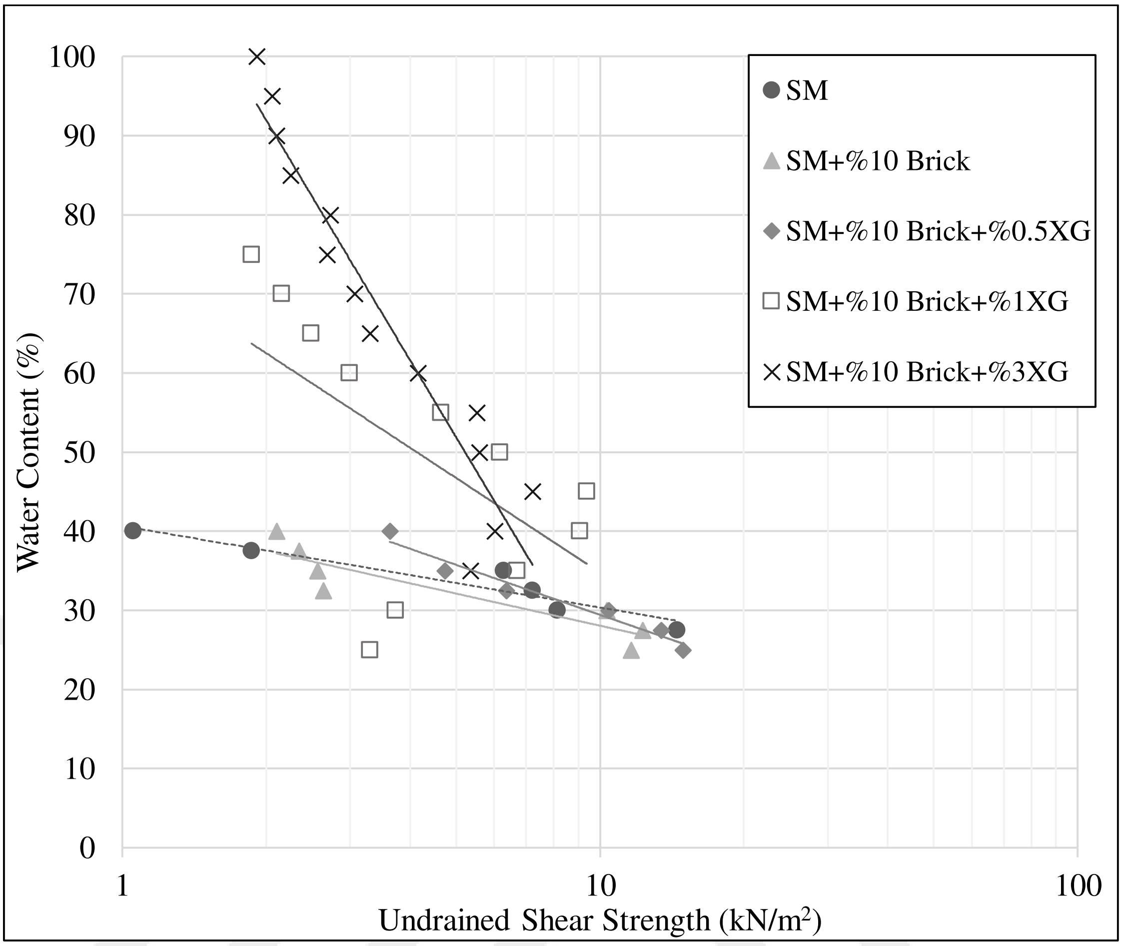


Figure 4.4. Undrained shear strength-water content

4.3. Compaction Test

According to compaction test results, a slight decrease in dry density (from 17,209 to 16,009) and a slight increase in water content was observed when only waste brick was added to the silty sand (from 18,32 to 22,58) like Al-Obaydi et al. (2022); Arulrajah et al. (2013b); Melbouci (2009); Rahman et al. (2014). This is due to the fact that the waste material used is composed entirely of clay. Due to its clay structure, it filled the voids in the soil and absorbed some of the added water as mentioned earlier by Leite et al. (2011). The addition of XG to the soil resulted in a noticeable decrease in dry density (from 17,209 to 15,893 for % 0,5 XG; 14,900 for % 1 XG and 14,403 for % 3 XG) and a significant increase in water content as seen in Figure 4.5 (from 18,32 to 22,874 for % 0,5 XG; 25,26 for % 1 XG and 26,16 for % 3 XG), similar results found by Ayeldeen et al. (2017); Cabalar et al. (2017); Hamza et al. (2022); Poon and Chan (2006); Singh and Das (2020). As Poon and Chan (2006) mentioned earlier, a less sharp moisture-dry unit weight curve was obtained when waste bricks were added to the soil and this sharpness was observed to decrease further with the addition of XG as seen in Figure 4.5.The reason for this is similar to the effect of the waste brick material. However, the reason why XG shows these properties more prominently is that it interacts better with the soil due to its much finer structure and the water absorption capacity of this biopolymer is higher. Figure 4.6 shows the relationship between XG ratio and maximum dry unit weight and optimum water content.

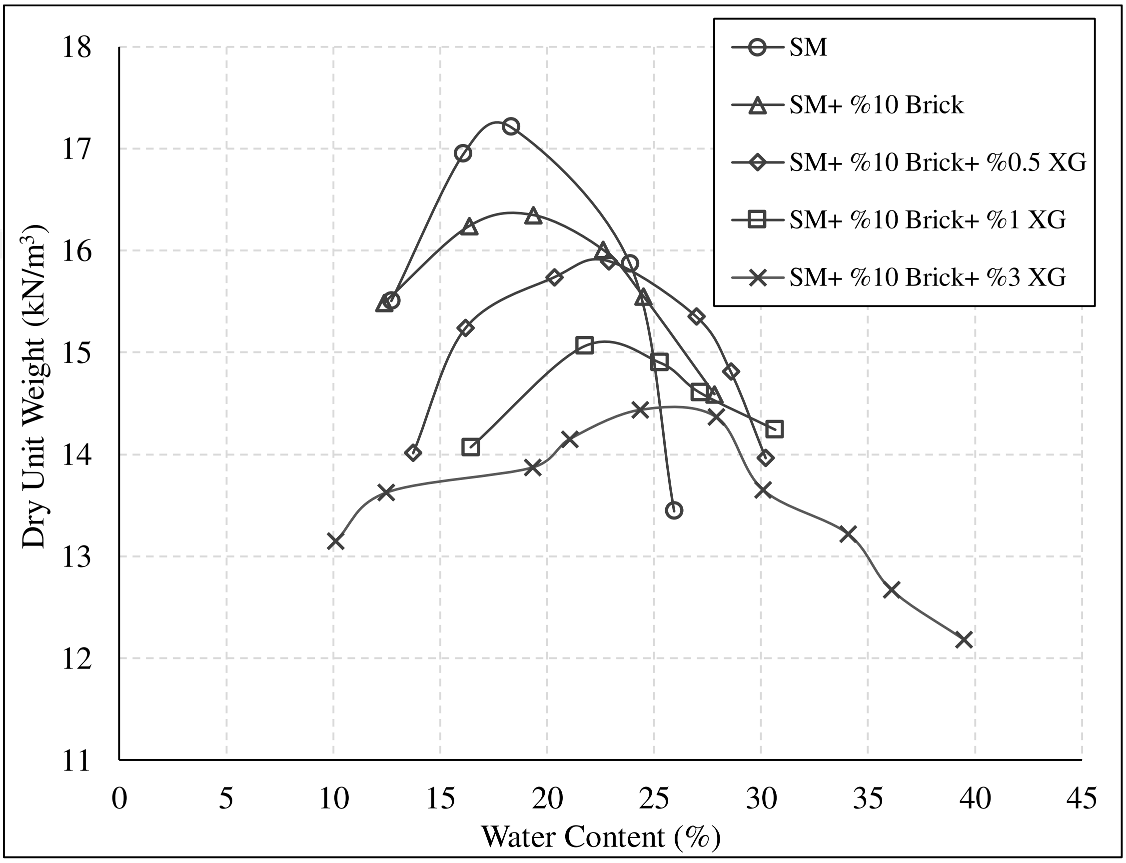


Figure 4.5. Compaction test

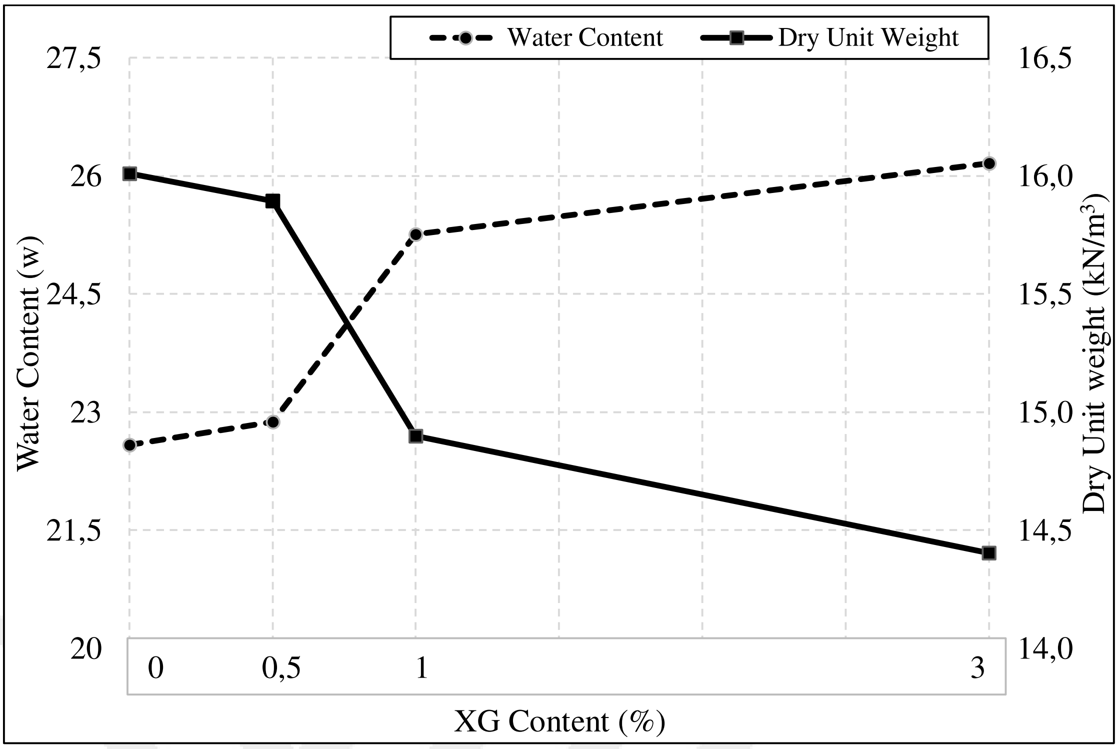


Figure 4.6. Variation of the γ_{drymax} and w_{opt} with XG content

4.4. Falling Head Permeability Test

Falling head permeability testing results showed that higher Xanthan gum content produced lower permeability values in the treated sand. The results showed that the permeability of samples was reduced from $1.46 \cdot 10^{-6}$ m/s (clean silty sand) to $3.07 \cdot 10^{-7}$ m/s by adding only %10 waste brick. The reason for the decrease in permeability when waste bricks are added is that the brick fragments, which are composed entirely of clay, fill the gaps between the soil particles and Arulrajah et al. (2013b); Blayi et al. (2020); Leite et al. (2011); Rahman et al. (2014); Sharma and Shrivastava (2022) mention that brick has high water absorption. Since it is necessary to ensure that the sample is completely saturated with water to start the experiment, water is introduced from the top of the sample and waited for that water to come out from the bottom. This period lasted about two and a half days for clean silty sand and eight days for a mixture of silty sand with 10% brick. However, although only 0.5% XG was added to the silty sand and brick mixture, it was observed that no water came out of the sample despite waiting for a month due to the biological clogging feature of XG and the fact that the waste brick was completely composed of clay. Therefore, the experiment was terminated and other mixtures were not tested. Joga and Varaprasad (2019); Singh and Das (2020) studies have also shown that XG reduces permeability.

4.5. California Bearing Ratio (CBR) Test

California bearing ratio (CBR) tests showed that higher XG contents caused less stress on soil sample. Samples with only silty sand, had a much higher maximum value of the CBR values than those with waste brick and XG. Especially when 10% waste brick was added to clean silty sand soil, there was a remarkable decrease in CBR% (from 7,11 to 2,96) and the stress carried by the sample (from 486 kPa to 202 kPa) as Melbouci (2009) found previously. This is because the waste material, which is composed entirely of clay, fills the voids in the silty soil and causes the soil to behave more like clay than silt. During the experiment, it was also observed that the soil with waste material and XG were softer than the sample consisting only of silty sand, similar inference was also made by Hamza et al. (2022). As shown in Figure 4.9, the decrease in %CBR and stress continued as 0.5%, 1% and 3% XG were added to the mixture.

(a) %10 Brick (b) %0,5 XG

Figure 4.7. Photo of penetration difference after CBR test (a) %10 Brick and (b) %0,5 XG samples

(c) %1 XG (d) %3 XG

Figure 4.8. Photo of penetration difference after CBR test, (c) %1 XG and (d) %3 XG samples

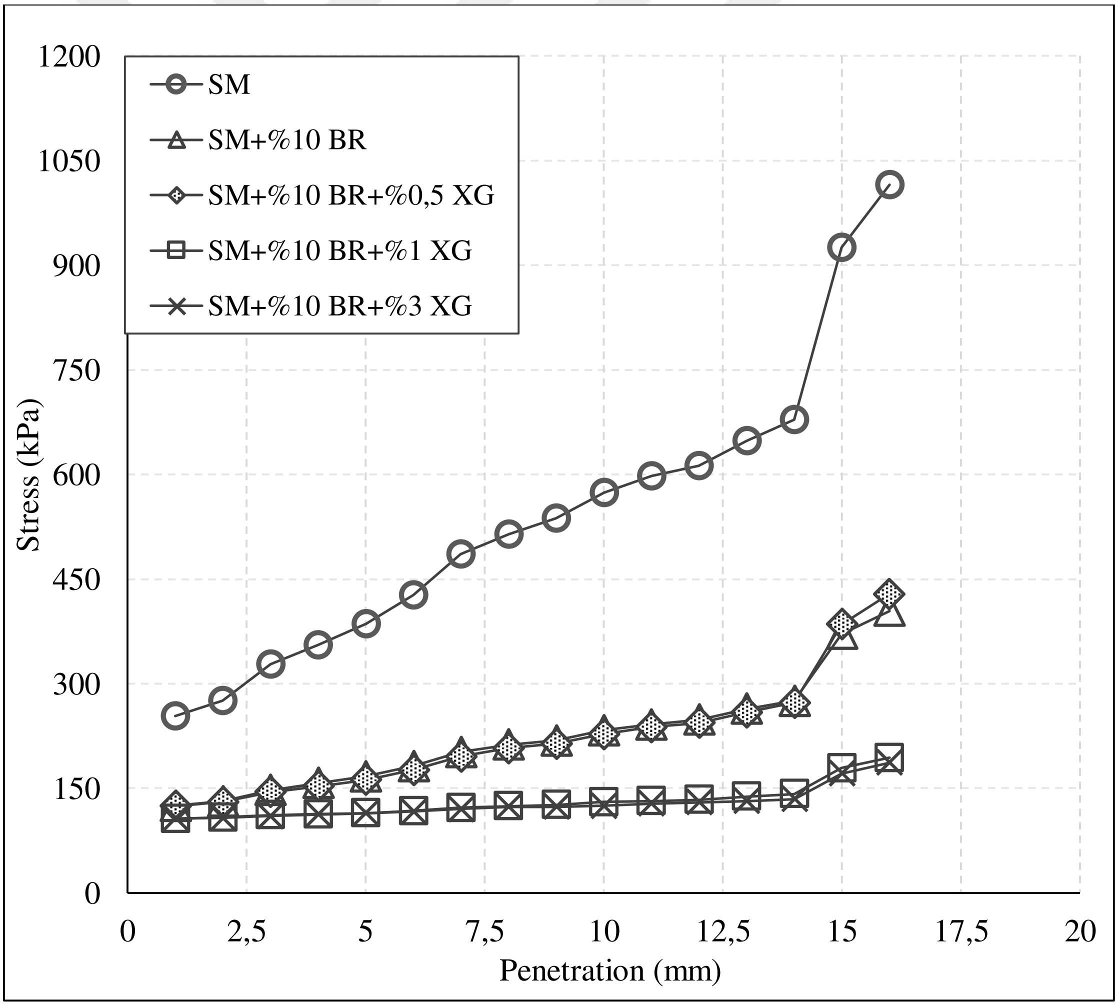


Figure 4.9. CBR test

4.6. Oedometer Test (Consolidation) Test

According to Oedometer test (consolidation) test results, the compression index (Cc) value on silty sand only was found to be 0,060 which decreased to 0,056 by adding %10 waste brick as stated earlier in Blayi et al. (2020). However, adding XG to this mixture Cc value increased to 0,207 by 3% XG addition while the recompression index (Cr) value changed from 0,0285 to 0,150. As the XG ratio in the soil increases, the repulsive force between the soil particles tends to increase, resulting in the expansion (Cr) of the soil. The coefficient of consolidation (Cv) value showed same behavior as Cc. Cv value changed from 0,003 to 0,224. Figure 4.10 shows relation between XG content, Cr and Cc. Figure 4.11 shows that the void ratio decreases as the XG ratio increases, similar result mentioned by Cabalar et al. (2017) previously.

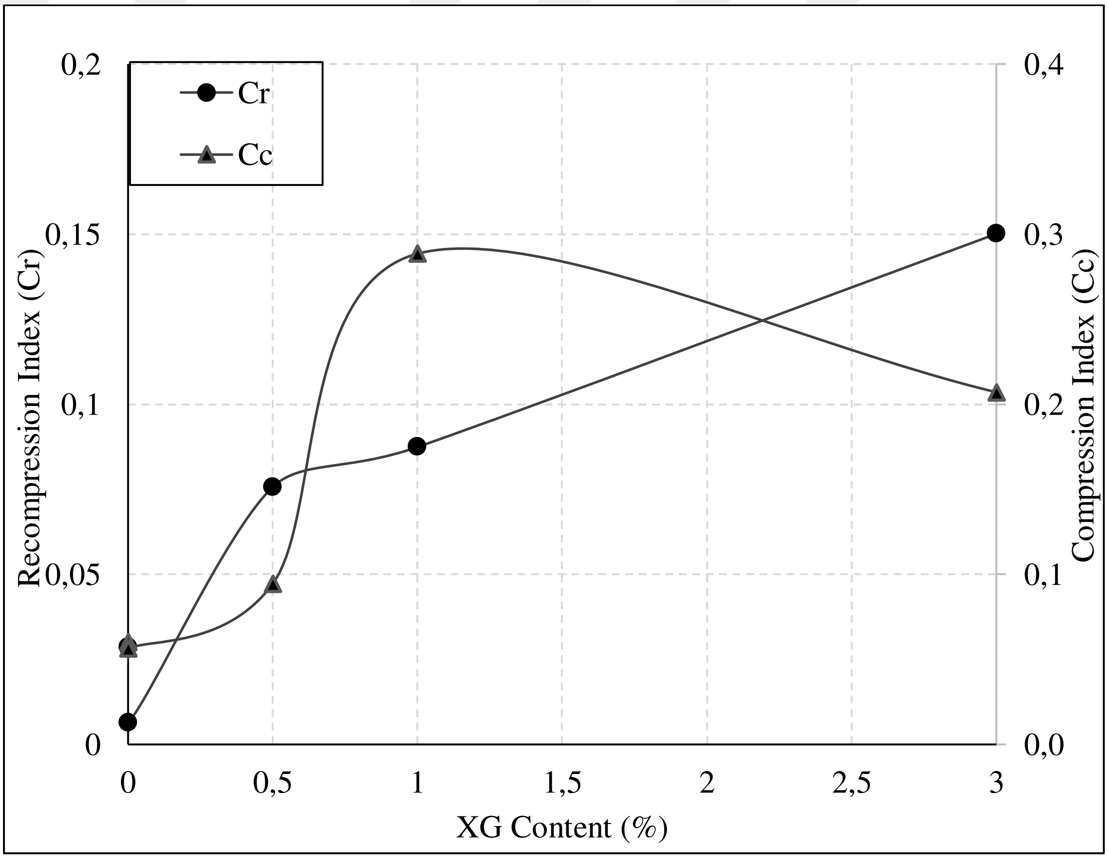


Figure 4.10. Relation between XG content, Cr and Cc

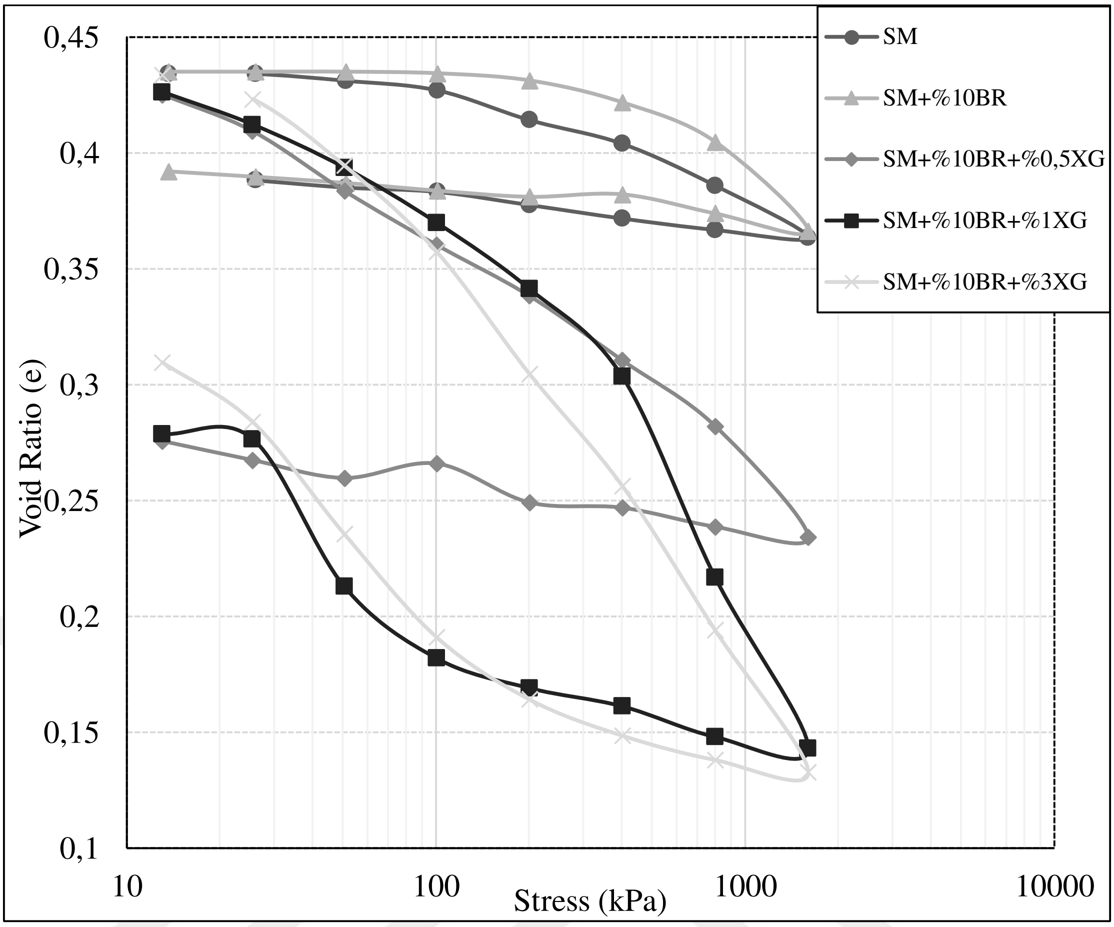
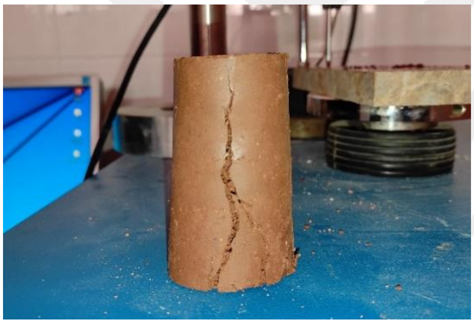


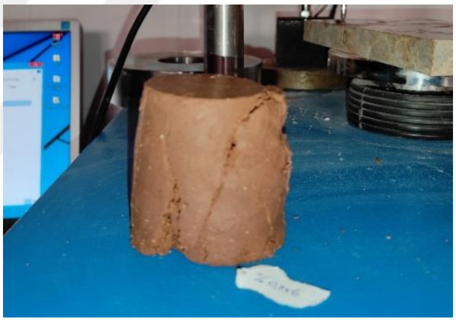
Figure 4.11. Consolidation test

4.7. Unconfined Compression Test (UCS)

Unconfined compression test (UCS) results showed that the curing time is as important as the XG content. When only 10% waste brick was added to the silty soil, a decrease in strength was observed for all curing times. For example, the strength of the samples cured for 7 and 28 days decreased from 5251 kPa to 1833 kPa and from 3627 kPa to 2190 kPa respectively. On the contrary, as XG was added to the mixture, a noticeable increase in strength was observed for 7, 28 and 56 days curing. XG biopolymer can provide a significant increase in compressive strength even when used in small amounts (from 1833 kPa to 3775 kPa). In 0 and 7-day samples, those with %0.5 XG content showed the best strength; in 28 and 56-day samples, those with %3 XG content showed the best strength. All mixtures and curing time effects shown in Figure 4.14. In 0 day and 7 days' samples, since a significant amount of water has not evaporated yet, the samples exhibit elastic behavior due to XG, therefore, a decrease in strength is observed while an increase in ductility is observed. For 28 and 56-days samples, due to the xanthan matrix formed on the soil surface and also as time passes, the water in the biopolymer evaporates so increases strengthen hydrogen and electrostatic bonds with soil particles so that strength increase. Cabalar et al. (2017); Hamza et al. (2022); Singh and Das (2020) also reported that increasing the amount of XG and curing time led to an increase in UCS. In addition, there was not much difference observed between the strength at 28 days curing time and 56 days curing time for all sample mixtures as seen in Figure 4.15 and similar result fount by Chang et al. (2015). Samples energy absorption capacity was calculated by performing the derivation of the area under the stress-strain curve up to the peak point. Addition of Xanthan gum to silty sand soil and curing time concluded an increase in energy absorption. In this way the materials were intended to deal with the problems of inelastic response to large dynamic loads. However, due to the evaporation of water in the clean silty sand over time, its resistance to dynamic loads decreased over time shown in Figure 4.16 and similar result found by Cabalar et al. (2018).

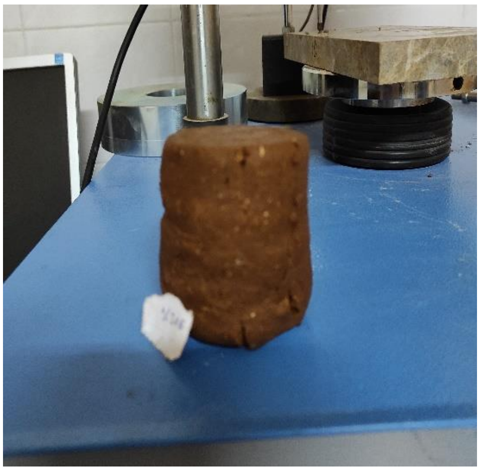


(a) %10 Brick



(b) %0,5 XG

(c) %1 XG



(d)%3 XG

Figure 4.12. Photo of UCS samples (0 day) (a) %10 Brick, (b) %0,5 XG, (c) %1 XG (d) %3 XG

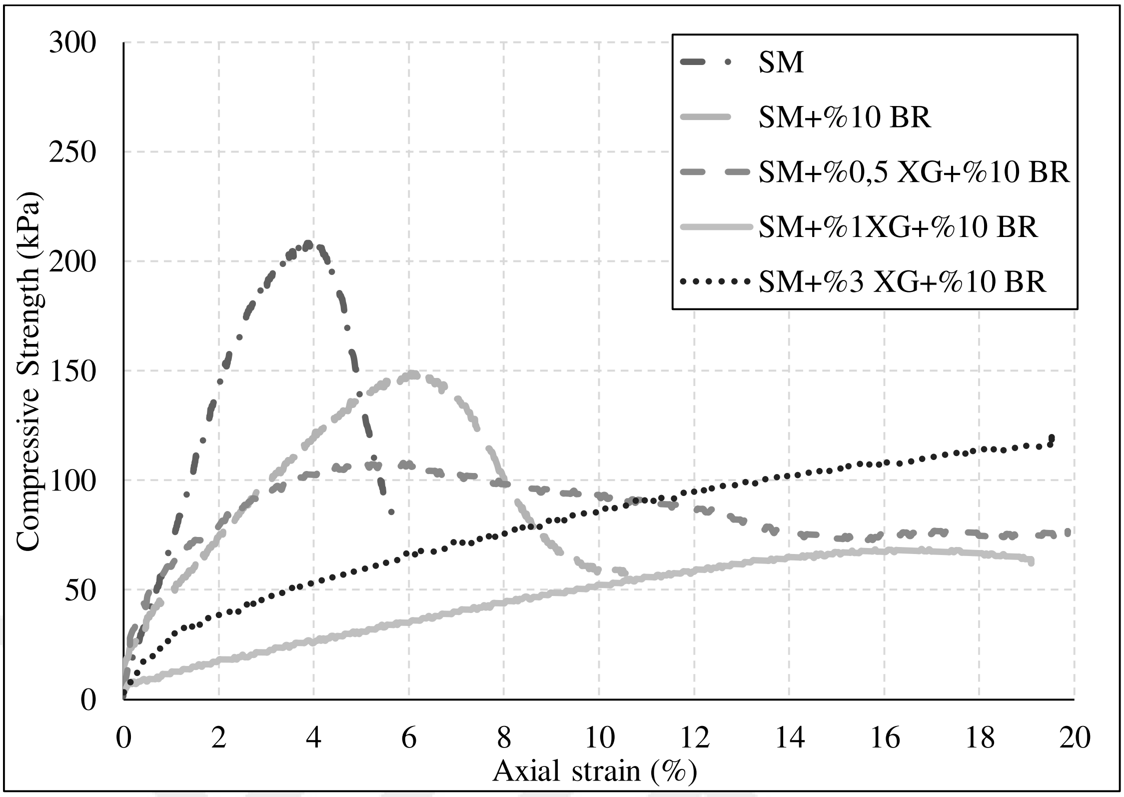
(a) %10 Brick

(b) %0,5 XG

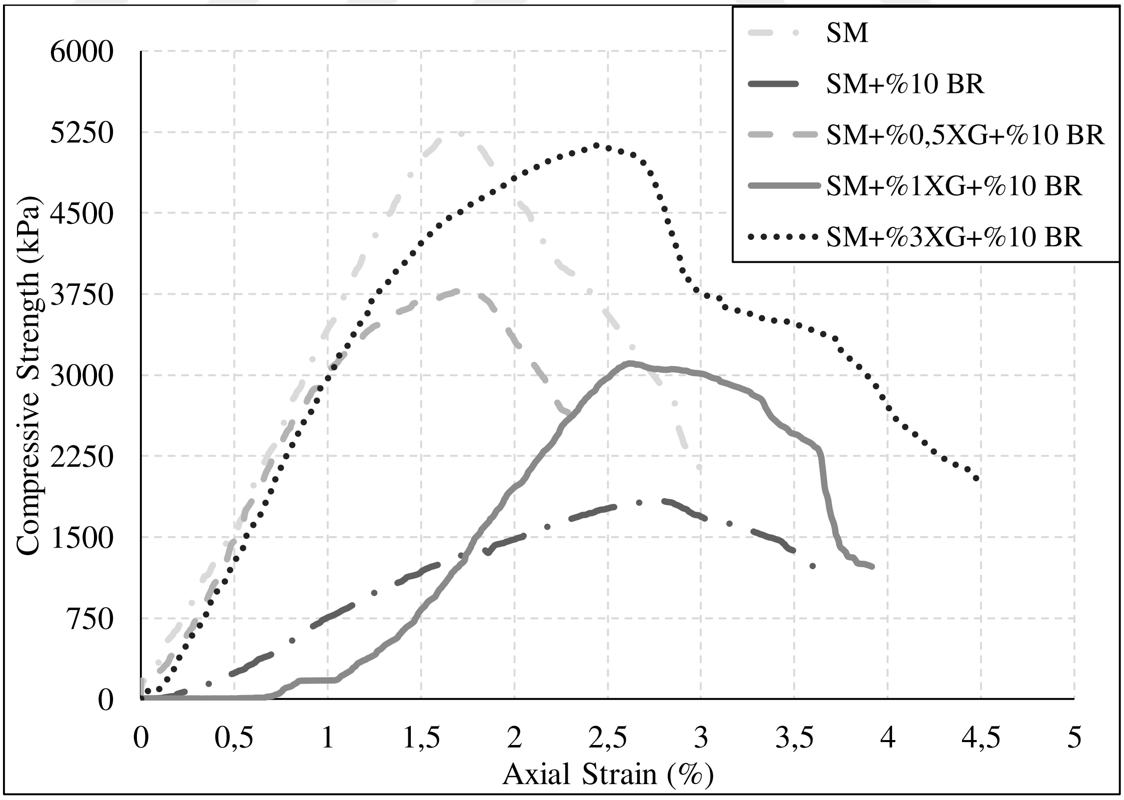
(c) %1 XG

(d) %3 XG

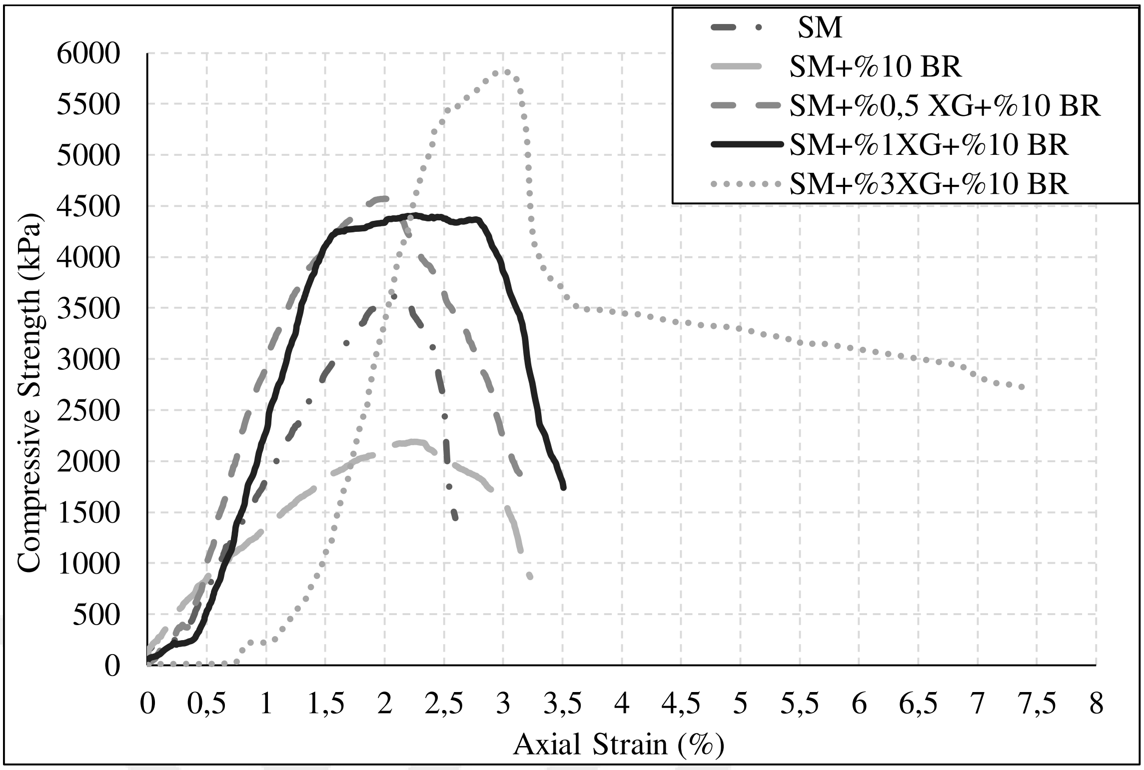
Figure 4.13. Photo of UCS samples (28 days) (a) %10 Brick, (b) %0,5 XG, (c)%1 XG, (d)%3 XG



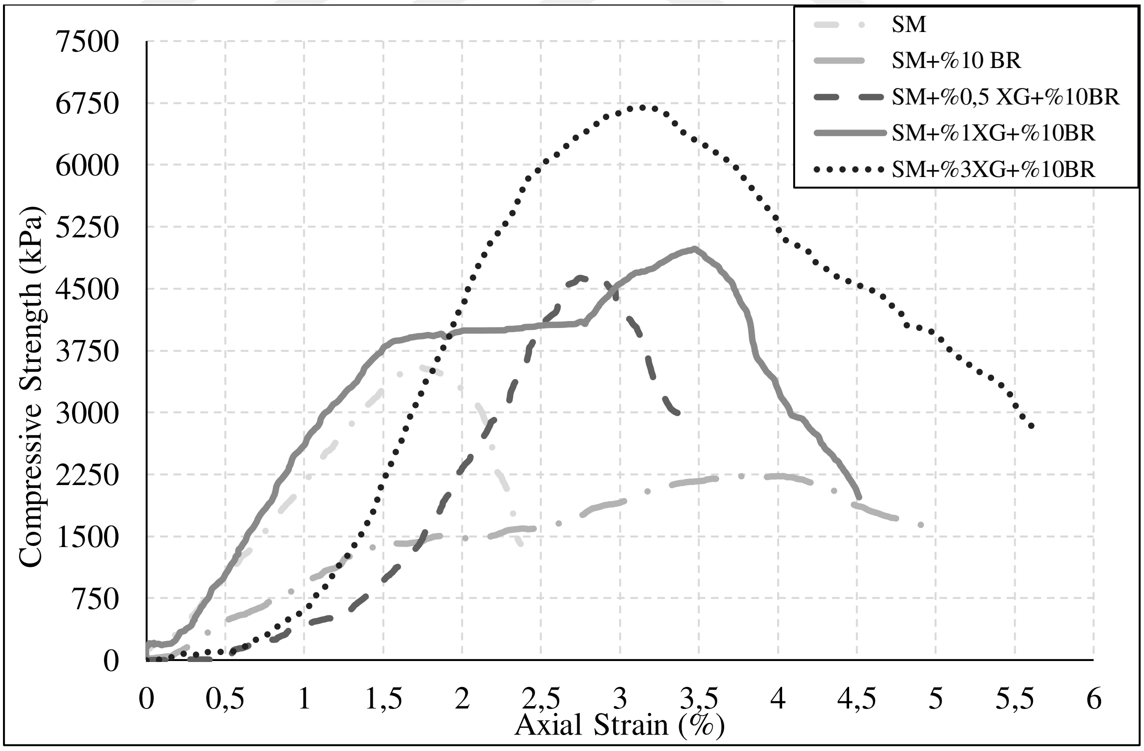
(a) UCS Immediate



(b) UCS 7 days

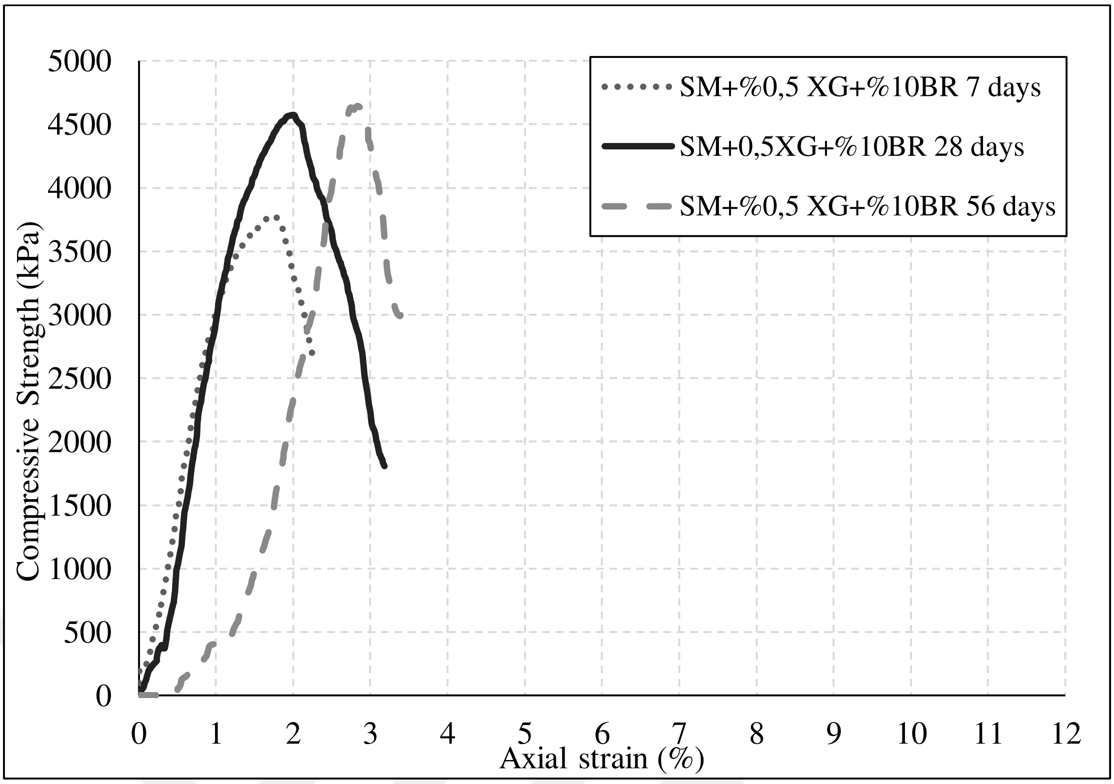


(c) UCS 28 days

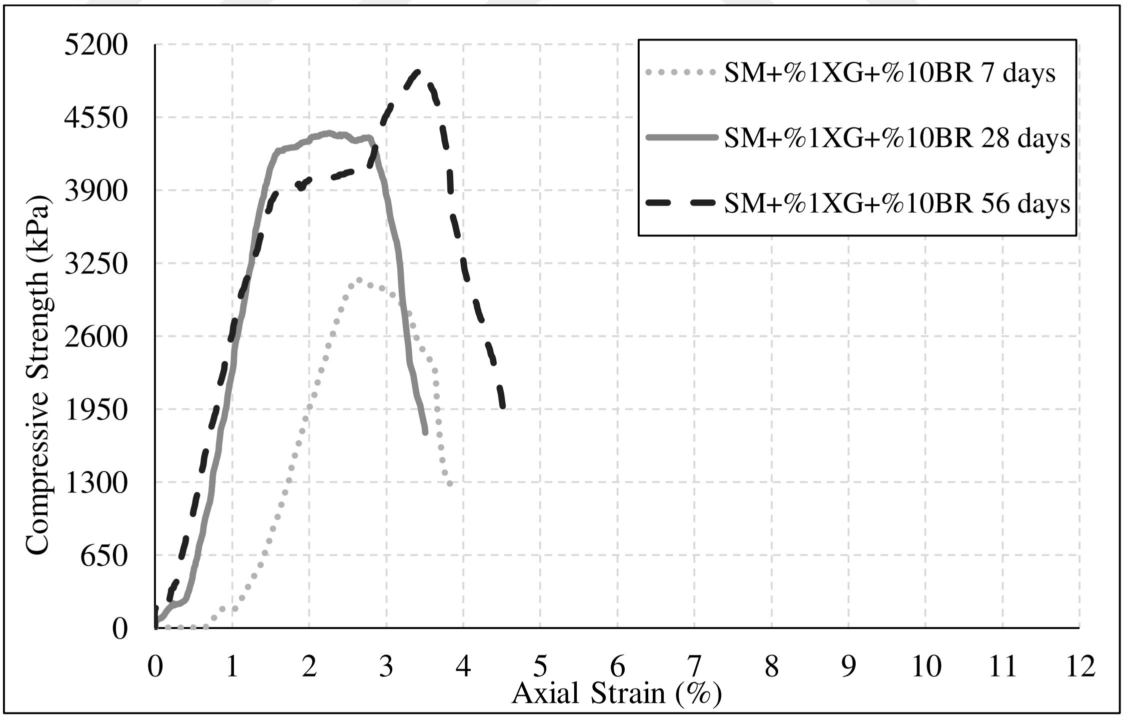


(d) UCS 56 days

Figure 4.14. (a)UCS Immediate, (b) UCS 7 days, (c) UCS 28 days, (d) UCS 56 days



(a) UCS 0,5 XG- all curing times



(b) UCS 1 XG- all curing times

Figure 4.15. (a) UCS 0,5 XG - all curing times, (b) UCS 1XG - all curing times

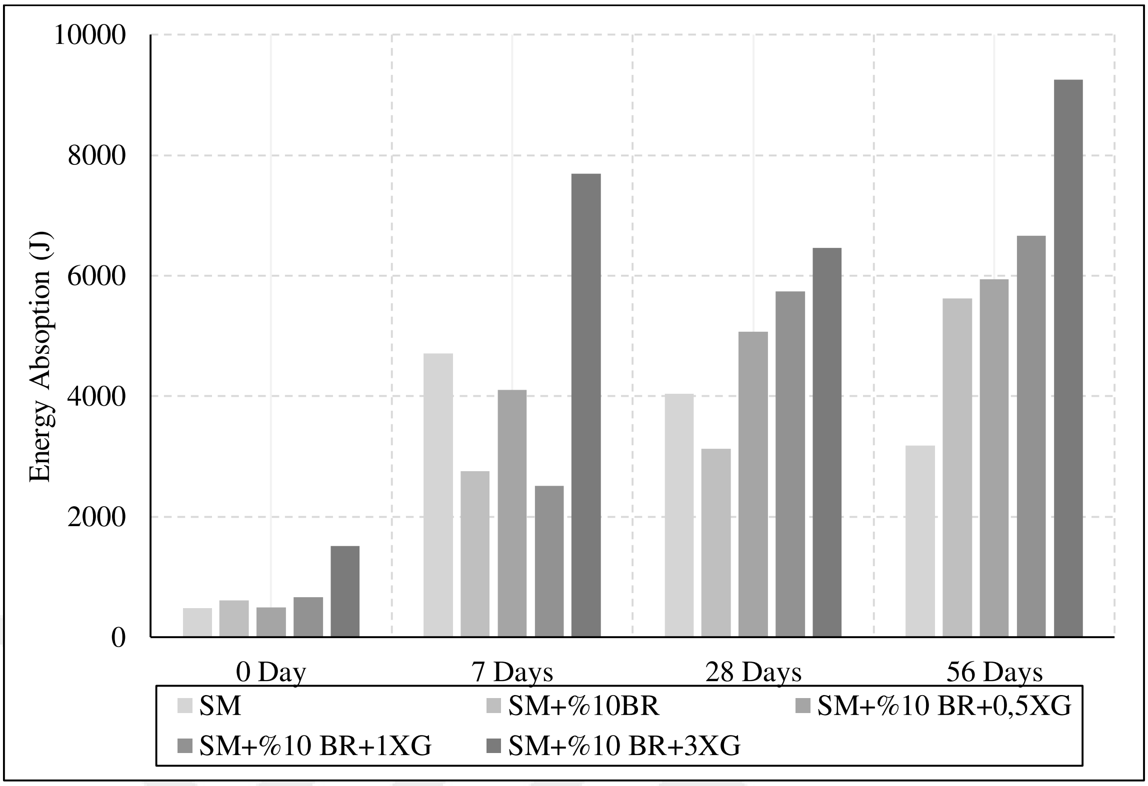


Figure 4.16. Energy absorption of the samples from UCS results

4.8. Direct Shear Test

Direct shear test results showed that the gradation of the soil, waste brick and XG grains play an important role in shear strength of the soil. When 10% waste bricks were added to the soil, internal friction angle increased as it affected the sliding or interlocking of the particles of the soil due to the angular structure of the brick grains so shear strength increased (from 0,564 kPa to 21,031 kPa). as mentioned before in Blayi et al. (2020). Conversely, cohesion decreased because there is no connection or cohesion between the waste brick grains. XG has the opposite effect to that of the waste brick. XG has filled the gaps between the soil particles and the waste brick by forming hydrogen and an electrostatic bond so hold the soil and waste material particles together. Therefore, as the XG content increased, cohesion increased (25,377 to 36,805) and the angle of internal friction angle decreased (21,031 to 5,4805) due to the XG holding the water inside and wrapping around the soil particles. As a result waste brick and XG have increased shear strength of soil that similar results found by Arulrajah et al. (2011); Ayeldeen et al. (2017); Chang et al. (2015); Melbouci (2009); Sharma and Shrivastava (2022); Soldo and Miletić (2019). Effects of waste brick and XG on soil shown in Figure 4.17 and Figure 4.18.

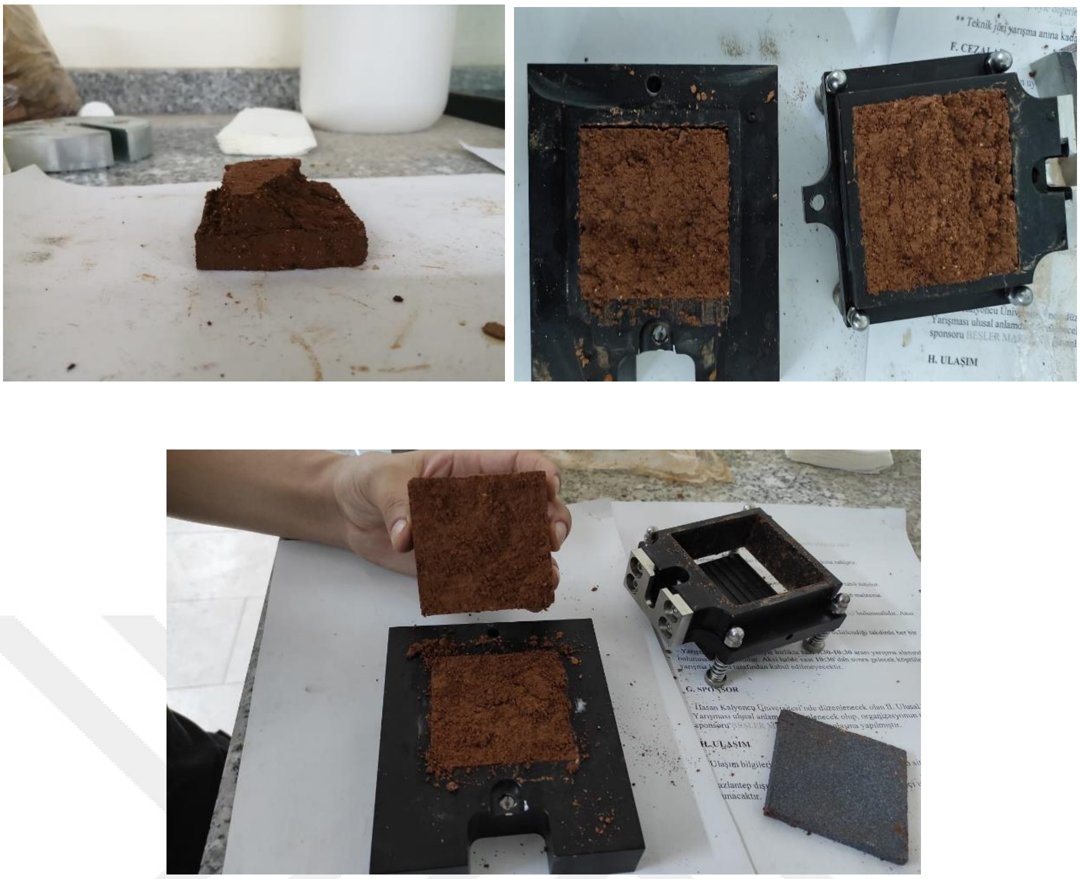


Figure 4.17. Photo of direct shear samples after testing

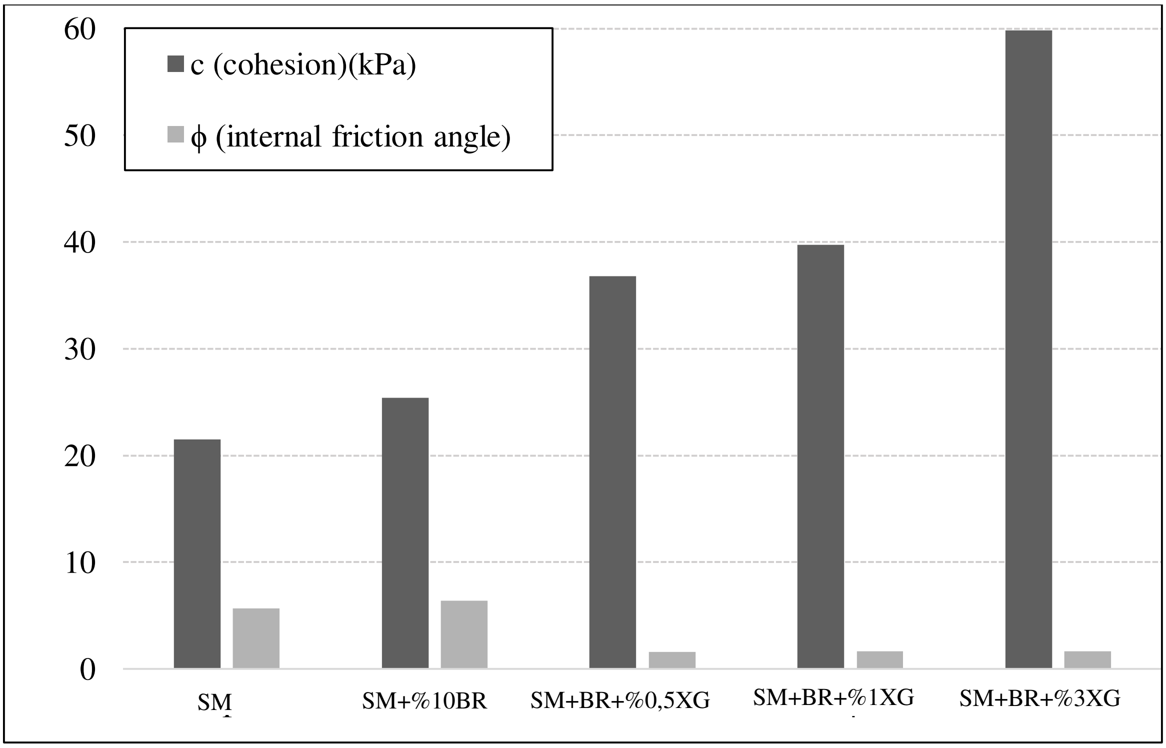


Figure 4.18. Cohesion and Friction angle

CHAPTER 5
CONCLUSIONS

Soil improvement can be done in many different ways like mechanical improvements and additives. As the population has increased, so have waste materials and carbon emissions. This has paved the way for more environmentally friendly approaches to soil improvement methods. This study concentrates on the use of xanthan gum biopolymer which is ecofriendly material and waste brick which is recycled demolition waste material in order to improve the geotechnical properties of a silty sand soil. The proportion of waste bricks in the soil was kept constant at 10% and the change in the engineering properties of the soil was reported by increasing the XG ratio added to this mixture.

1. Brick hasn't much changed liquid limit of soil but XG significantly increased liquid limit of soil (clean silty sand 31,37; with %10 waste brick 31,43; with mixture of %10 waste brick and %0,5 XG 44,58).
2. XG decrease dry density (17,2 kN/m^3 to 16 kN/m^3) of soil but increase water content (18,32% to 22,9%).
3. Both brick ($1.46 \cdot 10^{-6}$ m/s to $3.07 \cdot 10^{-7}$ m/s) and XG reduce permeability of silty sand (although only 0.5% XG was added to the silty sand and brick mixture, no water came out of the sample). XG can be concluded that it is very good at preventing permeability when it mixes with waste brick.
4. In the CBR test, waste brick (CBR% from 7,11 to 2,96) and XG much more softened the soil, thus reducing its strength (from 486 kPa to 202 kPa). It was observed that XG did not perform well in vertical loading when moist.
5. Cr continued to increase (0,0285 to 0,150) with the increase of XG in consolidation test. But the optimum value for Cc is 1% XG mixture.
6. The UCS test clearly showed that the curing time and XG ratio were important. Strength increased as XG ratio and curing time increased. According to the experimental results, it was determined that 0.5% XG was optimum for the first 7 days of curing in UCS, while 1% XG was optimum for the following curing days. There was not much difference observed between the strength at 28 days curing and 56 days curing time for all sample mixtures. Xanthan gum addition to the silty sand and curing time resulted in an increase in energy absorption.
7. It was determined that the most suitable liquid limit value in terms of workability was obtained in 0.5% XG mixture.

8. It was observed that both waste brick and XG increased the shear strength (0,564 kPa to 21,031 kPa).

Based on all the experimental results and conclusions that wrote above, it was determined that the best efficiency would be obtained when 0.5% XG was added to a mixture of silty sand and 10% waste brick for soil improvement.

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