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M.Sc. in CIVIL ENGINEERING

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EFFECTS OF STEEL CNC MILLING WASTE ON SOME GEOTECHNICAL PROPERTIES OF SILTY SOIL

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BY

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Supervisor
Assoc. Prof. Dr. Ali Fırat ÇABALAR

by

Ibrahim Abdulrahman ISMAEL

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Ibrahim Abdulrahman ISMAEL

ABSTRACT

EFFECTS OF STEEL CNC MILLING WASTE ON SOME GEOTECHNICAL PROPERTIES OF SILTY SOIL

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M.Sc. in Civil Engineering
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The aim of this study is to investigate the properties of silty soil mixed with steel computer numerical control machine (CNC) milling waste (St-CNC-mw). In this study; laboratory experiments including compaction, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), consolidation, swelling permeability and direct shear test have been conducted. Soil and St-CNC-mw mixtures at various rates (5%, 10%, 15%, 20% and 25% by dry weight) were tested at maximum dry density and optimum moisture content values of the mixtures. St-CNC-mw materials are coated by zinc to avoid high corrosion rate (electrogalvanisation) and corrosion rate of steel are reduced more than 100 times after coating. The results have shown that the optimum moisture content decreased and maximum dry density increased by increasing St-CNC-mw. Also the CBR increased and the swelling decreased by increasing St-CNC-mw. Soil with 15% St-CNC-mw has the highest UCS value. In addition, internal friction angle and cohesion increased while the coefficient of permeability (k) decreased by increasing St-CNC-mw. Furthermore, the consolidation tests demonstrated that the initial void ratio (e_o), swelling index (c_s) and the coefficient of consolidation (c_v) of the soil decreased while compression index (c_c) increased by adding the amount of St-CNC-mw content in the mixture.

Keywords: St-CNC-mw, Silty soil, Geotechnical properties.

ÖZET

ÇELİK CNC ÖĞÜTME ATIĞININ SİLTLİ ZEMİNİN BAZI GEOTEKNİK ÖZELLİKLERİNE ETKİSİ

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Bu çalışmanın amacı çelik CNC tezgahı atığı (St-CNC-mw) ile karıştırılan siltli bir zeminin özelliklerini incelemektir. Bu çalışmada, sıkıştırma, Kaliforniya Taşıma Oranı (KTO), tek eksenli basınç deneyi, konsolidasyon, şişme, geçirimlilik ve direk kesme deneyinin içinde bulunduğu bir seri laboratuar deneyi gerçekleştirildi. Kuru ağırlık itibariyle %5, %10, %15, %20 ve %25 oranlarındaki St-CNC-mw ile karıştırılan zemin örnekleri en fazla kuru birim hacim ağırlık (γ_{dry}) ve optimum su muhtevası (w_{opt}) değerlerinde sıkıştırıldıktan sonra deneylere tabi tutulmuştur. St-CNC-mw atıkları, yüzeylerinde oluşabilecek paslanmayı önlemek için çinko ile kaplanarak (elektro galvaniz), paslanmaya karşı 100 kat daha fazla dirençli hale getirilmiştir. Sonuçlar, St-CNC-mw ilaveleri ile birlikte optimum su muhtevasının azaldığını ve en fazla kuru birim hacim ağırlığın arttığını göstermiştir. Ayrıca, St-CNC-mw ilaveleri ile KTO değeri artarken, şişme yüzdesi azalmıştır. % 15 St-CNC-mw ilaveli zemin en yüksek tek eksenli basınç mukavemeti değerine sahiptir. Ek olarak, St-CNC-mw ilaveleri ile içsel sürtünme açısı ve kohezyon artarken, geçirgenlik katsayısı (k) azalmıştır. Ayrıca, konsolidasyon testleri, karışımlardaki St-CNC-mw içeriğinin artması ile zeminin sıkışma indeks (c_c) değeri artarken, başlangıç boşluk oranının (e_o), şişme indeksinin (c_s) ve konsolidasyon katsayısının (c_v) azaldığını göstermiştir.

Anahtar Kelimeler: St-CNC-mw, Siltli Zemin, Geoteknik özellikler.

To my parents

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All praise is due to Allah, the Almighty, on whom we ultimately depend for sustenance and guidance. I am ever grateful to God, the Creator, and the Guardian, and to whom I owe my very existence.

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LIST OF SYMBOLS/ABREVIATIONS

ASTM	American Society for Testing and Materials
c	Cohesion (kN/m^2)
c_c	Compression Index
c_s	Swelling Index
c_v	Coefficient of Consolidation (cm^2/sec)
e_o	Initial Void Ratio
Gs	Specific Gravity
k	Coefficient of Permeability (cm/sec)
LL	Liquid Limit (%)
MDD	Maximum Dry Density (kN/m^3)
ML	Silty Soil
OMC	Optimum Moisture Content (%)
PI	Plasticity Index
PL	Plastic Limit (%)
St-CNC-mw	Steel CNC Milling Waste
STS	Split Tensile Strength Test
UCS	Unconfined Compressive Strength (kN/m^2)

CHAPTER 1

INTRODUCTION

1.1 General

Since the history of human civilization began, ground improvement has been in action and employed in many fields. Nonetheless, there are many investigations on making it more effective and less costly. The ground improvement has become an essential component in geotechnical engineering projects, especially with ever-growing demand for civil infrastructure and ground improvement techniques. Many waste materials are utilized for ground improvement since their quantity has been rapidly increased. These waste materials contain tires, steel, aluminum, rubber, glass, plastic, etc. Notwithstanding the fact that these materials impact the human health and the environment negatively, getting rid of them can be considered critical and costly without endangering human lives as a whole (Roustaei and Ghazavi, 2012).

The process of treating these waste materials can be used to stabilize soils as both materials mixed together. Further, it is considered to be one of an essential method to reduce the cost as well as preserving environmental issues. The improvement of soil is the modification of one or more engineering soil properties by the mechanical or chemical method. Increasing strength and enhancing load-bearing capacity are some aims of soil improving method. Stabilized soil is usually a composite material, which is the result of combining and optimizing the properties of individual constituent materials (Basha et al., 2004).

Throughout the last two and a half decades, many trails and studies were carried out to improve the strength of the deformation properties by mixing fiber with soil. Clearly, it could be seen that adding an amount of fiber into the soil improves the overall performance of the engineering properties of soils (Singh and Bagra, 2013).

Using a waste material like fiber as a reinforcement in all types of soil, (such as silt, clay and sand), is similar to other used wastes and natural materials like aluminum, jute, coir, tires, bamboo, sisal, plastic and rubber materials for reinforcing soil. Furthermore, the steel CNC milling waste (St-CNC-mw) is a type of waste material used for soil improvement in this study. It is undoubtedly not an issue for the human and world environment. Instead, it benefits to reduce the danger of natural catastrophe and reducing the amount of the waste material. Thus, it is thoroughly suggested that finding proper applications is required in engineering. For instance, performing various experiments on the concrete mix using steel CNC waste and replacement of 50% natural coarse aggregate (NCA) by recycled concrete aggregate (RCA) can be possible to get desired strength (Shukla, 2013). There is even no proper guideline for the using different proportions of steel slag blended with natural aggregate to obtain adequate mix design, but it has enough potential and can be utilized in subgrade or embankments (Hainin et al., 2015).

In 1966 a soil reinforcement methods were suggested in which galvanized steel strips were used in cohesion less soil to improve its properties (Vidal, 1978). In this technique sheet, a bar or strip is located in the soil a specific position. Since then, this technique (known as the conventional method) is widely used in soil improvement properties. An alternative technique to enhance the soil mixture includes randomly fibers with a soil. A randomly distributed fiber-reinforced soil has recently attracted increased care in the engineering of geotechnical and many authors have investigated the influence of adding fibers to soil. Numerous experimental tests like unconfined compression, direct shear, CBR, and also triaxial experiments have been showed on randomly reinforced soils (Yetimoglu and Salbas, 2003; Miller and Rifai, 2004; Tang et al., 2007; Consoli et al., 2009;Ahmad et al., 2010). The above-mentioned studies concluded that with adding an amount of fibers will improve the strength of the soil. Moreover, It is believed that randomly reinforced soil has recently emerged into geotechnical engineering, yet, the reinforcement soil mixed with natural fibers were employed back in the times of pharaohs (Estabragh et al., 2011).

In recent years, soil reinforcement using discrete fibers has been developed as another soil improvement technique. Ghavami et al. (1999) demonstrated that the additions of natural fibers, such as coconut and sisal fibers, provide a ductile manner and increase the strength of the soil. In addition, similar outcomes have been reported by other researchers on the reinforcement of soils with natural fibers (Prabakar and Sridhar, 2002 and Bouhicha et al., 2005; Ahmad et al., 2010). Moreover, the desired effectiveness of synthetic fibers such as polyester, polyamide, and polypropylene fibers to improve failure properties and mechanical characteristics of soils confirmed (Michalowski and Cermak, 2002; Yetimoglu et al., 2005; Diambra et al., 2010). Furthermore, the inclusion of fibers to improve the engineering properties of compacted soil is becoming an increasingly common practice in geotechnical engineering projects. For instance, reinforced soil now a days utilized for stabilization of shallow slope collapses (Gregory and Chill, 1998), using marginal soil in construction of new embankments that decrease the shrinkage cracking in compacted clay liners (Rifai, 2000), to reinforce roadway subgrades (Santoni et al., 2001). It is also used to improve the stability of earth retaining walls (Park and Tan, 2005).

Moreover, several experimental investigations were conducted by including randomly oriented synthetic fibers into stabilized fine grain soils, using cementitious materials, like fly ash, cement and lime. For understanding the effect of fiber inclusions, demonstrating the inclusion of randomly oriented synthetic fibers into stabilized fine grain soil improves the ductility and tensile strength (Sobhan and Mashnad, 2003, Kumar et al., 2007). By adding randomly oriented synthetic fibers in fly ash stabilized soils, the shrinkage-swelling potential is also considerably reduced (Yarbaşı et al., 2007). Stabilization of soil by adding some types of fly ash, randomly oriented fibers and cement into the soil results in modification of expansive soils by combining polypropylene fiber and lime in soil (Puppala et al., 2006, Kaniraj et al., 2012).

The use of different industrial waste materials to replace the soil not only solves environmental problems but also offers a new resource for the construction industry. Some investigators utilized benefits of fiber reinforcing by using waste or by-product materials as an eco-friendly as well as a cost-effective solution to improve the engineering characteristics of weak soils. Clearly, waste plastic strip reinforced with soil (Choudhary et al., 2010), reinforcing light weight soil with waste fishing net (Kim et al., 2008), waste rubber with clayey soil (Cetin et al., 2006; Akbulut et al., 2007), and scrap tire rubber with sand (Hataf and Rahimi, 2006; Yoon et al., 2006). Moreover, several investigators have reported that waste tire shreds were used as a lightweight filling material in many retaining structure and embankments (Bosscher et al., 1997; Tweedie et al., 1998; Lee et al., 1999).

As the materials explained above are not deformed chemically in soil, they could be used for improvement of soil. However, mixture of metals with soil is not applicable as commonly used metals including steel, aluminum, magnesium and their alloys can be corroded (oxidized) and dissolved in aqueous media. Metals therefore should be coated in order to increase their corrosion resistivity.

Steels are versatile products, used in numerous applications including construction and automotive industries due to their high strength, low cost and easily availability. A serious limitation for the use of steel waste is their susceptibility to corrosion especially in chloride containing environment (Schuerz et al., 2009; Cruz et al., 1998; Perren et al., 2001). Chloride ions are adsorbed onto the steel surface in competition with other species and chloride ions break down passivity of the steel and cause higher corrosion rate of steel (Heusler and Cartledge, 1961; Foley, 1970; McCafferty, 1990). Chloride ions also penetrate into the passive film and break down the oxide form of steel. A chloride including aqueous solution are aggressive media for steel, the effect of chloride bath is studied for corrosion of steel. As corrosion behavior of St-CNC-mw is the same as steel itself, the general corrosion behavior of St-CNC-mw has not been studied before. In this work, specifically the corrosion behavior of bare and zinc St-CNC-mw will be studied.

The methods to reduce corrosion rate of metals electrochemists were investigated for ages were surface treatment (Johnston et al., 2016), cathodic protections (Bedir et al., 2015), anodic protections (Konno et al., 2015) and corrosion inhibitors (Burstein et al., 2016). In this work steel will be coated by zinc deposition. The reason zinc was chosen for coating is that zinc has passivation surface when it is in contact with the atmosphere and the surface beneath zinc film is not rusted.

1.2 Research aim

One of the techniques to avoid St-CNC-mw which is employed for geotechnical goals based on its usefulness for the St-CNC-mw regions and benefits for environmental hazard dispositions. The main aim of this research is to evaluate the mechanical properties of the soil-St-CNC-mw stabilization. Further, series of tests have been carried out by mixing soil with different percentage of St-CNC-mw (0.0%, 5.0%, 10.0%, 15.0%, 20.0% and 25.0% by dry weight). Consequently, various experiments were conducted (including compaction, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), consolidation, swelling, permeability and direct shear test) to prove what has mentioned above.

The objective of corrosion study in this work is to examine the effects of the chloride concentration on the corrosion rate of uncoated and coated steel CNC milling waste. The electrochemical processes affection St-CNC-mw corrosion was analyzed by means of linear sweep polarization curves. The corrosion rates of both uncoated and coated St-CNC-mw were compared in order to examine the resistivity of metals (steel and zinc coated steel) against corrosion. The effect of various levels of chloride ion concentration was also evaluated.

1.3 Outline of the Thesis

Chapter 1-Introduction: This chapter showed the general background of the study, the objective of the study and the thesis structure.

Chapter 2- Literature review and background: The present chapter defines the existence literature mainly on soil stabilization, which used various types of fibers, wastes material, and fibers with the chemical material.

Chapter 3- Experimental study: This chapter presents the introduction of the used materials and clarifying the performed tests and equipment.

Chapter 4-Test results and discussions: This chapter will discuss the outcomes get from all experimental and theoretical work with the scientific discussions of these results.

Chapter 5-Conclusions: Conclusions of the thesis are given.

Chapter 6- Recommendations

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

2.1 General

The use of different materials to stabilize various types of soil has been very important and extensive in the last decades. Since soil stabilization is currently used in construction easily and inexpensively, soil stabilized with fibers and waste material has been studied extensively. In this chapter, some use of fiber and waste materials in various geotechnical applications has been considered. In addition, the characteristics of the waste, equipment used, field and laboratory were discussed and clarified. The literature review includes stabilization of soil using fiber and some waste materials as well as soil stabilization using chemical stabilizer and fiber.

2.2 Stabilization of soil using fiber and some waste materials

Gray and Ohashi (1983) claimed an early research of fiber-reinforced soil including a mathematical model predicting shear strength increases through fiber reinforcement. Their research consisted of a series of direct shear tests on conventional equipment with both non-reinforced fibers and fiber-reinforced sand. An interesting and important conclusion of author's investigation found that fiber orientation has little effect on the result of shear strength.

Maher and Gray (1990) performed a drained triaxial compression tests to evaluate the static stress-strain response of reinforcing sands with discrete fibers as well as with randomly distributed fibers in the samples. These tests were performed to observe the effects of different properties of the fiber (i.e. fiber content, modulus and aspect ratio), soil particle size (ie, shape, particle size and gradation) and other test parameters on the behavior of soil. The results showed that fibers randomly distributed inclusions greatly increased the strength and stiffness of the sand.

Maher and Ho (1994) studied the mechanical characteristics of a kaolinite-fiber compound in unconfined compression tests. By adding the randomly distributed fibers into the kaolinite clay, the maximum compressive strength increased considerably and decreased the post-peak drop in compressive strength. When the moisture content decreases, the compressive strength is increased more markedly (Figure 2.1). It was found that the increasing of shear strength depends on the length of the fiber, the fiber content. As well as, the influence of the length of fiber for kaolinite clay was not as important as for cohesion soils. The researchers discovered that the fiber length has increased the fiber contribution to the strength of the clay decreased.

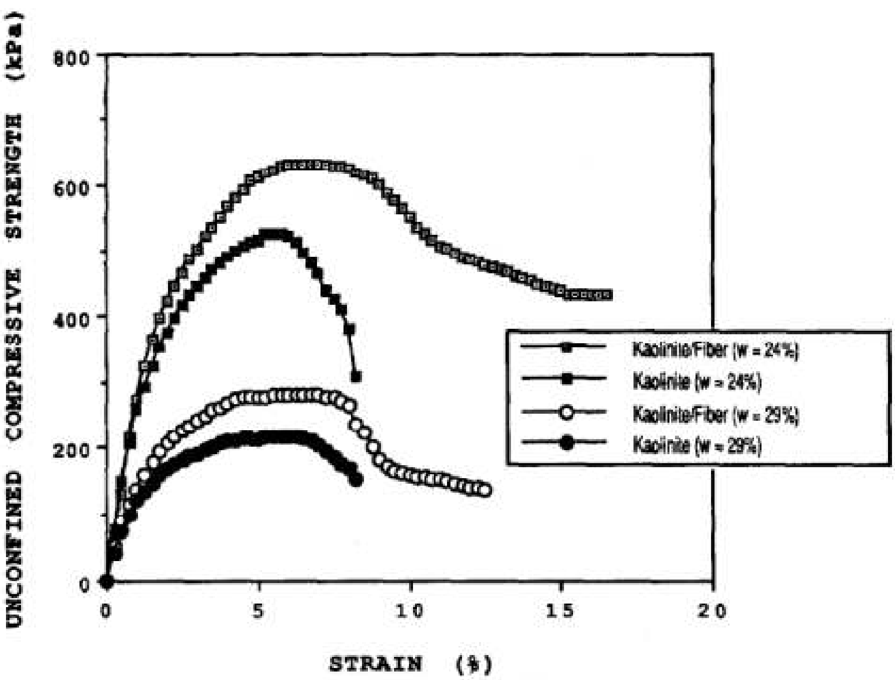


Figure 2.1 Effect of water content on contribution of fibers to UCS (Maher and Ho, 1994).

Gregory and Chill (1998) performed direct shear and drained triaxial compression tests on lean tone (CL) and fat tone (CH) reinforced with fibrillated polypropylene and randomly distributed fibers to study shear strength parameters as compared to unreinforced samples. Both effective friction angle and effective cohesion increased with fiber inclusion. It was also found that the effective fiber-reinforced sample shear strength increases in the range of 20 to 50%.

Santoni et al. (2001) quantified and identified the influence of many variables on the behavior of fiber-stabilized sand samples. Unconfined compression experiments on various sands strengthened with randomly oriented discrete fibers to separate the effect of variables on the behavior of fiber mixtures and soils were carried out. The researchers obtained five primitive conclusions (i), adding randomly oriented fibers increases the uncompressed compressive strength of the sand. (ii), the higher performance could be obtained at a fiber rate of 0.60 to 1.0% dry weight. (iii), in both wet and dry conditions the behavior of the samples were enhanced (iv), for reinforcing of sand sample the defined length of used fiber was 51.0 mm (2.0 inches). (v), the behavior of fiber reinforcement not influenced even the samples containing silt up to 8.0%.

Consoli et al. (2002) studied the engineering properties of sand reinforced with plastic waste. Drained triaxial compression tests with local strain measurement were carried out to assess the advantage of utilizing randomly distributed polyethylene terephthalate fiber, got from recycling waste plastic bottles, alone or combined with quick hardening Portland cement to enhance the engineering behavior of uniform fine sand. The outcomes demonstrate that the polyethylene fiber has enhanced the ultimate and peak strength of both cemented and non-cemented soil and has slightly reduced the fragility of the cemented sand. Moreover, the addition of fibers does not greatly affect the initial stiffness.

Zhang et al. (2003) evaluated the influence of nonwoven geotextile and synthetic fiber reinforcement on the stability of heavy clay embankment. The researchers discovered that increasing soil moisture content in clay soil had effective influence on its shear strength. Fiber reinforced clay soil will gain extra shear strength as the fiber interacts with the soil in a randomly oriented fashion. Breakage of the slope occurs when surface water trapped in cracks and cracks completely soaks the adjacent soil.

Michalowski and Cermak (2003) showed that the granular fines and relative fiber size have a great influence on the mechanical performance of the sand-fiber mixture and has given values for the size influence. The length of the fiber must be at least greater than the size of the soil particles. Otherwise, there will be no contact between the fiber and soil particles.

Romero (2003) performed numerous laboratory triaxial compression tests on randomly distributed polypropylene reinforced with soil according to undrained and drained conditions. The outcomes demonstrated that the addition of fibers significantly enhances the shear strength of soils. The researchers discovered that more strains were required to enhance fiber resistance for fiber-reinforced samples consolidated with higher influence stresses and greater strain was required to mobilize fiber resistance in undrained tests than drained tests.

Ghazavi and Sakhi (2005) investigated the benefit of enhancing the ratio of aspect shreds of the waste tires on california bearing ratio test of sand tire shred mixture. This mixture consisted of relatively uniform sand and tire shreds of various lengths with widths of 2.0 cm, 3.0 cm, and 4.0 cm. 15.0%, 30.0% and 50.0% by volume of shredded contents have been blended with sand. The outcomes demonstrate that the effecting parameters on CBR of the mixes are shred width, aspect ratios, shred content of tire shreds and sand matrix unit weight. A change in the aspect ratio could cause an increasing of the CBR reaches 850.0%. The amount of shred aspect ratio that affects CBR was about 161.0%. For a certain shred width, solely, there is a certain length that gives the maximum CBR for a sand tire shred mixture, without considering compaction effort and shredding content.

Kumar et al. (2006) investigated the relative strength increase of uncompressed compression by mixing polyester fiber with soft clay soil. Specimens had been tested in unconfined compression with 0.0%, 0.50%, 1.0%, 1.50% and 2.0% crimped and plain Polyester (synthetic) fibers. The outcomes demonstrate that the compaction degree has influenced the relative advantages of the fiber reinforcement for soil substance. Samples compacted after mixing different sand particles in clay (changing from 0.0% to 12.0%) were also examined. It has been noticed that the unconfined compressive strength of the clay increases with the addition of fibers, and it increases further when the fibers are blended in a mixture of clay sand.

Dutta and Sarda (2007) performed CBR test of saturated clay of waste plastic strip reinforced fly ash and dust of stone. In this study, three various sizes of waste plastic strips have been tested. The researchers investigated the influence of waste plastics strip length and content (0.25% - 4.0%) on the secant modulus and CBR of strip reinforced fly ash and/or dust of stone covering saturated clay. In this study, it was found that adding of waste plastic strips into fly ash and/or dust of stone on saturated clay greatly increased secant modulus and CBR. As length of the strips and amount of the waste plastic strips increased the effect of reinforcement become more influential. Benefits of adding waste plastic strips over 2.0% do not significantly improve the secant modulus or CBR. Reinforced dust of stone is more effective than reinforced fly ash above saturated clay to improve system behavior.

Naeini and Sadjadi (2008) investigated the influence of waste polymer materials on the shear strength of unsaturated clayey soils. They discovered that peak shear stress was greatly influenced by fiber content. Particularly, at high normal stresses the initial stiffness at the same normal stress to the reinforced clayey soils and unreinforced clayey soils remains substantially the same. The proportion of fiber content played a significant role in developing shear strength parameters, φ (internal friction angle) and c (cohesion) of fiber-reinforced soil; the value of cohesion (c) is increased by including fiber. The cohesion of the fiber samples increases with the fiber content is increased until 2.0% and then decreases with the additional fiber amounts. In general, the internal friction angle (φ) increases with the addition of fiber content. Moreover, when the soil is stabilized by the waste polymer fiber, the dry density of the soil is reduced due to a unit weight and low specific gravity of the polymer fiber and the optimum water content reduces with the addition of fiber content into the soil. The results clearly demonstrated a greatly improvement in the shear strength parameters, φ (internal friction angle) and c (cohesion) of the treated

Babu and Vasudevan (2008) studied the stiffness and strength performance of soil reinforced with coir fiber. Researchers found that incorporating coir fiber in the soil improves the stress-strain behaviour of the soil. For fiber lengths of 15-25 mm, a maximum increases in stress is noticed. Addition of fibers to the soil increases the stiffness of the soil and markedly reduces the immediate settlement of the soil.

Attom et al. (2009) investigated the influence of discrete, short, randomly oriented fibrous (synthetic and natural) on mechanical properties of soils. The investigated mechanical properties include the maximum compressive strength, ductility, and stiffness. Clay soil was mixed with the fiber in five various proportions (1.0%, 2.0%, 3.0%, 4.0% and 5.0%). The results showed that the maximum compressive strength, ductility, and stiffness of a mixture of clay-fiber materials increased with increasing fiber content. Furthermore, by increasing fiber content the post-peak softening in compression resistance decreased. The relative unconfined compressive strength increased with fiber content. Palmyra fiber exhibited a larger increase in relative unconfined compressive strength compared to nylon fibrous when mixed with clay soil.

Attom and Al-Tamimi (2010) studied the effect of polypropylene fibrous on the shear strength parameter of sandy soil. Primary physical characteristics of sand such as shear strength, specific gravity, and internal friction angle were acquired according to ASTM. Sandy soils have been mixed with two kinds of fibers at various rates depending on the dry density of sand and four various aspect ratios. The outcomes of the research demonstrate that the shear strength of sand with additional fiber content is increased. It was found that the aspect ratio of the fiber which increases the shear strength and the angle of internal friction increase.

Shukla et al. (2010) investigated the analytical model for fiber-reinforced granular soils under high rate confining stresses. The researchers found that shear strength and apparent cohesion increase in proportion to aspect ratio and fiber content. The shear strength of the granular soil increases due to the fibers is mainly from the apparent contribution and the cohesion of the increased normal confining stress is limited.

Jiang et al. (2010) investigated the engineering characteristics of reinforced soil with short polypropylene fibers. A number of tests was conducted investigate the effect of fibrous length and content on the fiber reinforced soil strength, as well as, the effect of fibrous additives and aggregate texture on the engineering features of the fibrous reinforced soil. The outcomes of the research demonstrate that the internal friction angle, cohesion and unconfined compressive strength of the fibrous-reinforced soils were higher than those of the native soil. The internal friction angle, cohesion and UCS of the fibrous-reinforced soil showed an initial ascending tracked by a rapid descending with adding length and amount of fibrous. Therefore, the optimum fibrous length and fibrous content have been measured to be 15.0 mm and 0.30% by weight of the native soil respectively. Finally, by the participant of polypropylene fibers could make an effective contribution to improving the stability and strength of the native soil.

Sadek et al. (2010) studied the shear strength of fiber-reinforced sands. The researchers found that the presence of a fiber grain scale influence is not satisfied in the previous forecast models. A comparison between predicted shear strengths and measured show that the energy dissipation model is influenced in predicting the shear strength of fiber-reinforced samples with respect to the tests performed.

Ahmed et al. (2010) showed the results of this study to evaluate the amount of recycled gypsum achieved from waste plasterboard and the strip of waste plastic trays to improve the behavior of the soil tested. The outcomes of the experimental tests shows that by increasing waste gypsum content the unconfined compressive strengths and splitting tensile increase. The increase in waste gypsum showed remarkable influence on unconfined compressive strength than tensile strength. Adding a strip of a waste plastic tray to specimens proceeded with waste gypsum improved split tensile strength. The content, aspect ratio and size of the waste plastic tray have an important influence on improvement of soil strength.

Choudhary et al. (2010) studied the potential reclaimed high-density polyethylene strips as soil stabilization to improve performance engineering subgrade soil. Polyethylene strips achieved from waste plastics have been blended with the soil according to the random principle. Many California Bearing Ratio tests were conducted on randomly stabilized soils at different amount of polyethylene strips with various lengths and proportions. The CBR outcomes showed that including waste of high density polyethylene strips into the soil with suitable quantities greatly enhanced deformation and strength performance of subgrade soils. Thus, this technique could be useful while constructing embankment and roads.

Estabragh et al. (2011) studied the influence of fiber on the shear strength behavior and consolidation of a clay soil strengthens with nylon fibers. A series of one-dimensional consolidation and triaxial laboratory experiments have been conducted on specimens of reinforced and unreinforced clays with various proportions of randomly distributed nylon fibers. The outcomes demonstrate that the compression and coefficient of swelling generally increase and the pre-consolidation pressure decreases with adding fiber content. In addition, the addition of fibers markedly increases the friction angle and shear strength of raw soil.

Maheshwari et al. (2011) studied the performance of fiber-reinforced clay soil with randomly distributed fibers. They found that the reinforcement of highly compressible loamy soil with randomly distributed fibers caused an increment in the ultimate load bearing capacity and a decrementing of the settlement at the final load.

Chegenizadeh and Nikraz (2011) studied the influence of fiber inclusion on the strength of subgrade material. Therefore, the plastic fiber used for this study. The contents of the fiber and the aspect ratio were modified throughout these experiments. The proportion of fibers ranged from 0.0% to 2.0%. The clay is used as a material for sub-grade. In order to study the behavior of the composite under various conditions, unconfined compression tests were conducted. The length of the fibers and the contents of the fibers have been found to indicate significant rules on the strength of the compound. In addition, it was noted that the ductility of the sample increases by including the fibers.

Roustaei and Ghazavi (2012) investigated the reinforcement effect of soil containing steel fibers and tire chips in order to reduce the effect of freeze-thaw cycles. As a result of the test, it was revealed that addition of tires to clay prevents a decrease in strength by freeze-thaw cycle. Soil samples mixed with 10.0% tire chips and 2.0% steel fiber were not influenced by freeze-thaw cycles as well as pure samples. These substances can reduce the influence of freeze-thaw cycles, especially in cold regions.

Singh and Gill (2012) investigated the influence of geo-grid reinforcement on California Bearing Ratio of a clayey soil. The researchers found that when clay soil reinforced with a single layer of geo-grid, the CBR of clay soil increases by 50% to 100%. The amount of improvement depends on the position of the geo-grid and soil type, also without reinforcement, the CBR sub-grade soil is 3.6% and the CBR value increased to 8.7% when the geo-grid placed at 0.2H from the top. When the geogrid was placed at the optimum position, the stress-strain behavior of subgrade soil under static load condition was greatly improved.

Pillai and Ayothiraman (2012) investigated soil stabilization by using human hair fibers. The effect of reinforcing fiber content on kaolinite clay has been noticed by a series of laboratory experiments like compaction experiments, unconfined compressive experiments, and consistency limit experiments. The UCS strength of the soil reinforced with fiber mixtures has a higher strength comparison of untreated soil. The results of the experiments show that the incorporation of human hair fibers randomly distributed in soils greatly improves the engineering properties of clay soil.

Malekzadeh and Bilsel (2012) studied the influence of polypropylene fibrous on the mechanical performance of clay soils. At the initial stage of the experimental program, the influence of polypropylene fiber on maximum dry density and optimum moisture content for various fibrous inclusions is studied. Dynamic compaction tests were performed on a clay soil sample with additives of 0.0%, 0.50%, 0.750% and 1.0% polypropylene fibers (dry weight of the soil) samples were prepared with the same dry density. The second stage of the experimental program focuses on the one-dimensional swelling, unconfined compression and tensile of the unreinforced and reinforced soil samples. Finally, it is concluded that the swelling characteristics are significantly reduced and the maximum value of the cohesions was achieved by adding 1.0% fiber. In addition, a maximum tensile strength of 1.0% fiber content is achieved. They suggest that better control of the soil and thus damage to the structure can be reduced by using polypropylene fiber at an amount of 1.0%.

Kar et al. (2012) investigated plate load test on the fiber-reinforced cohesive soil. The laboratory test outcomes showed that the addition of fibers in the soil increases the unconfined compressive strength and the corresponding strain at failure up to optimum fiber content and fiber length and decreases thereafter. The strain at failure increases by adding of fibers into the soil, and thus makes the reinforced soil matrix more flexible; the settlement under a particular load in reinforced soil is much higher than the unreinforced soil, minimal settlement of reinforced soil with polypropylene fibers was observed.

Jafari and Esna-ashari (2012) studied the influence of tire cord waste on the mechanical properties of lime stabilized and un stabilized clay soil under freeze-thaw condition. Several samples were prepared at four different amounts of discrete short nylon fiber (0.0, 0.50, 1.0, and 1.50%) and three percentages of lime (0.0, 4.0, and 8.0%) by weight of dry soil. The results showed that the stress-strain and compressive strength behavior of samples are significantly dependent on the lime and fiber proportions. For the stabilized samples, the reinforcing of the fiber was greater than that of un stabilized, and also through adding of fibers, 4.0% lime-stabilized samples showed increased strength compared to untreated samples and 8.0% lime-stabilized samples. In addition, as the number of freezing and thawing cycles increased, the impact of the fiber on the strength of the specimens increased.

Mirzababaei et al. (2012) investigated the UCS of clay soil reinforced by carpet waste fibers. The test was performed on the specimens which were prepared at maximum dry weight and optimum moisture content, as well as on the samples which were prepared under variable conditions of dry unit weight and moisture content. Samples prepared with the same fiber content were also compared by varying the dry unit weight without changing the moisture content or by changing both dry unit weight and moisture content. The study showed that adding of carpet waste fibers into clay soils prepared at the same dry unit weight greatly increase unconfined compression strength. Existence of carpet waste in clay soil reduces the post peak strength loss, and alters the failure performance from brittle to ductile. The outcomes also demonstrated that the relative advantages of the fibers to increase the UCS of clay soils are very reliant on the initial moisture content and dry unit weight of the soil.

Alqaissi (2012) studied the advantages of using tire chips to improve the control settlement and bearing capacity of strip footing on sandy soil. The outcomes show that adding an amount of tire chip significantly increases the CBR strength of the sandy soil; it is around 19.50% for size (10-20) mm and 29.0% for (5-9) mm at the percentage of tire chip of 20.0%, Table 2.1, Figure 2.2, and Figure 2.3, shows the improvement of the modified load settlement and bearing capacity performance of the foundation since the use of tire chips have decreased the settlement by 22.0%.

Table 2.1 CBR results from tests on sand– tire chips mixtures (Alqaissi, 2012).

Tire chips (% by wight)	CBR (%)	
	Size (5-9) mm	Size (10-20) mm
0	14.8	14.8
10	16.3	15.7
20	19.1	17.8
30	17.7	16.9

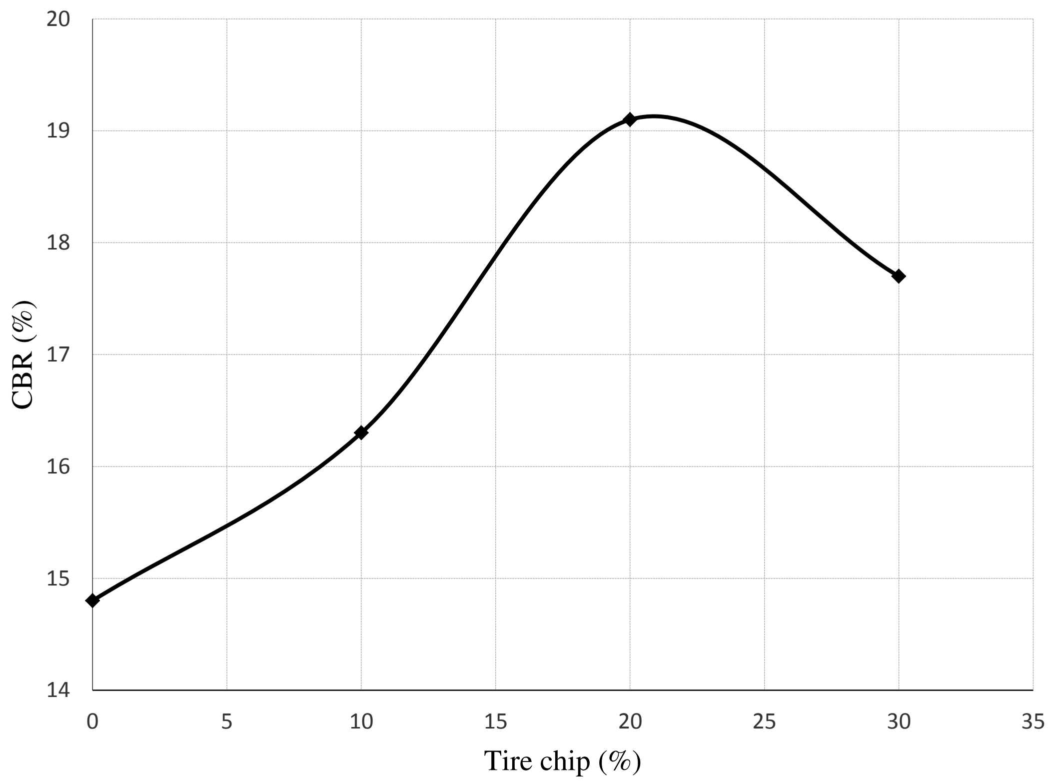


Figure 2.2 Effect of content of (5-9) mm tire chip on CBR (Alqaissi, 2012).

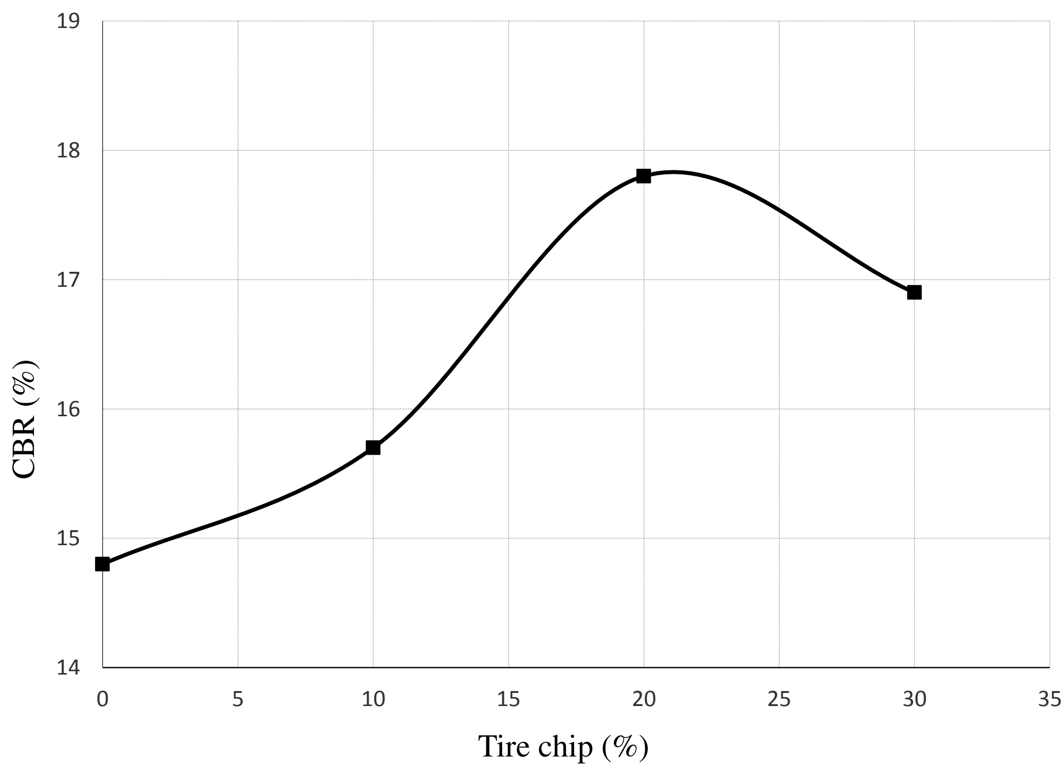


Figure 2.3 Effect of content of (10-20) mm tire chip on CBR (Alqaissi, 2012).

Maliakal and Thiyyakkandi (2013) studied the effect of randomly distributed coir fibers on the shear strength performance of clay. Authors found the presence of discrete coir fibers greatly improved the shear strength of clay soil. This can be used effectively in situations where in-situ mixing of soil with fibers is allowed.

Estabragh et al. (2013) studied the influence of discrete palm fibers on the shear behavior and consolidation of a randomly reinforced clay soil. The soil specimens have been prepared at three different fiber contents (10.0%, 20.0%, and 30.0%). Triaxial and consolidation experiments have been performed on these samples. The outcomes show adding of the fiber reinforcement in the soil originates a reduction in the pre-consolidation pressure and an increment in the swelling indices and compressibility. Furthermore, the internal friction angle and the strength significantly increase in the form of effective and total stresses.

Mohamed (2013) studied the improvement of the swelling properties of clay using hay fibers. He discovered that due to the addition of hay fiber, there was no significant or sensible change in the Atterberg limits. With the addition of an amount hay fiber, the maximum dry density reduces. The optimum moisture content decreased with adding hay fiber content until 1.0% of hay fiber and then increase with the further increase in hay fiber content. The shrinkage limit reduced with adding hay fiber content until 1.0% of hay fiber and then maximizes with increasing hay fiber addition. Also, the direct shear strength increases and unconfined compression strength reduced with the addition of hay fiber into the soil. In additional, the swelling decreases and tensile strength of the air-dried mixture increase with the addition of the hay fiber into the soil.

Karabash et al. (2015) investigated the influence of industrial waste aluminum pieces on the compaction properties and stress-strain behaviour of clayey soil. During the experimental work, a series of modified compaction and unconfined compression experiments were carried out. In the experimental work, four various amounts of waste aluminum pieces were used; namely; 0.0, 5.0, 10.0, 15.0 and 20.0% by the dry weight of the samples. The results showed that increase of maximum dry weight unit and reducing the optimum moisture content. Moreover, unconfined compression strength is significantly increased, as the amount of aluminum waste is increased to 10%, and then decreased.

2.3 Soil stabilization using chemical stabilizer and fiber

Puppala et al. (2001) studied the expansive soil stabilization with polypropylene fibers and fly ash. The researchers showed that by adding fiber and fly ash into the soil, reduced shrinkage strain and increased strength as well as free swelling properties and plasticity was reduced. Since both stabilizers are a recycled waste, by using it for soil stabilization, disposal costs are reduced and recycling efforts will increase.

Punthutaecha et al. (2006) investigated the stabilization of soil while mixing with nylon fibers, polypropylene fibers, bottom ash and class F fly ash. Although the ash stabilizer demonstrated an improvement which reduced the shrinkage, plasticity and swelling properties by 20.0% to 80.0%, while fiber treatment caused in different enhancements. In combined treatments, class F fly ash blended with nylon fibers was the most influences treatment on both Arlington and Dallas soils.

Puppala et al. (2006) investigated the stabilization of soil while mixing with polypropylene fiber and lime. The researchers discovered that lime-fiber mixing provides reproducible specimens that yield repetitive swell strain results and strength with low standard deviations. The curing time had a significant effect on the strength improvement moderate effect on the reduction of shrinkage strains in control soils.

Kumar et al. (2007) investigated the influence of lime and polyester fiber inclusions on the geotechnical features of fly ash-soil mixtures. Fly ash and lime have been added to an expansive soil in the ranges of 1.0-20.0% and 1.0-10.0%, respectively. The samples have been place in to compaction experiments, split tensile strength and unconfined compression tests. The samples have been tested with various percentages of plain and crimped polyester fibers by 0.0%, 0.50%, 1.0%, 1.50%, and 2.0% by dry weight. Based on the positive outcomes achieved, it can be decided that the expansive soil could be stabilized successfully by addition of fibers, fly ash, and lime into the soil.

Jadhao and Nagarnaik (2008) investigated the influence of fiber changeable (length and content) on the characteristics of fiber-reinforced soil- fly ash mixtures. A series of laboratory unconfined compressive strength and california bearing ratio experiments have been performed. The soil-fly ash samples have been compacted at the maximum dry unit weight with a low proportion of reinforcement (0.0, 1.50% by weight). A polypropylene fiber with various lengths of fibers (6 mm, 12 mm and 24 mm) was used as reinforcement. Through authors investigation four primitive conclusions were obtained. (i), adding randomly distributed fibers significantly will improve the unconfined compressive strength of the soil-fly ash mixtures. (ii), increasing fiber length decreased the contribution to peak compressive strength. However, the contribution to the strain energy absorption capacity was increased in all soil-fly ash mixtures. (iii), the optimum identified dosage rate of fiber was 1.0% by total dry unit weight of soil-fly ash, for all mixtures of soil-fly ash. (iv), using fiber length about 12mm gives maximum performance when used as reinforcement in soil fly ash samples.

Ayyappan et al. (2010) studied the engineering properties of soil while mixing with polypropylene fibers and fly ash for construction of road. The researchers found that including randomly distributed fibers, the unconfined compressive strength of the soil-fly ash mixture was significantly improved. By increasing, the length fiber decreased the contribution to peak compressive strength, whereas the contribution to the strain energy absorption capacity was increased in all soil-fly ash mixtures.

Kaniraj et al. (2012) investigated the stabilization of some sorts of fly-ash with soils, randomly oriented fibers, and cement. Researchers found that when fly-ash and soils were mixed, it reduced the MDD of the soil. Although polyester fiber inclusions had no important influence on OMC and MDD of untreated fly-ash or fly ash-soil mixture, but fiber inclusions significantly ascending the strength of fly-ash soil samples, it changed their behavior from brittleness to ductility. Even small cement contents upsurge the UCS of the fly-ash soil specimens significantly. Even small amounts of cement have considerably maximized the UCS of fly ash-soil samples. We were able to prepare a fly ash-cement design mix that satisfied the strength standard of pavement base course with a cement content of maximum 18.0%.

Sabat (2012) studied the effect of randomly distributed polypropylene fibers on engineering characteristics of soil stabilized with rice husk ash and lime. The researcher demonstrates that the soaked CBR and UCS values of the expansive soil increased by adding rice husk ash and lime into the soil. By adding polypropylene fiber to lime-rice husk ash stabilized expansive soil, soaked CBR and UCS values increase with the addition of up to 1.50% of polypropylene fiber and decrease with the polypropylene fiber content increases further. As the curing time increases, the soaked CBR and UCS values increase. However, the hydraulic conductivity of the expansive soil was reduced by adding lime-rice husk ash into the soil, and then, by increasing the proportion of polypropylene fibers added to expansive soils stabilized with lime-rice husk ash, the hydraulic conductivity increasing. Also, as curing time rises, the hydraulic conductivity decreases. In additional, the swelling pressure of the expansive soil was reduced by the addition of rice husk ash-lime into the soil, and then the swelling pressure continued to decrease with an increase in the proportion of polypropylene fibers added to expansive soils stabilized with lime-rice husk ash. Also, with the curing time increases, the swelling pressure decrease.

Senol et al. (2012) investigated the stabilization of clayey soils while mixing with homo polymer polypropylene (HPP) and fly-ash. The researchers have found that by adding fly ash content to soil the optimum moisture content of clay soils has been reduced. In addition, the unconfined compressive strength and maximum dry density reached the maximum value at 10% of the fly ash, which was blended with the clayey soil.

Pasupuleti et al. (2012) investigated the influence of fiber on fly-ash stabilized sub-grade layer thickness. The researchers discovered that the CBR value that increases by adding fiber and fly ash into the soils, as well as, the pavement thickness can reduce by increasing the CBR value.

Muntohar et al. (2012) studied the engineering characteristics of silty soil stabilized with lime and rice husk ash and reinforced with waste plastic fiber. The results show that the suggested method is very influenced for enhancing the engineering characteristics of silty soil with respect to shear, tensile and compressive strength, further improving soil durability and stability. Based on the california bearing ratio, failure, shear strength and compressive strength properties, the optimum amount of fibers mixed in soil-rice fly ash-lime mixtures is 0.40% to 0.80% of the dry weigh.

Chauhan and Sharma (2014) conducted an experimental study on CBR to improve the sandy soil-fly ash mix with geogrid layers. The fly-ash ranged from 15 to 35% in a sample of sand. All tests were performed at the maximum dry density and optimum moisture content of mixtures. Researchers have demonstrated that the CBR value increases as the proportion of fly-ash and soil maximizes. This increase was significant up to 25.0% fly ash, after which these values begin to decrease. In addition, when using the two-layered geogrid, the maximum increase in the CBR value with a geogrid was noted. The increment CBR value is 6.0% of virgin soil to 13.0% by geogrid use. Also, the maximum CBR value achieved with two-layered geogrid and 25.0% fly-ash.

Chen et al. (2015) investigated the laboratory assessment of the influences of polymer fibers on cement-improved soft clay and the strength of reinforced fiber. Two types of polymer fibers were used in the tests; the first one was fiber bundles split from polymer textile bags and the other one was monofilament polypropylene fiber. Researchers have shown that adding fibers can greatly improve the strength and ductility of cement-treated clays. The unconfined compressive strength of fiber-soil-cement admixture is associated with both the length and content of the fiber. Both types of fiber-reinforced cement clay achieved maximum strength with a fiber content of 0.50%. If fiber content continues to increase, UCS slowly reverses. Although the polypropylene fiber functions better than the fiber bundles, the variance is less than 50.0%. These outcomes show that the bundles of fibers separated from polymer bags could be used as reinforcement in the soil mixture, thereby innovating a new way for the treatment of waste polymer textile bags.

Kumar and Gupta (2015) investigated the influence of addition of fiber, pond ash, rice husk ash, and cement on the strength properties and compaction of clay. Split tensile strength tests and unconfined compression experiments were conducted to evaluate the strength behavior of clay, while modified proctor experiments have been performed to assess the compaction properties. Rice husk and Pond ash were added to clayey soil at a limit of 5.0%-20.0% and 30.0%-45.0%, respectively. Polypropylene fibers contents in the form of 0.0%, 0.50%, 1.0 % and 1.50% by dry weight are used in this investigation with various fibers of length 6.0 mm and 12.0 mm, while the cement contents are 0.0%, 2.0%, and 4.0%. The test outcomes demonstrated that adding of the admixtures raised optimum moisture content and reduced the maximum dry density but fiber addition had a marginal influence. As a result, the addition of fiber reinforcement in cemented soil and un-cemented soil aimed in an increase of STS, axial strain at failure, and UCS, reduced loss of post-peak strength and stiffness, and altered the brittle behavior of cemented soil to more ductile. The investigation demonstrated that the combination of clay, fiber, cement, pond ash, and rice husk ash can be used as lightweight filler substances in various structures such as the dam, retaining wall, etc.

Table 2.2 Summary of previous studies with fiber reinforced sands (Dahal, 2016).

Test Method	Soil and Fiber Used	Loading Type	Results	Reference
Cyclic Triaxial	Sand/geosynthetic fibers	Dynamic loading	Relatively higher increase in resistance to liquefaction for fiber reinforced samples	Noorany and Uzdavines (1989)
Triaxial Compression	Sand/randomly distributed fibers	Static loading	Increase in ultimate strength and stiffness of fiber added sand	Maher and Gray (1990)
Direct Shear	Sand/ randomly distributed fibers	Static loading	Increased in shear strength, friction angle ø, and ductility of fiber reinforced sample	Attom and Al-Tamimi (2010)
Ring Shear	Sand/randomly distributed fibers	Static loading	Increased in shear strength of sand and ductile behavior	Shao et al. (2014)
Cyclic Triaxial	Loose and medium dense sand/ randomly distributed polypropylene fibers	Dynamic loading	Shear modulus increased with fiber	Noorzad and Amini (2014)
Cyclic Triaxial	Clayey sand/ randomly distributed polypropylene fibers	Dynamic loading	Rate of shear modulus loss is lesser with fiber inclusion	Sadeghi and Beigi (2014)
CU Triaxial	Sand with randomly distributed polypropylene fibers	Static loading	Increased in dilative tendency and changed strain-softening into strain-hardening	Erdoğan and Altun (2015)
Triaxial	Sand with cement and randomly distributed polypropylene fibers	Static loading	Fiber inclusion increased the shear strength and peak axial strain	Kutanaei and Choobbasti (2016)

CHAPTER 3

EXPERIMENTAL STUDY

3.1 General

This chapter will explain the type and properties of the materials used in this study. Furthermore, it will describe the procedures and the test equipment used. This chapter also presents the various laboratory test methods used in this research to study the properties of soil (i.e., natural soil from Gaziantep, Turkey) when stabilized with the steel CNC milling waste material. Numerous of laboratory tests were achieved including Unconfined Compressive Strength UCS, California Bearing Ratio CBR, swelling, permeability, direct shear, and consolidation test. In this research, all of the samples used in the tests were prepared in the laboratory based on the standard procedures of American Society of Testing and Materials (ASTM).

3.2 Materials and equipment description

3.2.1 Soil

The silty soil used in the experiments was quarried at the University of Gaziantep campus (Figure 3.1). Properties of soil including specific gravity, liquid limit, plastic limit and plasticity index were found to be 2.7, 35.3%, 25.8% and 9.5%, respectively. The particle size distribution curve for the sample is presented in Figure 3.2. Hence, the soil was classified as ML according to the unified soil classification system (USCS). Liquid limit and plastic limit have been found according to ASTM D4318 (Figures 3.3, 3.4, and 3.5) and the engineering properties of soil are shown in Table 3.1.

Figure 3.1 Soil sample.

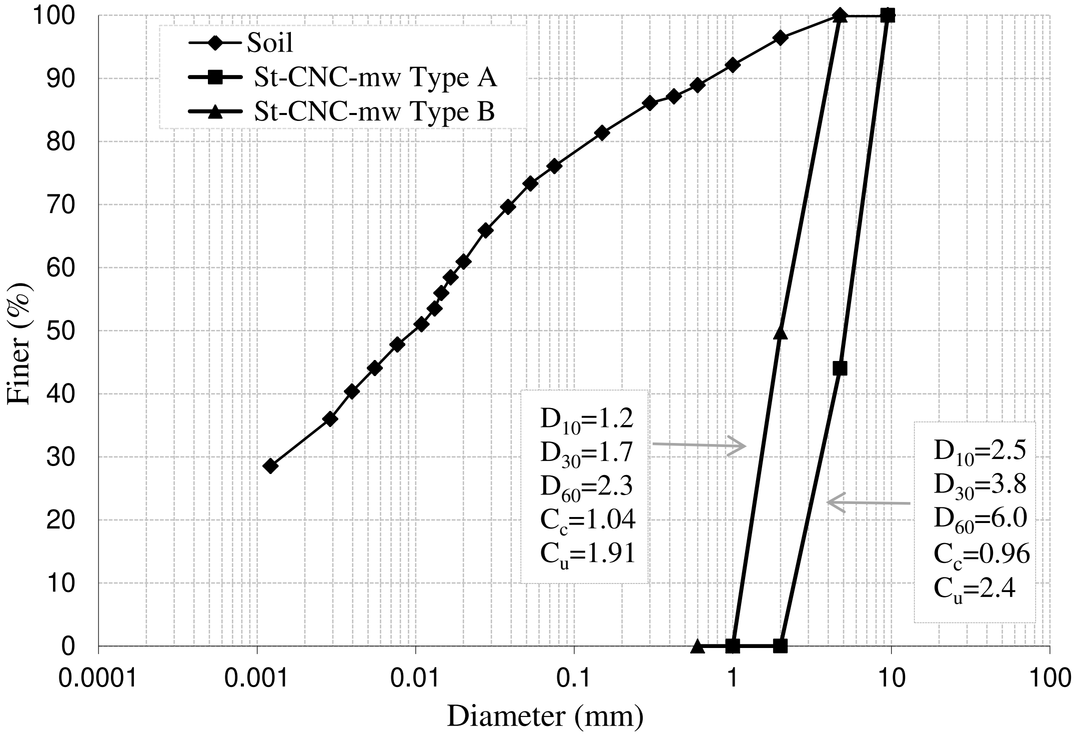


Figure 3.2 Grain size distributions of soil and steel CNC milling waste.

Table 3.1 Some engineering properties of soil.

Engineering Properties of soil	
Properties of soil	Value
Liquid limit (%)	37.20
Plastic limit (%)	23.30
Plasticity index (%)	13.90
Specific gravity	2.70
Maximum dry density (kN/m^3)	18
Optimum moisture content (%)	18
Soil type (USCS)	ML

Figure 3.3 Liquid limit test.

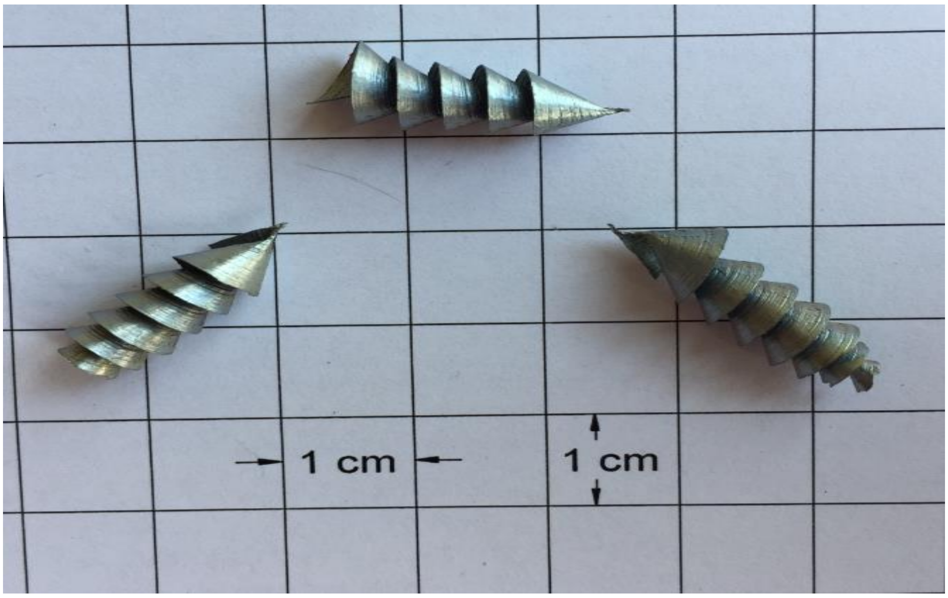
Figure 3.4 Hydrometer test.

Figure 3.5 Specific gravity test.

3.2.2 Solid waste material

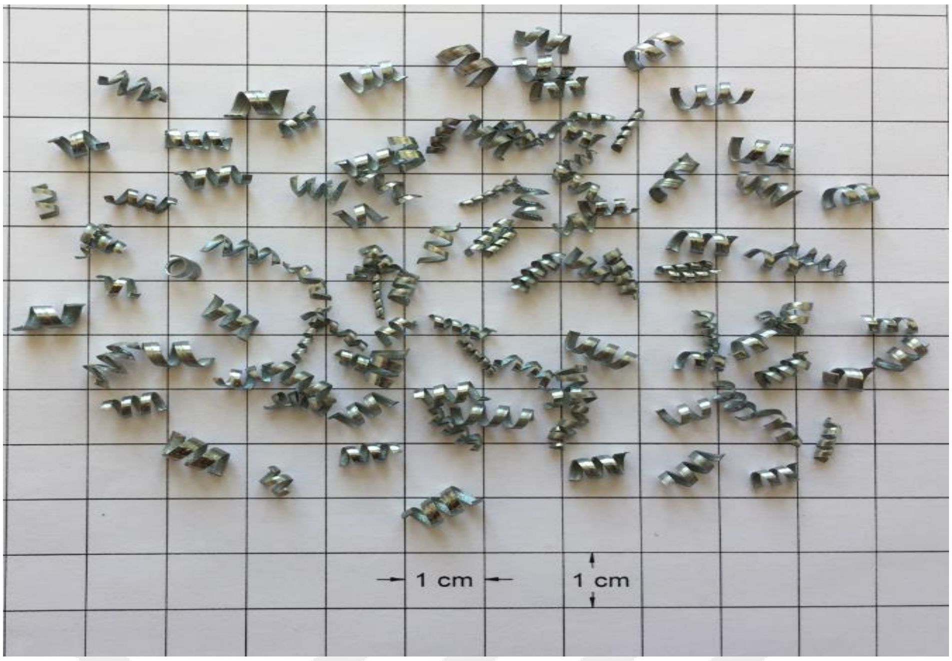
The waste material used during the experimental work was steel CNC milling waste (St-CNC-mw). The steel CNC milling waste (St-CNC-mw) was produced from mechanical processing of the metal using CNC (Computer Numerical Control machine) in the industrial area of Gaziantep, Turkey. The St-CNC-mw used in this study is shown in Figure 3.6 and 3.7.

(a)

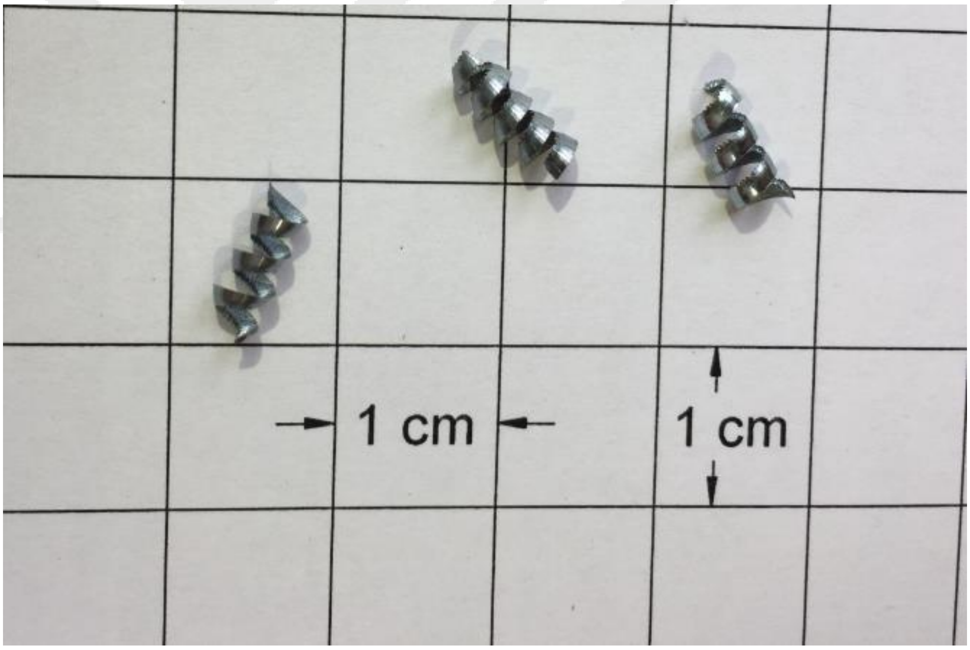


(b)

Figure 3.6 Photographs of (a,b) steel CNC milling waste (type A).



(a)



(b)

Figure 3.7 Photographs of (a,b) steel CNC milling waste (type B).

The steel CNC milling waste (St-CNC-mw) had a specific gravity of 7.12 .The grain size distribution of the waste material is presented in Figure 3.2. From Figure 3.2, it can be observed that the waste material consists of two types, type A and type B. the first type has a large particle while D_{10} ,D_{30}, D_{60}, the coefficient of curvature (c_c) and the uniformity coefficient (c_u) of waste material were found to be 2.5, 3.8, 6, 0.96

and 2.4 respectively. Further, this type used for california bearing ratio and permeability test because these tests have a large mold. And the second type has a small particle while D_{10}, D_{30}, D_{60}, the coefficient of curvature (c_c) and the uniformity coefficient (c_u) of waste material were found to be 1.2, 1.7, 2.3, 1.04 and 1.91 respectively. Also, this type used for compaction, unconfined compressive strength, consolidation, swelling and direct shear test because these tests have a small mold. In additional, both types of the steel CNC milling waste have a spiral shape (see Figure 3.6 and 3.7).

Zinc coated material: The St-CNC-mw was coated by zinc galvanostatically in an electrolyte including zinc (50 g/l), $ZnCl_2$ (70 g/l), KCl (150 g/l) and boric acid (35 g/l). In this process St-CNC-mw materials were cathode and zinc was an anode. As zinc coating is bonded to steel, steel does not have direct contact with soil and moisture because there is zinc interface between soil and steel. This zinc interface protects steel against corrosion. Bright zinc films on St-CNC-mw were shown in Figure 3.6 and 3.7.

3.2.3 Water

Tap water was used in the preparation of samples.

3.3 Testing and characterization

3.3.1 Specimen preparation

The steel CNC milling waste (St-CNC-mw) ratios were selected for the tests, 0%, 5%, 10%, 15%, 20% and 25 % by dry weight of the mixture. At a dry condition, the steel CNC milling waste (St-CNC-mw) with the soil was mixed, and after that, the amount water was added which was required for the mixture. After preparing samples according to standard specifications, they stored in plastic bags and knotted the bag to prevent weather affecting because the temperature of samples store was not adjusted, and it was as or close to outside temperature. Some of the samples needed to be remolded to carry out the test, and it can be utilized the same mix ratios at an optimum water content of those specimens.

3.3.2 Unconfined Compression Strength (UCS) test

The optimum moisture content and maximum dry unit weight for each test was determined using modified compaction test (ASTM D1557). In order to define the nature of mixtures at different points of the compaction curves, five different amounts of water contents were selected. The unconfined compressive strength testing equipment, is a conventional laboratory testing method used to determine the stress-strain behavior of soil- St-CNC-mw mixtures (ASTM 2166). The UCS tests were carried out on soil mixtures with various ratios of St-CNC-mw namely 0%, 5%, 10%, 15%, 20% and 25% from the dry weight of the mixture. For preperation of the UCS samples, two-part split mold with a diameter 4.2 cm, and a height of 10.2 cm were used (Figure 3.8). The specimens were compressed slowly in the mold in 5 layers by sticking 31 blows for each layer with an effort equivalent to modified proctor compaction ASTM D1557 utilizing special designed hammer defined by Cabalar et al. (2014). The UCS tests have been conducted using a loading frame that consists of 4.5 kN proving ring, and 0.01 mm sensitivity of a dial gauge. The ELE device was used to testing these specimens as demonstrated in figure 3.9.

Figure 3.8 The plastic split mold and the compaction hammer for the UCS samples preparation.

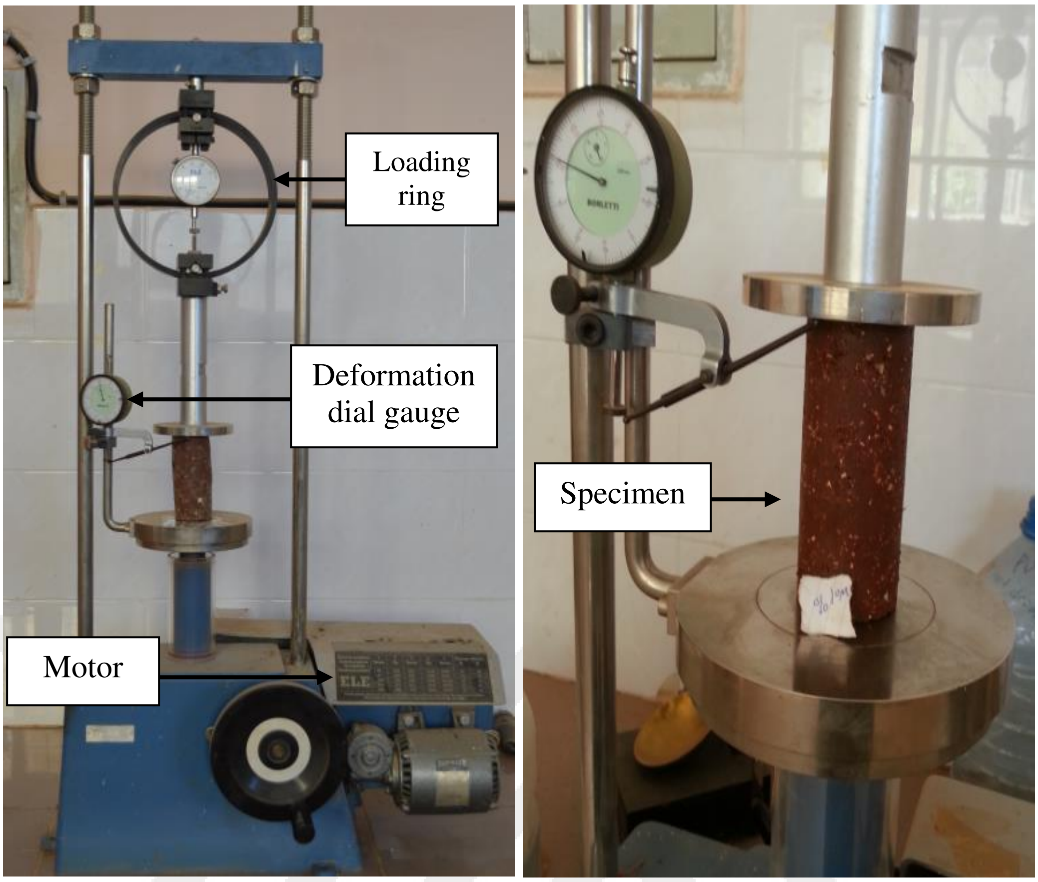


Figure 3.9 The machine UCS testing.

3.3.3 California Bearing Ratio (CBR) test

The California bearing ratio (CBR) testing equipment, is a conventional laboratory testing method used to determine the stress-strain behavior of soil- St-CNC-mw mixtures (ASTM 1883), the molds used have 101.6 mm and 154.2 mm in height and diameter respectively (Figure 3.10). The CBR tests have been conducted on the samples prepared at the soaked condition. For preparing samples, the St-CNC-mw materials were mixed with soil in the dry case and for each mix, five different water contents were used. The samples were compacted according to ASTM D1557. After compaction, two filter papers were putted into bottom and top of the specimen for avoiding loss of fines during the soaking period.

Figure 3.10 The mold and the compaction hammer for the CBR samples preparation.

After that, the sample subjected to a surcharge load which is 4.5 kg weight, a dial gage with 0.01mm sensitivity were installed on the sample to recording swelling percentage, before putting the sample inside the water the first reading on the gage must be taken which is the initial reading.

Figure 3.11 Sample in the water.

After this for getting the fully saturated case the samples were put into the box fill with water for 96 hr, then on the fourth day, final reading on the swelling gage was taken then the swelling percentage of the sample can be calculated (Figure 3.11). After that, the samples were taken out from the water and left for 15 minutes to drain water. The CBR machine which has a loading frame with a 28kN capacity of proving ring with dial gage that has 0.01mm sensitivity (ASTM D2166) and another dial gage 0.01mm sensitivity for recording penetration were used to determine the behavior of the specimens (Figure 3.12). After the test was started and readings of the proving ring dial gage were taken at every 0.25mm penetration, then the CBR values of specimens were obtained at 2.54 and 5.08mm penetration (ASTM D1883).

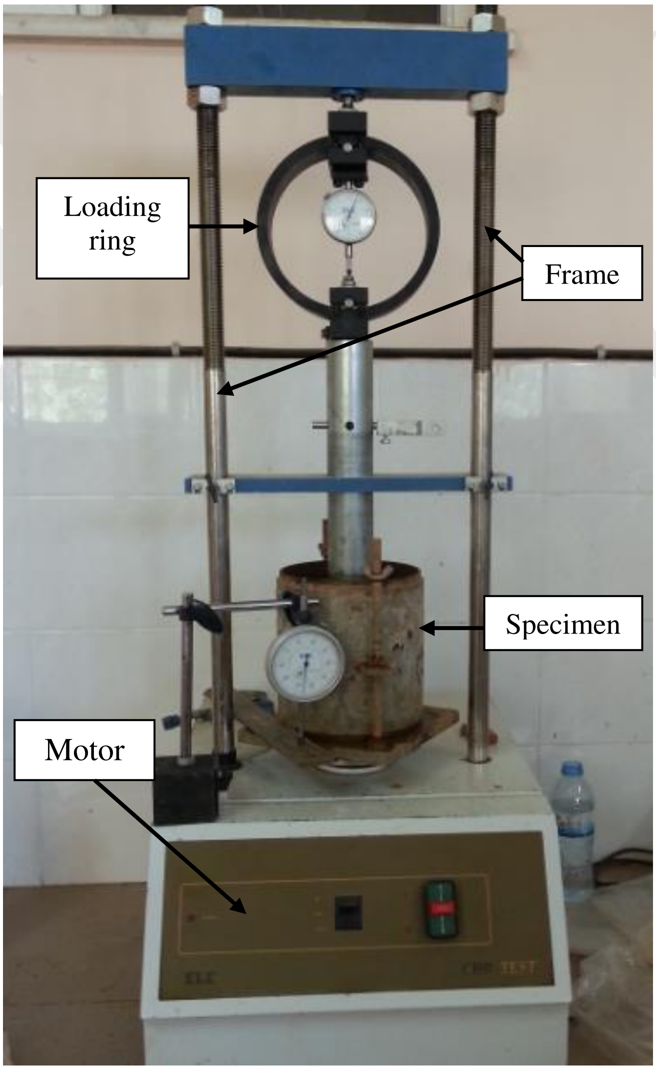


Figure 3.12 CBR testing equipment.

3.3.4 Consolidation test

The one-dimensional consolidation testing equipment shown in Figure 3.13, considered as a conventional laboratory testing method used to determine the compressibility characteristics of untreated soil and soil stabilized with St-CNC-mw to estimate its influence in decreasing the compressibility of the soil. These characteristics have been explained by constructing the relationships between effective stress and void ratio. In order to find rate of consolidation, the initial void ratio (e_o), swelling index (c_s) and the coefficient of consolidation (c_v) and compression index (c_c) have been calculated from the remarks taken through the process of testing (ASTM 2435).

Figure 3.13 Consolidation testing equipment.

Cylinder-shaped samples have been compressed by static compaction at optimum water content in 7.5 cm diameter consolidation ring to the required height of 2 cm. Figure 3.14 shows the consolidation samples preparation mold with all composition The internal surface of the ring was muddy with mobile oil to help minimize friction between the inner surface of the ring and the soil sample during the consolidation process. The wet homogenous mixture was located inside the specimen ring using a spoon that was leveled. Samples were placed in specimen ring with extension collar which was enclosed and both the exposed sides of the samples were covered with filter papers.

Figure 3.14 The mold and all composition for the consolidation samples preparation.

Thereafter, porous stone and pressure pad were inserted into the extension collar and the whole assembly was statically compacted in loading frame to obtain the wanted density. The samples were kept under static load for not less than 20 minutes in order to account for any subsequent increase in height of sample due to swelling. Pressure increment was 25, 50,100, 200, 400 and 800 kN/m^2 during the loading stage and unloaded up to 200 kN/m^2.

3.3.5 Swelling test

This test was done under the ASTM D4546. Swelling tests were performed in ELE consolidometer apparatus. The specimens have been prepared at the particular maximum dry density and optimum moisture content obtained from the compaction curves of soil and soil- St-CNC-mw mixtures. All the samples were pressed in the consolidation ring, for 24 h, the samples were soaked in water, and this allowed the samples to swell freely. Also, the samples subjected to 2.85 kN/m^2 during swelling processes. To measure the swelling of the samples, the dial gauge was used for that purpose and it was fixed on the top of the specimen. The sample rings which were tested were 75 mm in diameter and 20 mm high in standard oedometer apparatus. The swelling ratio (SR) was expressed by this equation:

$$SR = \frac{Hf - Hi}{Hi} * 100 \qquad (1)$$

Where H_f is the height of sample after swelling, Hi is the initial height of the sample.

3.3.6 Permeability test

The samples were remolded according to ASTM D1557 where the optimum water content of each ratio was used. The permeability mold was fixed between two cups at top and bottom with filter paper to prevent losing fine particles and the upper was connected to burette via a pipe for measuring the change of water head show figure 3.15. Samples were soaked in water at least for 6 days to get fully saturate then; the tested were conducted on the samples for 24 h to record many data with different time ranges. Falling-head permeability tests have been conducted according to the ASTM D 5084. Composted soil samples with St-CNC-mw in various percentages of 0%, 5%, 10%, 15%, 20%, and 25% were subjected to the permeability tests. And the hydraulic conductivity (k) values have been calculated by the equation:

$$K = \frac{\mathrm{aL}}{\mathrm{At}} \ln\left(\frac{h1}{h2}\right) \qquad (2)$$

Where a is cross-sectional area of the reservoir containing the influent liquid, L is length of the specimen, A is cross-sectional area of the specimen, t is elapsed time between determination of h1 and h2, h1 is head loss across the specimen at time t1 and h2 is head loss across the specimen at time t2.

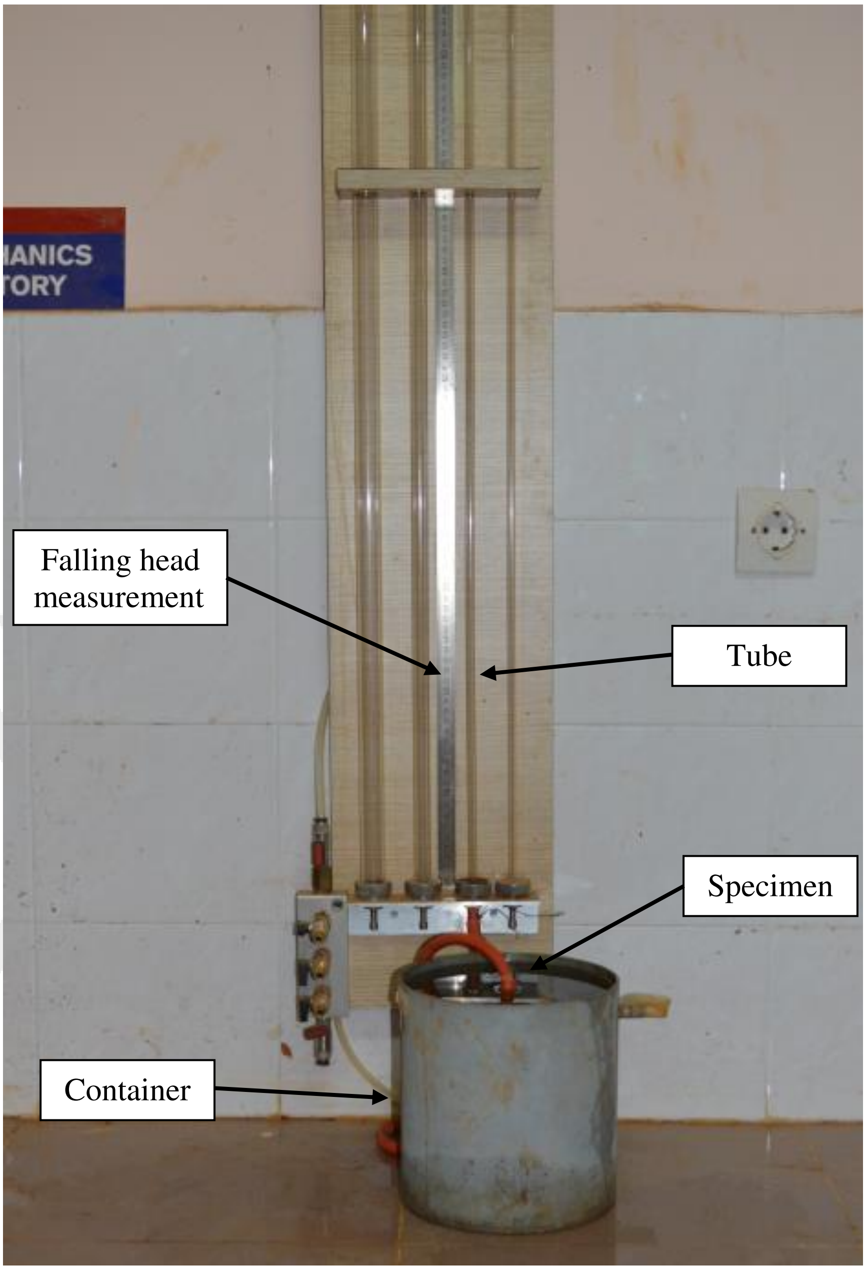


Figure 3.15 Falling head tube with specimen in water.

3.3.7 Direct shear test

The direct shear test in this study was performed according to ASTM D3080.The specimens will be compacted into a mold of size 6×6×2 cm by static compaction where optimum water content a d maximum dry density were used for each percentage. Each specimen was taken from the mold to direct shear machine after compaction. A picture of the sample tested is shown in Figure 3.16. For determining the cohesion and internal friction angle for each proportion, three normal stress values (100, 200, 300 kPa) were applied.

Figure 3.16 Sample after performing direct shear test.

In addition, the samples were subjected to a displacement rate of 0.5 mm/min. Deformation values were recorded during the test (Figure 3.17). The cohesion and internal friction angle values of soil samples were studied.

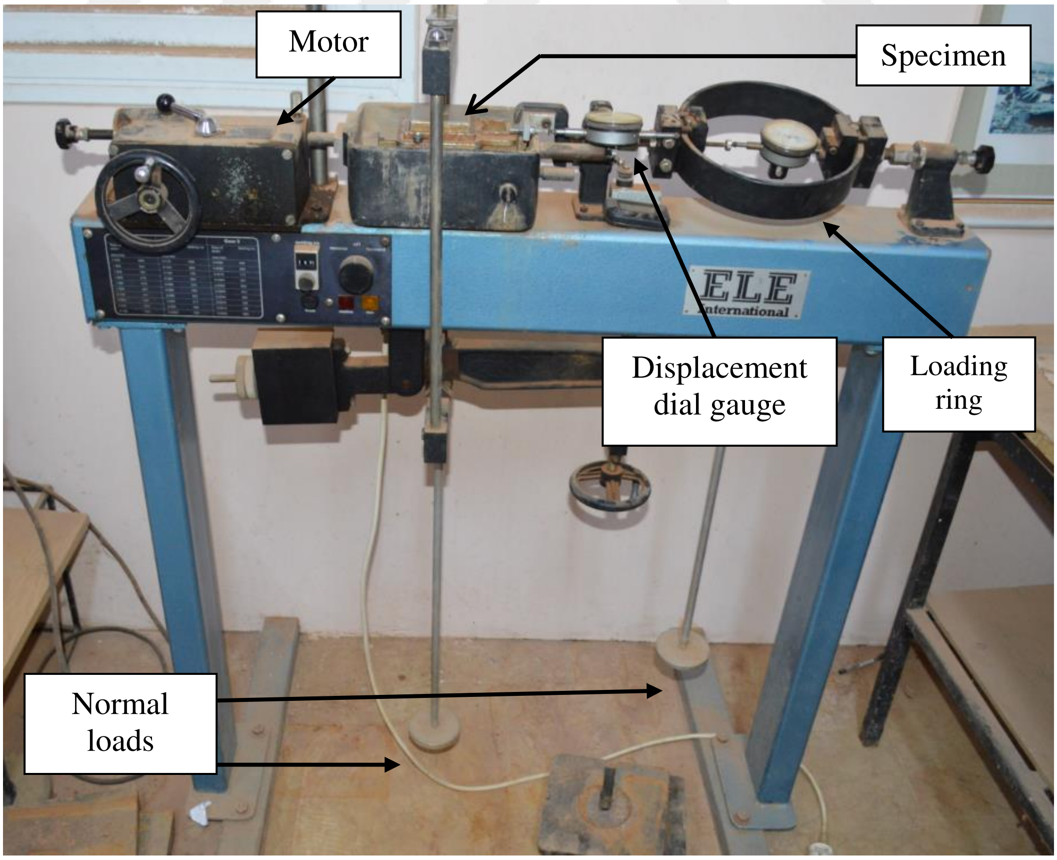


Figure 3.17 Direct shear testing machine.

3.3.8 Corrosion study of steel CNC milling waste

Corrosion characteristics of uncoated and zinc coated steel CNC milling waste (St-CNC-mw) were examined by the potentiodynamic function of a three electrode configuration (CHI inst. USA) shown in Figure 3.18. Polarization measurements were conducted in a cell containing corrosion solution (HCl, NaCl or NaOH) using a three-electrode configuration: Ag/AgCl (saturated KCl) reference electrode was used as a reference electrode with a titanium mixed metal oxides counter electrode which is commonly used for water ionizer. Bare and coated St-CNC-mw were immersed in the test solution as working electrode and the electrochemical polarization was scanned from more negative potential at a rate of 10 mV s^{-1}. The specimens were not given a metallographic polishing as corrosion behavior of St-CNC-mw is aimed to examine. In each measurement step, the specimens were only cleaned in distilled water (10 µS cm^{-2}). The spiral shape of St-CNC-mw working electrode was directly immersed in NaCl solution for potentiodynamic polarization (presented in Figure 3.18). The polarization curves were obtained after 24 hours of immersion of the sample in tap water.

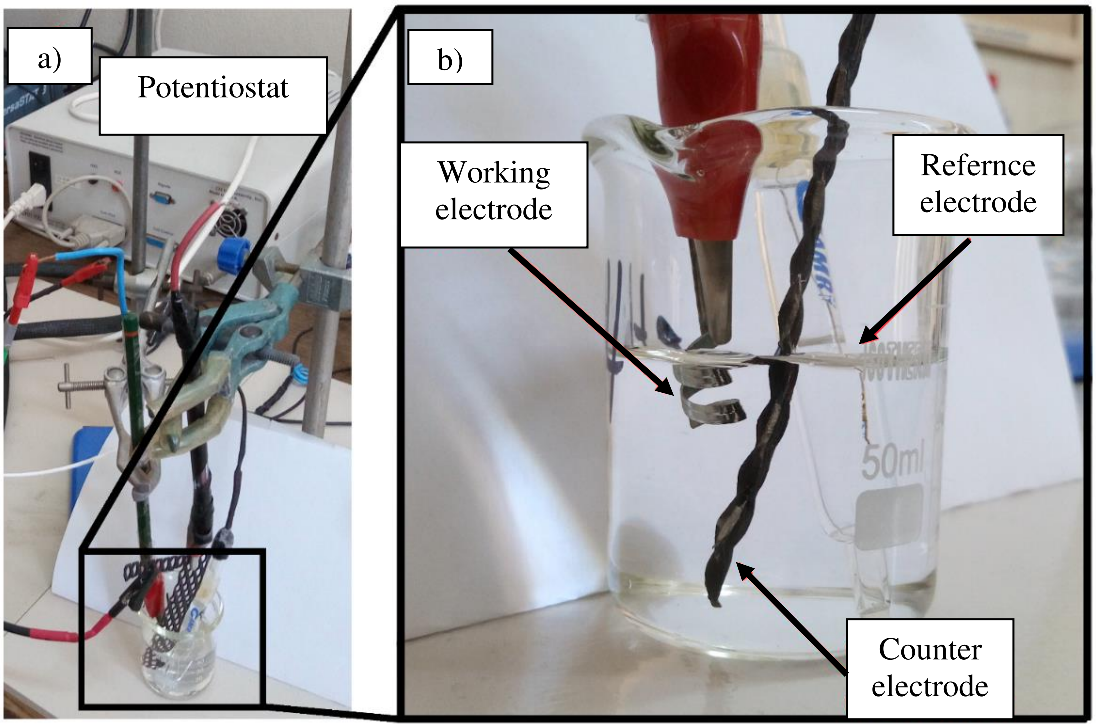


Figure 3.18 Experimental set-up of three-electrode configuration with steel CNC milling waste working electrode.

All experiments were repeated at least three times in all the solutions and a new St-CNC-mw were used each time. All experiments were conducted at room temperature (20 ± 2 °C). The corrosion resistance measurements of uncoated (left sides of Figure 3.19) and coated (right sides of Figure 3.19) steel CNC milling waste were performed in solution having various amount of chloride concentration from 0 wt% to 3 wt% in order to examine the effect of chloride ions. The effect of electrolyte pH is also conducted by using electrolyte having varies pH.

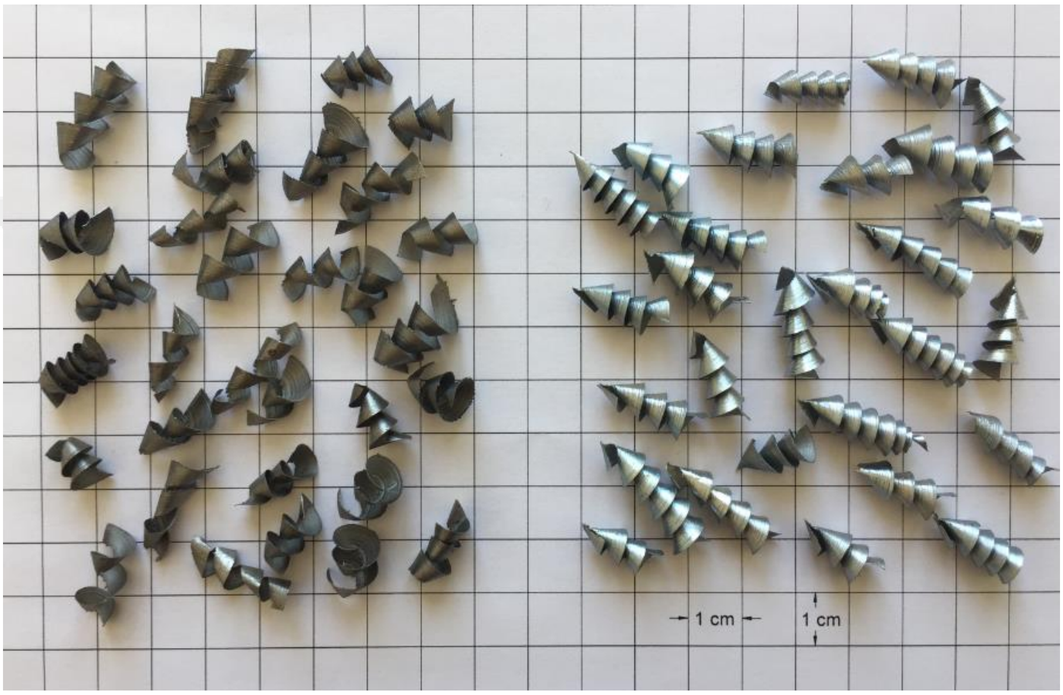


Figure 3.19 Photo of uncoated (left) and coated (right) steel CNC milling waste (type A).

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Compaction test

The compacted unit weight of the material depends on the quantity and energy application method, grain size distribution, plasticity characteristics and moisture content at compaction. The maximum dry unit weight and optimum moisture content for each test were determined according to ASTM D1557. As shown in Figure 4.1, the typical maximum dry unit weight and optimum water content relation is clearly presented while Figure 4.2 and 4.3 shows the variation optimum water content and maximum dry unit weight against the steel CNC milling waste.

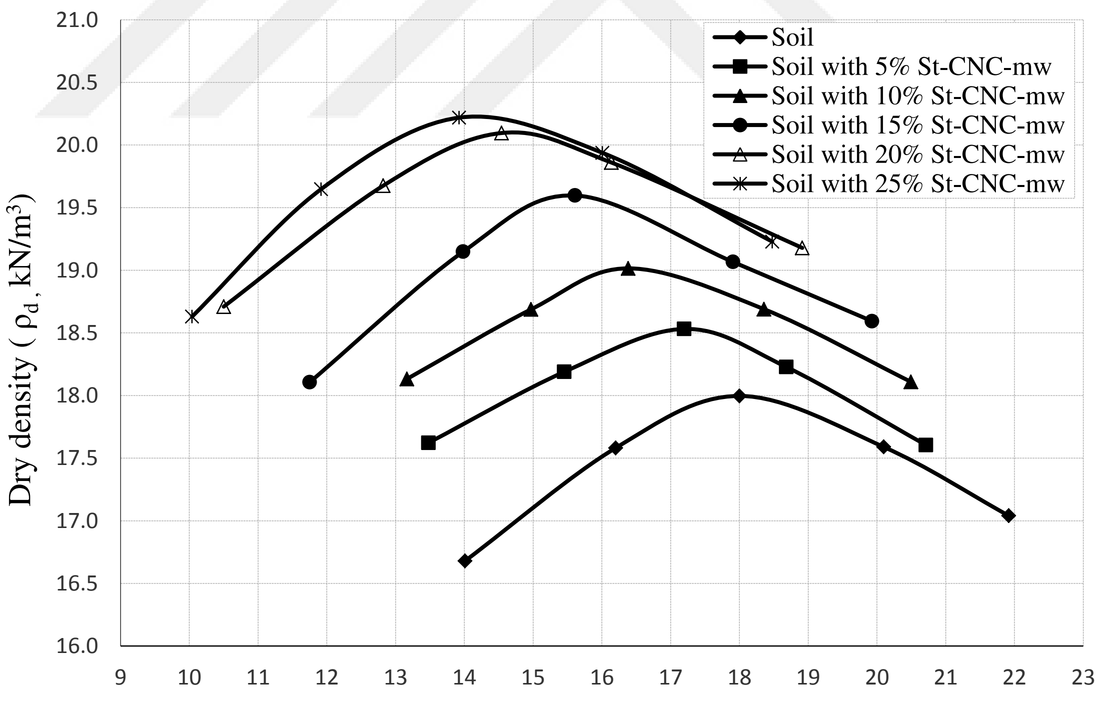


Figure 4.1 Maximum dry unit weight- optimum water content.

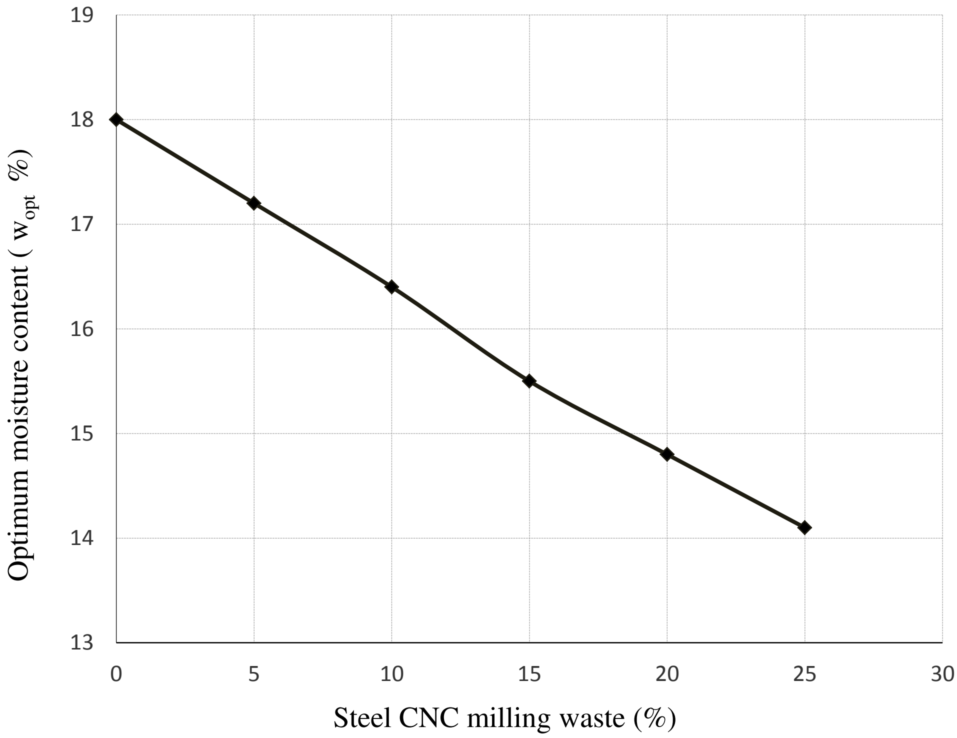


Figure 4.2 Variation of optimum moisture content with steel CNC milling waste content.

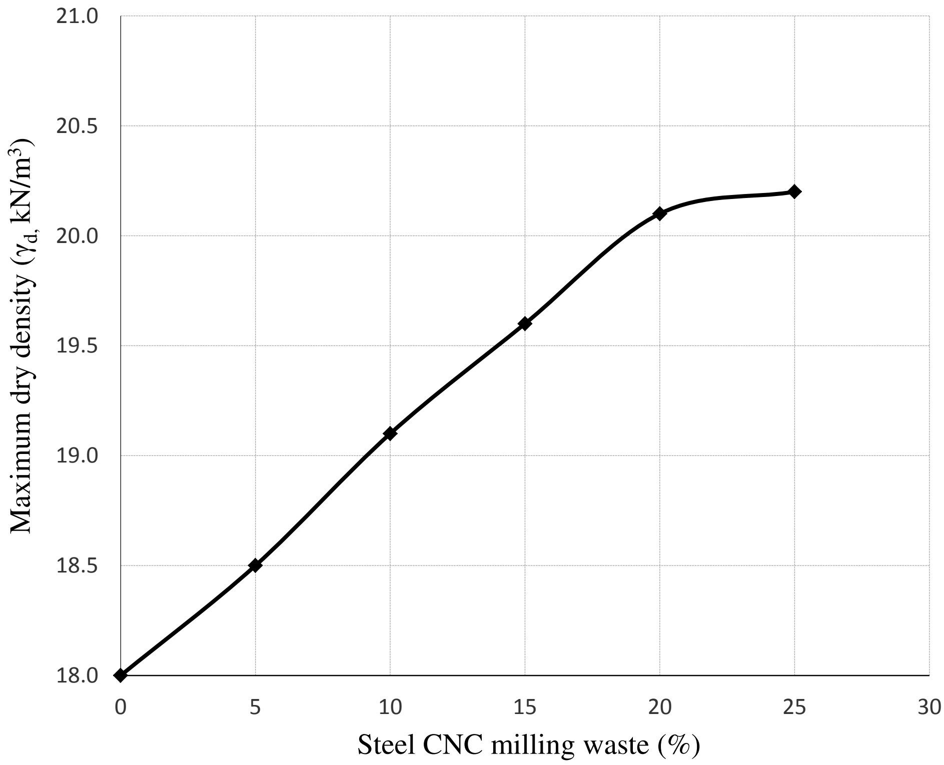


Figure 4.3 Variation of maximum dry unit weight with steel CNC milling waste content

The result shown in Table 4.1 has shown that by increasing the St-CNC-mw, maximum dry unit weight was also increased. However, the optimum moisture content decreased.

Table 4.1 OMC and MDD of soil mixed with different percentage of steel CNC milling waste.

Property	Steel CNC milling waste (%)					
	0	5	10	15	20	25
OMC (%)	18	17.2	16.4	15.5	14.8	14.1
MDD (kN/m^3)	18	18.5	19.1	19.6	20.1	20.2

These results were supported by Karabash et al. (2015). In their study, they concluded that by adding waste aluminum to clay soil, the maximum dry density increases and optimum moisture content decreases. Additionally, other studies by Miller and Rifai (2004) concluded that maximum dry unit weight increases and optimum moisture content decreases by adding fiber content into soil.

These behaviors may be due to the specific gravity of the St-CNC-mw being greater than that of silty soil, and the St-CNC-mw needs a lower amount of water for covering the particle surface. Furthermore, the waste material does not have the capability to absorb water as the silty soil particles do.

4.2 Unconfined Compressive Strength (UCS) test

The UCS tests were carried out with respect to ASTM-D 2166. The UCS tests were conducted on St-CNC-mw content mixed with soil. The results were showed in Table 4.2 and Figure 4.4 presents the variation between the UCS with the St-CNC-mw content. A failure occurs during the UCS increases until 15% of St-CNC-mw content which can be shown in the figure. Similarly, the same results were found by Mirzababaei et al. (2012) and Akbulut et al. (2007). They showed that the UCS value of poor soils increases with the addition of natural fibers and waste materials. Also, Kumar et al. (2007) concluded that when polyester fibers were added to fly ash- lime stabilized expansive soil, unconfined compressive strength increases with increasing fiber content.

Table 4.2 UCS of soil mixed with different percentage of steel CNC milling waste.

Property	Steel CNC milling waste (%)					
	0	5	10	15	20	25
UCS (kN/m^2)	298.46	334.76	369.14	390.11	-	-

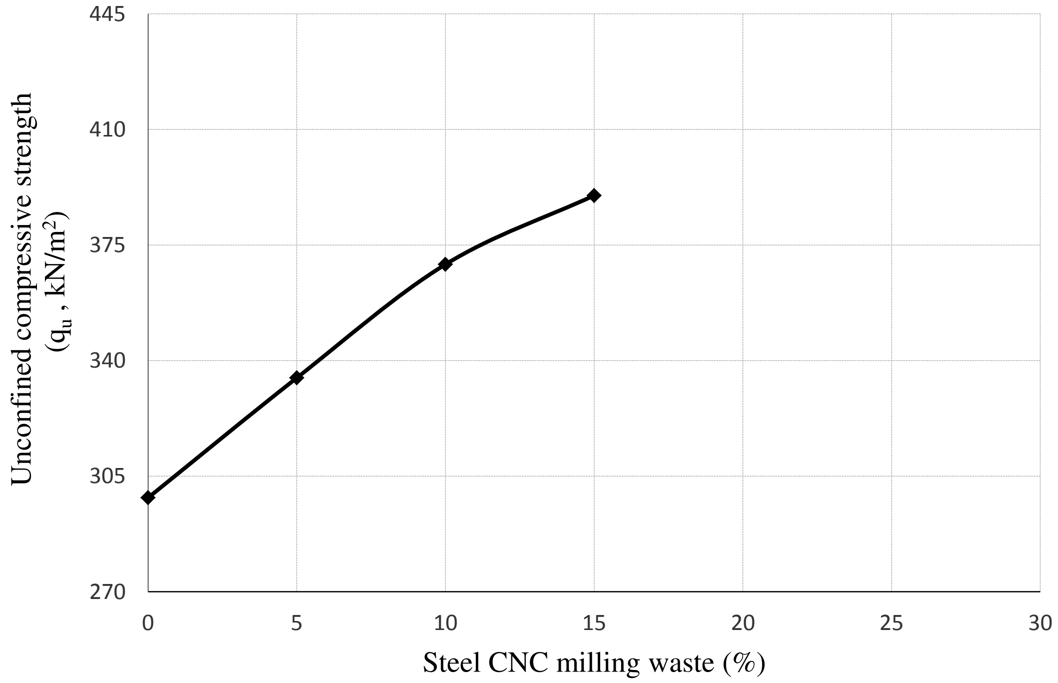


Figure 4.4 Unconfined compressive strength with steel CNC milling waste content.

As discussed earlier, this behavior may be due to a better gradation of the mixture at the 15% of St-CNC-mw happens. Another reason for this behavior is the steel CNC milling waste (St-CNC-mw) materials work as reinforcement between soil particles. Notwithstanding the fact that the cohesion between the mixtures of particles was strongly combined together and, therefore, UCS fails after 15% (Figure 4.5).

(a)

(b)

Figure 4.5 Photographs of (a) UCS sample when increase 20% of steel CNC milling waste, and (b) UCS sample when increase 25% of steel CNC milling waste.

4.3 California Bearing Ratio (CBR) test

One of the most important engineering parameter to evaluate a sub-grade or sub-base materials for pavement design is the CBR value. The CBR test was carried out with respect to ASTM D 1883. The CBR test was generally performed on the raw silty soil and altered soil specimens at ideal percentages of St-CNC-mw. Figure 4.6 presents the variations of the CBR with the compaction water content of the mixture for all mix percentages. The CBR of the mixtures increases as the water content increases until the water content comes close to optimum water content and then decreases. This behavior occurs due to the material becoming denser at these water contents. The compacted silty soils become soft as the water content increases after the optimum water content.

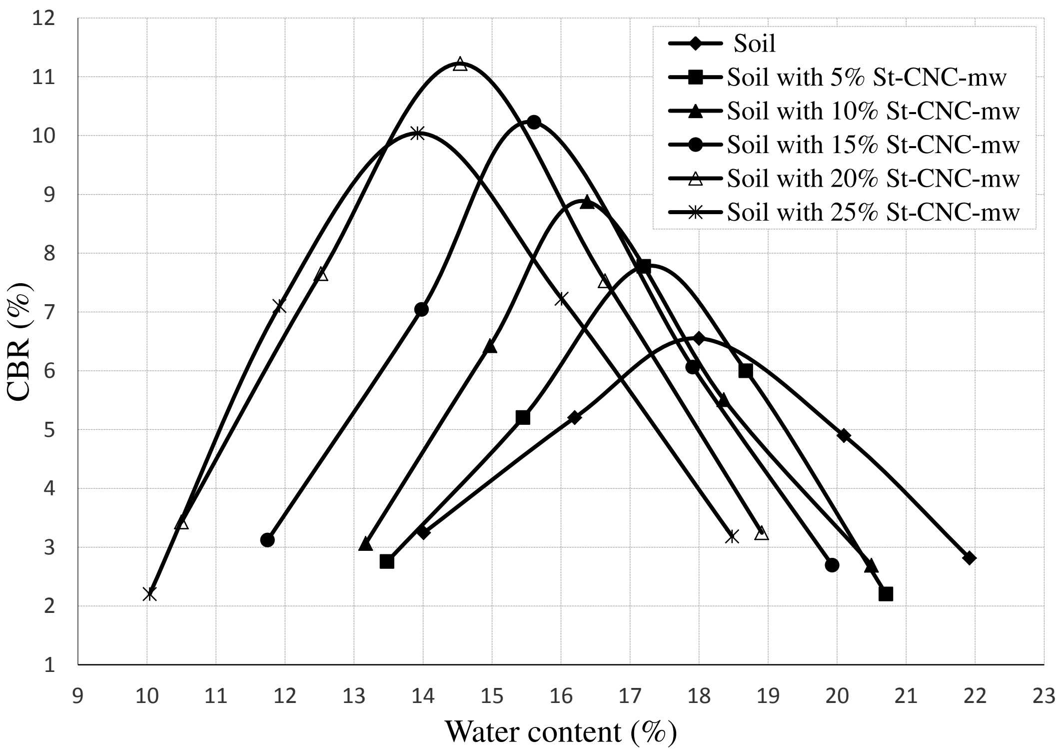


Figure 4.6 California bearing ratio variation with the water contents and steel CNC milling waste content.

Figure 4.7 presents the variation of the CBR with St-CNC-mw content. It can clearly be observed from this figure that the CBR increase until 20% of St-CNC-mw material content and then decreases. In the previous researches conducted by Chandra et al. (2008) showed that with the addition of fiber to subgrade soil, the

CBR value increases. In addition, soil reinforced with waste tire shreds pieces showing improvement in CBR value with its addition tire shreds pieces (Ghazavi and Sakhi, 2005).

The increment in CBR is due to the reason that St-CNC-mw combined into soil mass improves its load deformation behavior by interacting with the soil particle mechanically through surface friction and interlocking too. The strength and stiffness of reinforced soil increases with the increase of St-CNC-mw content and may be due to this reason also the CBR value of reinforced soil has been observed to be greater than that of raw soil. As the St-CNC-mw material content increases after %20, the interlocking of soil particles and waste material particles decrease and consequently the CBR decreases after 20%. The same results obtained by Singha (2013), Kumar et al. (2015) and Singh and Bagra (2013) who employed jute fiber and cotton fiber showed that CBR value of soil increases with the increasing of fiber contents. Another study which was carried out by Sabat (2012) showed that with the addition of polypropylene fiber to rice husk ash-lime stabilized expansive soil, the soaked CBR increases up to 1.5% of polypropylene fibers, and decreases with further increase in polypropylene fiber content.

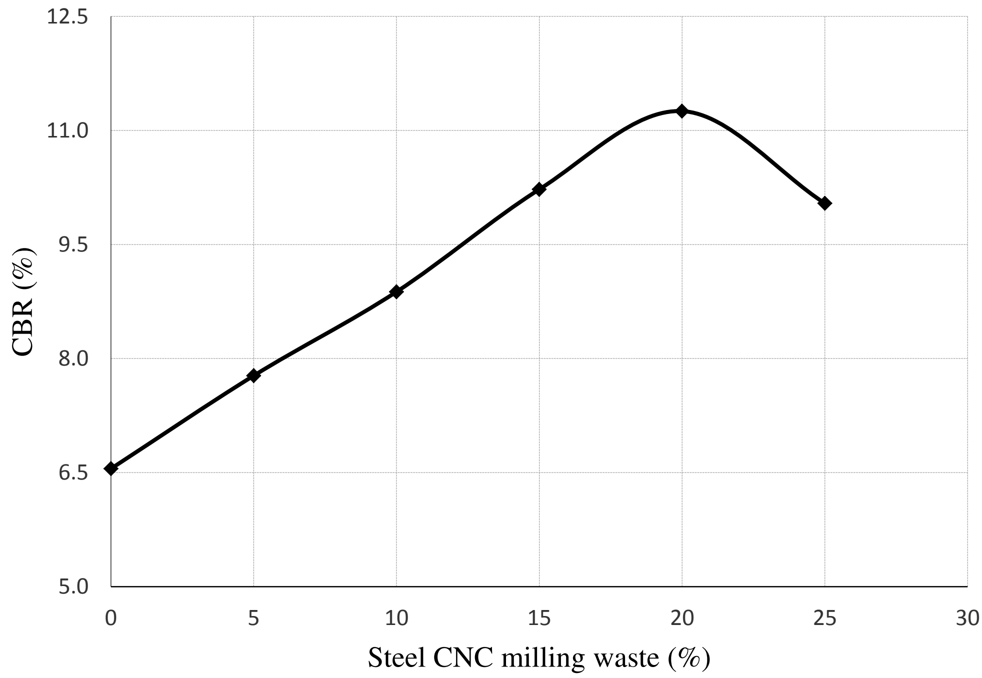


Figure 4.7 Variation of california bearing ratio with steel CNC milling waste content.

This test is used for determining pavement thickness design alternatives (highway agency, 1994), shown in Table 4.3, and Figure 4.8, according to CBR (%) results. It can be concluded that the thickness of sub-base and capping decreases when the CBR values increase.

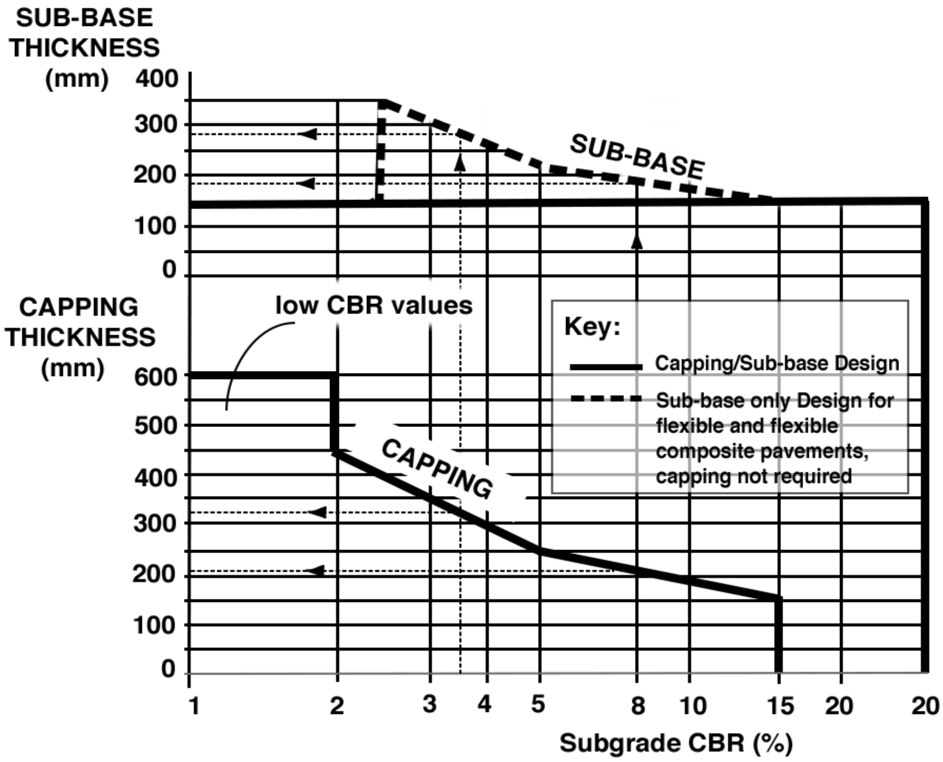


Figure 4.8 Capping and sub base thickness design (Highways agency, 1994)

Table 4.3 Summary of testing results.

Specimen	MDD (kN/m^3)	OMC (%)	UCS (kN/m^2)	Swelling (%)	CBR (%)	c (kN/m^2)	φ (degree)	Pavement design alternative		
								1		2
								Subbase (mm)	Capping (mm)	Subbase (mm)
Soil	18.00	18.00	298.46	3.00	6.55	86.58	32.63	150	240	205
Soil with 5 % St-CNC-mw	18.50	17.20	334.76	2.82	7.78	90.84	35.41	150	215	195
Soil with 10 % St-CNC-mw	19.10	16.40	369.14	2.66	8.88	95.76	37.89	150	200	190
Soil with 15 % St-CNC-mw	19.60	15.50	390.11	2.42	10.23	100.14	40.71	150	190	175
Soil with 20 % St-CNC-mw	20.10	14.80	-	2.16	11.22	96.57	44.15	150	175	165
Soil with 25 % St-CNC-mw	20.20	14.10	-	1.98	10.04	90.47	46.55	150	190	175

4.4 Consolidation test

Consolidation is considered one of the main problems in clayey soil. The large consolidation happens in silty soil when it becomes saturated. The effect of using St-CNC-mw mixing with the silty soil was investigated. From the results obtained by this test for soil sample with different addition of St-CNC-mw, it can be concluded that the initial void ratio (e_o), swelling index (c_s) and the coefficient of consolidation (c_v) of the soil decreases by adding St-CNC-mw content while compression index (c_c) of soil increases.

Figure 4.9 demonstrates the relation between initial void ratio (e_o), which was calculated at test beginning and the variation of St-CNC-mw content. A slight decreasing in e_o happened with increase of St-CNC-mw content, due to the increasing in maximum dry unit weight values by the addition of St-CNC-mw.

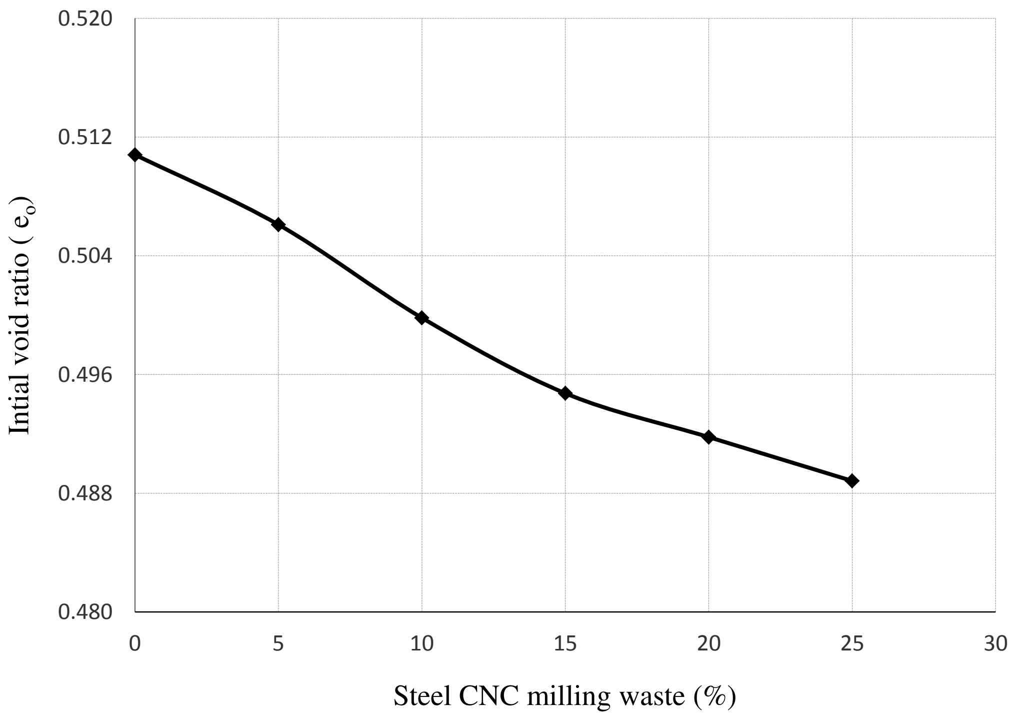


Figure 4.9 Variation of initial void ratio (e_o) with steel CNC milling waste content.

Consequently, Figure 4.10 shows the compression index c_c increases by increasing of St-CNC-mw for load increment from 200 to 400, 200 to 800 and 400 to 800 kN/m^2 respectively. A similar outcomes achieved by Estabragh et al. (2011) and Estabragh et al. (2013) founded that the pre consolidation pressure, compression index (c_c) increase with the increasing of natural fiber and nylon fiber content in reinforced soil. Also, Figure 4.11 shows the swelling index (c_s) decreasing with increasing of St-CNC-mw for load increment from 200 to 800 and 400 to 800 kN/m^2 respectively. A similar performance was observed by Okoro et al. (2011) which their results showed that class C fly ash (CFA), lime and plastic waste stabilization reduced the compressibility, the swelling index (c_s) and the initial void ratio (e_o).

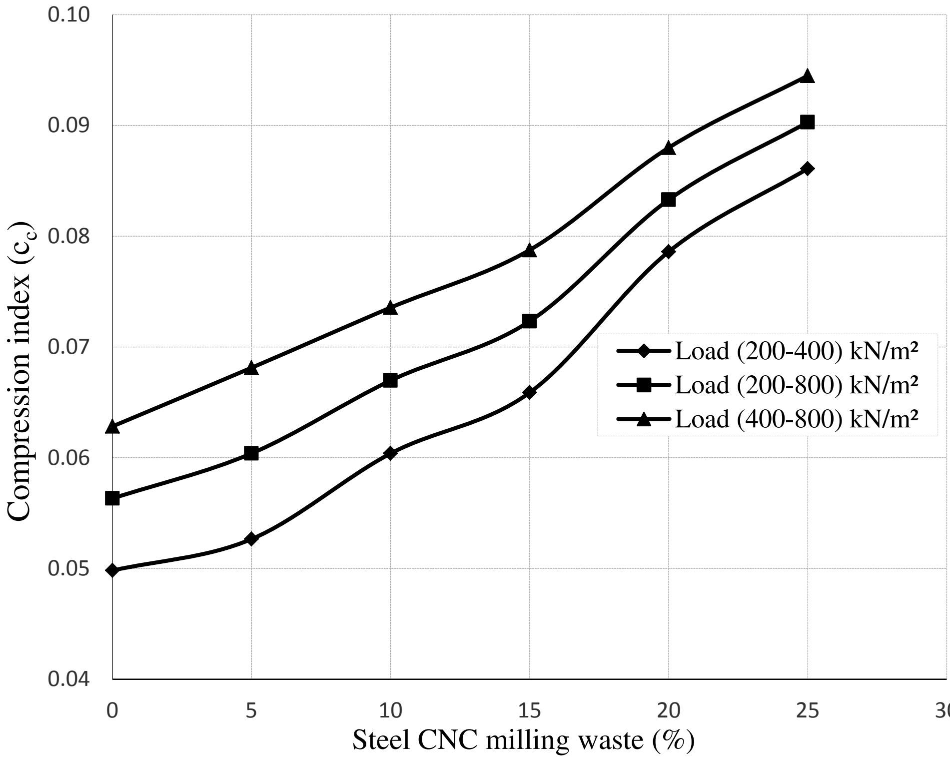


Figure 4.10 Variation of compression index (c_c) with steel CNC milling waste content.

From the data in Figure 4.12, the coefficient of consolidation (c_v) decreasing with increasing of St-CNC-mw for loads 400 kN/m^2 and 800 kN/m^2, respectively. The same results were found by Manikandan et al. (2014), from the consolidation test result, it can be concluded that the coefficient of consolidation decreased with the increases of bagasse ash and lime content. The result mentioned above support the researcher's test results. Also, a summary of the consolidation test results are shown in Table 4.4.

The reason behind that is the soil particle gets closer to each other which lead to reducing voids, also the St-CNC-mw act as reinforcement between soil particles, finally the cohesion between St-CNC-mw and soil particles are strongly interlinked together.

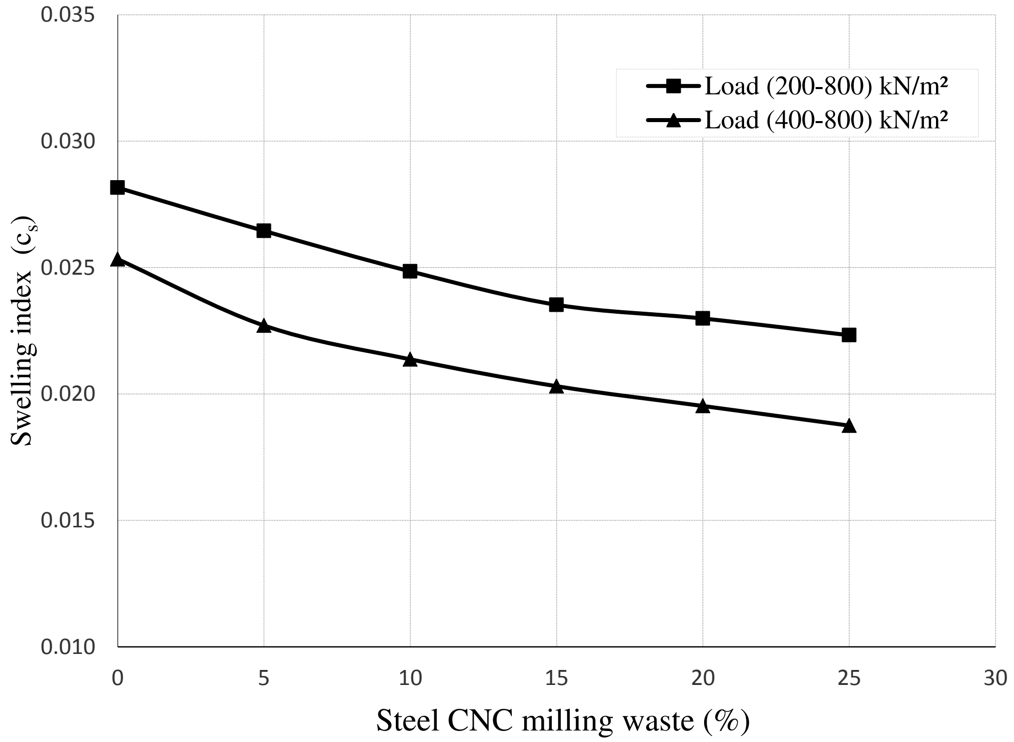


Figure 4.11 Variation of swelling index (c_s) with steel CNC milling waste content.

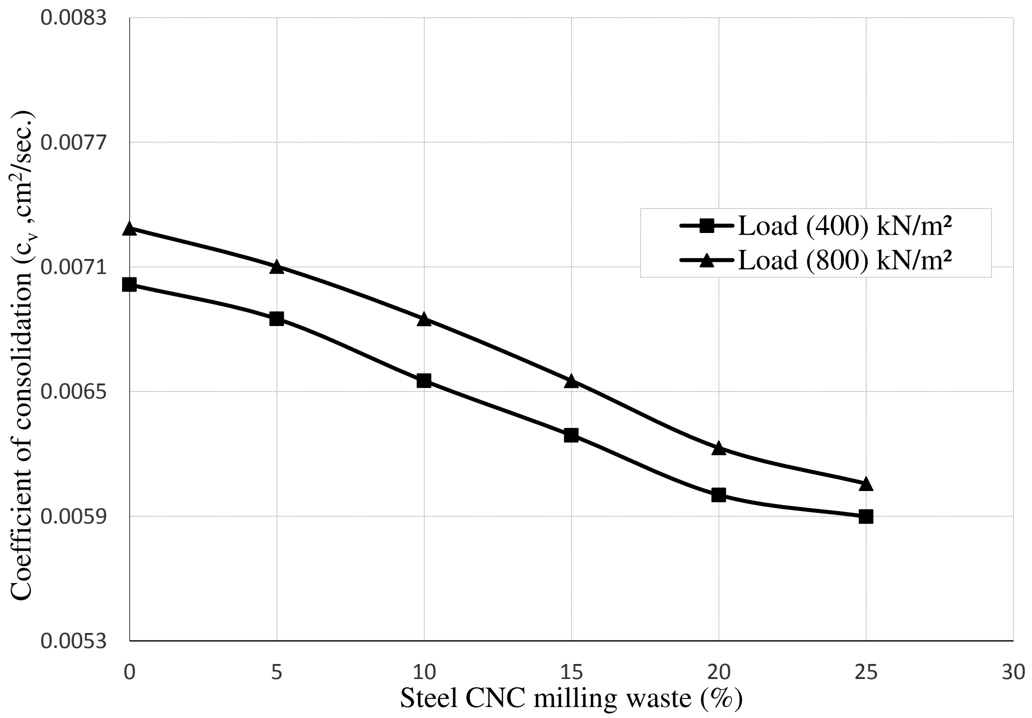


Figure 4.12 Variation of coefficient of consolidation (c_v) with steel CNC milling waste content.

Table 4.4 Results of consolidation test.

Specimens	Initial void ratio(e_o)	Compression index (c_c)			Swelling index (c_s)		Coefficient of consolidation (Cm^2/sec)	
		Load (200-400) kN/m^2	Load (200-800) kN/m^2	Load (400-800) kN/m^2	Load (200-800) kN/m^2	Load (400-800) kN/m^2	Load (400) kN/m^2	Load (800) kN/m^2
Soil	0.511	4.9813E-02	5.6321E-02	6.2829E-02	2.8160E-02	2.5332E-02	7.0149E-03	7.2865E-03
Soil with 5 % St-CNC-mw	0.506	5.2652E-02	6.0387E-02	6.8123E-02	2.6451E-02	2.2708E-02	6.8498E-03	7.1020E-03
Soil with 10 % St-CNC-mw	0.500	6.0384E-02	6.6969E-02	7.3554E-02	2.4849E-02	2.1370E-02	6.5519E-03	6.8498E-03
Soil with 15 % St-CNC-mw	0.495	6.5875E-02	7.2314E-02	7.8753E-02	2.3527E-02	2.0307E-02	6.2897E-03	6.5519E-03
Soil with 20 % St-CNC-mw	0.492	7.8597E-02	8.3293E-02	8.7989E-02	2.2986E-02	1.9526E-02	6.0023E-03	6.2289E-03
Soil with 25 % St-CNC-mw	0.489	8.6098E-02	9.0292E-02	9.4485E-02	2.2326E-02	1.8749E-02	5.8979E-03	6.0566E-03

4.5 Swelling test

To study the swelling characteristics of unreinforced and St-CNC-mw reinforced samples, one- dimensional swell tests have been conducted. The values of swelling in different percentages with untreated soil are presented in Figure 4.13 and Table 4.5. It could be concluded that the swelling value of soil decrease with the additional percentage of St-CNC-mw. The similar result was found by Cai et al. (2006) who found that increasing fiber content and lime content to the clayey soil led to a reduction of swelling. And another study obtained same results Al-Akhras et al. (2008) and Mohamed (2013) the outcomes demonstrated that the swelling of soil decreasing with adding palmyra, nylon and hay fiber content.

This behavior due to the strong inter-particle bond developed between soil and St-CNC-mw offer great resistance to swelling. One other reason for decreasing swelling of soil is by increasing that waste material water absorption decrease.

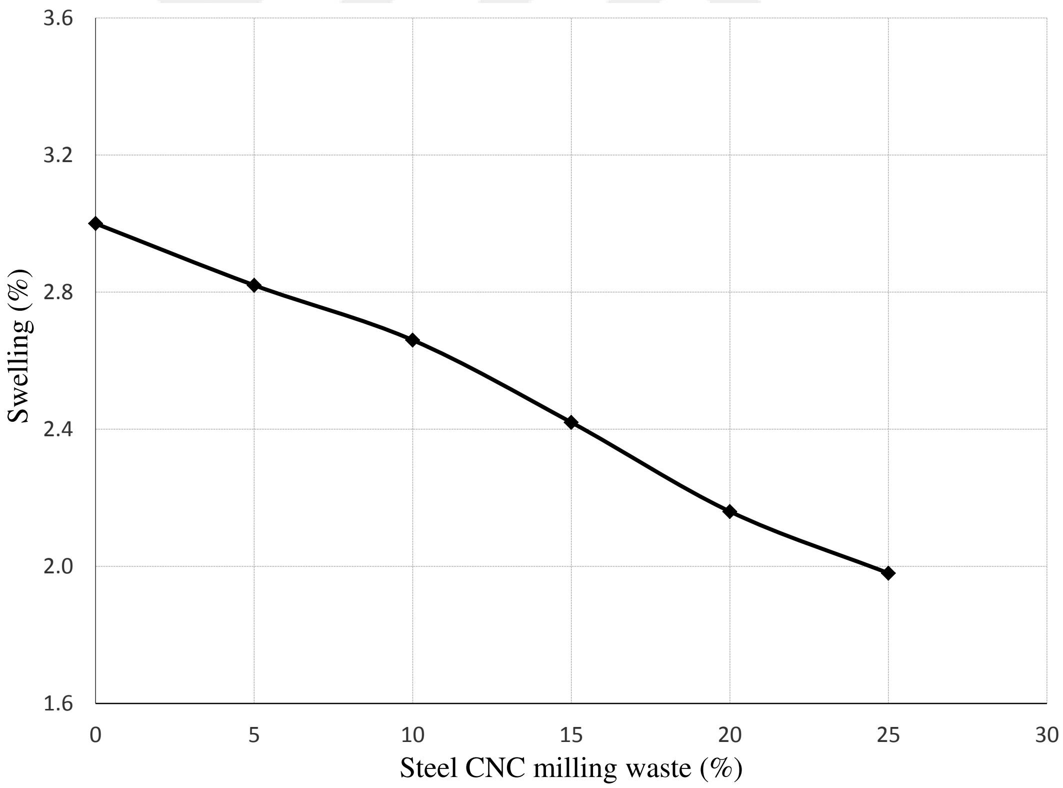


Figure 4.13 Variation of swelling with steel CNC milling waste content.

Table 4.5 Swelling of soil mixed with different percentage of steel CNC milling waste.

Property	Steel CNC milling waste (%)					
	0	5	10	15	20	25
Swelling (%)	3.00	2.82	2.66	2.42	2.16	1.98

4.6 Permeability test

Falling head method was utilized to reveal permeability behavior of samples. Figure 4.14 illustrates the relation between hydraulic conductivity (k) and the variation of St-CNC-mw content. In that figure, there is a clear trend of decreasing of hydraulic conductivity (k) with the increasing of St-CNC-mw content. This outcome is similar to the previous studies by Osinubi (1998) and De Brito et al. (2004) who argued that the Coefficient of Permeability (k) decreased with increasing lime content. Also Attom et al. (2007) from the test results, it was vividly appeared that at adding the proportion of shredded waste tires, the soil mixture permeability was diminished. . Result of permeability test shown in Table 4.6.

Table 4.6 Result of permeability test.

Property	Steel CNC milling waste (%)					
	0	5	10	15	20	25
k (cm/sec)	5.3888E-05	4.6880E-05	4.4277E-05	4.0992E-05	3.9619E-05	3.9375E-05

The reason behind that is because the shape of waste material particles is like spiral-shaped, thus, the soil particles goes to inside waste materials and reinforces the bond between the particles when added the waste material to the soil. Considering this fact, this would result of decreasing void, and thus, it would prevent water into the mixtures (Figure 4.15).

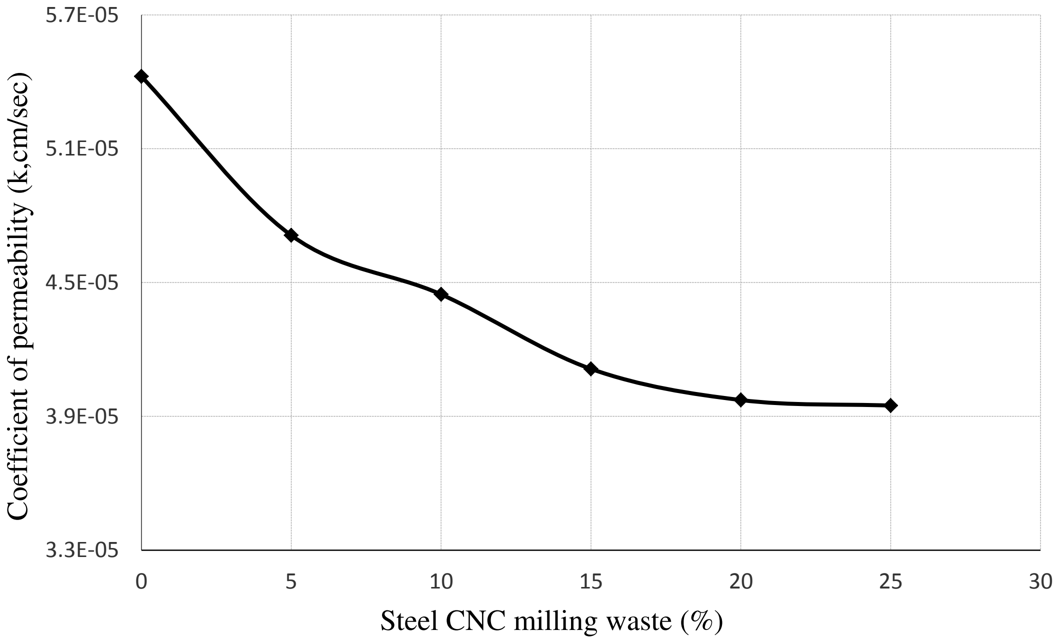


Figure 4.14 Variation of coefficient of permeability (k) with steel CNC milling waste content.

Figure 4.15 Particle of soil with the particle of steel CNC milling waste.

4.7 Direct shear test

This test was applied on the raw soil specimens and soil with St-CNC-mw. This test provides a process for finding cohesion and internal friction angle for raw soil and soil with St-CNC-mw. Figure 4.16 shows the cohesion of specimens increases while increasing St-CNC-mw content up to 15 % and then decrease with addition amounts of St-CNC-mw. The same behavior was found by Jiang et al. (2010) who showed that with an increase fiber, the cohesion of fiber-reinforced soil smoothly increase and then decrease with addition amounts of fibers. Additionally, other studies which were carried out by Akbulut et al. (2007) and Cetin et al. (2006) Showed that the cohesion value of soil increased by the addition of tire rubber and synthetic fibers. The outcomes of direct shear test shown in Table 4.7.

Table 4.7 φ and c of soil mixed with different percentage of steel CNC

Property	Steel CNC milling waste (%)					
	0	5	10	15	20	25
c (kN/m^2)	86.58	90.84	95.76	100.14	96.57	90.47
φ (degree)	32.63	35.41	37.89	40.71	44.15	46.55

As discussed above, this behavior may be due to a gradation of the mixture at 15% of St-CNC-mw material. One other reason for this behavior is the St-CNC-mw work as reinforcement between soil particles. The decrease in cohesion of soil- St-CNC-mw matrix with addition amount of St-CNC-mw (more than 15% St-CNC-mw) was due to separation of soil particles by the addition of St-CNC-mw.

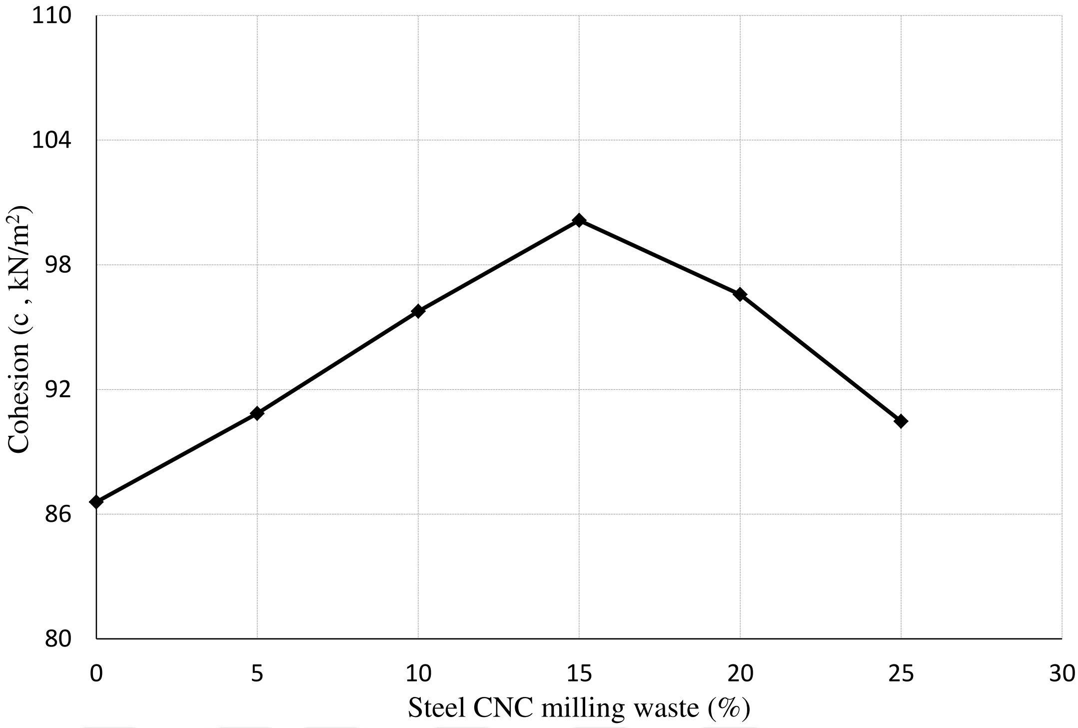


Figure 4.16 Variation of cohesion with steel CNC milling waste content.

As seen in Fig 4.17 the variation of internal friction angle with St-CNC-mw contents showed a non-linear variation. In general, the internal friction angle value of each reinforced sample increased, and these values ranged from 32.63° to 46.55°. Similar outcome was attained by Prabakar and Sridhar (2002) and Ahmad et al. (2010). The results of these researchers have clearly shown increasing internal friction angle of soil with increasing fiber. Also, other studies which were carried out by Akbulut et al. (2007) and Cetin et al. (2006) showed that the internal friction angle value of soil increased by the addition of tire rubber and synthetic fibers. As illustrated earlier, because of particle shape and particle size of the waste material result the increasing of interlocking between the particles.

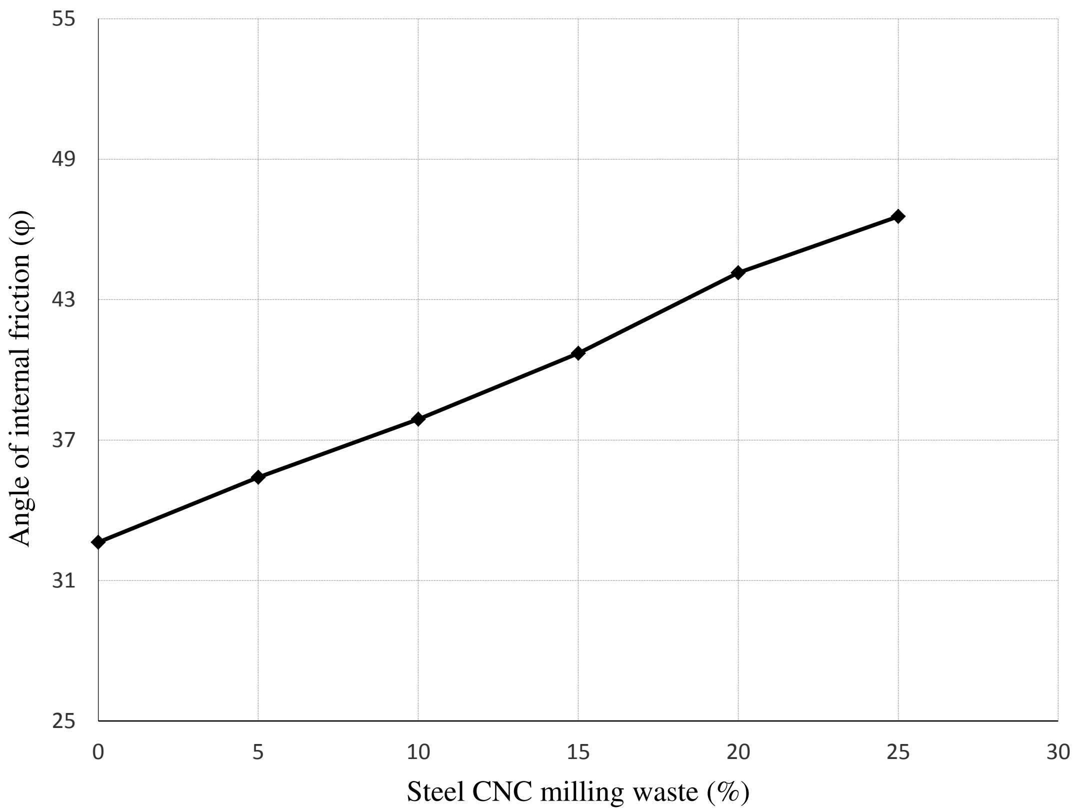


Figure 4.17 Variation of internal friction angle (φ) with steel CNC milling waste content.

4.8 Corrosion study of steel CNC milling waste

4.8.1 Macroscopic scale study

As galvanization of low carbon steel in various media including acidic (Agrawal and Sahu, 2009), alkaline (Short et al., 1996) and non-aqueous (Abbott et al., 2001) have been studied in detail, the focus of this work is only to present the corrosion behavior of St-CNC-mw after and before zinc deposition without deposition study of zinc. Corrosion behavior of St-CNC-mw will be compared with coated steel to examine whether coated steel can be used in soil as improvement for long duration.

It is known that chloride ions trigger corrosion in the steel reinforcements of concrete (Tritthart, 2009; Dehghan et al., 2017; Malek et al., 2018). Chloride content of cement can be limited to minimize this risk. However, the concentration of chloride cannot be controlled in soil as water can be in contact with soil at any moment. Therefore, the coated steel should be resistive against corrosion. The corrosion resistivity of St-CNC-mw should be elucidated. Next section is given in order to examine the effect of chloride ions on coated and uncoated St-CNC-mw. Before that, the St-CNC-mw samples were immersed in tap water and the change in both water and St-CNC-mw are photographed and presented in Figure 4.18. Uncoated St-CNC-mw immersed in tap water are on the left sides on the Figure 4.18 and coated ones on the right sides. The photo in Figure 4.18a is immediately taken after immersion of steel. The photo in Figure 4.18b is taken after 3 hours immersion of steel in tap water. Water including uncoated steel (left side of Figure 4.18b) becomes brownish because uncoated steel are corroded although there is no any macroscopic change in water including coated steel. Figure 4.18c and Figure 4.18d also clearly show the progress of corrosion as color of water including uncoated St-CNC-mw become darker by time. Zinc coated steel does not change the color of tap water after 3 days. Although, color of zinc coated steel is the same, a film of iron oxide appears over the surface of bare steel seen in Figure 4.19 as corrosion rate of galvanized steel is much lower than that of steel itself. Corrosion rate of uncoated and coated St-CNC-mw is compared in next section.

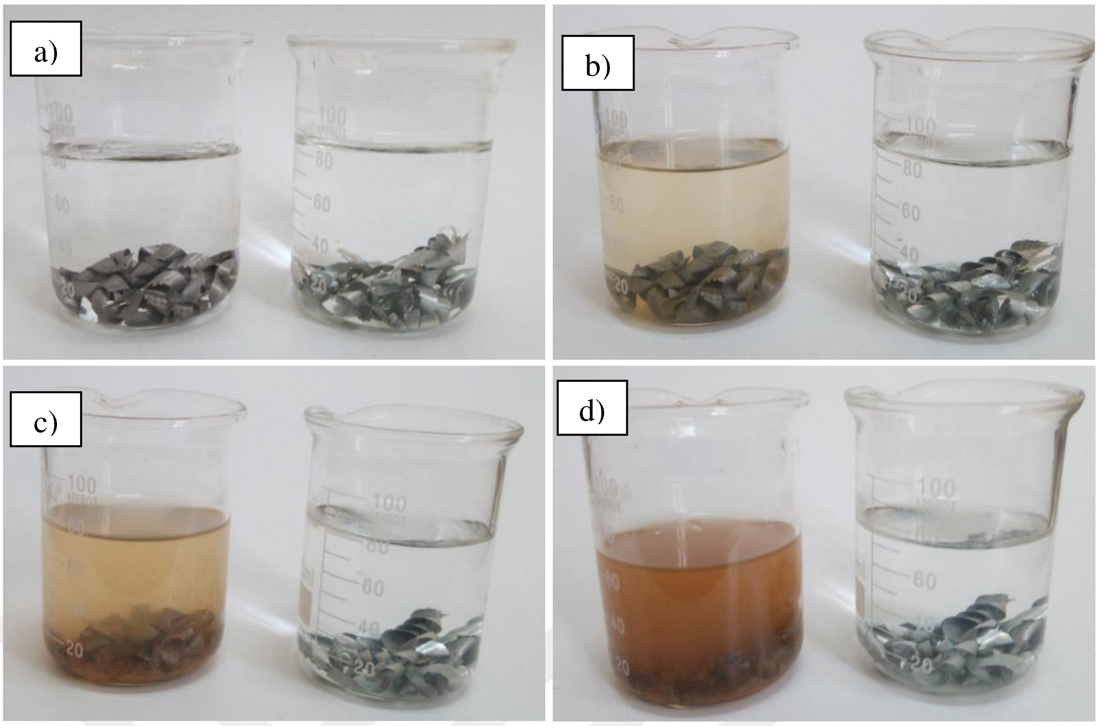
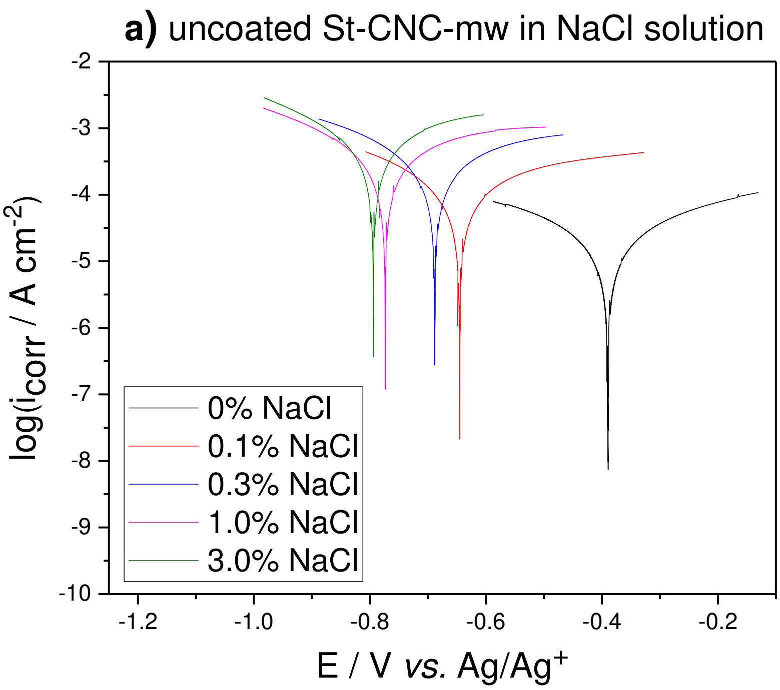


Figure 4.18 Photos of bare steel CNC milling waste (on the left sides) and zinc coated steel (on the right sides) in tap water a) after immediately steel CNC milling waste immersed in tap waters b) after 3 hours; c) after 24 hours; d) after 72 hours.

Figure 4.19 Photo of uncoated (left side) and coated (right side) steel CNC milling waste after immersion in tap water for 72 hours.

4.8.2 Atomic scale study

As the risk of corrosion occurred in aqueous media is associated with the chloride ions (Otieno et al., 2016; Schuerz et al., 2009; Cruz et al., 1998; Perren et al., 2001), corrosion resistance of uncoated and zinc coated steel is studied in sodium chloride media. Anodic and cathodic behaviour of steel have been studied widely in literature (Veloz and Gonzalez, 2002; Guo and Tomoe, 1999; Yadav et al., 2004; Meng et al., 2008). The focus in this work is to present the difference of corrosion resistivity between uncoated St-CNC-mw and galvanized St-CNC-mw in order to calculate corrosion rate of the products used in soil. Typical potentiodynamic polarization curves for uncoated and zinc coated St-CNC-mw in different chloride concentrations are presented in Figure 4.20a and 4.20b, respectively in order to investigate the corrosion resistivity of bare and coated St-CNC-mw. Figure 4.20 shows that the E_{corr} (corrosion potential) and i_{corr} (corrosion current density) values of steel in chloride ion media are affected by the concentration of chloride. The intersecting point of the cathodic and anodic curve called E_{corr} shifted to more negative potential (more active area) upon increasing chloride ion concentration for both uncoated (Figure 4.20a) and coated St-CNC-mw (Figure 4.20b) because the activity of steel increases in higher chloride ion electrolyte. Electrochemical parameters derived from the polarization curves at various NaCl concentrations are tabulated in Table 4.8.



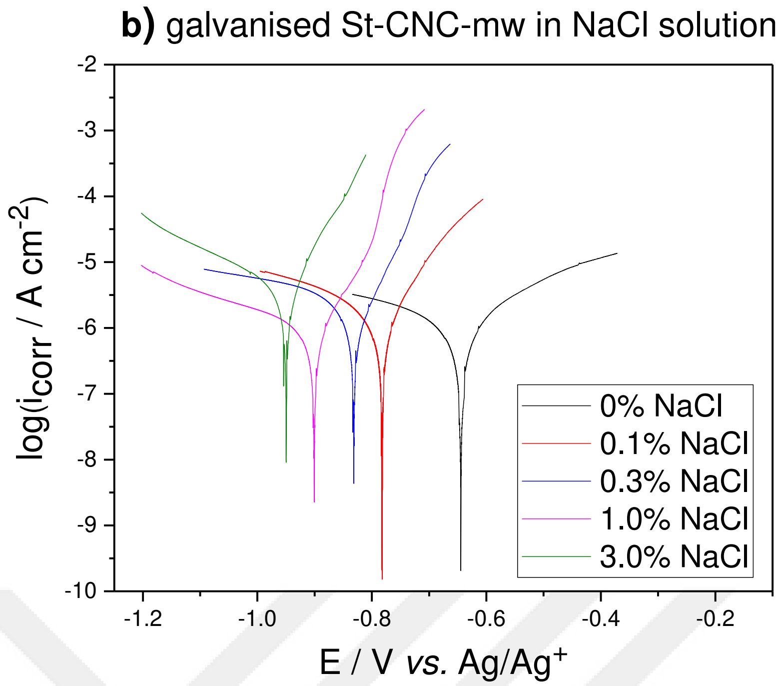


Figure 4.20 Potentiodynamic polarization curves for a) uncoated and b) coated steel CNC milling waste as a function of chloride ion concentration at pH 7. Scan rate 10 mV s-1. After 24 hours of immersion in tap water solution.

As the participation of chloride ions in the dissolution reaction takes part in the oxidation of iron (steel), the increase in chloride ion concentration increase corrosion rate of bare steel (Glass and Buenfeld, 1997; Hansson et al., 1985; Donahue and Burns, 2016; Wan et al., 2016). Current density values (i_{corr}), which is directly related to corrosion rate, for uncoated steel increase with increase in chloride ion concentration from 83.2 µA cm^{-2} for 0.1 % NaCl solution to 457 µA cm^{-2} for 3 wt% NaCl solution meaning that corrosion rate increases from 963 µm $year^{-1}$ to 5290 µm $year^{-1}$ given in Figure 4.21. However, current density of zinc coated St-CNC-mw does not reveal a significant shift as current density of galvanized St-CNC-mw increases from 1.10 µA cm^{-2} to 2.69 µA cm^{-2} for 0.1 % and 3.0 % NaCl solution, respectively. The reaction of Fe to Fe^{+2} and Zn to Zn^{+2} were considered for corrosion rate calculation to have an approximate number of corrosion rates.

Table 4.8 E_{corr} and i_{corr} parameters extracted from Tafel plot presented in Figure 4.20.

Ratio of NaCl by weight	Uncoated (bare) St-CNC-mw			Zinc coated St-CNC-mw			Ratio of corrosion rate
	E_{corr} (V)	i_{corr} (µA cm^{-2})	Corrosion rate (µm $year^{-1}$)	E_{corr} (V)	i_{corr} (µA cm^{-2})	Corrosion rate (µm $year^{-1}$)	$\frac{i_{corr}\ (\text{uncoated})}{i_{corr}\ (\text{coated})}$
0%	-0.39	16.6	192	-0.64	0.871	10	1.92
0.10%	-0.64	83.2	963	-0.79	1.1	12.7	75.8
0.30%	-0.68	245	2830	-0.84	1.23	14.1	201
1.00%	-0.77	302	3470	-0.9	1.66	19.1	182
3.00%	-0.79	457	5290	-0.96	2.69	30.9	171

Corrosion rate ratios of uncoated and coated steel are given in Table 4.8. The corrosion resistivity of coated St-CNC-mw was found to reach a value more than two order of magnitude higher than that of uncoated St-CNC-mw in high concentration of chloride solution (between 0.3 % and 3.0% NaCl solution.). Corrosion rate of uncoated and coated St-CNC-mw in terms of chloride ion concentration is presented in Figure 4.21. As steel without coating has pitting corrosion (Cheng and Luo, 2000; Streicher 1956; Haciibrahimoglu et al, 2016), bare St-CNC-mw has high corrosion rate. Zinc coated steel has passivation behaviour (McKubre and Macdonald, 1981; Thomas et al, 2013) and corrosion rate of coated steel is much smaller than steel itself (more than 100 times lower corrosion rate).

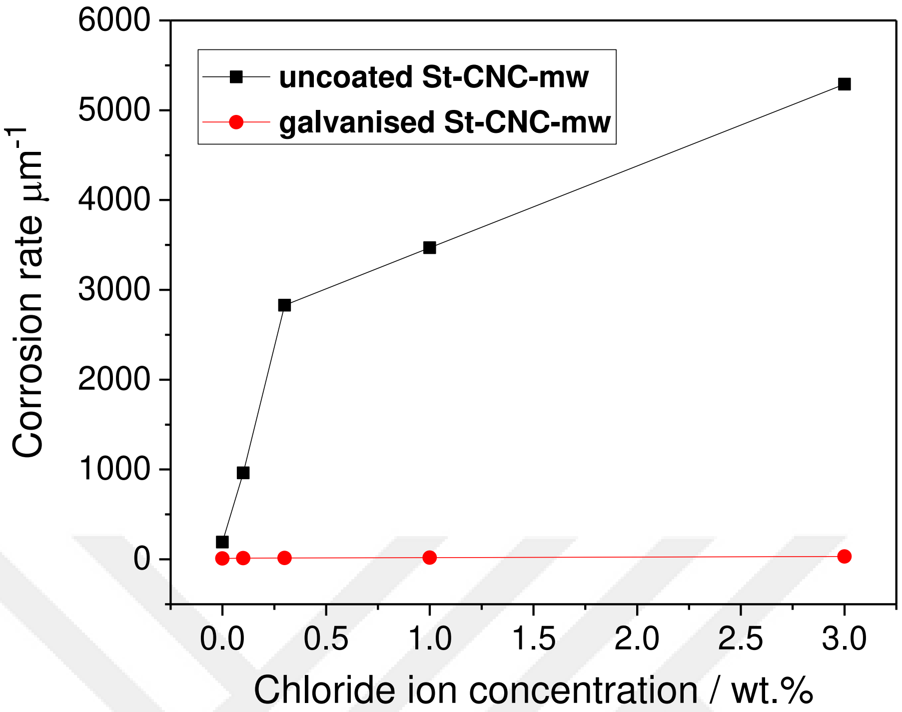
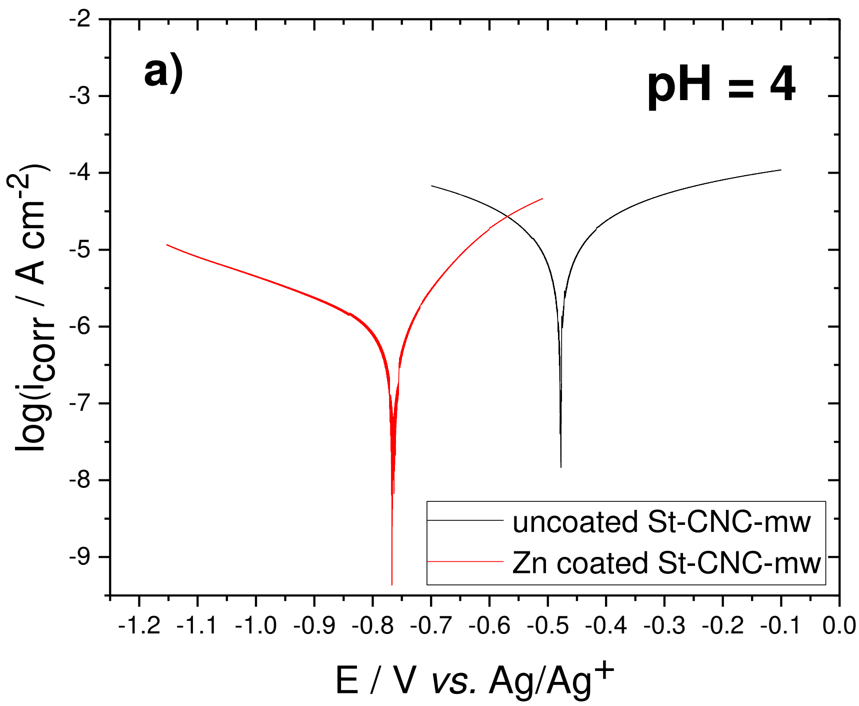


Figure 4.21 Corrosion rate of uncoated and zinc coated steel CNC milling waste as a function of chloride ion concentration.

Figure 4.20b showed that the current density of coated St-CNC-mw has no appreciable change with change of chloride concentration. The lowest current density was observed when electrode in deionized water. In the absence of chloride ions, anodic dissolution is controlled by a charge transfer step (Foroulis and Thubrikar, 1975) and steel (iron) still can be corroded. Even in the chlorine free solution, steel illustrated high values of the corrosion rate (around 10^{-5} A cm^{-2}) (Moreno et al., 2004). Coated St-CNC-mw in chlorinated water has similar results with St-CNC-mw in deionized water as a value of the order of 10^{-6} A cm^{-2} was observed (Figure 4.20b). Current density of coated steel almost remain unchanged as seen in Figure 4.20b and Table 4.8 by increasing the concentration of Cl^{-} ions. As Type A and type B both have the same corrosion behavior, only the results of type A are presented in this study. Corrosion products were observed on uncoated St-CNC-mw surface after polarization in 3.0 wt% NaCl solution as steel is oxidized. The steel surface is the same as St-CNC-mw shown in the left side in Figure 4.19.

Potentiodynamic polarization curves for bare and galvanized St-CNC-mw are presented in Figure 4.22. E_{corr} (corrosion potential) and i_{corr} (corrosion current density) extracted from Figure 4.22 are tabulated in Table 4.9. Potentiodynamic curve of coated St-CNC-mw shifted to a more active potential (more negative E_{corr}) than that of uncoated steel. Corrosion rate of uncoated St-CNC-mw at any pH is greater than that of zinc coated St-CNC-mw meaning that corrosion resistivity of St-CNC-mw is increased after galvanization. The corrosion rate (calculated from i_{corr} values) of pH 7 was higher than that of pH 10 and pH 4 probably due to higher chloride concentration. As there is no direct trend between pH value and corrosion rate, the corrosion behavior of St-CNC-mw is more related to the concentration of chloride rather than pH of media.

The values of polarization resistance (Rp) are inversely related to i_{corr} and values of anodic and cathodic Tafel constants formulated by the Stern-Geary equation (1957). Rp is not necessary to give here as this paper focus on mainly the mechanical behavior of soil mixed with St-CNC-mw. The corrosion section is presented here to express that bare steel can be prevented from corrosive environments by zinc coating.



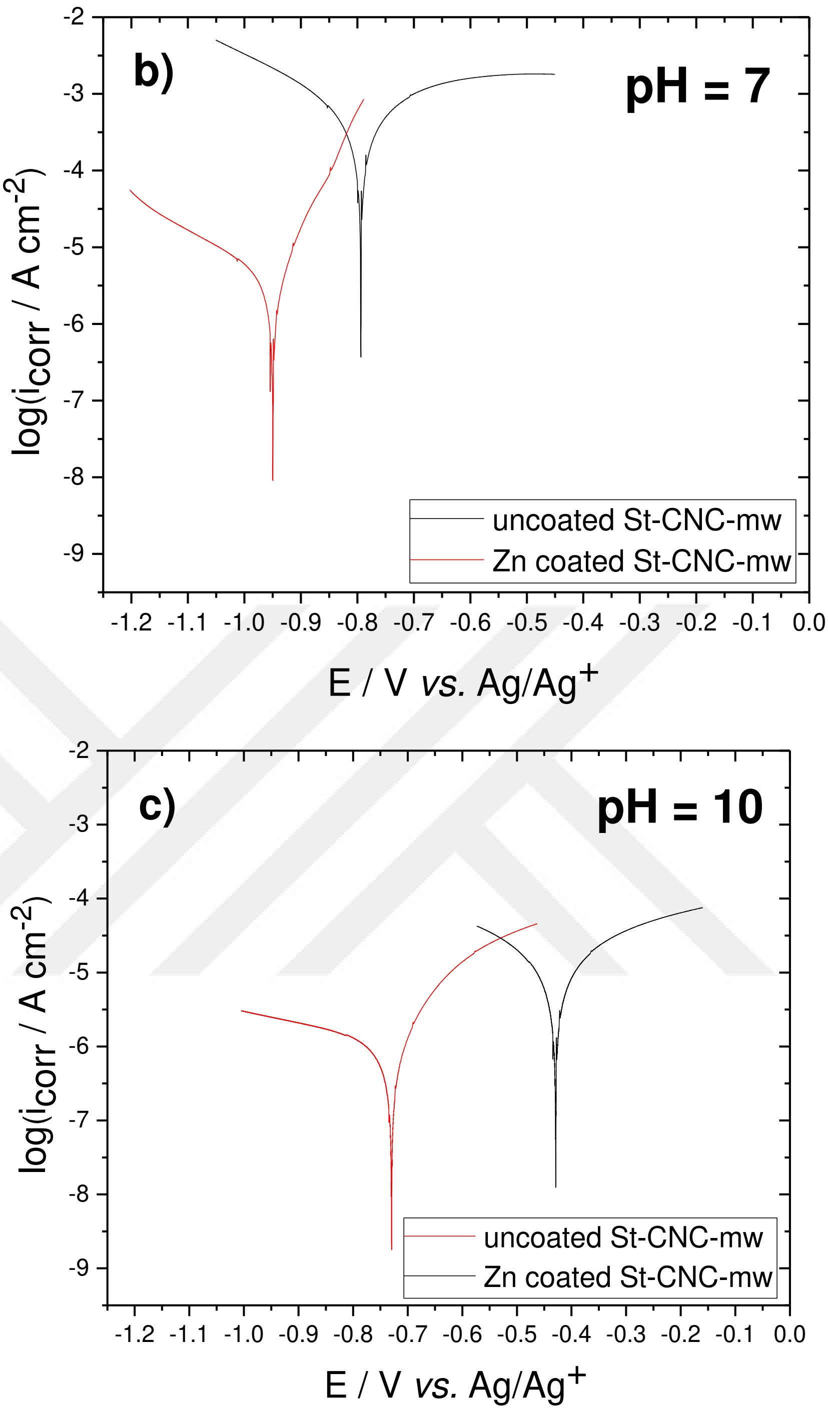


Figure 4.22 Potentiodynamic polarization curves for uncoated and coated steel CNC milling waste in pH a) 4; b) 7 and c) 10. Scan rate 10 mV s-1. After 24 hours of immersion in tap water solution.

Table 4.9 E_{corr} and i_{corr} parameters extracted from Tafel plot presented in Figure 4.22.

pH of electrolyte	Uncoated (bare) St-CNC-mw			Zinc coated St-CNC-mw			Ratio of corrosion rate
	E_{corr} (V)	i_{corr} (μA cm^{-2})	Corrosion rate (μm $year^{-1}$)	E_{corr} (V)	i_{corr} (μA cm^{-2})	Corrosion rate (μm $year^{-1}$)	$\frac{i_{corr}\text{ (uncoated)}}{i_{corr}\text{ (coated)}}$
pH = 4	-0.48	17.8	206	-0.77	0.89	10.2	20.2
pH = 7	-0.79	457	5290	-0.96	2.69	30.9	171
pH = 10	-0.43	13.2	153	-0.73	1.12	12.9	11.9

CHAPTER 5

CONCLUSIONS

The effect of steel CNC milling waste (St-CNC-mw) on the some engineering properties of soil was studied by various laboratory tests including compaction, UCS, CBR, consolidation, swelling, permeability and direct shear tests. It was realized that the addition of St-CNC-mw to the soil causes a great impact on soil properties and it improves soil in regarding of geotechnical properties. One drawback to use metal waste in soil is that metals can generally be easily corroded. In order to use any metal waste effectively in water included media, corrosion rate of these metals should be reduced. As galvanized steel has lower corrosion rate due to its passivation behavior, St-CNC-mw was coated by zinc. Following conclusions can be drawn from the results of this study.

1. Adding the St-CNC-mw to the silty soil has a great ability to the progress of maximum dry density and optimum moisture content. By putting extra St-CNC-mw to the soil (from 0% to 25%), it was concluded that maximum dry density increases by 12.22 % and optimum moisture content decreases by 21.66 %.

2. An increase in UCS values has been observed until 15% of St-CNC-mw which means that more than 15% would lead to a failure. By adding more St-CNC-mw to the soil, the UCS increased by 30.70%.

3. Soaked CBR value increased with adding St-CNC-mw content until 20% of St-CNC-mw by 71.33%, and then decrease with the further increase in St-CNC-mw content.

4. The thickness of sub-base and capping decrease by 20.83% and 14.63% respectively, when St-CNC-mw to the soil increases.

5. Comparing to the natural soil, the swelling percentage vividly reduced by 34% while the silty soil was mixed with St-CNC-mw up to 25% by whole specimen dry weight .

6. In consolidation test, it was found that the initial void ratio (e_o), swelling index (c_s) and the coefficient of consolidation (c_v) of the soil decreases by 4.3%, 23.22% and 16.41% respectively, by adding St-CNC-mw materials while compression index (c_c) of soil increases by 60.31%.

7. The study indicates that the stabilized soil with various amount of St-CNC-mw that the coefficient of permeability (k) was decreased by 26.93% with the addition in proportion of St-CNC-mw.

8. Utilizing of St-CNC-mw up to 15% content in the soil treating, gives a biggest cohesion (c), by 15.66%. It has been noticed that adding more than 15 % of St-CNC-mw is helpful in reduction of the cohesion (c).

9. The angle of internal friction (φ) magnitude goes on increasing with addition of St-CNC-mw content. There is 42.66% increase in φ of stabilized soil as compared to raw soil.

10. Corrosion behavior of bare and zinc coated St-CNC-mw were studied as a function of chloride ion concentration and pH of electrolyte. While the corrosion behavior of uncoated steel waste strongly depends on chloride concentration of the solution, the effect of chloride ions was found negligible for corrosion rate of coated St-CNC-mw.

11. The corrosion rate was found to be high in neutral pH than acidic and basic solution as it is more related to choline concentration rather than pH of the electrolyte.

The soil stabilized by St-CNC-mw solves poorly structured problems by considering the environmental and economic aspects, coated St-CNC-mw is suitable to be used as a stabilizer. This study shows that improvement of soil with St-CNC-mw is an effective way of dealing with problematic soils. Obtained results of this research can be utilized in designing foundations on compacted treated soil beds.

CHAPTER 6

RECOMMENDATIONS

The evaluation of the St-CNC-mw stabilization of silty soil was conducted using some types of laboratory tests in this study. Despite the facts that this study found some interesting results, it is not flawless study. Therefore, some recommendations are suggested for further studies. First, it is highly recommended that using theoretical method is necessary to find the exact point of employing St-CNC-mw material if the study was aimed at finding out the optimization point of employing the mentioned materials. Taken the experimental study into consideration, the best amount can be seen at 20% of St-CNC-mw, whereas, with a theoretical software program, the optimize point lies between 15-20 % or 20-25 %. Second, to realize whether the behaviour of St-CNC-mw would not change with the same character, it is thoroughly recommended that other type and soil from different places should be used. Third, it would be of grave necessary to change the particles of this material may influence the obtained results of test. Fourth, employing St-CNC-mw in stabilizing soil could be estimated, and consequently, compared with the other soil stabilization materials. Finally, in this work, mechanical property of soil with zinc coated St-CNC-mw is presented. The corrosion behavior of bare and galvanized St-CNC-mw are only studied here. However, other types of coating can also be applied to St-CNC-mw for instance conducting polymers (polyaniline, polypyrrole, and copolymers) and alloys to reduce corrosion rate of steel.

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