DETERMINATION OF ENGINEERING PROPERTIES AND SUSTAINABILITY OF A SANDY SOIL WITH SLAG AND TIRE CHIPS

by

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DETERMINATION OF ENGINEERING PROPERTIES AND SUSTAINABILITY OF A SANDY SOIL WITH SLAG AND TIRE CHIPS

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ABSTRACT

DETERMINATION OF ENGINEERING PROPERTIES AND SUSTAINABILITY OF A SANDY SOIL WITH SLAG AND TIRE CHIPS

There are various soil improvement techniques for soil types with poor engineering properties. Two techniques are commonly used in the geotechnical world due to the cost-effectiveness of these techniques; soil replacement and reinforcement. The soil replacement is achieved by proven sustainable materials that could be industry by-products or construction materials such as slags from steel manufacturing or tire chips. Tire chips, as microplastics, have been causing scarcity and impacts on environmental conditions. Researchers have begun to consider recycling these materials in several applications. This study explored the use of the slag at different particle sizes and the other techniques besides the replacement, such as reinforcement using geogrid. Also, the study investigated the use of tire chips representing microplastics to reduce environmental concerns and increase soil improvement at a low cost compared with strategic natural resources deployment. The experimental program includes slag-sand mixtures with 20 and 50 (1:1) percent slag and tire chips, including 0.05, 0.1, 0.2, 0.4, 1, and 2 percent, along with soil reinforcement using geogrid to investigate their influence on shear strength, dry unit weight, and soil density. Slag particle size in the sand was taken as (4.75 mm – 2.36 mm), (2 mm -1.18 mm), (0.85mm – 0.60mm – 0.425mm), and (0.25 mm – 0.15 mm -0.075 mm). The results revealed improved maximum dry unit weight obtained by Proctor compaction tests. This improvement occurred at slag-to-sand ratio of 1:1. The density of the slag-sand mixture obtained from sand cone tests provided better results than that of the sand. The results also showed that particle sizes (4.75 mm – 2.36 mm) and (0.25 mm – 0.15 mm -0.075 mm) of mixed 20% slag with sand provided better shear strength than other sizes, even those reinforced by geogrid. From the results, the geogrid in 20 percent slag-sand mixture with a particle size of (0.85 mm– 0.60 mm– 0.425 mm) slag provided higher shear strength than the other sizes reinforced with geogrid. Finally, the optimal percentile of tire chips that caused an enhancement in the maximum unit weight of the sand was revealed at 0.4 percent with a value of 1.735 g/cm^3.

ÖZET

CÜRUF VE ATIK LASTİK PARÇALARI İLE İYİLEŞTİRİLMİŞ KUMLU BİR ZEMİNİN MÜHENDİSLİK ÖZELLİKLERİNİN BELİRLENMESİ VE SÜRDÜRÜLEBILIRLIĞI

İyi mühendislik özelliklerine sahip olmayan zemin türleri için çeşitli zemin iyileştirme yöntemleri vardır. Kötü zeminleri iyi zeminler ile değiştirme ve zemin güçlendirme, kolaylık ve maliyet bakımından bu yöntemler arasında en çok tercih edilenlerdendir. Zemin değişimi, endüstrinin yan ürünleri olabilecek sürdürülebilir ve yenilikçi malzeme olarak değerlendirebileceğimiz çelik cürufu veya araç lastiği ile sağlanabilmektedir. Fakat mikroplastik olarak ele alınan araç lastiği atıkları, çevresel yaşam alanı üzerinde olumsuz etkilere neden olabilecek malzemelerdendir. İklim değişikliği sorunları ortaya çıktıkça ve çevresel kaygılarla, araştırmacılar bu malzemeleri çeşitli uygulamalarda geri dönüştürmeyi düşünmeye başlamışlardır. Bu çalışmada, cürufun farklı dane boyutlarında kullanımı ve geogrid kullanılarak zemin değiştirmenin yanı sıra zemin güçlendirme de ele alınmıştır. Ayrıca mikroplastiği temsil eden araç lastiği atıklarının da zemin üzerinde bazı etkileri irdelenmiştir. Çalışma, araç lastiği atıkları tarafından çevreye verilebilecek zararı azaltmayı hedefleyerek doğal kaynaklara kıyasla düşük maliyetle toprak iyileştirmenin faydasını artırmayı amaçlamaktadır. Deneysel programda, kum zemine yüzde 20 ve 50 (1: 1) cüruf ile yüzde 0.05, 0.1, 0.2, 0.4, 1 ve 2 araç lastiği atığı eklemenin kayma mukavemeti, kuru birim hacim ağırlığı ve zemin yoğunluğu üzerindeki etkileri araştırılmaktadır. Ayrıca geogrid ile zemin güçlendirme de değerlendirilmiştir. Kuma katılan cürufun dane boyutları, (4.75– 2.36), (2 -1.18), (0.85– 0.60– 0.425) ve (0.25– 0.15 -0.075) mm olarak alınmıştır. Sonuçlar, Proctor kompaksiyon deneyleri ile elde edilen maksimum kuru birim hacim ağırlıklarında iyileşme olduğunu ortaya koymuştur. Zemindeki bu iyileşme, cüruf-kum oranının 1:1 olduğu koşullarda sağlanmıştır. Kum konisi deneylerinden elde edilen sonuçlara göre cüruf-kum karışımının yoğunluğu, kontrol olarak kullanılan kumdan daha yüksek ölçülmüştür. Ayrıca dane büyüklüğünün (4.75– 2.36) mm, ve (0.25– 0.15 -0.075) mm olduğu, kumla karıştırılmış yüzde 20 cürufun diğer dane boyutlarından, hatta geogrid ile güçlendirilen kumdan bile daha iyi kayma mukavemeti sağladığı belirlenmiştir. Kumla karıştırılmış dane büyüklüğü (0.85– 0.60– 0.425) mm olan yüzde 20 cüruflu kuma eklenen geogridli karışım, diğer dane boyutlarında eklenen cüruflu ve geogridli karışımlardan daha yüksek kayma mukavemeti sağlamıştır. Son olarak, kuma eklenen araç lastiği atığının optimum miktarı % 0.4 olarak saptanmış ve bu orandaki karışımın maksimum birim hacim ağırlığı 1.735 g/cm³ değerinde ölçülmüştür.

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LIST OF SYMBOLS/ABBREVIATIONS

(MSW)	Municipal solid wastes
CCL	Compacted clay liners
UCS	Unconfined compression
EAF	Electric arc furnace
BOF	Basic oxygen furnace
CaO	Calcium oxide
MgO	Magnesium oxide
SiO_2	Sulfur dioxide
FeO	Iron (Ii, Iii) oxide
SSA	Steel slag aggregate
MSW	Municipal solid waste
CCL	Compacted clay liners
OMC	Optimum moisture content
LWD	Light weight deflectometer
GBS	Granulated blast furnace slag
BCR	Bearing capacity ratio
SRR	Settlement reduction ratio
LFS	Ladle furnace slag
CRIII	Trivalent chromium
CBR	California bearing ration
KOBM	Klockner oxygen blown maxhutte
GRSS	Geogrid reinforced steel slag

1. INTRODUCTION

1.1. BACKGROUND

There is a rising scarcity of viable infrastructure development land. Engineers use diverse methods since land with desirable geotechnical qualities is rare and expensive. Stabilization, grouting, compaction, and other ground improvement procedures make existing land acceptable for building. It has been known that soil improvement techniques depend mainly on exchanging or adding another material to replace a specific behavior or to be replaced. Soil improvement techniques cannot be calculated as it changes all over the world from one country to another depending on the country's resources and the soil conditions, which rarely appear to be the same from one place to another. Thus, essential geotechnical experimenting is required to evaluate the soil improvement method assigned before executing any procedure. This process includes quantifying the amount of soil exposed to replacement or mixing, the products in the country in question, and their physical properties.

Nevertheless, these procedures may be expensive, time-consuming, and laborious. Although the latter, many other materials can be used in soil replacement or added to soil to improve its properties. These materials recycle industrial wastes such as slag and tires, which have recently become very popular. Lahar and Flood Hazards Mapping and Assessment after Super Typhoon Reming and Typhoon Seniang, Philippine Institute of Volcanology and Seismology, Report of Investigation [1] reported that the automobile population increased rapidly, expecting to exceed two billion cars by 2030. Because every manufactured tire is considered waste after passing its life cycle, the sheer quantity and volume connected with such garbage create difficulty for its safe disposal. Thus, it was suggested by many researchers (Humphrey & Manion [2]; Humphrey [3]; Edil & Bosscher, [4]; Bernal [5]; Cecich [6]; Foose [7]; Masad [8]; Bergado, [9]; Ahmed and Lovell, [10]; Edil [11]) who discussed usage of tires waste in many different geotechnical engineering applications because they have desirable features such unit weight low value, pressure of soil, effective insulations for temperature, densification using vibrotechniques machinery with considering cost concern. Some applications include embankments, leachate fills, vibration dampening, and liquefaction control. Recent model footing research has shown that discarded tires can be prepared to improve granular soils properties through the bearing capacity. Yoon [12]

used laboratory plate load experiments to investigate the scrap tire sidewalls as sand reinforcement. The results showed that utilizing a single layer in classified relative density as medium sand reduces settling into half of its value and doubles the bearing capacity. Additionally, Hataf and Rahimi [13] observed that the best amount of tire shredded reinforcement is around 40% of its volume, behind that bearing capacity decreases. Yoon [14] investigated the 'Tire cell' reinforcement effects (made using waste tire) with sand. Their results revealed that three layers would be optimal and demonstrated that using tire cells boosts bearing capacity while decreasing settlements compared to unreinforced sand, which appears in the BCRu (i.e., 3.5). Moghaddas Tafreshi and Norouzi [15] approved that tire chip usage for depth of 5% (by volume) and footing width of 0.25B from testing data and recommended covering the sand-tire combination with a top layer of soil. This action reduced the settlement by more than 2.5 times that of unreinforced sand. Others studied the waste tire fiber Naval [16]and addressed the improvement in bearing capacity that occurs even the high-density sand. The fiber particles optimal percent and depth were recommended at 0.75 percent and depth of 1.5B which revealed BCRu up to 2. Contrarily, Anvari and Shoospasha [17] explored the coarse rubber-reinforced sand and ensured that the optimal tire composition, reinforcement depth, and breadth achieving BCRu up to 1.55 were 10% by weight, 1B and 5B, respectively. Consequently, Mittal and Gill [18] concluded that the optimal content of discarded tire chips to substitute sand depends on the applied stresses. Their results provided recommendations based on stress, high or low, and assigned tire ship optimal weight content for lower and higher stresses was at 20 percent for lower and 40 percent for higher with reinforcing 1B depth. It was also reported that the BCRs reached 2.82 for low and 7.8 for high strains when using the latter recommendation.

This approach in the past years has shifted waste materials conducted from industrial process, as stated earlier, to minimize garbage in landfills, as environmental sustainability has become a more significant issue. The use of industrial waste as an improving material in construction engineering applications is achieving prominence in research Dayalan [19]. Several slag materials are produced by various processes of steel-making industry, including electric arc furnaces, basic oxygen furnaces, and blast furnaces. These types of slag products have various properties and applications, including additives with cement, filling material, and stabilizing material (Tomellini [20]; Motz & Geiseler [21]; Gobetti [22]). Electric arc furnace slag type is created through the electric arc furnace (EAF) method of producing

crude steel. The slag itself is a thick and robust substance. It has better mechanical strength and specific density values than dirt. This material has a wide variety of aggregate sizes that can be refined. As a result, EAF slag might be an appropriate aggregate for the highways, railways, and subgrades in structures. Subbases, embankments and even bituminous surface pavement combinations Oluwasola [23]; Marta [24]. Electric arc furnace slag is also a popular element in the manufacturing process. Hydraulic based concrete Arribas [25]; Monosi [26]; Santamara [27,28]).

Other than adding or replacing soil for improvement, soil reinforcing techniques using geosynthetics have shown to be a feasible and cost-effective alternative over time. It is valued and recognized in the technical world for its effectiveness, economy, and being environmentally safe. Its use for increasing shallow foundations' load-bearing capacity has received much attention. The highest optimal improvement in bearing capacity measured to score three to four times that of sand without reinforcement. Adding a geosynthetic layer enhances the ability of soil through three main mechanisms: reducing of shear stresses (Guido [29], Love [30], Espinoza [31], Adams & Collin [32]); slab or containing effect (Huang & Tatsuoka [33]; Michalowski [34]; Banquet and Lee [35]; Kumar and Saran [36]) and membraning effect [35,36].

As shown from the above background, a variety of improved methods for soil most used would-be soil replacement or addition of material; however, no clear guidance to the percentile and the depth of the implenting these replacements or addition or combining between the materials added for replacement and mixing the soil in concern. Thus, this project was developed to help solve a big issue in the field of geotechnical engineering, which may face some engineers as a duty towards humanity and economics. The study tried to fix some of these problems by serving two main aspects: construction and environmental.

1.2. RESEARCH MOTIVATION

1.2.1. Construction Aspects

Construction mainly concentrates on the soil properties as an issue to improve. However, the program will consider well-graded soil as a start for trying this method of soil replacement to avoid deploying natural raw materials such as (Gravel, well-graded sand, and dolomite gravel) in order to save money during the construction, help raise the country's economy and as a motivation for building new places with more problematic soil. Thus, the focus would be on this study's most available waste material, slag. Many researchers (Mozejko and Francisca [37]; Poh [38]) denoted the importance of slag in soil improvement. Mozejko and Francisca [37] investigated the slag particles effect on the stiffness and soils stabilization strength, especially loess compacted soils. Poh [38] denoted that employing slag fines had promise as a stabilizing material in the domain of fine-grained soil stabilizating through their exploration of adding basic oxygen steel slag to English China clay and Mercia mudstone. They recommended further exploring studies on the EAF slag's impact on the engineering features of soft soils.

The current study contributed by exploring using of high EAF slag percentile according to weight of dry soil could be a beneficial solution to reduce environment problems occurred from slag disposal and support waste recycling to develop from the related industry. Additionally, EAF slag could increase stiffness, improve clay's strength, and improve other soil properties. The results of testing the efficacy of electric arc furnace slag as a replacement for the modification of that clays might open up a brand-new avenue with an ecologically benign use in geotechnical engineering.

1.2.2. Environmental Aspects

The environmental aspect is one of the primary and most essential fields nowadays because the world is more alert about environmental degradation and the greenhouse effect of CO2 emissions. So, in order to save more for the next generation, the environment is the main interest in this study to save more raw materials and get rid of some wastes which may appear in huge numbers even if it is not the most harmful in order to be used in the geotechnical

field safely and save space within sanitary landfill places. This impact should be studied through a case of study to an existing landmark that requires soil improvement and estimates the saving of natural resources and the landfills' spaces.

1.3. AIM, OBJECTIVE AND SCOPE

This project discusses a particular way of soil modification named soil replacement. This study uses industrial waste, such as slag, while adding geosynthetic and microplastic materials, such as tire chips, into the soil for further improvement. The main goal targeted in this thesis is to open horizons and ideas for the most sustainable environmental soil improvement while using some environmental wastes like slag and microplastic in the form of tire chips to determine basic geotechnical engineering experiments. This thesis adopts more than just the idea of using these wastes in poor-quality soil, or the soil needs improvement. However, it can play a role on the economic side with replaced the use of gravel to slag in the soil replacement improving technique, which will be approved with some experiments and other improvement techniques like geogrid.

1.4. THESIS STRUCTURE

This thesis is composed of five chapters. Chapter one will discuss the background and the brainstorming, taking the topic to the construction problem and solving some environmental issues to achieve sustainability by mentioning the procedure of determining the existing environmental waste. Then, chapter two discusses the literature review for some studies until reaching this study. At the same time, the third chapter mentions the performed experiments with the methodology for each and the chosen environmental waste materials. Chapter Four provides the results of each experiment for different soil types to reach the optimum percentage for each environmental waste. Chapter five narrates the conclusion and potential future recommendations.

2. LITERATURE REVIEW

2.1. BACKGROUND

One of the most common issues in the field of geotechnical engineering is the construction over soils with limited bearing capacity and high settlement potential. Most stabilization must be performed in silty, clayey, organic soils, and sometimes granular sand to increase bearing capacity, reducing the concrete section assigned for the substructure of any building. Effective stabilization is made possible by the silt and clay size soils' substantial surface areas relative to their particle sizes to access the desired engineering qualities [39]. Replacing the current soil with dense, granular soil is one of the traditional techniques for stabilizing soft, shallow soil. As environmental sustainability has grown in importance in recent years, its application has changed the waste materials extracted from industry used to minimize the trash in landfills. The use of industrial wastes as improving materials in construction engineering applications are being studied more and more [19]. This chapter will cover the rationality for using geosynthetics as soil reinforcement, a material developed in the middle of the 20th century during the revolution in the plastics industry. In addition, plastic recycling implies an environmental impact to protect the planet from chemical deterioration. Thus, the study addresses utilizing industrial waste such as slag and, tires chips, as soil replacement providing improvement. These materials may aid in its cost-efficient disposal by conserving the strategic natural resources for building and substituting wastes with natural resources. Other methods could be reinforcing the soil, nailing the soil, cementitious grouting materials, or creating stone columns for soil stabilization and improvement.

2.2. IMPROVEMENT METHODS

Several methods for improving and stabilizing soil have been introduced throughout the decade. Usually, the soil of any land piece requires improvement for various reasons, such as increasing the soil density, soil bearing capacity, ground settlement control, controlling soil permeability, increasing soil stability, and reducing soil liquefaction [40]. This soil improvement would consume less time in the design and implementation of the substructure, which would be more cost-efficient than usual in the case of applying soil improvement. For

instance, the sub-structure could change from raft to shallow footing because of the soil's improved bearing capacity [41].

Generally, "soil" means the loose layer of earth covering the planet's surface. Soil is a component of the earth's surface that consists of decomposed rock, humus, and inorganic and organic components. It takes an average of 500 years or more for soil to develop from rocks. Soil is often generated when rocks are broken down into their essential pieces. When various pressures work on the rocks, they break down into smaller pieces to produce soil. These factors also include the response of wind, water, and salt. Thus, various rock types and substantial soil exist. The soil is classified as cohesion and cohesionless, including sandy, silty, clayey, and loamy [42]. Consequently, not all the soil improvement techniques would fit most soil types. Thus, various techniques fit the cohesion soil, and others can fit cohesionless soil, which is the target of this study.

(a) (b) (c) (d)

Figure 2.1. A schematic diagram showing types of soil from; (a) sandy soil, (b) silty soil, (c) clayey soil, and (d) loamy soil

Thus, the soil improvement techniques can be classified [43] based on soil types into techniques for cohesive soil, which include precompression/loading Radhakrishnan [44]; Stapelfeldt [45], sand/wick drains Aboshi [46]; Varghese [47]; Das [42]; Kirmani [48] and stone columns Bryson and El Naggar [49]; Das [42]; Wang [50]; Terzaghi [51]; Deb [52]). Other for cohesionless soil encountering Vibro-flotation, terra probe (Brown [53]; Welsh [54]; Wightman [55]), and compaction piles. Other general techniques include removal and soil replacement (Abdel Salam [56]; Varghese [57]; Wightman [58]; Abdel Fatah [59];

Stapelfeldt [45]), deep mixing of the soil (Bryson and El Naggar [49]; Burke [60]; ASCE [61]), and grouting (ASCE Committee on Grouting [62]; Borden [63]; Yonekura [64]; Grouting Committee of Geo-Institute [65]; Burke and Welsh [66]; Xanthaks [67]; Burke[62]), in addition to soil reinforcement (ASCE [68]), soil stabilization (Makusa [69]; Celaya [70]; Li [71]; Raj [72]; Rao and Rajasekaran, [73]; Thomas and Dallas [74]; Huybrechts and Denies [75]) and thermal stabilization (Katagiri [76]; Mitchell [77]). Underneath each technique, a serious classified group related to the material added, whether it was artificially manufactured or wastes or from natural resources.

For instance, the soil replacement technique acquires industrial wastes, mineral additives, and natural resources. This study explored only soil replacement (ASCE [68]) in addition to soil reinforcement techniques using geogrid. These general techniques can be used for both cohesive and cohesionless soil. Soil replacement can be subcategorized according to industrial wastes and mineral additives (Hausmann, 1990[78]). These industrial wastes and mineral additives differ from one country to another. The main concern would be the cost-efficient effectiveness of waste use. In the next section, the environmental wastes will be introduced, and the impact of each on the soil capacity will be used for further reference.

2.3. ENVIROMENTAL WASTES

Civil engineering projects built in places with difficult soils are one of the most typical issues all over the world. This dirt can be removed prior to construction and replaced with soil that has better qualities. This procedure would be costly and inefficient when the soil depth is deep. As a result, researchers seek alternative strategies to enhance soil qualities before building. Soil stabilization is one of the most often utilized ways to improve soils' physical and mechanical characteristics, satisfying the engineering requirements of specific projects (Al-Homoud [79]; Al- Murshedi, 2014[80]). Many wastes might have a negative impact due to their vast quantity and different types because of the revolution in the industrial field, such as damaged lead batteries, electronics devices tires, slag, Bypass from cement factories, and petrochemical sludges. Mainly these wastes are disposed of and buried in sanitary landfills or burnt, which costs hauling and transportation in addition to their negative environmental impact. Some wastes in various countries are obliged by industries to burn as an alternative fuel by a 10% minimum for energy generation, such as tires. However, unfortunately in

developing countries, filtration is at its worst, so some factories are receiving organic substances like diapers and food waste. Some other wastes are classified as dangerous wastes and should be treated with much precaution and be burnt well in healthy landfills to prevent many diseases like medical obligations and wastes from pesticides.

Different methods are generally applied to stabilize difficult soils; some techniques use compaction methods, reinforcements, and prewetting. While other techniques use different additives like cement, lime, and sand and add river mixture soil, chemical additives, fly ash, quarry waste, silica fume, cement kiln dust, tire rubber, and rice husk (Okagbue and Onyeobi [81]; Al-Taie and Al-Shakarchi [82]; Al-Taie [83,84]). Many of these methods are used to improve the geotechnical properties of expansive soils.

The cement dust is a waste of the cement industry, which deposit is rarely recycled in the local Iraqi industry. There are significant amounts of cement dust available as waste materials. Cement dust is used in different civil engineering fields to replace ordinary cement, building units in concrete technology, engineering materials production, and geotechnical engineering (Hussein [85], Al-Naje [86]). Some industries found that owning land behind the factory to put their waste is the cheapest solution; however, it is still not cost-efficient. In these industries, steel, cement, and ceramic manufacturers adjust a landmark for their wastes, which contains only hills of slag, bypassing dust and ceramic waste.

2.3.1. Bypass

Figure 2.2 shows the Bypass (cement dust) produced while the clinker manufacturing process for cement production. A bypass has a very low density and is hazardous to the environment due to the existence of chlorine and sulfate in its chemical composition. The factory produces a large quantity of Bypass, which produce 120 ton/day from one production line. Moreover, some people use it instead of cement, but a thirst for water was found, which gives a high swelling index leading to a change in mass. Also, the high percentage of chlorine and sulfate will cause steel corrosion and concrete cracks, see Table 2.1. Recently Bypass has been used for some roads asphalt with a low percentage but causes some cracks when water appears. Some other companies decided to use it as a filler in concrete borders, which

appear on highways, so the recycling of Bypass did not reach further uses. In contrast, it appears in huge quantities, especially in developing countries.

Figure 2.2. A bypass dust

The Bypass waste could be used as soil replacement; however, there is a scarcity of data on the influence of cement dust on the engineering impact on soils. Al-murshedi [87]. investigated combining the expanding soil at optimal moisture content with varying quantities of cement dust; 4, 8, 12, 16, and 20% through created samples exposed to wetting and drying cycles, evaluating the swelling behavior. Their results revealed that adding cement dust to expansive soils effectively improves their properties, such as decreasing consistency limits, raising maximum dry density corresponding to lower optimal water content, and decreasing the swelling pressure and potential [87]. Similarly, Al-Rubaiee and Hussein [88] reported that gypseous soil in Iraq created several technical challenges, collapse, or settlement of footing under construction. Thus, their study suggested cement dust waste as an additive at 5%, 10%, and 15%, enhancing this soil type's physical and engineering properties. Consequently, the results showed a minor enhancement in several terms, such as increased liquid limit percentage, reducing the specific gravity and the unit

weight as the additives percentile increased, whereas the ideal moisture percentage rose. Further, the direct shear test enhanced cohesion values when implementing dry and wet soil cases with 15% additives. The bonding explained this enhancement; thus, there is still a gap to fulfill in this area.

Table 2.1. Sequence of the preliminary

Chemical composition	Percentile (%)
SiO_2	11.5
AL_2O_3	3.53
Fe_2O_3	3.26
CaO	55.62
MgO	1.89
SO_3	5.81
K_2O	5.53
Na_2O	1.77
Cl	5.03
LSF	144.84
SM	1.69
AM	1.08
HM	3.05
LOI	4.23
Moist.	0.17
Rate	5.17

On the other hand, Hussein [89] investigated using cement kiln dust at concentrations of 0%, 5%, 10%, 15%, and 20% as stabilizers on the shrinkage, plasticity, and shear strength behavior of plastic soil through a series of shrinkage and plasticity tests, in addition to, unconfined compression tests. The findings showed that combining the soil with 15% or 20% cement dust may minimize plastic soil's crucial behavior and improve the undrained shear strength. In reality, the curing duration had an impact on its strength. When the cement dust percentage reached 20%, the undrained shear strength rose more than three times. İn 2022, Hussein [89] explored the consolidation properties when adding cement dust on

expansive Iraqi soil at 0% to 30%. The results indicated that cement dust considerably impacts the consolidation properties of expansive soil, especially the swelling index, which was reduced by one-third of virgin soil. (i.e., before adding the cement dust).

2.3.2. Petrochemicals

Not only waste from the cement industry would be a possible technique to stabilize the soil properties, but natural admixtures or petrochemical additives would be more effective. Eventually, there are some synthetic additives used like 'Krilium' and polyvinyl alcohols for soil improvement Theng [90]. Since the middle of 19 century, geotechnical engineers started to use synthetic chemical macromolecules such as polyacrylamides and lignosulfonates for changing conventional binders in improving the soil. However, these materials expand concerns about contamination and pollution problems, which require regulations and control for chemically synthesized polymer usage in the future as it is presently accepted globally Karol [91].

On the other hand, electro-osmotic chemical treatment (ECT) was explored and reported to improve the strength of soft soils, although the chemical chelating agents that should be injected enhance the osmotic pressure, as recorded by Ou [92]. Biju and Arnepalli [93] explore the ability to change some petrochemicals that might contaminate the soil into green material that can be used for improvement. Wang & Tang [94] stated that oil is one of the most critical energy sources today; however, oil spills and leaks increased oil contamination throughout oil extraction, storage, transportation, and use (Blumer et al., 1973) [95]. Petroleum hydrocarbon-based compounds enter into the soil and alter its spherical composition, metabolic cycles, and microbes' diversity, resulting in soil toxicity, which disrupts the ecological scale and slows environmental deterioration [96,97]. Thus, the petrochemical factories discussed the issues with the responsible people reaching a very successful level of recycling, nearer to zero waste, as they get polymers in the shape of solid boxes to be used in plastic industries. Thus, this field has grown substantially, and their environmental impact and influence under saturation were a concern; thus, a trend toward the employment of the biopolymers to serve engineering applications shows an increase directly proportional with environmental sensibility according to the realization of hazardous appurtenances. Biopolymers are well used in many fields as food processing, the chemical

industries, energy field and agriculture, as well as in environmental protection. The most common biopolymers used for soil improvement such as guar gum (which is derivative of the ground endosperm of a legume), xanthan gum (from bacteria Xanthomonas campestris), chitosan (crustaceans derivative) and sodium alginate (brown algae from cell walls) which can cause lower permeability, higher value of shear strength parameters, enhancement of swell–shrink behavior, and higher resistance towards erosion. Biopolymer-induced soil stabilization is a perfect solution for slope stability and erosion. Karimi [98] mentioned that 1940s was the starting of using biopolymers in soil application for improvement and stabilization under the supervision of agricultural engineering.

Different works found that several biopolymers, including chitosan, sodium alginate, xanthan gum, poly-hydroxybutyrate, poly-glutamic acid, and guar gum, reduce the soil's permeability up to a magnitude of five orders [99,100,101,102,103]. Researchers stated that adding biopolymers to different soil types enhances compressive strength through unconfined reaching higher than 150% than usual and reduces the potential for soil erosion Chang & Cho [104], Liu [105]. Furthermore, it increases the shear strength and considerably changes cohesion intercept with a negligible effect on the angle of friction [106,105,107]. Also, the Biopolymer-modified soil enhances the dry density of virgin soil and provides higher values than usual while no significant change in optimal moisture content (Karimi [106]; Taytak [102]). Similarly, adding biopolymers increased the liquid limit for cohesive soil. Consistent limit variation will differ with biopolymers' properties (Karimi [106]; Nugent [108]; Chen [109]).

Not only polymers nor biopolymers were the only product of safe petrochemical that could be used in soil improvement. Recently, new bioremediation has been highly recommended over traditional physical and chemical treatments due to its high effectiveness, cheap cost, and minimal toxicity (Zhen LS [110]; Li [111]; Yang [112]). Bioremediation is an approach used for treatment by stabilizing toxins through absorbing, converting, or degrading them into safer forms such as CO_2 and H_2O, mostly through soil organism remediation Youngsook [113]. This remediation accelerates microbial metabolic activities using fertilizers or other additives in oil-contaminated soil to enhance the efficiency of bioremediation and effect of remediation on soil petroleum pollutant treatment. At the moment, the majority of research concern about ways of improvement of biochemical properties of soil after oil contamination

through remediation technology with lower research on the use of natural organic matter from agricultural waste for the enhancement of oil contaminated soil [114].

Various studies have investigated the influence of various material addition on the restoration of petroleum-contaminated soil by usage of hay, straw, and leave as agricultural wastes [115]. Three ordinary agricultural wastes, such as lemon leaves, corn cobs, and soybean straw, were added to investigate the result of soil with petroleum hydrocarbon-contaminations and its enhancement effect [116]. Song [118] tended to provide scientific evidence that various types of nutrient materials added to soil microbial diversity and clarified the structural properties of microbial soil with petroleum-contaminated in response to different nutrient additives. They also analyzed the mechanism of responding towards soil-microbial ecosystem to nutrient additives. Their results revealed that these additives would improve the petroleum-contaminated soil and provide a good characterization of soil in shearing, friction, and cohesionless. Nevertheless, further investigation is required in this area, as recommended [118] .

2.3.3. Ceramic

Another waste product material that causes environmental impact and faces many problems for hauling to landfills. Ceramic production is considered one of the industries that produce large amounts of waste, see figure 2.3. Several trials were considered in mixing these wastes in the clinker for cement manufacturing or even as a filler in concrete manufacturing, partially replacing cement, fine and coarse aggregate; other trials concerned the use of ceramic waste in red brick manufacturing. Nevertheless, all these trials were under investigation with their pros and cons. These pros and cons were not yet settled; thus, they were not approved or applied in those industries. Recently, a specific type of soil widely distributed in many regions of the world, gypseous soil, which contains more than 20% gypsum, proved to be improved when using ceramic waste, which gained some attention to improving gypseous soil capacity. Several researchers explored the gypseous soil in terms of behavior solely [118,119]) or underneath shallow footing (Zedan & Abbas, 2020 [122]) or while improving their characterization using sand.

Alphen & Romero [123] discussed the problems gypseous soil might encounter, including low strength, compressibility, volume change, permeability, structure stability, water

seepage, and dissolving of gypsum, causing settlement and ground-level failure. Zedan and Abbas [122] showed that the bearing capacity improved when sand's 80 percent relative density was compared with the gypseous soil. Their results reveal that sand resistance reduces when soaking gypseous soil under the sandy layer.

Ahmed and Zedan [124] examine treating the three types of gypseous soil with gypsum contents of (61%, 45.3%, and 27.9%, respectively) with ceramic wastes, a construction waste product and explored the behavior of a shallow foundation resting on the treated gypseous soil. Four proportions of ceramic waste (0%, 3%, 6%, and 9%) were added under dry and wet conditions at depths for each ratio of B/2, B, and 3B/2 underneath the footing. The results revealed that the soil's bearing capacity improved at 9% ceramic waste by 233%, 256 %, and 289% for high gypseous soil and by 78%, 94%, and 111% for medium gypseous soil, with a percentage of 60%, 87%, and 113% for low gypseous soils. Moreover, the wet gypseous soil with added ceramic wastes improves the bearing strength of the soil, lowers settlement to some extent, and reduces the influence of water on it.

Figure 2.3. Ceramic wastes

2.3.4. Slag

This section discusses the usage of Slag as an additive material in soil improvement techniques. This action will help in disposing of waste, preserving natural resource materials in construction, and reducing their deployment. Historically, Slag was used as filler

materials, and some with percentages in constructing roads. In addition, it plays a role as a cement additive and landfill cover material Proctor [125].

As per World Steel Association [126], one ton of steel, about 200 kg – 400 kg of Slag, is generated, which depends on the atmosphere, country, and manufacturing technique. Slag materials are obtained after the different processes of steel making named as blast furnaces, electric arc furnaces, and basic oxygen furnaces.

Those mentioned slag materials have different properties and areas of application, such as additives material for cement, filling material, and stabilizing use [20,21,22]. The Slag has also approved the usage of Slag in the manufacture of concrete process and for asphalt-designed mixing for roads and highways Dippenaar [127].; Meiling [128].; Mohi Din [129]. and Oluwasola [130].). Ground granulated blast furnace slag (GGBS), a by-product of pig iron production with high calcium, silica, and alumina, has a high potential and is widely used as a base material instead of Fly-ash and Metakaolin for the reasons mentioned earlier. Furthermore, Alkali Activated Slag (AAS) exhibits good mechanical properties, such as high compressive strength reaching up to 60.4 MPa after 7 days Amer [131]. Also, it is cured at ambient temperature, unlike Fly-ash and Metakaolin, which requires heat curing to undergo polymerization Manjunath & Narasimhan [132]. Figure 2.4 shows that Slag (Steel waste) was found through EZZ steel company.

Figure 2.4. Electric arc furnace slag (EFAS)

Slag, in general, is a by-product of various metal extraction and refining processes which appears as a block honeycomb with some pores. It is a strong material that is difficult to crush and has a high hardness ratio and high friction ability. A by-product of steel-making recovering after the oxidizing process used as aggregate, there are many studies done to know Slag's physical and chemical properties concerning its application in the construction industry and its chemical reactivity. The Slag consists mainly of calcium oxides, iron, silicon, magnesium, aluminum, and other combinations of manganese. These compounds can be found naturally in the environment. This study resulted that the Slag have high mechanical properties and high density that helps in the construction of breakwater blocks, foundation, shoring walls, noise barriers, and radiation insulators because the weight factor was important in this study. There are three types of Slag according to the way of production. Slag produced using

1) Electric arc furnace slag
2) Blast furnace slag
3) Ladle Slag

Electric arc furnace slag (EAF) producing takes place in the manufacturing of crude steel in the process of electric arc furnace. The Slag is named to be dense and strong material with a high value of specific density and mechanical strength compare to soil. This material exists in many aggregate sizes. Therefore, electric arc furnace slag can be used as an aggregate for soil replacement purposes. In railway constructions and even highways, electric arc furnace slag can be used as subgrades, subbases, and embankments (Oluwasola [23]; Marta [24].). EAF slag is also desirable used in the manufacturing concrete through the hydraulic way (Arribas [25]; Monosi [26]; Santamaria [133]).

Two types of Slag are generated from the electric arc furnace during different stages of steel-making ladle furnace slag (LFS) and electric arc furnace slag (EAFS), which is produced in percentages through the recycling of the steel scarp Maghool [134]. During the melting process, the fluxes combine with nonmetallic scrap components and incompatible steel elements to form liquid Slag. Slag has a lower density than steel, so it floats on a molten steel bath. The liquid Slag is tapped at a temperature around 1600 °C and allowed to slowly air-cool, forming crystalline Slag, see Figure 2.5. It was found that Slag enters cement production, which has a similar chemical composition to cement. However, Slag has a

different setting time slower than cement, and to come over this, it will cost more money to put in the proper additives.

Figure 2.5. Air cooled electric arc furnace slag

Slag was chosen because of its high friction and low crushing value as it is so hard to be crushed, even more than some coarse aggregates. Moreover, it has a high hardness index compared to other materials. it also has some cementitious properties, good particle interlocking, durability to abrasion, and takes advantage of the massive quantity of Slag. This Slag will cost so much money to bury and may negatively affect the environment due to dust contamination. Thus, many applications can be using Slag; for instance, as a soil stabilizer and on roads due to its high friction value to prevent slipping, which opened a way of thinking to use these good chemical and physical properties in our field.

Iron blast furnace slag is a nonmetallic by-product produced in a high-temperature pig iron production process. Iron ore and coke are the two primary raw materials fed from the top of the blast furnace. Limestone is added as a flux or chemical cleaning agent to capture impurities in iron ore. The combustion process of iron ore, along with the added materials, is initiated by blowing hot air from the bottom of the blast furnace. This process results in molten pig iron in the bottom of the furnace with molten slag waste on top García-Lodeiro [135].; Ramezanianpour [136].

According to Ramezanianpour [136]., Slag is formed due to the high-temperature fusion of acid clay gangue existing in iron ore and sulfur ash from coke (Al2O & SiO2) with essential

lime and magnesia found in limestone (CaO & MgO). Based on that, the chemical composition of the molten Slag consists of silica and alumina combined with magnesia and lime. The molten slag temperature is in the range of 1400 to 1600ºC and can be cooled in two regimes:

1) **Slow cooling:** crystalline structure and stable solids are produced in this process. The Slag produced in this process is used as base materials for roads and as aggregates in particular types of concrete as they hold very low or no pozzolanic properties [136].

2) **Rapid cooling:** granular glassy materials are formed in this process by avoiding crystallization by using large amounts of water or spraying jets that spray water under pressure. A semi-dry method developed in Canada for cooling Slag produces different sizes of slag particles, as shown in Figure 2.6. Particles in the range of 4 to 15 mm, partially crystalline, are used as expanded Slag for lightweight concrete. Particles smaller than 4 mm with a glassy structure are used as a hydraulic binder which can replace cement partially in concrete or entirely in the presence of an alkaline activator (Geopolymer) [136].

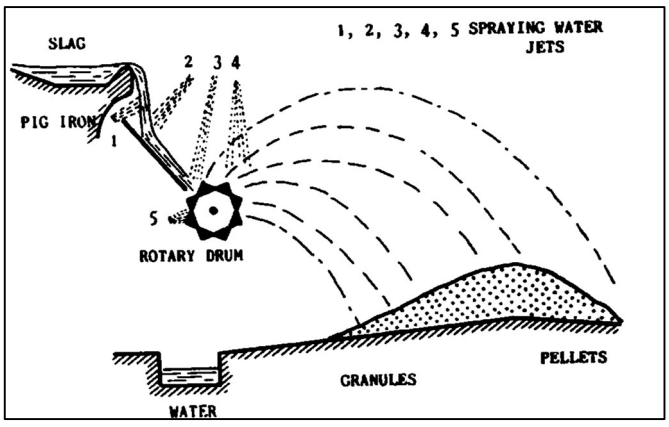

Figure 2.6. Canadian method for slag granulation. Granules are less than 4 mm while pellets are more than 4 mm [136].

Granules are less than 4 mm, while pellets are more than 4 mm [136]. The abrupt cooling of Slag produces a vitreous glass phase which consists of anions $(SiO_4)^{4-}$, $(AlO_4)^{5-}$ and $(MgO_4)^{6-}$, known as a network forming anions, and cations (Ca^{2+}) (Al^{5+}) and (Mg^{2+}), known as

network modifying cations. These anions and cations from around 90 to 95% of the produced Slag highly influence its reactivity. Moreover, they affect the final product properties upon mixing with an alkaline activator [136].

Steel Slag is a secondary product from two industries: converting the iron to steel or making steel from melting scrap in EAF Shi [137]. (EAFS) is an outcome during the manufacturing of crude steel in the process of electric arc furnace. With the addition of fluxes (e.g., limestone and dolomite), steel scraps are heated to a liquid state utilizing an electric current.

Literature reviews presented that recent research on the steel slag mostly concentrated on use in asphalt and concrete (Manso [138]; Abu-Eishah [139]; Ameri [140]; Anastasiou [141]; Kavussi & Qazizadeh [142]; Kavussi [143]; Rondi 144] and in cement industry Iacobescu [145]; Pasetto & Baldo [146]; Autelitano & Giuliani [147]). Slag was occasionally studied in the geotechnical field to evaluate the enhancement of engineering properties and the shear parameter of various soils. International Trade Administration (2020) [148] reported that Turkey is one of the high-ranking countries for steel producers and exporters in the world. In 2017, Turkey owned around four percent of world steel exports with 19.8 million tons of steel in 2018 where this represents around 75 percent of annual steel production is obtained from electric arc furnaces (EAFs). Yonar [149] reported that 150 kilograms of Slag was through the manufacture of one ton of steel produced in electric arc furnaces. Only 1% of steel slag is produced through the manufacture process of pave stones interlocking as the pioneer role of turkey in the steel making generating around five million tons of slag each year. Mahmudi [150] reached on numerical analyses bases that the duration of consolidation and settlements level for clay with addition of EAF slag decreased compared to the same soil without. Various types of steel slag have been used to enhance the soils with fine graded sieve .Rajakumaran [151] evaluated the effect of increasing the rate of steel slag in the steel slag with fly ash mixtures as it reduced the cohesion and internal angle of friction .Shalabi [152] recognized that soil's maximum dry unit weight can be increased with increase the steel slag content ,even, it reduced the clay's plasticity .Increasing the steel slag content increased the internal angle of friction with decreasing clay's cohesion intercept based on the experiment of consolidated undrained shear strength .Bensaifi [153] showed the effect of crushed and granule slag on the unconfined compressive strength ,bearing capacity load and shear parameter through increased results . The increasing of cement and electric arc furnace slag effect with the increase on clay's

compressive strength was concluded. Ismail [154] proved the decrease of percent of free swelling of an expansive soil with adding of optimum amount of electric arc furnace slag. Mozejko and Francisca [155] showed an increase in soil strength when adding steel slag with the compaction of the loess soils. Poh [156] concluded an increase in strength durability of English China clay and Mercia mudstone as an enhancement due to the addition of basic oxygen steel slag.

Moreover, more research needs to evaluating the effect of electric arc furnace slag on the engineering soil parameters especially for soft soils. (Mozejko & Francisca [155]; Lopes [157]) discussed using of electric arc furnace slag as a stabilization agent while (Lopes et al., 2021[157]; Akinwumi [158]) explored EAF slag utilization for improving the permeability, plasticity and strength of tropical soils. The results revealed that using higher contents of electric arc furnace slag can decrease the environmental problems exists due to the existence of slag in huge quantities which carry more dusts to air. Furthermore, electric arc furnace slag can provide more strength for clay and other soil properties, in addition to, use for replacement in order to stabilize the clay or bad property soils introduces a new environmentally friendly application in geotechnical engineering. On the other hand, Manso [136] and Serjun [159] discussed the limitation of LFS usage as a by-product for soil stabilizing in powder form due to the cementation property. Maghool [160] and Sudla [161] showed that LFS and EAFS can be geotechnically and environmentally approved as an aggregate for road applications works according to some standards. Chaurand [162] and Dayioglu [163] investigated the chemical analysis for a long-term assessment which reported the release of Chromium trivalent (Cr (III)) not characterized as a toxic chemical because of its stable form during the leachate process. Hanumasagar [164] conducted a pullout test on geogrid with slag and soil mixtures in different percentages, which approves an increasing resistance in some mixtures properties and introduces improvement for soil was achieved by using geogrid reinforcement with steel slag to improve some pullout properties.

OSINUBI [165] were concerned with fixing contaminations caused by toxic liquids leaked from waste in landfills, which were observed due to the rise of environmental awareness to study clayey liners in landfills. Their results revealed that using 15 percent of blast furnace slag has a good impact as needed for the landfill, which maintains low conductivity, and requires high conductivity barriers in landfills. It works as good lining material, which proves a higher percentage of Slag passing through the sieve No. 200 gives better results in

preventing leachate from passing, which may be checked by conducting initial and final setting time to see how could a slag paste intermolecular between its particles.

BOF slag formation takes place while converting the hot metal into steel at the blast furnace by adding some lime or dolomite, consisting of silicate compound and oxides, to get the liquid Slag. That stage of Slag is then exposed to dry air cool at pits. During manufacturing, physical properties can be adjusted using different measures like a sieve and crushing value. The variability exists in Slag because of the difference between the chemical composition from one place to another. Long-term expansions can exist due to the chemical composition of the Slag, which is represented in a high concentration of CaO and MgO in different forms of oxides and silicates. The determination of free CaO content in steel aggregate could be done with standard methods as described in the European standard EN 1744-1:2009. A1 (2013) [166]. ASTM D-4792[167] describes testing methods to determine the submission of steel slag containing ingredients which faced hydration with evaluating the potential expansion of the oxidized Slag. The delay in CaO and MgO's hydration is responsible for cement-based materials' expansion.

Steel Slag as a construction material is effective because of its volume stability. Yi [168] evaluated the volume stability by immersion expansion ratio test. In Germany, the steel slag is reviewed using a steam test for construction and a boiling test for hydraulic construction. In Germany asphaltic layer upper bond value consists of 4 % free CaO Motz & Geiseler, [169]. After 2009, China developed a standard for immersion expansion tests. Steel slag should pass through some practical methods to reduce expansive oxide content: steam, curing, autoclave, and weathering of Slag. A general method was discovered to overcome the steel slag's expansion behavior, which is to be stored in stockpiles for six months with contact with water to allow the hydration process. This steel slags, without overcoming the expansion problem, are suitable for aggregate applications unbounding [170]. Outdoor aging is one of some aging ways for improving steel slag volume stability [171,172]. The Autoclave treatment can lower free lime content. In addition, the cementation of steel slag can be improved in thermal and mechanical ways (Ducman & Mladenovicˇ [173]; Qian & Suna [174]) or chemically (Li [175])

The modification of steel slag SS is MSS-modified steel slag which is affected differently for each product according to the chemical composition. Mixing of the blast furnace slag with electric arc furnace slag in acceptable quantities and then repeat heating at higher

temperatures was done by Li [175]. Cement hydration shows some similarities with the hydration of Steel slag where C2S and C3S activity is deficient while the speed of hydration can be accelerated when decreasing the particle size. A hydration study of BOF slag pastes was done by Belhadj [177]. BOF slags consist of some CaO, which hydrate, causing pastes swelling where; it opened an idea of proposing lime extinction steps to the standard EN 13282-2; this approach was believed to be more effective in avoiding volume expansion of pastes cured in water. In structural concrete, sand was replaced with a crushed and sieved slag with a determined particle size of 19.13 percent water absorption ability as a secondary replacing material by Olonade [178]. As it was discovered the water content percentage decreased for a constant slump value with the replacement ratio increasing.

Steel slag as aggregate was checked through the workability of concrete by Subatra Devi and Gnanavel [179] and Yang [180]. They figured out that the slump decreases as SS percent increases. Maghoola [181] performed a mixture sample between LFS and EAFS to modify the engineering properties of EAFS as it has poorly graded size while using LFS to improve strength properties as the size gradation curves approved according to the specification requirement for local road organization. Wang [182] used geogrid layers to evaluate their effect on various steel slag conditions. The geogrid showed an improvement in the compressive moduli with various slag conditions, either dense state or lose state, as the best improvement appeared in the two-layer geogrid. For Slag, the dense condition was the best value.

Pisini [182] performed different mixtures of KOBM slag with subgrade soil with a variation of geogrid reinforcement through the CBR test to assess the effect of using 15 and 20 percent slag usage with geogrid reinforcement. The result obtained a more significant increase in the reinforcement mixture directly proportional to the slag percentage increase. Nevertheless, 20 percent of the slag mixture revealed the highest CBR value.

2.3.4.1. Factors affecting properties of Alkila Activated Slag (AAS)

2.3.4.1.1 Chemical Composition Of Slag (GGBS)

The chemical composition of Slag varies based on the raw materials used in pig iron production and the production process itself Amer [183]. Table 2-2 presents slags produced in different countries. It can be easily observed that Slag's chemical composition varies from source to source.

2.3.4.1.2 Fineness And Particle Size Distribution Of Slag (GGBS)

Blast furnace slag is available in many forms with different physical and chemical natures, determining their potential use as hydraulic binders. Granulated blast furnace slag, which consists mainly of glassy phases with some minor crystalline phases, exhibits hydraulic activity. For achieving acceptable properties of slag, further grinding of granulated Slag to specific surface areas ranging from 4000 – 6000 cm^2/g should be performed [183, 133, 134].

Table 2.2. Chemical composition of slags (GGBS) (Ezz Inc ©) [184]

Oxides	Percentile
CaO	33
SiO_2	13.1
AL_2O_3	5.51
Fe_2O_3	36.8
MgO	5.03
SO_3	0.14
K_2O	-
P_2O_3	0.7
Cr_2O_3	0.8
Mn_2O_3	4.18
TiO_2	0.6
LOI	-

Specific surface area or fineness and particle size distribution of Slag (GGBS) are among the essential factors with a substantial impact on the intensity and rate of reaction, workability, setting behavior, mechanical properties, shrinkage …etc. Saedi [186] studied the effect of two levels of Blaine fineness of 2900 cm^2/g and 4200 cm^2/g for Slag from the same source. Setting behavior was found to be significantly affected by the fineness of Slag (GGBS). Results confirmed that as fineness increases, setting occurs more rapidly. The setting times of the Slag with a higher fineness (4200 cm^2/g) were 10% lower than that of the Slag with a lower fineness (2900 cm^2/g) [186]. This behavior also agrees with the findings of Humad [187] which indicated that the shortest setting time was recorded for the

Slag with the finest particles (4980 cm^2/g), while Slag with the coarsest particles (4350 cm^2/g) yielded the longest setting time. As postulated by the authors, fineness directly impacts the speed and temperature of the activation reaction, which in turn affects setting behavior [187]. The reason for the accelerated setting of finer slags is that more slag grains with smaller particle sizes are available, providing more surface areas for contact with an alkaline activator. This behavior leads to a more intense and faster activation reaction [186, 188].

Additionally, smaller particle sizes ensure the complete reaction of slag grains (Amer [185, 189]. Slag particles with sizes less than 10 µm enhance early strength development for up to 28 days. On the other hand, the hydration of particles having a size from 10 to 45 µm continues beyond 28 days which in turn enhances strength at a later age. Particles of size more than 45 µm are not used as cement replacement as they almost have no activity [134]. Moreover, Wang [190] concluded that particles with sizes exceeding 20 µm show very poor and slow reactivity, while particles with sizes less than 2 µm entirely react in the first 24 hours. Sizes below 5 µm were crucial for the hydration of Slag.

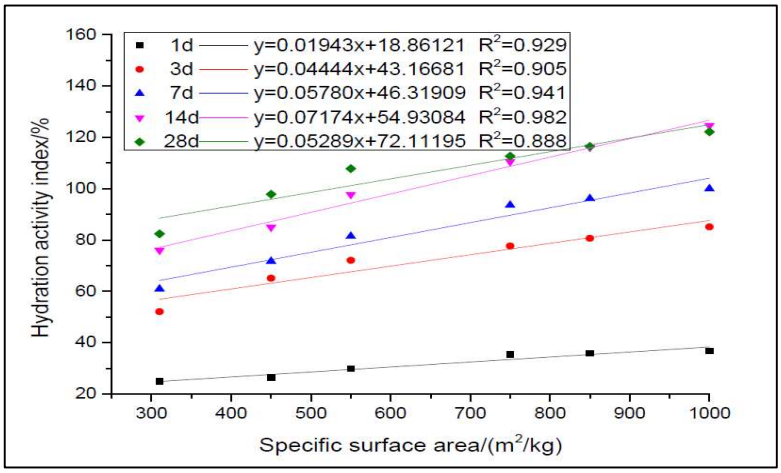

Figure 2.7. Hydration activity for 6 levels of slag fineness (Dai) [189]

Dai [189] studied the hydration activity of 6 different specific surface areas of one type of Slag. Hydration activity was obtained using the compressive strength ratio of a slag cement mortar, with a 1:1 slag-to-cement ratio, to that of pure cement mortar. As the fineness of slag

increases, the hydration activity increases regardless of the testing age, as shown in Figure 2.7.

Furthermore, the mechanical behavior of AAS is affected by the different fineness of Slag (GGBS). Finer slag particles enhance the mechanical properties of AAS significantly. Based on the work of Humad [187], the Slag with the highest fineness yielded the highest 7 and 28 days compressive strength, whereas the Slag with the lowest fineness had the lowest values for compressive strength. Dai [189] demonstrated that compressive strength increases with Slag (GGBS), having higher fineness due to its vital role in the degree of hydration and rate of reaction. Figure 2.8 shows the compressive strength of AAS mixes having the same activator parameters but with two levels of slag (GGBS) fineness [186].

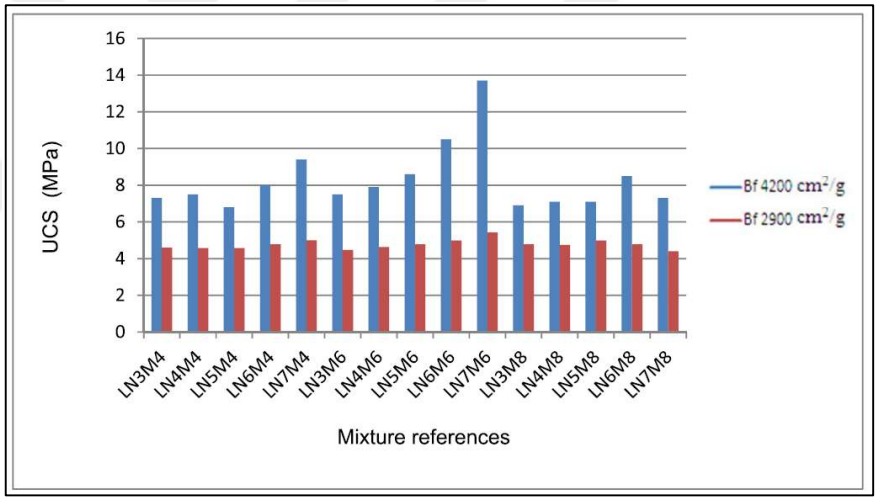

Figure 2.8. 1 day compressive strength of different AAS mixes using 2 levels of slag (GGBS) fineness (Saedi) [186].

Similarly, flexural strengths followed the same trend as compressive strength. Results show that an increase of approximately 40% in flexural strength occurs due to the fineness increase from 2900 to 4200 cm^2/g [186]. P. Z. Wang [190] vreported that particle sizes of less than 20 μm contributed effectively to compressive strength development, while particles with sizes more than 20 μm had almost no effect on strength for up to 7 days. It is worth mentioning that the authors stated that particles of over 40 μm showed almost no reactivity. Due to incorporating Slag (GGBS) with high fineness, enhanced mechanical properties are

related to the high filling ability and well distribution of finer particles that fill the voids in the AAS matrix [189]. Furthermore, fine particles yield more reactive than coarser particles. Moreover, coarse particles have less uniform distribution, negatively affecting mechanical performance [189].

Other properties such as workability, shrinkage, and microstructure of AAS are also affected by the fineness of Slag (GGBS). Workability decreases as fineness increases due to more alkaline solution consumption as Slag (GGBS) particles' surface area increases. The development of a sound and full binder with lower porosity and higher homogeneity was achieved using fine Slag (GGBS) [186,189]. This behavior is also reflected in compressive strength and shrinkage results, as Humad [187] reported. The results showed that shrinkage decreases with the increase of slag fineness due to the faster reaction and the formation of a dense matrix. On the other hand, microstructure with high pores was formed for slags with large particle sizes, resulting in low compressive strength.

Generally, Slag (GGBS) should satisfy the following requirements to yield excellent and reliable properties when used in AAS systems, according to García-Lodeiro [133]. These requirements are granules having a vitreous phase in the range of 85-95% and a glass structure with the slightest degree of polymerization (high structural defects), implying that it has high reactivity with specific surface areas ranging from 4000 to 6000 cm2/g.

In this study, soil improvement ways will be discussed using geosynthetic materials it may be supported with Slag in order to benefit the environment and economic aspect. It may not be the first study to use Slag with soil, but it will support new ways with the basic geotechnical standards and experiments to prove the material's workability. Slag can be an excellent competitive material to coarse aggregate in the case of replacement soil, which is the most straightforward soil improvement and modification technique because of the cohesion and angle of friction.

2.3.5. Microplastic

On the same side, according to statistical organizations, the plastic industry reaches a higher innovation level every year with a larger production quantity of nearly a billion kilograms per day with a rate of 20,000 bottles of water and soft drinks per second worldwide , annual

rate of plastic products with 400 million tons per year produced investigation by Lim [191]. where similar numbers were investigated as 368 million tons supported by Association of Plastic Manufacturers in Europe (2020) [192]. Microplastic are the disintegrated plastic particles having particle sizes between 0.0001 mm and 5 mm according to Zhang and Liu [193], where it comes in massive quantities as environmental waste which causes effects on the marine side and agricultural aspect along with the soil degradation part through mitigation from landfills to soils. Landfills are one of the biggest causes of microplastic contamination as they play the most significant role in their formation. At the same time, some other geotechnical application can use tire chips as polystyrene particle exists for lightweight fill applications. This action would intend the optimum quantity successfully for soil properties while eliminating a good percentage of microplastics as waste. It was mentioned before in the U.S department of transportation Federal Highway Ground Modification manual section 2 the use of tire chips parts mixed with sand as a lightweight fill to reduce unit weight and obtain the needed modulus, see Figure 2.9.

Figure 2.9. Tire chip particles used in lab

As the danger hazard caused by the contaminated microplastic in marine, freshwater, and groundwater, these contaminated parts are caused by degradation. This degradation happened in the physical activities between the microplastic and other deposits to form those

significant amounts of contaminated parts. Many studies contain valuable data on microplastic in soils and focus on environmental and chemical concerns.

The geotechnical engineering perspective should be checked and considered by discussing the role of the migration of microplastic from landfills to soils. As a primary Geotechnical structure source of high microplastic contaminations comes Landfills, then the soil improvement using tire chips or using it as a filling material [194, 195 ,196, 197]. Many reviews about the impact of microplastic MP on ecosystems were tolerated by Thompson [198] at the beginning of the 1960s when seabirds' guts were found full of plastic particles appears to be the reason.Gregory [199], in 1970, the recognition of microplastic was then observed, which was reported in high quantities on New Zealand beaches. Microplastic at first ignores the concern about the soil. It all concentrated on marine and the environment (Monkul and Özhan [200]) (Steinmetz [201]; [195]; Weithmann [202]). Nowadays, Microplastics particles have their way into agriculture and grassland, which depends on sewage water. Even in other cases mulching foils ins the form of irrigation with contaminated water at lakes along with decaying and scattering of plastic (Huerta Lwanga [203]), and leaching through landfills managing unsuitable from dispersion [204, 205].

Coastal areas like river banks typically get MP through diffusing sources by the aqua marine life (Barnes [206]). Considerable accumulation in soils happens due to the regular application of MP suggested by evidence (Corradini [207]; Berg [208]). Microplastic that is intervene into the soil is supposed to effect the physical properties as (WHC) the microbial community composition of soil and soil aggregation (Machado [209]; Lehmann [210]; Fei [211]). Data on the microplastic mentioned in the broad collection is essential for the design of biological effects on soil, like size, shape, and concentration.

According to the European Union, these data cannot be provided with monitoring data. Experimental applying must be applied to detect the properties and concentrations while focusing on the impact assessments.

In order to avoid this lack of data about MP concentrations were derived by modeling inputs. Lots [212]; Eo [213]; Scheurer and Bigalke [214] and Karthik [215] collected data more than ever collected for soil MP. These studies appear to be more numerical ones based on the terrestrial sites in other parts to be comprehensive. Some studies started to spot the already existence of microplastic in soil. Lwanga [216] collected 10 samples from 10 different

homes in Mexico from depth (0–20 cm), discovering a microplastic concentration of 870 to 1900 pct./kg . Zhang and Liu [193] concluded more than four sites in China through riparian forests and some agricultural sites. The samples were taken from the surface layer with an average of 18,760 ptcl. /Kg, where microplastic represents 95% of the particles.

Briassoulis [217] showed that burying low-density polyethylene for 8.5 years in the soil had no disintegration. This behavior concludes how stable is the microplastics. While there was another study made for a more extended period of about 10 years by Albertsson and Karlsson [218] showed similar results. Similarly, another one made for about 32 years to shows the biological degradation of different types of polymers with various depths of (10–50 cm) from the top surface, including LDPE and polystyrene, where some of LDPE shows slight degradation caused. Otake [219] discovered that the degradation affects microplastic gathered from the top surfaces more than the deeper ones.

2.3.5.1. Tire Chips

It is well-known that the car industry is getting more innovations every year and increasing in number. However, some things never change, such as the tire industries, which are increasing according to the increase in the number of cars in order to serve production needs; even though technology and innovations but tire use never changes in cars and never gets old. These studies widen the horizon to reach the use of microplastic in the case of tire chips on purpose to be like a getting rid of environmental waste. Tire chips are the outcome of vehicle and plane tire abrasion, considered a vast and essential microplastic waste source.

As a result of this abrasion, tires wastes can enter the soil quickly as an outcome of this abrasion which was calculated as 0.81 kg/year per capita approximately Kole [220], where the annual mass emission of microplastic per capita in the EU countries is tire abrasion with 1784.8 $g.cap^{-1}$ a^{-1} Meixener [221]. Along with considering that tire chips are already used in geotechnical applications for improving the shear strength of soil to respect an economic concern with an appreciation for environmental enhancement. Promputthangkoon [222] are considering the importance of using tire chips for construction purposes to avoid the effect of recycling them as their basic properties are accepted engineering-wise. The study conducted CBR and unconfined compressive strength tests on the tire chips mixed with soil to be used with low-strength soil, which shows success for getting a greater CBR and Unconfined in some conditions. Singh and Sonthwal [223] and Solanki [224] studied the effect of tire chips on clay, which increases the shear strength. Another study was made

about the effect on Sandy soil by Daud [225]. the study experimented with tire chips mixed with sandy soil to show increased shear strength of sandy soil. Al-Neami [226] shows the effect of the tire chips on sand regarding the bearing capacity, which shows that adding 8% tire chips. Zsuzsanna Kerekes [227] proved through different tires types the behavior of burning tires and the high fire resistance of tires which reaches 900 °C for 100 percent burning while reaching between 200°C and 300°C to be effected from fire . Juma [228] reviewed some papers about pyrolysis for tires to conclude the 250 °C as the temperature of tires pyrolysis and 550 °C as the end of the procces as the average of most results . Epic´ [229] experimented a cylindrical granulars of tires with diamter of 3,7 and 11 mm concluding that 200 °C–500°C are the temperature where the thermochemical decompistion starts to take place in waste tires .

Tang [230] prepared 12 samples with three different polymer fibers (0.05%, 0.15%, and 0.25%) with various cement percentages by applying an Unconfined compression test and direct shear with different curing times, which shows an improvement in strength and the better interface between surface and soil. On the other hand, Hamidi [231] conducted conventional triaxial compression tests. They prepared a specimen of polypropylene fiber reinforcement sand mixed with cement passing through curing, which approves a practical effect on the shear strength parameter at a relative density of 70%. Soil modification techniques take place with the addition of polymer-based fibers. MuChena [232] examined the behavior of cement clay admixture with two different polymer fibers using UCS after curing the specimen for some time which shows the improvement of the strength at its peak, with 0.5%, until reversing down again. Ayeldeen and Kitazume [233] added 1% of synthetic polymer with a cement content of 15% to clayey soil, and 0.5% was found to have a shear strength of 240% increase, whereas increasing the polymer-based content was found to decrease the shear strength. Punthutaecha [234] added polypropylene fibers mixed with waste ashes to increase the shrinkage strain of expansive soil.

According to experiments, a soil mixture's compressive and tensile strength was increased when adding 2% microplastic to expansive soil Öncü [235]. Statistical studies show that more than 15 million tons of waste tires are formed yearly, and India is responsible for 1 million tons of them (Rubber Asia, 2016) [236].

Kaneko [237] investigated tire chips existence in sand, either mixed in layers, may prevent the liquefaction of soil. Yasuhara [238] stated differences between liquefaction resistance in

three patterns of sand-gravel, untreated sand, and sand-tire chips drain as it appeared to be the most effective way for excess pore pressure dissipation improving the resistance towards liquefaction. Marto [239] applied a shear stress experiment on different percentages of sand-mixed tire chips. They spotted an increase in shear strength for that mix in different percentages achieving an optimum amount at 20% of tire chip, where adding more decreases the shear strength directly proportional with increasing everyday stresses. Daud [225] confirmed the benefit behind using tire chips in sandy and silty sandy soil on shear strength and internal friction angle, but with increasing the percentage of tire chips, a decrease in the maximum unit weight was recognized with a higher compressible value than sand.

On the other hand, Tatlisoz [240] investigated tire chips mixed with soil in backfills. They reported that it could cause an increase in the lateral sliding of the embankments because of the lower active earth pressure. Guleria [241] concluded that unconfined compressive strength would decrease with increasing the tire chips percentage content between 5 to 15% in the case of the dry mix. In contrast, similar mixing has higher unconfined compressive strength when cured in water. Hong [242] discussed the ability of sand and tire chips mixture to achieve a higher compressibility level without achieving a higher shear strength and peak friction angle, mentioning the importance of respecting a larger grain size of tire chips which plays a role in liquefaction behavior. Annadurai [243] proved that the more tire chips percentage used, the lower the standard proctor test value conducted to be directly proportional to the tire chips percentage because of its lightweight. Also, the optimum moisture content was found to be approximately the same with the increase of tire chips percentage, where it has a relative grain size with sand particles. Aksoy [244] discovered that the improvement of (ϕ) can be achieved when adding a small percentage of tire chips, which can be accomplished in many geotechnical applications. Lee [245] observed that using soil rubber as a backfill material can reduce economy wise by about 20%, which achieves improvement through the environmental and economic aspects considering that the coefficient of permeability of rubber soil material is that sand gravel and less than half of unit weight. Grassland areas were found to have air transport microplastic parts in studied concentrations of 0.2±0.1 mg kg-1 and 38±17 items kg-1 [246]. Dierkes [247] discovered some contaminations in soil from tire abrasion due to the friction of car tires on roads. These studies determined average microplastic usage based on the optimum percentage of tire

abrasion in soil roads. This study will discuss some lower percentages and higher ones to use microplastic tire chips to eliminate the waste produced in huge quantities.

2.4. SOIL REINFORCEMENT TECHNIQUE

Weak strength subgrade soil used in paved and roads can be enhanced by the use of geosynthetics material espicially for geogrid even there is many different chemical and mechanical mthods used for soil modification .Giroud and Noiray [248] established analysis for treating geotextiles in order to be used for reinforcement.Geosythetics material can be used in pavement according to design which is used for tensile strength improving and stablization of weak soil . It can aslo be used for the separation and improvement for weak property soils as it can help in reducing the aggregate thickness due to its durablity characterstics . Many studies showed the benefits behind using the geosynthetics material in reinforcment for subgraades in roads and embankments for increasing the bearing capacity and achieved the needed value due to design procedure Palmeira and Antunes [249] . For the granular soil,CBR tests were applied with using layers of geogrid ;in addition, to the investigation of using clayey soil with high values of compressiblity on unpaved roads .Many laboratory tests explained of reducing the subgrade depth of roads due to the effect of geogrid strengthen behavior with incresasing service life and reducing filling materials quantities [248] . The depth of the pavement is directly proportional to the amount of aggerated used. Palmeira and Antunes [249] proven that the cost of unpaved roads ,running cost and overall cost can be lowered by the use of geosynthetics reinforcement.Although environmental regulations restrain the traditional construction materials it allowed the using of geosynthetics material approach in road construction and projects [248, 249].

2.4.1. Geogrid

Geogrid is considered as a polymeric material derivative from the polyethylene industry, which consists of perpendicular and parallel sets of ribs that allow this form of sheets to stand for the striking of the surrounding soil. This kind of reinforcing is a multi-function material that can be used according to the design purpose: separation, reinforcement, or drainage. Easley, SC: (IGS) Secretariat (2009) [250] announced geosynthetic materials that the contaminant on behalf of geogrid containing the soil and preventing its loss, acting as a barrier to prevent leakage in landfills , drainage layer as its significant role for collecting water and directing its passes in some sites , a protection layer for its role towards reducing stresses on soil . Thus, it can be used as a soil reinforcement method to resist tensile strength or separation layer in slope stability sites due to its ability to separate soil layers and soil stresses. In addition to the cost-effective and easy transport , it plays the most prominent role of being widely spread with growing its market. One of the essential applications of composite drains was steep slopes of landfills, (Figure 2.10).

Figure 2.10. Applying a geocomposite along the slopes on top or bottom of landfills [251].

Another important use of geogrid is to prevent slope failure even at the landfills, not only to prevent leakage, as shown in Figure 2.11.

Figure 2.11. Usage of geogrid to prevent slope failure in landfills [251].

On the other hand, the application of road , highway reinforcement and embankments takes a role of the usage of the geogrid material in the form of layers due to its ability to overcome tensile stress Figure 2.12.

Figure 2.12. Geogrid use for road reinforcement (Huesker) [252]

The usage of geogrid has been a big innovation point of view for how to get the maximum usage of geogrid in soil applications in retaining walls, slope stability, or landfills . Braja M. Das [253] concerned about using geogrid as reinforcement in railway track beds which decreases the settlement of track subsoils by controlling the elastic deformation. Yadua [254] approve the effect of using granulated blast furnace slag on increasing the bearing capacity ratio with improvement in the strength towards settlement , while a different increase of bearing capacity ratio was observed while using the geogrid reinforced granulated blast furnace slag accompanied by an increase in SRR . Maghool [180] performed a mixture sample between landle furnace slag and electric arc furnace slag to modify the engineering properties of electric arc furnace slag as it has a poorly graded size .

In comparison, using landle furnace slag to improve strength properties as the size gradation curves approved according to the specification requirement for local road organization where shear stress ratio is decreased in all samples because of the particles dilation, which prevents the entire rotation for the particles. Hanumasagar [255] conducted a pullout test on geogrid with slag and soil mixtures in different percentages, which approves an increasing resistance in some mixtures reading while decreasing in the other fine materials. Finally, the results introduced that soil condition improvement can be achieved using geogrid reinforcement with steel slag to modify and improve the pullout resistance. Pisini [182] performed different mixtures of Klockner oxygen blown maxhutte slag with subgrade soil with geogrid reinforcement variation were discussed through the CBR test . They noticed the increase in value for 15 and 20 percent slag usage with geogrid reinforcement during a tremendous increase in the reinforcement mixture directly proportional to the slag percentage increase. 20 percent of the slag mixture was the highest CBR value . Wang [256] investigated expansive soil long-term weathering atmosphere on the strength parameter and added geogrid, where a better resistance for expansive soil failure profile on shallow depth was found . Wang [257] used different numbers of geogrid layers to evaluate their effect on various steel slag conditions . The use of the geogrid showed an improvement in the compressive moduli with various slag conditions , either dense state or loose state . They recorded that the best improvement appeared in the two-layer geogrid , which concluded that different slag and geogrid layer mixtures could assemble work and graded soil . Müller [258] discussed the great benefit of using geosynthetic material and mentioned the wide applications that can be applied with different functions depending on various case studies.

The importance of geosynthetic anchorage in the case along steep slopes for long-lasting landfills applications was mentioned , synchronized with referring to the environmental concern of plastic life span in construction, which should be fixed in the longer term. Sabouri [259] conducted a 108 LWD test to prove elastic modulus of coarse sand can be increased by using geogrid reinforcement; even the glass reinforced plastic graded material can be improved to be equivalent to the well-graded soils.

2.5. RESEARCH GAPS

The steel industry is one of the most popular industries worldwide. The steel industry possessed various by-products, such as slag, which provides good engineering properties. Due to its low prices and huge quantities, these properties motivated scientists and researchers to conduct more experiments applying slag to soil improvement techniques. However, for the soil replacement application, the parameters regarding this application were neglected. From the literature review, researchers evaluated the shear strength, and CBR tests were conducted mainly on different soil mixtures using slag types. Most investigations did not encounter proctor compaction and sand cone for sake of soil replacement to study of effect of slag on the dry unit weight and compaction quality. This study opened the way to evaluate the shear strength using various grain particle sizes of slag under various mixed techniques, such as geogrid at the most common percentage approved by Pisini et al. (2022) [182].

Moreover, the microplastic waste presented from tire chips strongly impacts the environment . The quantities of tire chips cannot be calculated due to the expansion of car usage . Most studies are concerned with microplastic as it exists in the soil or propagates underground and marine life , while the waste disposal method through geotechnical studies is insufficient . In this study , proctor compaction tests were conducted by using a low percentage of tire chips (the average percentage in the soil beneath roads) mentioned by Dierkes [247] , experimenting with slightly higher and lower percentages to discuss their effect on the soil property.

2.6. RELIABILITY CHECKING

As a procedure to test reliability of using slag in geotechnical field various experiments were performed to be applied in some soil techniques:

1) Water required for slag paste of standard consistency
2) Initial and final setting times of slag paste using VICATS apparatus.
3) Determination of compressive strength of hardened slag specimen.
4) Sieve analysis for slag and sand.
5) Direct shear test to evaluate the increase of internal friction angle for different soil mixes.
6) Direct shear test for geogrid material with sand.
7) Sand cone and compaction test for sand and slag.
8) Proctor Compaction test for sand and microplastic.

3. EXPERIMENTAL PROGRAM

3.1. INTRODUCTION

This chapter is divided into five sections . The first section represents the description of materials used in the experimental process . The second section focuses on the applied experiments to prove some of the materials' physical properties . The third section discusses the testing procedure for slag material in Proctor compaction and sand cone test, mentioning the reason behind the exact percentages. The fourth section mentions the shear test procedure and material preparation in the form of 4 different mixes in two parts ; the first part includes Sand with Slag, while the second part focuses on the addition of geogrid to these mixes in order to examine the effect on the results. The fifth section explains the microplastics in the form of tire chips on behalf of the Proctor compaction test through different percentages with sand.

3.2. MATERIALS

3.2.1. Slag

Slag , in general, is a byproduct of various metal extraction and refining processes . In the specific case of steel making, the Slag is generated at three stages of processing and accordingly classified as blast furnace slag, electric arc furnace slag, or ladle Slag. Slag is a granular material that appears in different grading sizes according to the type of industry and the chemical composition , along with the extraction step. All tests are applied according to the Egyptian code and the American Standards for Testing Materials (ASTM) requirements.

3.2.1.1. Production process

Electric arc furnace slag is produced during the manufacture of crude steel by the electric arc furnace (EAF) process. In this process, steel scrap with the addition of fluxes (e.g., limestone and or/and dolomite) are heated in the liquid state employing an electric current. During the melting process, the fluxes combine with non-metallic scrap components and incompatible steel elements to form liquid Slag. As the Slag has a lower density than steel, it floats on top of the molten steel bath. The liquid Slag is tapped at temperatures around

1600℃ and allowed to slowly air-cool, forming crystalline Slag.

3.2.1.2. Chemical composition

The chemical analysis of slag showed that slag consisted of different minerals such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Na_2O, and K_2O. Tables 3.1 and 3.2 show the chemical composition provided form Ezz company Inc © and Sabapathy [260].

Table 3.1. Chemical composition of slags (GGBS) (Ezz Inc ©) [184]

Mineral	EAF slag (wt. %)
SiO_2	8-18
Al_2O_3	3-10
Fe_2O_3	20-30
CaO	25-35
MgO	3-9
SO_3	<0.5
Na_2O	<0.1
K_2O	<0.1

Table 3.2. Chemical composition of EAFS (Sabapathy) [260]

Compound	EOF slag (%)
CaO	36.96
Fe_2O_3	28.93
SiO_2	13.81
MgO	7.46
Al_2O_3	2.53
MnO	3.00
P_2O_5	1.58
TiO_2	0.60
Na_2O	0.057
K_2O	0.032

The scanning electron micrographs of EFAS by microscope (model S-3400N, HITACHI, Japan) shows the component in slag after cooling, which include three essential components corresponding to the four of the cement; Tricalcium silicate (C3S), Dicalcium silicate (C2S), Tricalcium aluminate (C3A), Tetra calcium Aluminoferrite (C4AF). The lighter areas represent a higher present of Mg, Fe and Al while darker one shows CA and Si Bankole [261] .

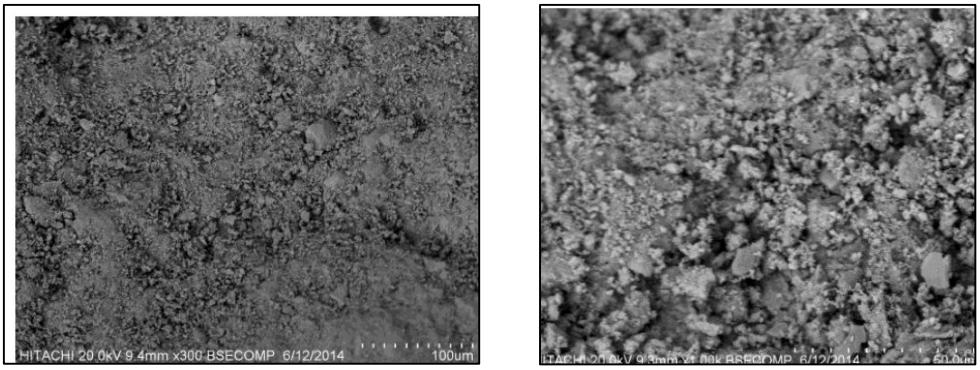

Figure 3.1. SEM micrograph of unreacted EAFS at magnification of 300x and 100x [262]

3.2.1.3. Physical properties

Slag has different physical properties , that can be considered better than aggregates used in concrete manufacturing; see Tables 3.3. The specific gravity of the slag is similar with that of Ordinary Portland cement, which is around 3.15. The specific gravity provided by Ezz company Inc © for slag 3.4.

Table 3.3. Physical properties of slag (EZZ Inc ©)[184]

Property	Slag
Size (mm)	0-20
Proportion after primary crushing %	24-76
Apparent specific gravity (Mg/m^3)	3.35-3.7
Water absorption (%)	10.5
Los Angeles loss (%)	<20
Expansion average	0.25%
Magnesium sulfate soundness	1
Aggregate Abrasion Value	2.7
Polished Stone Value	63

3.2.1.4. Slag preparation

In order to prepare a different mixture of slag, the slag should be crushed regarding the high hardening value and abrasion resistance. Thus, a mechanical machine was responsible for crushing aggregates to a specific grading size. Slag crushing passed through two ways; manually way in the Proctor compaction mold to avoid scattering while using a steel rod and hammer, and it succeeded in giving a minor grade; and crushing in the compression machine, which helped to reach excellent grades, as shown in the mixtures.

3.2.1.5. Slag laboratory tests

Water Required For Slag Paste Of Standard Consistency

The consistency of the paste was determined by measuring the required amount of water to create a standard paste for the initial and final setting time test, soundness, and compressive strength. Slag aggregate was crushed at the laboratory through the two methods mentioned earlier, reaching the fine grading size responsible for making the paste. This test was applied according to ASTM C187 (2016) [263].

Test Method

The consistency of the paste was determined through the VICAT apparatus using a plunger ASTM 187 (2016), The needle has reached about 33 to 35 mm of the mold depth (i.e., from the top of the mold). Otherwise, the needle should be 5 to 7 mm from the bottom of the mold, as shown in Figure 3.2.

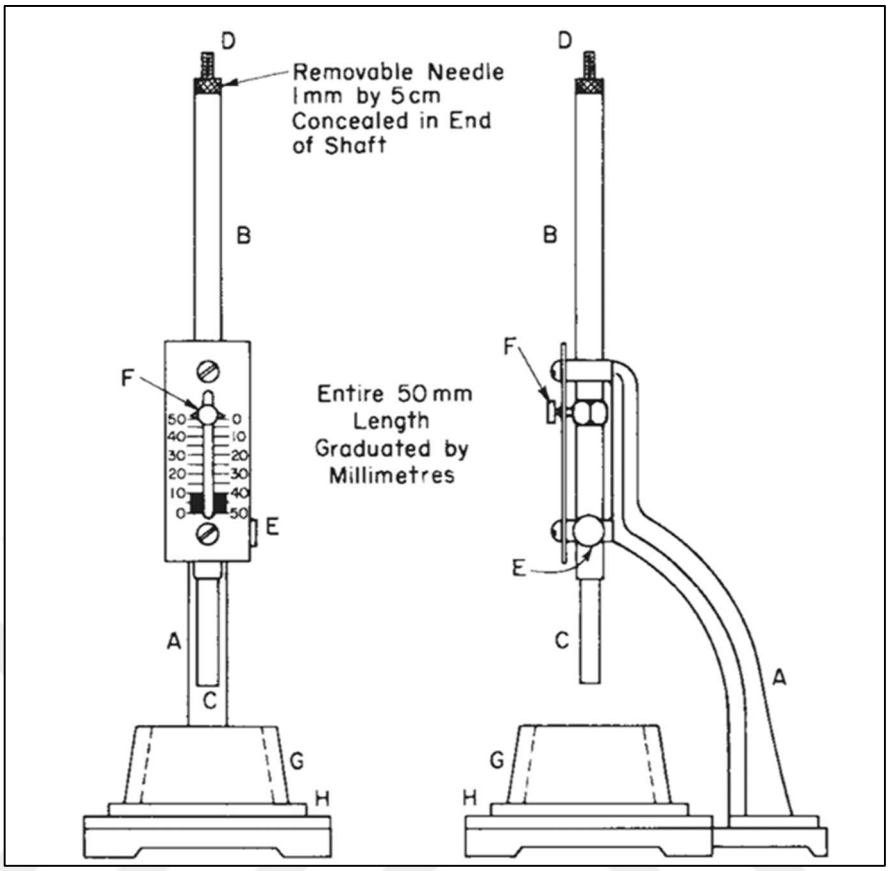

Figure 3.2. VICAT Apparatus (ASTM 187, 2016) [263].

Specimen Preparation Procedure

Determination of the water required to form the standard consistency slag paste is usually performed after several attempts , (Table 3.4) . 400 g of paste was taken and placed in the enameled tray mixed with 80 ml of water thoroughly to get a slag paste. The total time recorded for mixing the water with slag should not be more than 180 to 300 seconds, which is “Gauging time.” Then, the Vicat mold was filled with paste on a glass plate. After filling the mold, smoothen the surface of the paste and pour the paste onto two layers by shaking or vibrating the mold or the glass plate. The surface was levelled of the paste after reaching the top of the mold. Then, lower the plunger gently to touch the surface and quickly release the plunger allowing it to sink into the paste. The depth of penetration was measured and the values was recorded . The values of penetration depth should be between 33 to 35 mm. Repeat this test procedure if needed until the plunger reaches 5 to 7 mm before the bottom of the mold; see Figure 3.3.

Figure 3.3. Prepared slag paste specimen for standard consistency test

Table 3.4. Test results of standard consistency slag paste

Trial No.	Water (%)	Water Volume (ml)	Plunger Drop (mm)
1	20	80	18 (From Bottom)
2	21.25	85	6 (From Bottom)

The optimum water content to prepare a standard slag paste was 21.25% percent. This result shows an acceptable limit of water quantity compared to the water percentage needed for concrete to start hydration, representing between 25 - 35 percent according to ASTM C187 (2016) [263].

Figure 3.4. Mold of slag

Initial and Final setting times of slag paste unsing Vicat's Apparatus

Determining the initial setting time provides the slag paste to set ; otherwise, it cannot be reshaped. The final setting time also helps to know when the slag starts to solidify, which helps to determine the effect of fine slag particles presented in the soil, whether it will achieve homogeneity or adhere between particles to determine the final rigidity.

Test Method

The test is designed to determine the initial and final setting time of standard paste using the Vicat apparatus, where the specimen starts to lose its plasticity. Initial setting time is the measured time from zero measurements until the needle of diameter 1 mm reaches a distance of 5 mm from the mold base. The final setting time is the measured time from zero measurements until the penetration of the needle to a distance of 0.5 mm while not leaving the ring on the needle impact on slag. This experiment is applied according to ASTM C191 (1982)

Specimen Preparation Procedure

The specimens are prepared using optimum water content obtained from the consistency test for preparing the mixture.

Determination of Initial Setting Time:

The mold should be filled with the standard slag dough then transferred to the apparatus then placed under the needle slowly to touch the surface of the paste, which has to be stopped in place for 2 seconds to avoid the impact of the initial speed (See Figure3.5), the moving parts

was leaved to implement the needle vertically in the paste . Staging reading starts when the needle stops or after 30 seconds of leaving the moving parts, whichever is earlier. Then, the record of the staging reading indicates the distance between the base of the mold and the end of the needle. The time starts from zero measurements. Needle penetration was repeated on the same paste in spaced positions so that the distance between the stitches, the edge of the mold, and the nearest stitching point is less than 10 mm and after successive intervals (about 10 minutes). The needle was cleaned immediately after each test, where the measured time shall be recorded from zero measurements until the needle of the device reaches 5 mm from the base of the mold as the initial setting time of slag paste.

Figure 3.5. Determination of initial setting time

Determination of Final Setting Time:

The final setting time of the slag paste was determined by using the needle as shown in Figures 3.6 and 3.7, which follows the same procedure used in determining the initial setting time of the paste where the time taken from zero is measured until the needle reaches 0.5 mm as the final setting time. This action is performed by monitoring the effect of the needle and ring on the sample surface, then the time of final setting is when the effect of the needle appears and does not leave the connected ring any effect.

Figure 3.6. Final setting time experiment using Vicat apparatus

Figure 3.7. Final setting time experiment using Vicat apparatus

Table 3.5. Test results of initial and final setting time

Test No.	Water (%)	Initial setting time	Final setting time
1	21.25	1 Hr. + 11Min.	13 Hr. + 42 Min

The results show that slag material has hydration like cement. The values of the initial setting time for slag were the nearby the initial setting time of cement, but the final setting time was far away from the final setting time of cement. This setting time result appears on the left-over sand and slag mixes which choose contaminated parts like the common cement percentage mechanism.

Determination of compressive strength of hardened slag specimen

The compressive strength of hardened slag samples is the essential mechanical property, as this resistance indicates the potential uses of this material in soil applications.

Test Method

This test is designed to determine the compressive strength of a hardened slag sample after 7 days and after 21 days, according to ASTM C 109 (2019) [264].

Specimen preparation procedure

A slag specimen was prepared using the crushed slag into fine particles, which were allowed to be mixed with water to conduct a past then formed inside the used cube with inner dimensions of(10cm×10cm×10cm) at least 3 cubes must be tested after 7 days to determine compressive strength, the machine surface of the loading plate and the sample surface should be clean, see Figure 3.8, to be placed on the bottom panel of the sample concerning the axis to allow the loading axis of the machine with an error in axis adjustment 1/100 of the diameter of length of sample rib should not be exceeded. The loading rate should be increasing regularly at a rate of 0.6 N/mm2/sec, where the sample must be left under load bearing without changing the load rate directly when sample deformations begin to increase rapidly before collapsing completely. The sample breakdown is the final point in the load increment where the loading process stops, as shown in Figure 3.9, and load failure in Figure 3.10.

Figure 3.8. Slag specimen clean surface

Figure 3.9. Failure of slag specimen

Figure 3.10. Failure of slag specimen

Table 3.6. Sample failure results

Test No.	Dimensions	Maximum Load (KN)	Compressive stress (Mpa)	Loading Rate MPa/s
1	Cube (10×10×10) Cm	18.5	3.7	0.5
2	Cube (10×10×10) Cm	22.3	4.46	0.5
3	Cube (10×10×10) Cm	21.8	4.36	0.5

This test was conducted to determine slag fines effect of if present in patches used for soil replacement as it shows a sound effect of reasonable values of compressive strength when mixed with water and accumulated if there are adhesion characteristics between particles which allow the homogeneity compared with cemented soil which reaches maximum 4.5 MPa after 28 days with 30% of cement due to (Anagnostopoulos et al. 2008) [265].

Sieve Analysis

Test Method

In order to know the grain size distribution for all used materials in this project, sieve analysis was performed to determine the grain-size distribution of soils according to ASTM D6913 (2017) [266].

Specimen preparation procedure

A representative dry soil sample was gathered in the oven. Samples with larger particles of the sieve No.4 openings (4.75 mm) should be passing the 500 grams of soil sample into individual particles. Then, a rubber-tipped pestle breaks the soil sample into individual particles (i.e., the idea is to break up the soil into individual particles, not the particles). The mass of the sample should be weighted accurately to 0.1 g (W) to prepare the stack of sieves. Thus, the larger sieve openings exist above smaller openings until reaching sieve No. 200 at the bottom and a bottom pan beneath it. Sieves that are used in a stack are Nos. 4, 8,10, 16, 20, 30,40, 5, 60, 80, 100, 200, and the pan.The soil prepared in step 2 was poured into the stack of sieves from the top, then place the cover on the top of the stack of sieves. The test was conducted twice, one on the used control sand and the other on the slag specimen.

Sand sieve analysis

Table 3.7. Sieve analysis calculation for sand specimen

Sieve No.	Sieve opening	Mass of Soil Retained (g)	Percent of Mass Retained (%)	Cumulative Retained Percent	Percent Finer
No.4	4.75	22	0.55	0.55	99.45
No.8	2.36	88	2.20	2.75	97.25
No.10	2	39	0.97	3.72	96.28
No.16	1.18	257	6.42	10.14	89.86
No.20	0.85	343	8.56	18.70	81.30
No.30	0.6	1488	37.15	55.86	44.14
No.40	0.45	990	24.72	80.57	19.43
No.50	0.3	496	12.38	92.96	7.04
No.60	0.25	61	1.52	94.48	5.52
No.80	0.18	127	3.17	97.65	2.35
No.100	0.15	34	0.85	98.50	1.50
No.200	0.075	46	1.15	99.65	0.35
Pan		14			
Total		4005			

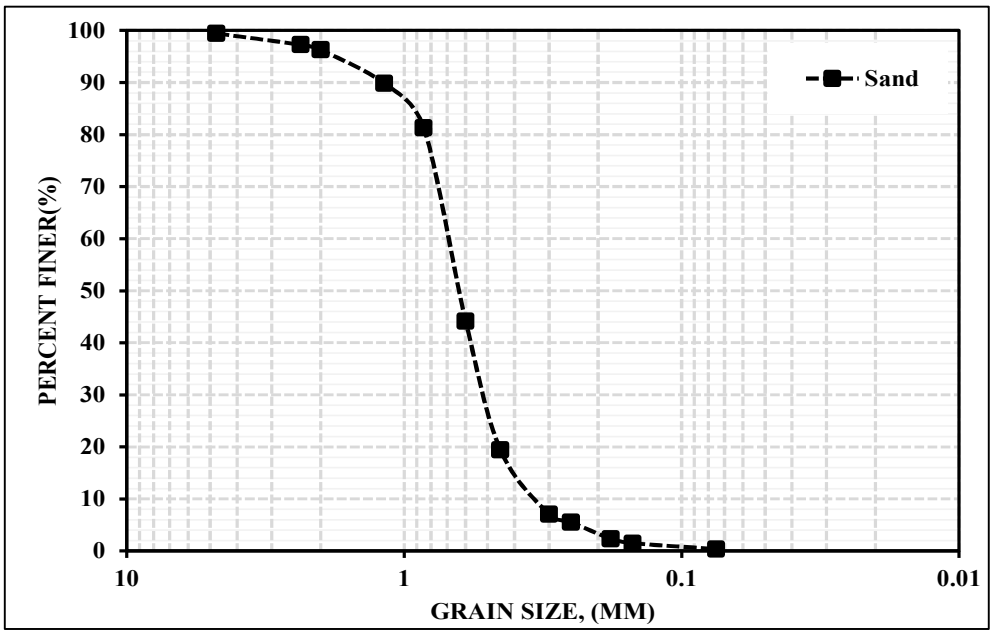

Figure 3.11. Particle size distribution graph for sand sample

Table 3.8. Sand 1 specimen specifications

Parameter	Sand 1
Gs	2.67
D10	0.17
D30	0.31
D60	0.48
CU	2.82
Cc	1.18
USCS symbol	SP

Slag Specimen

Table 3.9. Sieve analysis for slag specimen

Sieve opening	Mass of Soil Retained (g)	Percent of Mass Retained (%)	Cumulative Retained Percent	Percent Finer
14	15	0.29	0.55	99.45
10	202	3.87	4.16	95.84
6.3	3324	63.76	67.93	32.07
5	571	10.95	78.88	21.12
3.35	571	10.95	89.83	10.17
2.36	215	4.12	93.96	6.04
Pan	306			
Total	5204			

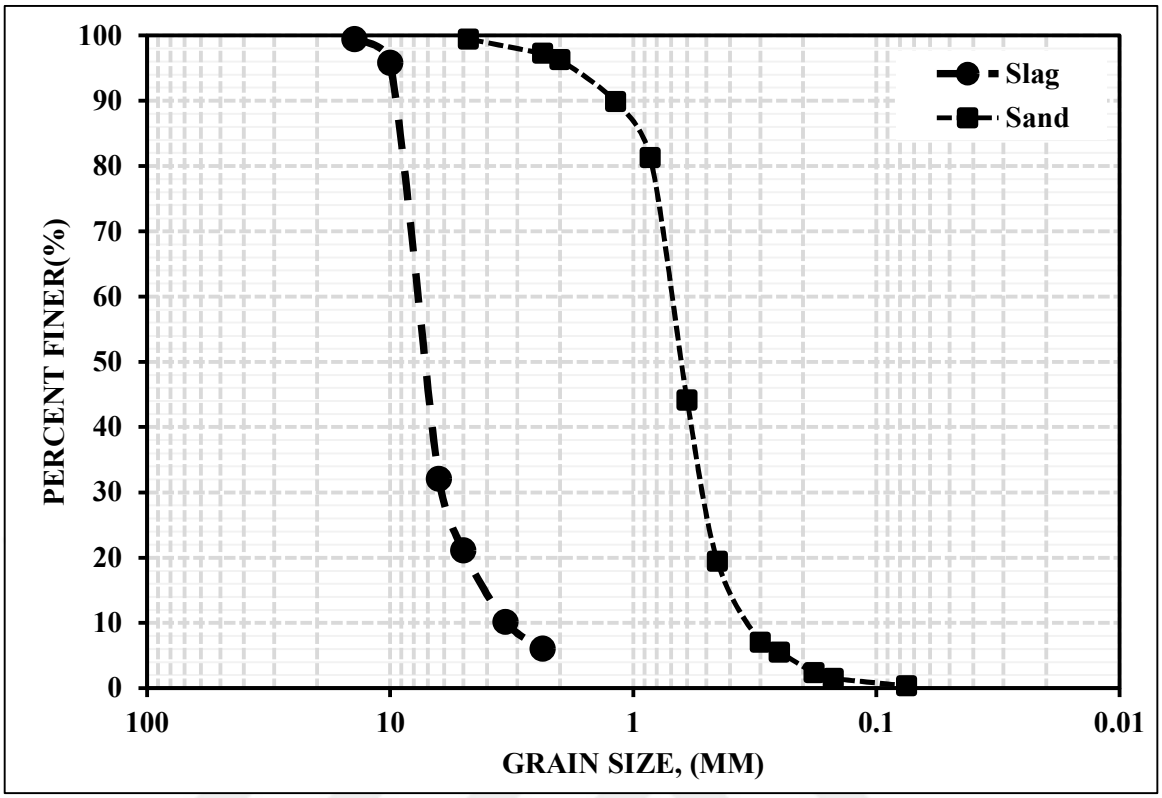

Figure 3.12. Particle size distribution for slag specimen compared to sand

Sieve analysis shows that the Slag mainly consists of granular substances which achieve the needed function in replacement soil instead of gravel, decreasing the void ratio and creating size consistency with sand particles. The slag sieve shows even the consistency of grade size between Sand and dolomite gravel particles which is convenient to the study of Laxmikant Yadu [267]. The latter conducted a sieve analysis on slag, which appears to be nearly similar to Figure 3.12.

3.2.2. Geogrid

Geogrid materials are widely used for soil improvement techniques where it proves the marked improvement in the soil characteristics and physical properties. Geogrid is classified into different types according to the design need; its choice process is determined according to the pattern, which can be uniaxial, biaxial, or triaxial see Figure 3.13.

Figure 3.13. Geogrid applied for MSE walls (Porto Sokhna, Cairo 2022).

3.2.2.1. Production Process

The production of geogrid is carried out in three ways; the first way is by extrusion, where a flat polymeric sheet is used in order to be punched with the needed hole dimensions and stretched to define the tensile strength; the second way is by knitting and weaving which is the toughest one conducted by weaving threads and fiber slots. The third way is by extrusion and welding, where this method depends on a roller passing to the welding machine to form needed apertures from ribs.

3.2.2.2. Chemical Composition

Geogrid is conducted from of polypropylene material used in expanded forms where mostly recycled plastic materials are treated to shape and conclude the desired object. The recycling process passes through many routes, including the most important one, which is densification to eliminate the air in the material. The polystyrene material is derivative monomer styrene in the form of liquid hydrocarbon manufactured from petroleum. The geogrid material approved no chemical degradation for a long time, where each factory responsible for this material industry assigns a long life span to each product mentioned with selling it. Leshchinskya [268] examined a geogrid sample placed under an MSE wall near the Pacific Ocean in the United States at thirty-six years old in order to check deterioration and degradation of the material through its archived properties from the same company where mechanical properties proved same values with a low decrease in single rib strength

accompanied by a slight decrease in chemical properties in the form of black carbon content concerning harsh environmental condition.

3.2.2.3. Physical Properties

Geogrid physical properties differ from one company to another and from the way of manufacture to another. The geogrid selection is based on the country's availability and design parameters according to each project and function. This study tested the effect of geogrid usage with mixed sand and slag, so no specific tensile strength is needed as it has been used only for modification comparison. Table 3.10 shows the specifications of the used geogrid.

Table 3.10. Technical specification (Symn Group, 2013) [269]

Test	Standard	Unit	Conclusion
Tensile strength	EN ISO 10319	KN/m	Transverse ≥ 40 Longitudinal ≥ 40
Nominal elongation	EN ISO 10319	Percentage %	Transverse 12 (±2) Longitudinal 12 (±2)
Unit weight		gr/m²	280
Aperture		mm	30 x 26
Roll Dimensions		m	6,00 x 100

3.2.2.4. Geogrid Preparation

Geogrid exists in the form of rolls mainly to prepare the geogrid specimen for the projected study in the shear machine. A 100 mm x 100 mm of geogrid must be cut and ready to be glued on the top surface of a rigid wooden block to fit the rigid wooden block with the geogrid sheet inside the lower direct shear box, see Figure 3.14, then prepare different soil mixes.

Figure 3.14. Geogrid specimen used for shear test

3.2.3. Microplastic (Tire Chips)

Microplastic (typically smaller than 5 mm) materials cause environmental problems and plastic industry its a non-stop growing market, where the use of social media and scientists have played a vital role in opening eyes to its harmful existence, especially in marine life and soil. In this part, the study concentrates on tire chips which appear to be one of the biggest problems due to the increased number of cars that need at least four tires with an expiry date to be a continuous hazardous environmental waste despite its abrasion where it can be transferred automatically to soil particles in different percentages according to weather condition and speed. In order to study the effect of tire chips, they must be shredded into small particles to simulate the abrasion rate and to represent how they can use in the soil as a product of soil improvement by getting rid of it for environment saving.

3.2.3.1. Production Process

Tire chips are the source remnants of the vehicle tires that were previously made from natural rubber that exists in the forest (Brazilian rubber tree)., But due to the enormous use of cars , some synthetic rubbers are added to the rubber manufacturing from petroleum with 1 – 4%

of Sulphur to achieve the needed elasticity mixed with a catalyst like zinc oxide [270] . Moreover, (22 – 40) percent carbon black is added as a filling material. Manufacturers replace carbon with silica due to its resistance towards roads friction with clarifying it with oil to be less stiff as it affects the specific gravity . One of the leading tire chips existences in the environment is the abrasion between tires and road surface, which depends on many factors like quality, temperature, vehicle weight, and speed Alexandrova [271]. Particle emission from tires can be gathered in a laboratory test with simulation of situation or via driving car on the road. This action can be achieved by installation of flow suction to measure particles of different sizes, the size ranges of which are affected by the specifications of each equipment and used analytical techniques.

3.2.3.2. Physical Properties

Sieve analysis was applied for tire chip particles to determine grain size distribution, which shows nearly the same as sand . 100% particles are smaller than 5mm (upper limit for microplastic size) where critical sizes; 92.57% smaller than 1mm and 18.67% smaller than 0.25mm.as shown in Figure 3.15.

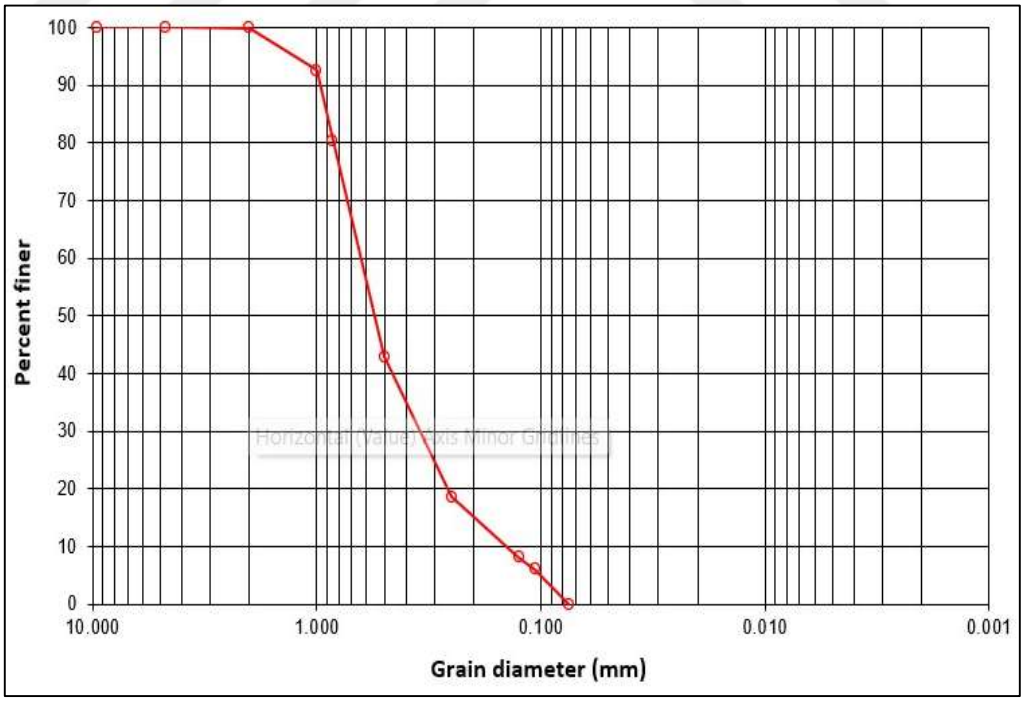

Figure 3.15. Sieve analysis for tire chips

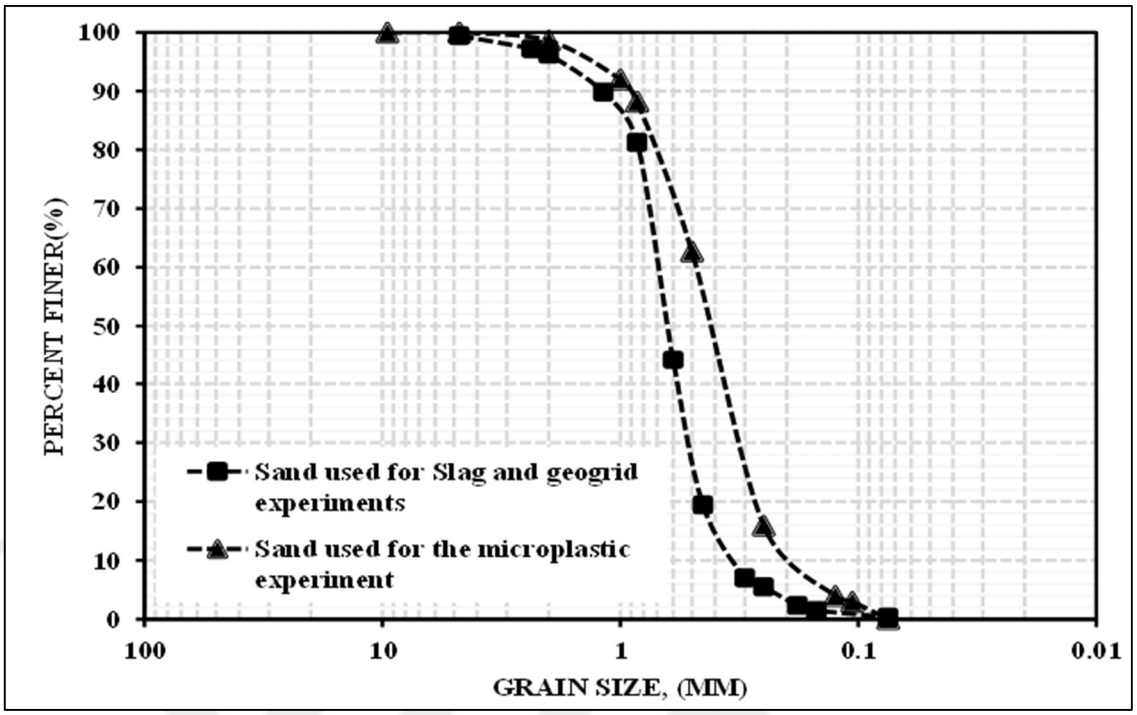

Figure 3.16. Sieve analysis comparison between sand 2 and tire chips

Table 3.11. Sand 2 specimen specifications

Parameter	Sand 2
Gs	2.69
D10	0.35
D30	0.58
D60	0.7
CU	2.00
Cc	1.10
USCS symbol	SP

3.2.3.3. Microplastic Preparation

The production of tire chip waste occurs through shred and tire heat, where shear is responsible for the presence of large particles, while the relatively small particles are conducted through the heat process, causing a hot spot in tires. The size of the particle emission is different according to four studies that adopted the discovery of particle size.

Grigoratos [272] researched an overview study to discuss factors affecting particle size, as shown in Figure 3.17.

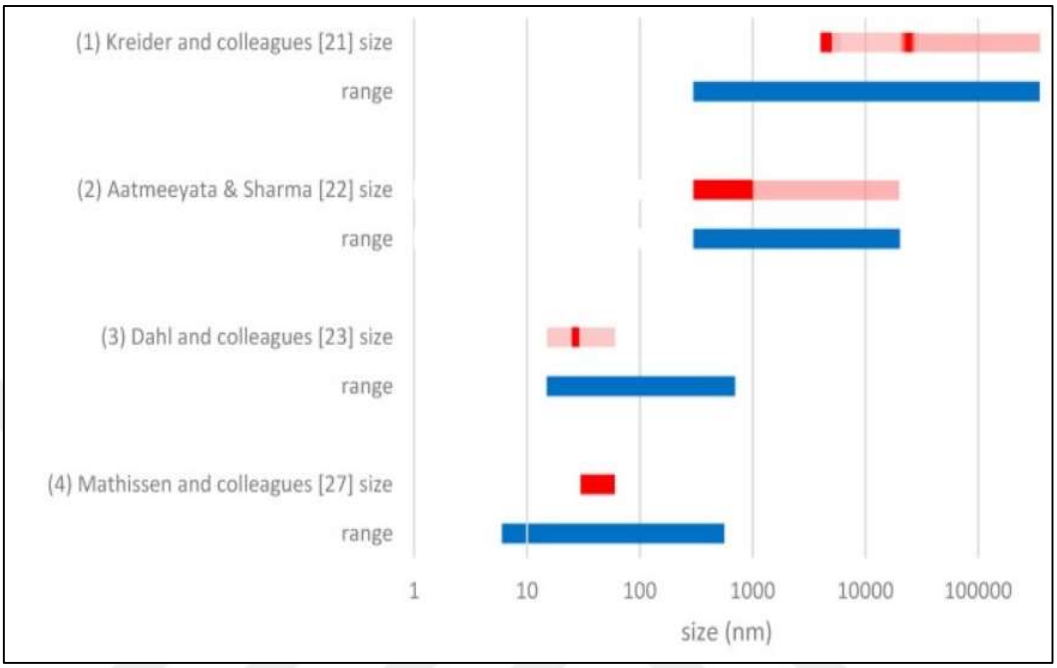

Figure 3.17. Overview study for particle size emission (Grigoratos) [272]

Kreider [273] confirmed that particle size was collected by suction installed near the tires > 0.3 µm without specifying an upper size limit where most average sizes appeared between 5 µm and 25 µm. At the same time, Aatmeeyata [274] constructed a simulator for concrete pavement roads with an air suction instrument to collect particles of sizes between 0.3 to 20 µm. Dahl [275] also experimented with the simulation of the Swedish national road, which concentrated on particles between 15 – 700 nm where some contaminated mineral oils mixed with fillers and carbon black appear. On the other hand, Mathissen [276] calculated that the particles carried by air adjacent to car's wheel housing while driving were between 6 to 562 nm through different driving conditions. There were two approaches to estimate the amount: first, distance multipied by the emission per vehicle. Secondly, the weight loss of tires multiplied by the number of tires.

3.3. EXPERIMENTAL PROGRAM

The experimental program is divided into three sections; each section is responsible for a specific material to approve the theory of using an environmental waste in construction to save the environment and economy. The first section examines the slag instead of sand in terms of a soil improvement technique. This technique is the easiest and simple way, and this application should be approved through main experiments like the Proctor compaction test, sand cone test, and direct shear test .These tests were conducted according to ASTM standards. The experiments were applied on poor graded sand but a non problematic soil to signify the effect of the slag on this soil, where the effect if it appears positive, will have a positive impact on the poorly graded soil. For the soil replacement, slag is used instead of sand with a content of 1:1 percentage in sand . In order to examine this application Proctor compaction test was applied with the mentioned percentage to obtain the maximum dry unit weight curve and optimum water content. Then two trials of sand cone tests were conducted on the same soil to be compared with a full sand specimen . Another aspect of slag was performed as a vital experiment where it can open many ideas for soil improvement application which will help in more ways of waste disposal to obtain the shear strength for using the slag material with sand. This experiment was applied using 20 percent of slag as approved by Pisini et al. (2022), who performed CBR tests on different slag percentages and concluded the best results for 20 percent of slag. In this experiment, the soil mixes were compared to the control sand as a reference result in addition to comparing between different slag grading size mixes, which contibuted to the investigation of the optimum slag grading size in shear strength . Moreover , the addition of geogrid to the slag-sand mixes was chosen for examining the workability of slag as a secondary material with sand and geogrid to open more ways of waste disposal techniques in different aspects (grading size, applications, and percentage). The third section discusses the use of microplastics as one of the most available wastes, which causes environmental problems due to its existence in enormous quantities. This study is concerned with the construction point of view and environmental waste disposal in an economical way. The tire chips were examined through the Proctor compaction test according to Dierkes et al. (2019) [260], who approved the existence of tire chip particles in soil naturally due to the abrasion of car tires by studying its effect, reaching an optimum value of 0.1 percent . This percent was the starting point of this test as a reference for artificial (on purpose) soil mixes to strengthen the same aspect; other percentages were

examined, like lower percentages (0.05, 0.1, 0.2, 0.4) and a higher percentage of (2 percent).

3.3.1. Slag Experiments

3.3.1.1. Standard Proctor Compaction Test on Sand-Slag Mixture

3.3.1.2. Test Method

Standard Proctor test is applied for soil compaction application in order to improve the dry unit weight of the soil in the field for construction of highways , airports , and other structures . Proctor (1933) developed a laboratory compaction test procedure to achieve the maximum or optimum dry unit weight for different types of soils, which can be used for specification of field compaction that , indicates enhancement in stability of slopes and reduction in , the probability of settlements . This test is referred as the standard Proctor compaction test based on the compaction of soil fraction passing the No.4 sieve according to ASTM D698 [277] .

3.3.1.3. Specimen preparation procedure

4.5 kg (10 lb.) of air-dry soil, consisting of Sand and Slag, with a ratio of 1:1 was prepared to act like a replacement soil where Slag was replaced by sand . This ratio was chosen according to the field experience in the geotechnical because it is the most commonly used percentage depending on many trials, where decreases in the void ratio among gravel-sand or full sand specimen to make the water path harder and without taking any sand particles according to its flow. A compaction test can be conducted with consideration of breaking all soil lumps, where the soil can pass the soil through U.S Sieve No.4. This soil sample consisted of sand and slag with percentage (1:1) as this is the most commonly used percentage for the replacement soil that is composed of sand and gravel. Then , the soil that was seived was collected in the large pan to be mixed with water to reach a moisture content of about 5 percent (5%) of the sample weight mixed with the soil in the large pan. The balance was used to weigh the Proctor mold and base plate without the mold extension (W1), then the extension part was bounded to the mold and the moist soil was put in the mold in three equal layers where each layer was compacted by standard Proctor hammer 25 times before the next layer of loose soil was poured in the mold. The top extension of the mold was removed with extreme caution not to break any compacted soil inside the mold, as shown in Figure 3.18.

Figure 3.18. Mold after removing the extension

The excess soil above the mold was cut and trimmed by using the straight steel ruler to be even with the top mold, see Figure 3.19. The mold , base plate and the compacted moist soil in the mold were weighed (W2) . Then , the base plate was removed from the mold and the jack was used in order to get out (extrude) the compacted soil cylinder from the mold, see Figure 3.20.

Figure 3.19. Removing extra soil with the steel ruler

Figure 3.20. Removing extra soil with the steel ruler

The weights of the empty cans (W3)were measured and samples from the extruded soil were taken as in Figure 3.20 to be collected in the can; then they were weighed (the mass of the can and moist soil ,W4) as shown in Figure 3.21.

Figure 3.21. Moisture can and moist soil weight

The moist can was taken into the oven and dry weights were determined . Then the rest of the compacted soil was mixed with the rest of the soil in the pan. More water was added while in order to raise the moisture content by 2 percent (2%) . These steps were repeated , until reaching a point where the weight of the mold and moist soil started to decrease . The test continued until two successive down readings were taken , where the weights of the cans and dry soil samples were designated as W5 .

3.3.1.4. Sand Cone test

3.3.1.5. Test Method

This test is conducted to check the dry denisty of the compacted soil and make a comparison with the specifications needed in construction. It is known as the simplest method of determining the in-situ unit weight of compaction where the experiment is conducted as outlined in ASTM D1556 [278].

3.3.1.6. Specimen preparation procedure

The sand and slag were prepared with 1:1 ratio; see Figure 3.22. Then, a 50 cm x 50 cm hole was excavated to conduct the soil replacement of slag and sand instead of sand and gravel, see Figure 3.23.

Figure 3.22. Slag and sand used for soil replacement

Figure 3.23. Excavated hole to pour replaced soil inside

The slag and sand mixture was prepared with a ratio of 1:1 (Weighted quantities), see Figure 3.24, to be poured into the excavated hole in layers by compacting each layer using shovel and stack of 45 kg of slag with same energy applied for each layer and mixing with water , as shown in Figure 3.25.

Figure 3.24. Weighted quantities of slag and sand

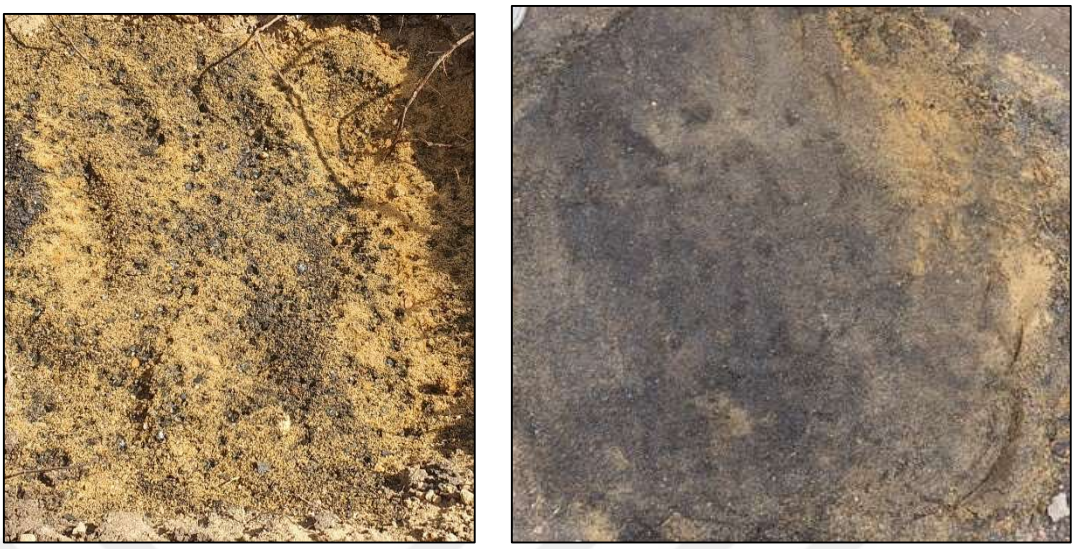

Figure 3.25. Mixed replacement soil layers

The surface of the replaced soil was mixed with low amount of water in order to cause lubrication between soil particles for minimizing the void ratio and obtaining the needed value. The sand was poured into the gallon bottle , then attached to the cone, see Figure 3.26.

Figure 3.26. Ottawa sand poured into bottle

The base plate was placed on the leveled ground to avoid any pockets, and a hole was excavated . The whole volume must be smaller than the cone’s volume substracted to the bottle's sand volume (according to the code ASTM D1556 [277] , the maximum depth is 15 cm); see Figure 3.27.

Figure 3.27. Base plate to take a soil sample for sand cone test

The soil inside the hole was removed and put into the plastic bag and the bag was closed tightly to avoid losing moisture with taking care not to move the base plate, as shown in Figure 3.28.

Figure 3.28. Excavated hole for pouring weighted sand

The tape in the cone was opened while attaching a bottle filled with weighted sand that was placed on the center of the base plate in order to allow sand to flow into the hole in the ground through the cone until the flow of sand stopped , see Figure 3.29.

Figure 3.29. Excavated hole for pouring weighted sand

The moist soil was taken from the field and weighed .The remained sand was also weighed to determine the soil density .

3.3.1.7. Direct Shear test (first section)

3.3.1.8. Test Method

This test evaluated the friction angle of sand and slag soil mixes. In this part, the goal is to discuss the effect of addition of slag to the sand and see whether it improves or gives the same result, at least to replace natural resources and decrease the existence of wastes like slag. The slag amount in the sand was taken as 20 percent of the whole specimen dry weight. The following equation is used to express shear strength S, as shown in Eq. (1) according to (ASTM D3080-04) [279].

$$S = \sigma' \tan \phi \qquad (1)$$

where σ' = effective normal stress, and ϕ= angle of friction of soil.

3.3.1.9. Specimen Preparation Procedure

Different soil mixes were prepared , see Table 3.12, and added into the shear box . These soil mixes were determined according to the grading size of slag to compare the effect of the granular size of slag particles.

Table 3.12. Different soil mixes with a slag ratio of 20%

Soil Mix	Slag Particle Size (mm)	Figures
Control coarse sand	-	Figure 3.30
Soil Mix 1	(4.75-2.36)	Figure 3.31
Soil Mix 2	(2.00-1.18)	Figure 3.32
Soil Mix 3	(0.85-0.6-0.425)	Figure 3.33
Soil Mix 4	(0.25-0.15-0.075)	Figure 3.34

Figure 3.30. Control sand

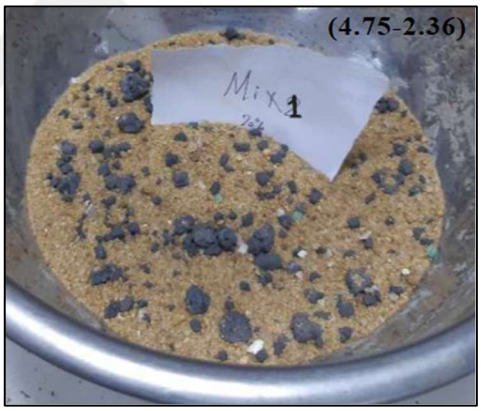

Figure 3.31. Soil mix 1 with 20 % slag

Figure 3.32. Soil mix 2 with 20 % slag

Figure 3.33. Soil mix 3 with 20 % slag

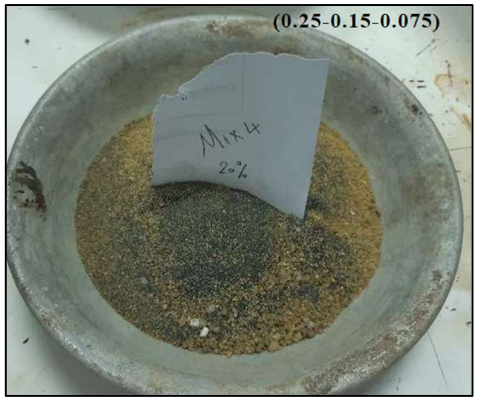

Figure 3.34. Soil mix 4 with 20 % slag

A tamper was used to compact the soil layers . Tamper should be applied with same energy and hitting times to soil for avoiding of denisty variation . About 6.4 mm below the top of the shear box should be compacted from the top. The surface of the specimen was levelled , Figure 3.35.

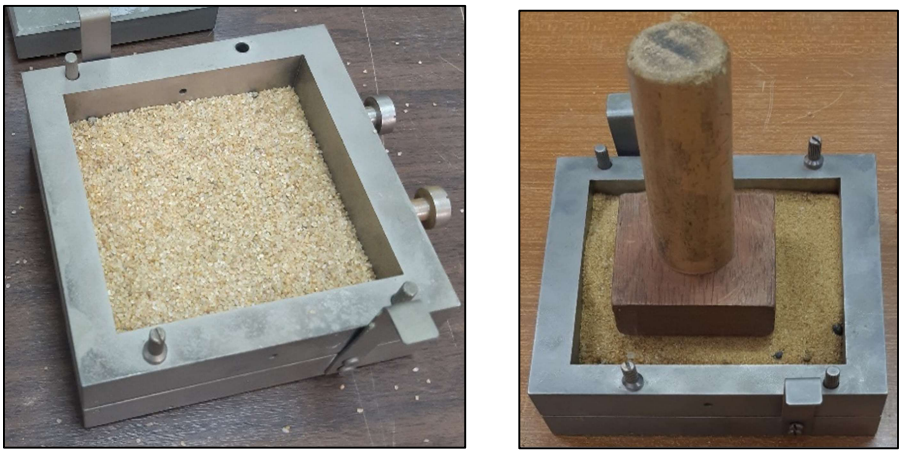

Figure 3.35. Control sand in the shear box

The dimensions of soil specimen were determined (i.e., length L, width B, and height H of the specimen). The loading head was moved down from the shear box to rest on the soil

specimen.The shear box was put to assembly in the direct shear machine . The needed average load N was applied on the ready specimen , which can be done by hanging dead weight to the vertical load yoke . The loading head of the specimen loads on the soil specimen because of the top crossbar resting on it . The two vertical pines was removed at the top half of the shear box on the side walls, two vertical screws was advanced. This step was done to separate the two halves of the shear box, while the space between the two halves is slightly larger than the largest grain size of the soil specimen (observed visually). After setting the loading head and, the two horizontal screws located at the top half of the shear box was stiffened and the two vertical screws was released , there is no connection between the box parts (halves) except soil. Two dial gauges had to be attached vertically and horizontally to the box to measure the displacement during the test ; see Figure 3.36.

Figure 3.36. Shear test procedure

The horizontal load should be applied to the top half of the shear box the read the vertical dial gauge and the proving ring gauge, see Figure3.38, (which measures horizontal load S); keep measuring until the proving ring dial gauge reads a maximum and then falls or reaches a maximum and then remains constant.

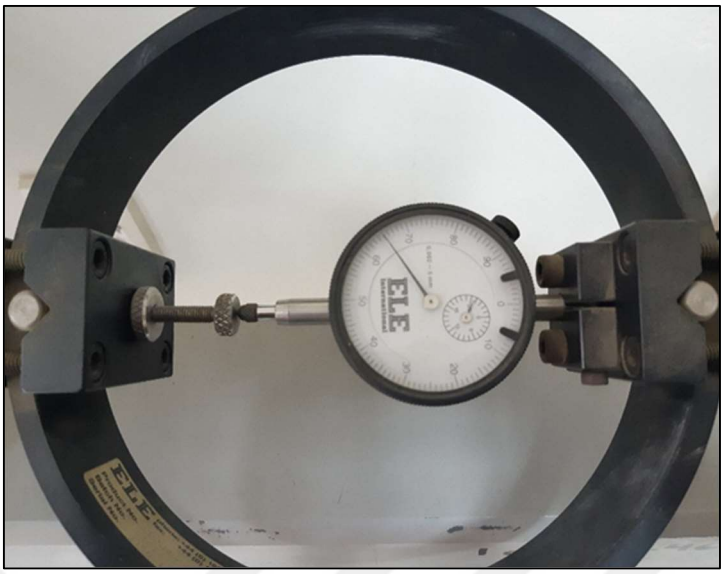

Figure 3.37. Proving ring of the shear test instrument

3.3.2. Geogrid

3.3.2.1. Direct Shear test (second section)

This test was conducted to evaluate the interface angle for biaxial geogrid for different soil mixes composed of sand and slag with a slag ratio of 20 percent (20%) and different grain sizes. The reason behind this experiment is to know the effect of slag with sand and whether it improves the interface between sand and geogrid, as it will show the workability of slag as environmental waste in many applications and different composite materials to open wide usage of slag through many aspects.

3.3.2.2. Test Method

The equation may express the shear strength, S, of a granular soil as in Eq. (2)

$$S = \sigma' \tan \delta \qquad (2)$$

where σ ' = effective normal stress , δ= Interface angle between soil and geogrid.

3.3.2.3. Specimen Preparation Procedure

Similar procedures for the specimen preparation in section 3.3.1.7 should be followed except the following: A100 mm x 100 mm geogrid sheet was glued on the top surface of a rigid to fit the rigid wooden block with the geogrid sheet inside the lower direct shear box, as shown in Figure 3.38 . Different soil mixes were prepared , see Table 3.13.

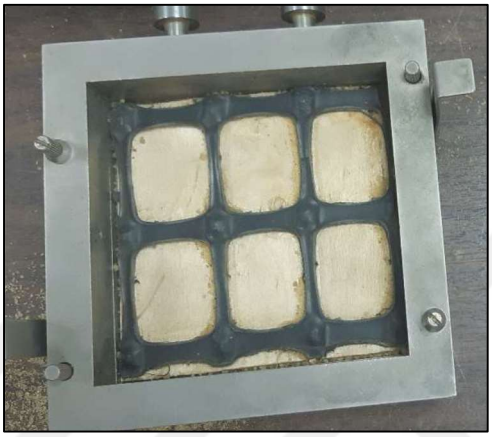

Figure 3.38. Preparation of geogrid for direct shear test

The shear box was filled in small layers using sand. Sand layers was compacted using a tamper. The top of the compacted specimen was about 6.4 mm below the top of the shear box. The surface of the sand specimen was equalized for the geogrid layer to avoid voids in sand and slag while spreading in the shear box.

Table 3.13. Different soil mixes with a slag ratio of 20% to use in direct shear test with geogrid

Soil Mix	Slag Particle Size (mm)	
Control coarse sand	-	
Soil Mix 1	(4.75-2.36)	Figure 3.39
Soil Mix 2	(2.00-1.18)	Figure 3.40
Soil Mix 3	(0.85-0.6-0.425)	Figure 3.41
Soil Mix 4	(0.25-0.15-0.075)	Figure 3.42

The same test procedure of the shear test was completed as mentioned previously with respecting the saving of the result changing, which may vary because of the readjusting of soil particles and slag with the geogrid layer

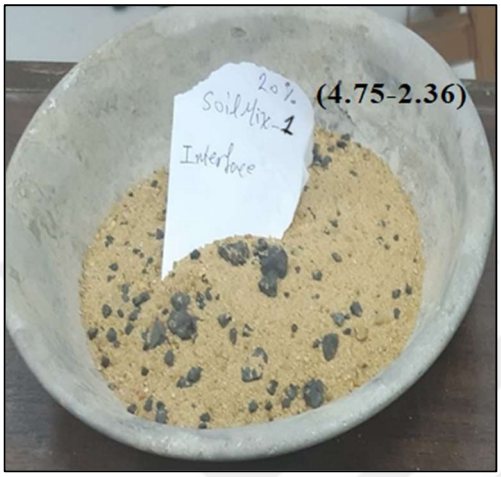

Figure 3.39. Soil mix 1 with 20 % slag

Figure 3.40. soil mix 2 with 20 % slag

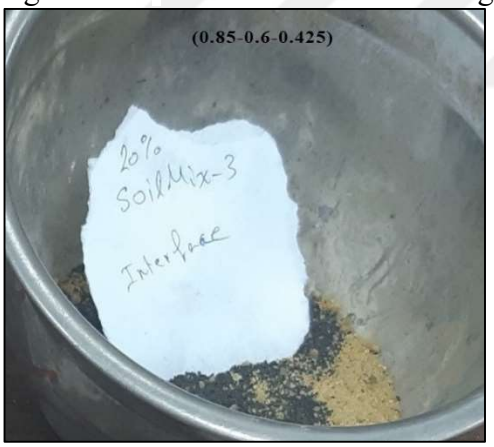

Figure 3.41. Soil mix 3 with 20 % slag

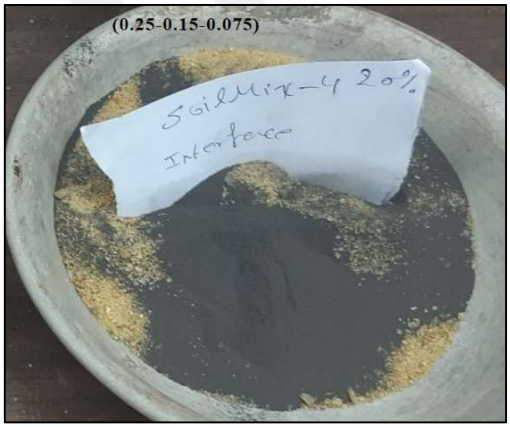

Figure 3.42. Soil mix 4 with 20 % slag

3.3.3. Microplastic (Tire chips)

3.3.3.1. Compaction Proctor test with microplastic (Tire Chips)

This experiment was conducted on behalf of environmental waste disposal for a primary source that may exist naturally due to natural factors . The tire chips used in this study were obtained from the remnants of vehicle car tires that were stored by Lastik Sanayicileri Dernegi (LASDER) which are composed of the synthetic polymenr , polystyrene to be used artificially with a purpose and aim of construction used to simulate the nature of tires wearing. The Proctor compaction test was conducted by using the previous steps on the same control sand, but another sieve analysis was applied to avoid any error in results.

Different soil mixes were used and they were chosen according to the previous study by Dierkes [247] who discovered as average tire chips amount in the soil beneath the roads as 0.1 percent where it was the starting percentage for the experimental program illuminating the usage of purposed different tire chips percentage added to the sand to get rid of an environmental waste. Thus, 0.1 percent was used with a slightly higher percentage of microplastics and a lower percentage, see Table 3.14, in order to compare and discuss the effect of tires chips used in the sandy soil in terms of compressibility . This mixture can be considered as an outcome between the friction of car tires and highway roads and the optimum percentage which can be used for filling or a secondary material in the soil .

Table 3.14. Different soil mixes with different percentages of tire chips

Soil mixes	Percentage	Figures
Control Sand	-	Figure 3.44
Soil mix 1	0.05%	Figure 3.45
Soil mix 2	0.1%	Figure 3.46
Soil mix 3	0.2%	Figure 3.47
Soil mix 4	0.4%	Figure 3.48
Soil mix 5	1%	Figure 3.49
Soil mix 6	2%	Figure 3.50

At first the control sand was tested in the experiment program in order to act like a dateim or refrence for the comparison and discussion of tire chips addition effect on soil Figure 3.43.

Figure 3.43. Control sand mix for Proctor compaction

0.05 percent of tire chips is the least percentage added to the control sand in order to determine lower percentage effects figure 3.44 .

Figure 3.44. Soil mix 1 (0.05%) for Proctor compaction

Adding 0.1 percent of tire chips is crucial as this percentage was the average tire chips percentage considered as microplastics due to the mitigation into the soil beneath roads

(Dierkes et al. 2019) as shown in Figure 3.45.

Figure 3.45. Soil mix 2 (0.1%) for Proctor compaction

Other trials were applied using higher percentage as 0.2 , 0.4 1 and 2 to discuss the effect of tire chips on control sand (Figure 3.46, 3.47, 3.48 and 3.49).

Figure 3.46. Soil mix 3 (0.2%) for Proctor compaction

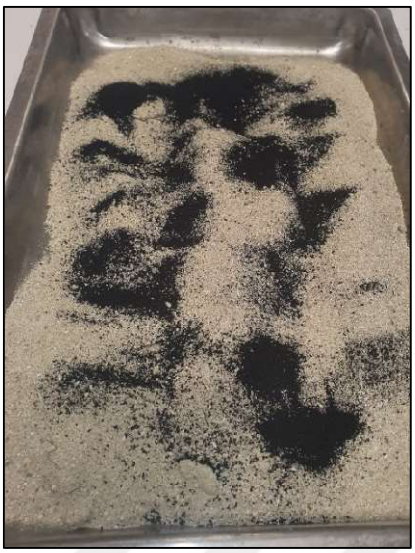

Figure 3.47. Soil mix 4 (0.4%) for Proctor compaction

Figure 3.48. Soil mix 5 (1%) for Proctor compaction

Figure 3.49. Soil mix 6 (2%) for Proctor compaction

4. RESULTS AND DISCUSSION

4.1. INTRODUCTION

This chapter discusses the results of the experimental work that were given in chapter 3 in detail. Workability and physical and chemical properties are described in detail for each experiment by giving results in graphs and values. The materials selection is approved by discussing the parameters assigned in chapter 3 through the experimental program. A comparison between material usage and the replacement of the used waste with natural material is also discussed with results to indicate whether it shows improvement or remains just within the same range. Both outcomes are considered as a success for the study where two aspects are achieved by saving a natural resource to serve the economy and construction application with waste disposal way for saving the environment. Physical properties of the materials that were discussed in chapter 3 are strengthened by the results of the geotechnical experiments . This chapter spreads the results of the three used materials compared with other studies' results and other similar materials .

4.2. MATERIAL BEHAVIOR

4.2.1. Slag

Slag material passed through different ways of preparation in order to complete and draw a full picture of the behavior and workability benefit. At first, slag was crushed in two ways, manually with a hammer and mold and automatically in a compression machine to reach the fine particle size, which needs to be used in some experiments to see the effect of fine particles' existence . This grading size showed a good paste behavior represented in the initial setting time that is nearly similar to cement, even if the experiment's goal was not to reach a cement behavior as slag was experimented to play a role in soil mixture like gravel due to the grading size. However, while transporting any material, a percentage of fines exists. From another perspective, this paste in the form of a cube was examined in the compression machine showing promising results compared to the cemented soil, as the cementation behavior of slag fines can achieve good harmony between slag and soil particles. This

harmony is maintained by the sieve analysis, where the slag can be classified as a granular material that can take place in soil mixes, especially the soil replacement instead of gravel. For the soil replacement tests, it is commonly taken as 1:1 percent for sand and gravel . The sand cone test was applied for three specimens with two trials which showed a good result when compared to the same sand. The percentage of slag used for the shear experiment had to be determined based on the previous study, which used different percentages for the CBR test and concluded that the best value appeared at the 20 percent use of slag, outlined by Pisini [182] . According to the manufacturing process, slag particles in different sizes differ from country to country. Thus, it can be classified according to the grading size. The shear test took place on different soil mixes depending on the grading size, starting with the control sand as the reference results.

4.2.2. Geogrid

When shear strength is mentioned, it is crucial to emphasize geogrid as an essential material for this parameter application ; Nowadays, most geotechnical applications nowadays tend to use geogrid material for its ease of transport and installation. Thus, it was essential and crucial to apply the shear test on the same soil mixes between sand and slag using geogrid, which was mentioned in the literature review with various studies by gathering the slag with geogrid. However, the percentage of slag used here was concerning but applied by different grading sizes. Geogrid may differ from one country to another according to the composition and manufacturing process, so it is essential to consider the physical properties of the used geogrid

4.2.3. Tires Chips

Tire chips were imported from Lastik Sanayicileri Dernegi (LASDER) with the mentioned grading size to be ready directly for the desired experiment as it is a lightweight material in colossal numbers. This way of waste disposal in the geotechnical application through construction is practical, never stops, never gets old, and appears in various ways. For geotechnical use, the most straightforward and spread way of soil improvement appears to be the soil replacement technique, where the study can be performed with a certain

percentage of the tire chips to evaluate the effect of the tire chips on the dry unit weight as an essential parameter for geotechnical applications . This property is shown through Proctor compaction test as mentioned.

4.3. EXPERIMENTAL RESULTS AND DISCUSSION

4.3.1. Slag

4.3.1.1. Proctor Compaction Tests

Standard Proctor compaction test was conducted to show the dry unit weight of the slag and sand mixture versus the optimum water content to be compared with the ordinary soil replacement materials such as ; sand, and gravel. Compaction of the specimens was maintained as the water content was raised with the same percentage (almost 2 %) . For each trial until reaching the first decreasing point and then the second one; in that case, after achieving two decreasing weights for the soil, the experiment was terminated for 50% of slag mixed with sand, as shown in Figure 4.1.

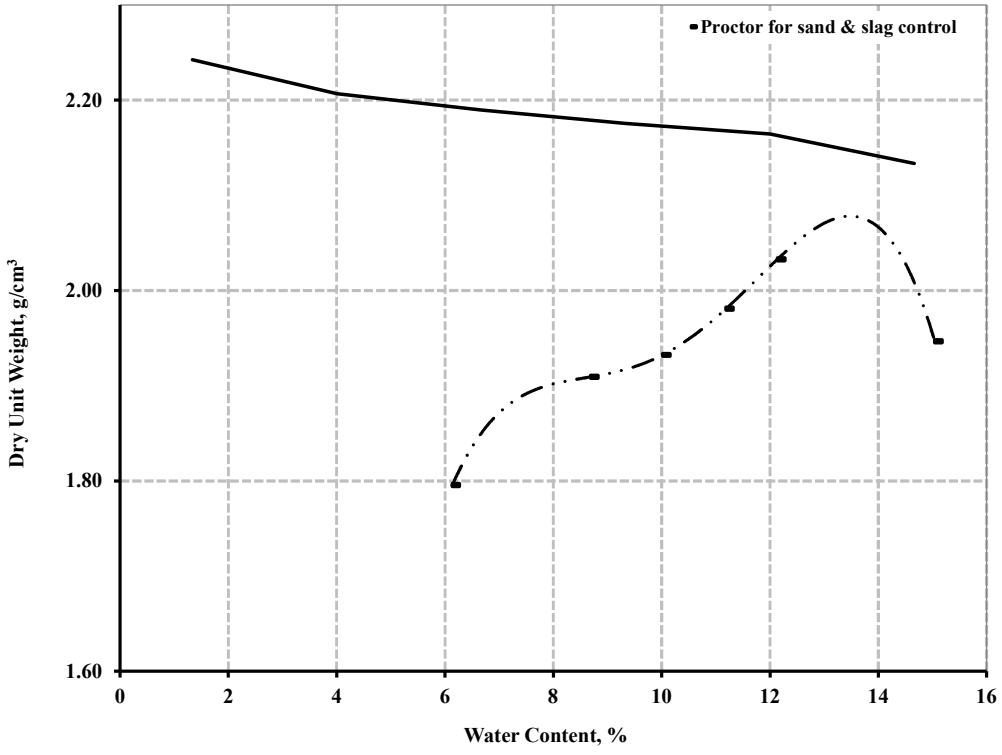

Figure 4.1. Proctor compaction of sand- slag (1:1) specimen

The parabolic curve for the compaction test shows a maximum dry unit weight (γ_{dmax}) of 2.033 gf/cm³ with an optimum water content (w_{opt}) of 17.98 %, which is a good result due to the effect of the slag on the sand as standard control ranges between 1.6 to 1.8 gf/cm³. For the applied experiment on the control sand , a maximum dry unit weight 1.640 gf/cm³ was observed; see Figure 4.2. As a result , adding 50 percent slag to the sand, improved the compressibility by increasing the maximum dry unit weight from 1.64 to 2.033 gf/cm³ .This results can be considered as an enhancement in the workability of the slag and sand particles in the replacement soil in order to produce the homogeneity between the soil particles and gives the needed compressibility for the application with the lubrication of the water to achieve the maximum dry weight.

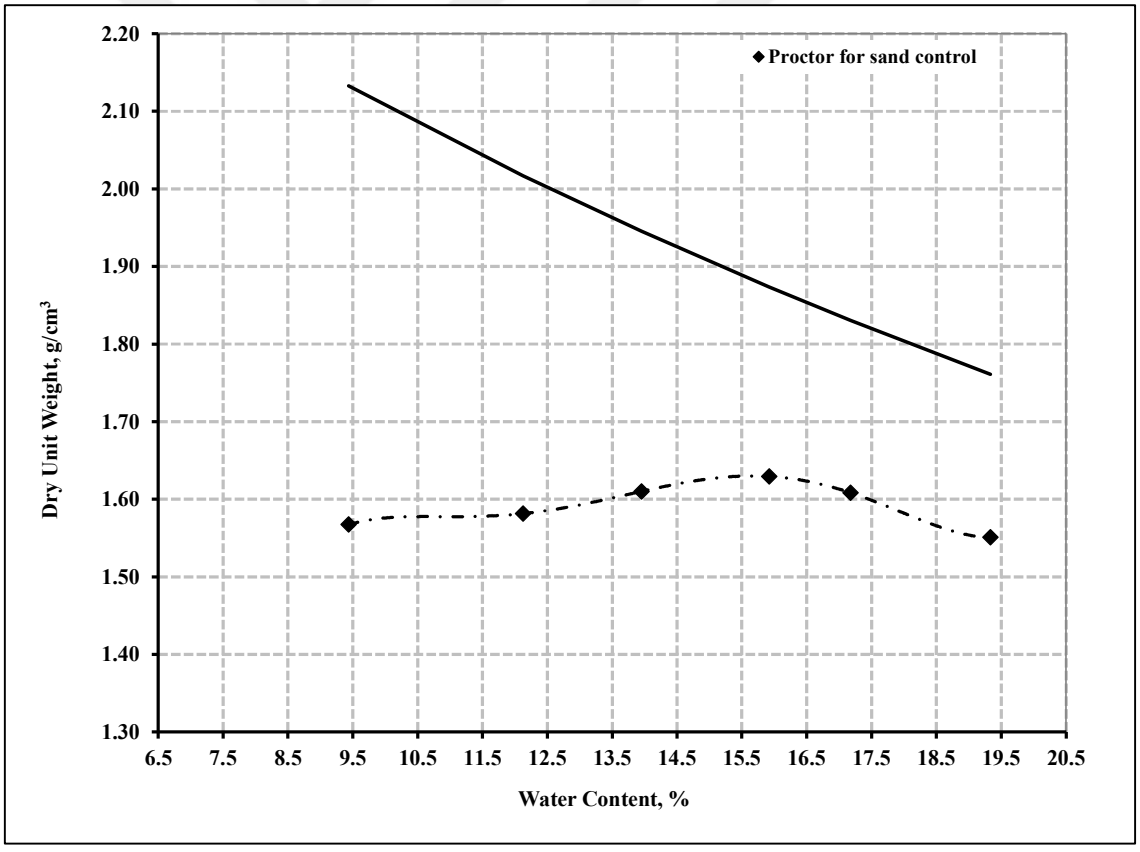

Figure 4.2. Proctor compaction test curve of sand

The applied percentage is the most commonly known and used for the soil replacement technique as it gives the most innovative results and the least void ratio as; well-graded sand

combines with the gravel by addition of water, which gives a lower void ratio causing a higher compressibility with good behavior as demanding.

The result of Proctor compaction using the slag shows a better effect and a good impact than sand specimens, as it can be used for soil improvement without any worries. This study can open more ways to use slag for waste disposal techniques with better results than natural resources .

4.3.1.2. Sand Cone Tests

The sand cone test was applied to measure the density to approve the workability of slag in the soil replacement technique. The testing process passed through two parts to evaluate the effect of slag; the first phase took the place on a sand specimen. Sand density is known to vary between 1450 – 2082 kg/m³, but it was tested to find accurate results; three holes in Table 4.1 were examined for conducting the compaction quality while the slag was applied twice to ensure results; each trial presents three holes Table 4.2 for determining the quality according to ASTM D1556 (2007).

Table 4.1. Sand cone test results on the control sand

Sample No.	Dry Density in gm/cm³	Percentage of Compaction
1	1.81	97
2	1.81	97
3	1.79	96

The sand specimen shows an average of 1.81 gm/cm³ as dry density, which is compaction degree for the poor-graded sand.

Table 4.2. Sand cone results first trial on the slag-sand mixture (first trial)

Sample No.	Dry Density in gm/cm^3	Percentage of Compaction
1	1.98	99
2	1.95	96
3	1.93	98

The first slag trial showed an average of 1.953 gm/cm³ as dry density, which indicates the tremendous impact of slag on the sand with a percentage of compaction quality using the same type of compaction as the previous trial on the sand. The results prove the effect of slag on the soil properties with an improvement in the dry density of the sand.

Table 4.3. Sand cone results on the slag-sand mixture (second trial)

Sample No.	Dry Density in gm/cm3	Percentage of Compaction
1	1.99	97
2	1.96	95
3	1.95	96

In the second trial, tests were performed in three holes to ensure the results of the first trial by concluding nearly the same range of results with an average of 1.967 gm/cm³ as dry density. These results assure the tremendous impact of slag by, showing the improvement achieved by the slag addition . Furthermore, the specimen showed a kind of cementation after a couple of days at its surface. This Interaction approved the cementation behavior which was shown before the initial setting time .

4.3.1.3. Direct Shear Tests

Adding the slag to the sand specimen opened the idea of determining the shear strength as a well-needed property for most of the soil improvement techniques where much geotechnical application needs this parameter to show the shear strength and the friction angle for slope stability, embankments , pavements , retaining walls, dams and even in the evaluation of bearing capacity. Slag-added sand can also enhanced with other materials like fly ash and geogrid in order to improve engineering properties such as shear strength and bearing capacity . In the study , the grading size of the slag particles were classified into the ranges of (4.75 - 2.36), (2.00 - 1.18), (0.85 - 0.60 - 0.425), and (0.25 - 0.15 - 0.075) mm . The optimum slag amount can be obtained and the best grading size can be used in various geotechnical applications . The experiment was applied first on the control sand showing maximum shear strength of 0.1 kg/cm² and friction angle of 32.93°, as shown in Figures 4.3, 4.4 and 4.5.

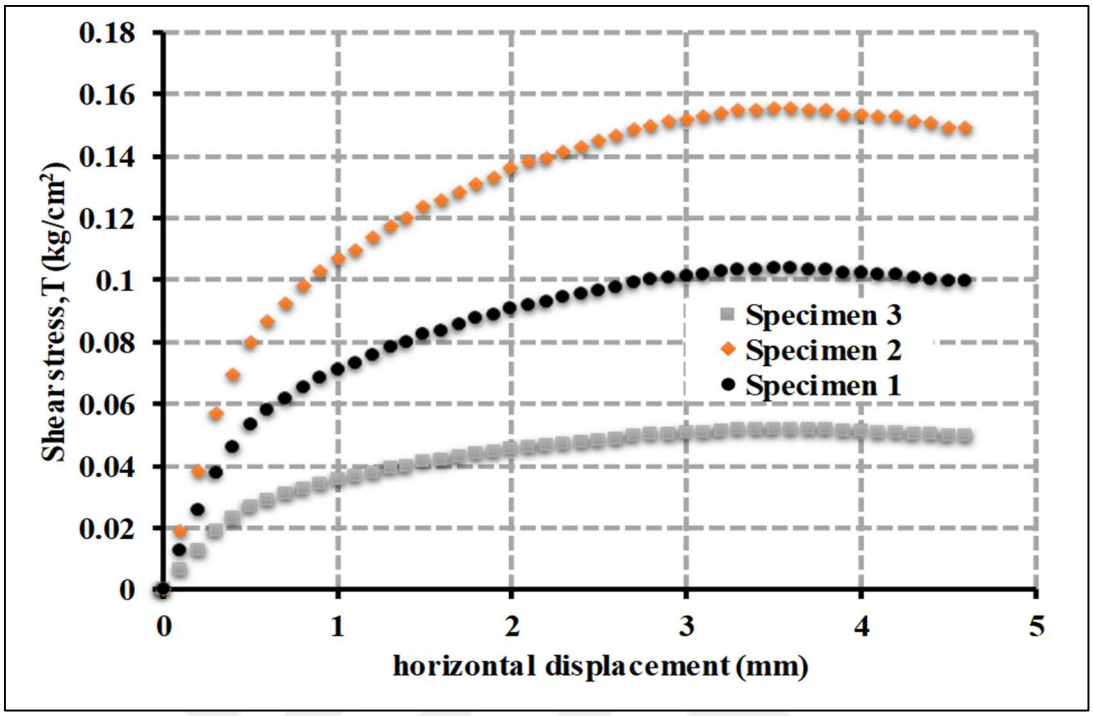

Figure 4.3. Shear stress - horizontal displacement curve for control sand sample

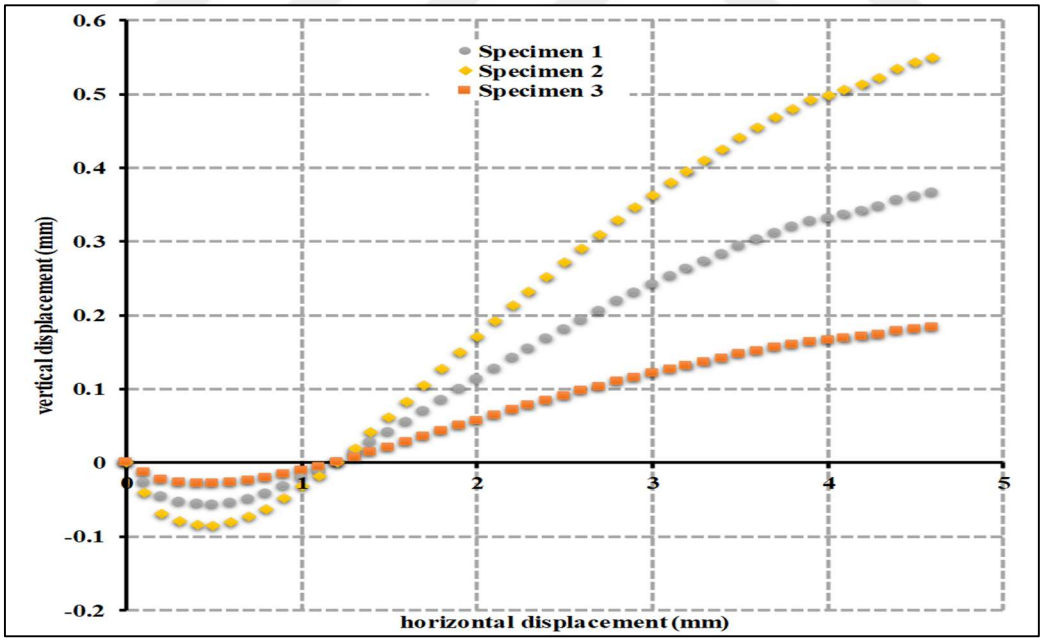

Figure 4.4. Vertical displacement-horizontal displacement curve for control sand sample

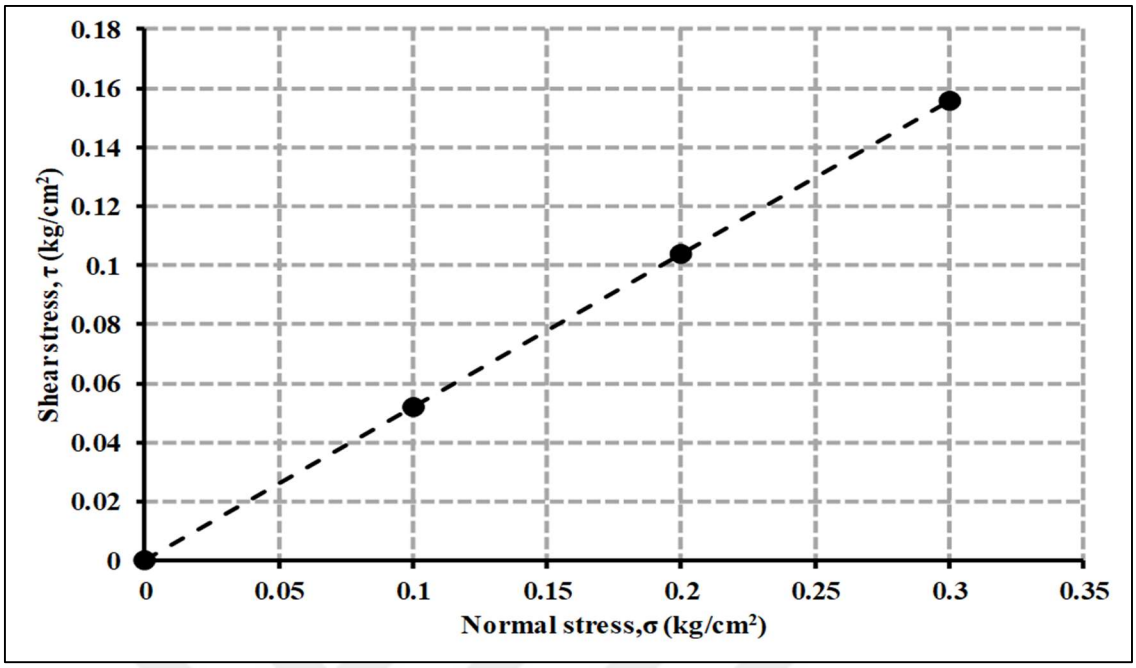

Figure 4.5. Shear stress -normal stress curve for control sand sample

Control sand showed the same range of shear strength and angle of friction to act as references for the coming mixtures. Soil mix 1 was obtained with 20 percent slag with grading size of (4.75mm - 2.36mm), showing a recognizable improvement on the maximum shear strength with value of 0.15 kg/cm² and angle of friction of 53.14°, as shown in Figures 4.6 ,4.7 and 4.8 .

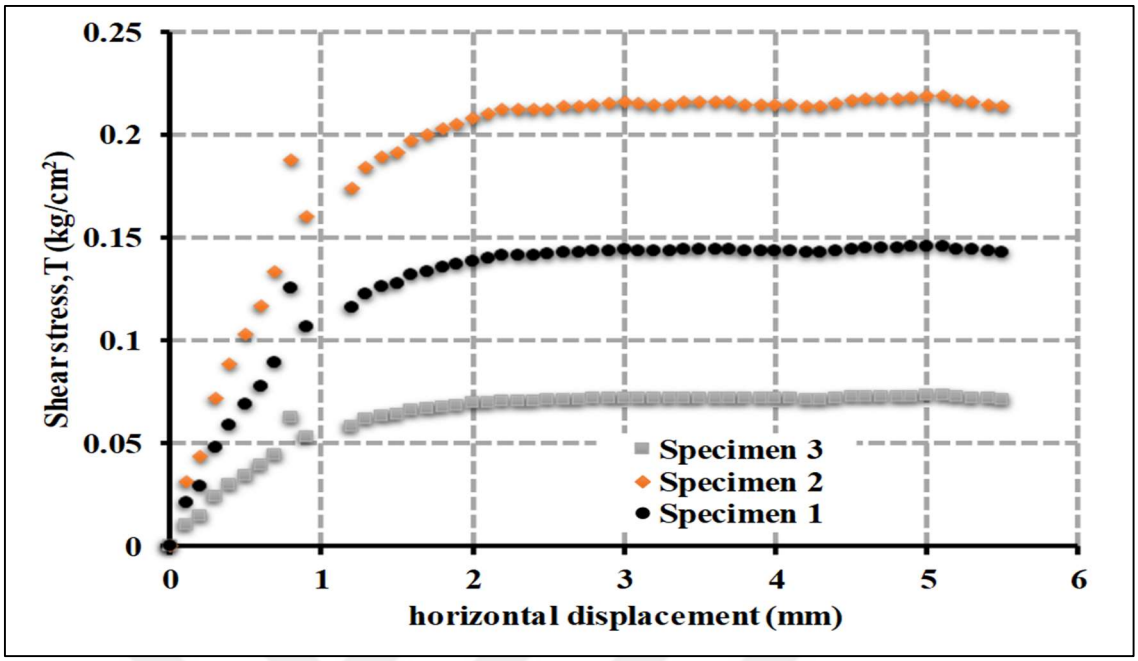

Figure 4.6. Shear Stress - horizontal displacement curve for soil mix 1(20% slag)

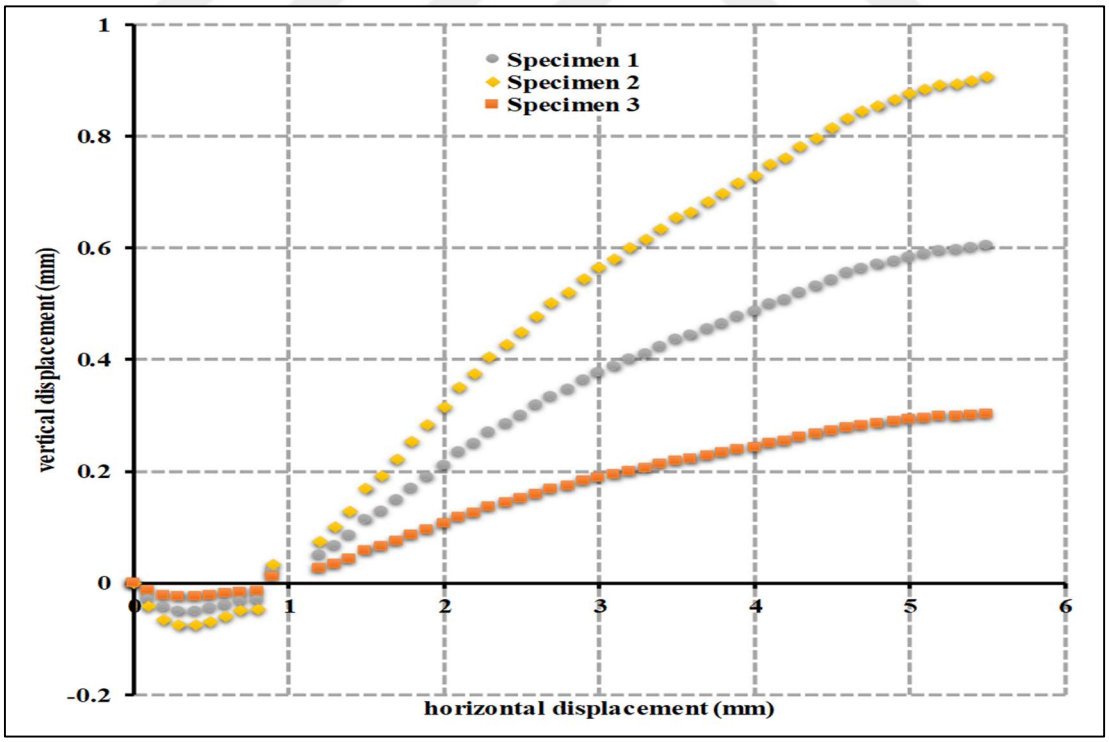

Figure 4.7. Vertical displacement - horizontal displacement curve for soil mix 1 (20% slag)

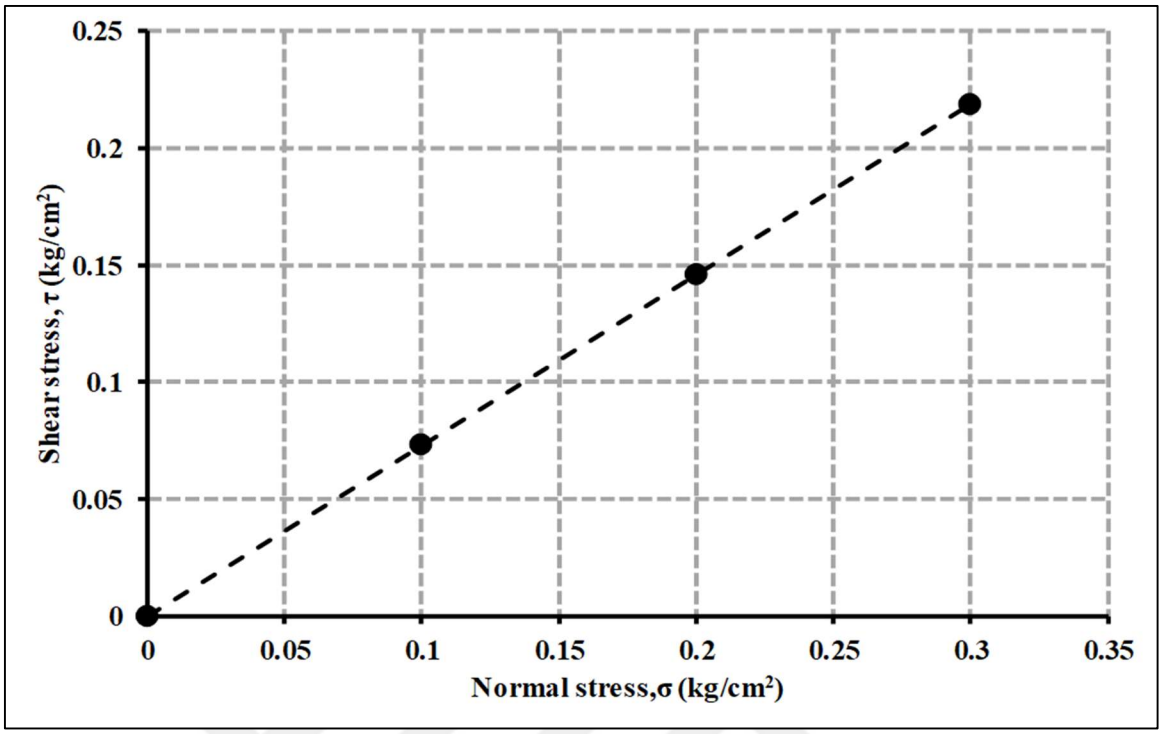

Figure 4.8. Shear stress – normal stress curve for soil mix 1 (20% slag)

Soil mix 2 with a grading size of (2.00 mm - 1.18mm) showed a slight decrease in the maximum shear strength, reaching down to 0.12 kg/cm² and an angle of friction of 38.88°, see Figures 4.8,4.8 and 4.9, which is considered the lowest angle of friction achieved in the experimental program. This grading size is expressed as the intermediate grading size and the most available size of slag. The horizontal curve indicates a change in the pattern of results due to the rearranging of granular particles at the beginning by showing an increasing pattern.

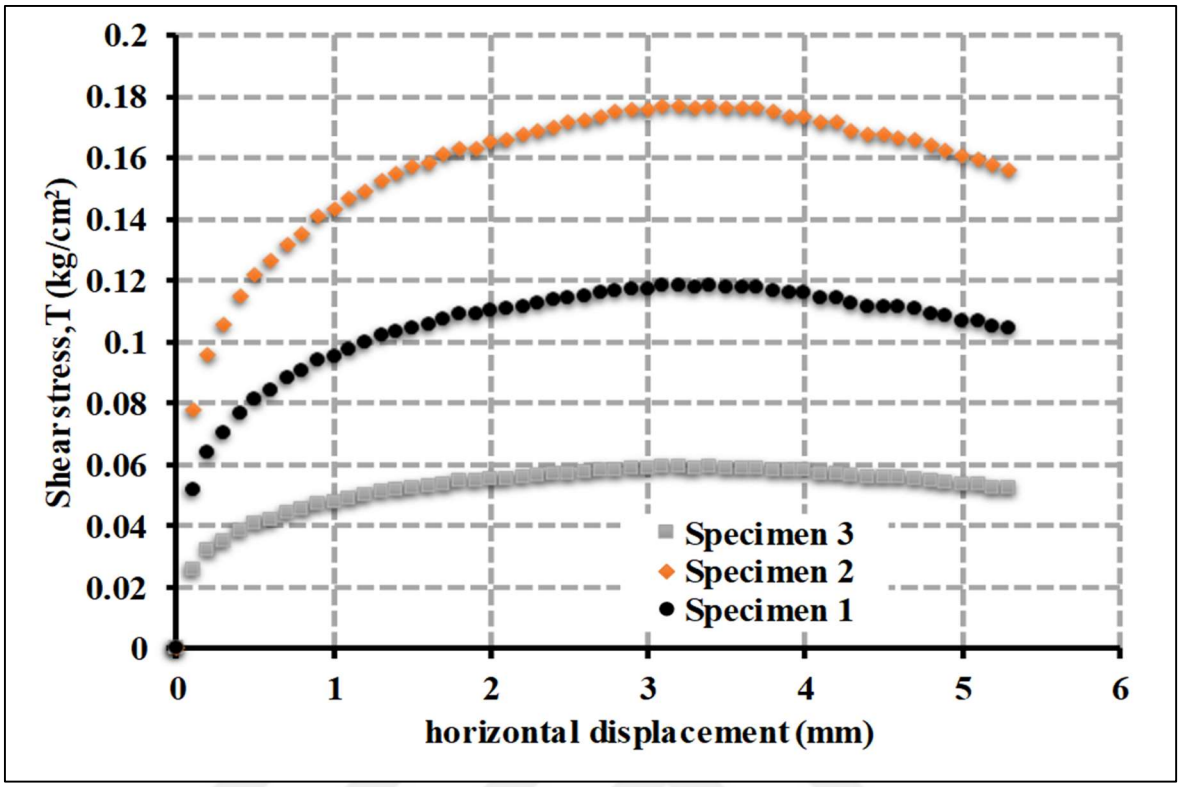

Figure 4.9. Shear stress - horizontal displacement curve for soil mix 2 (20% slag)

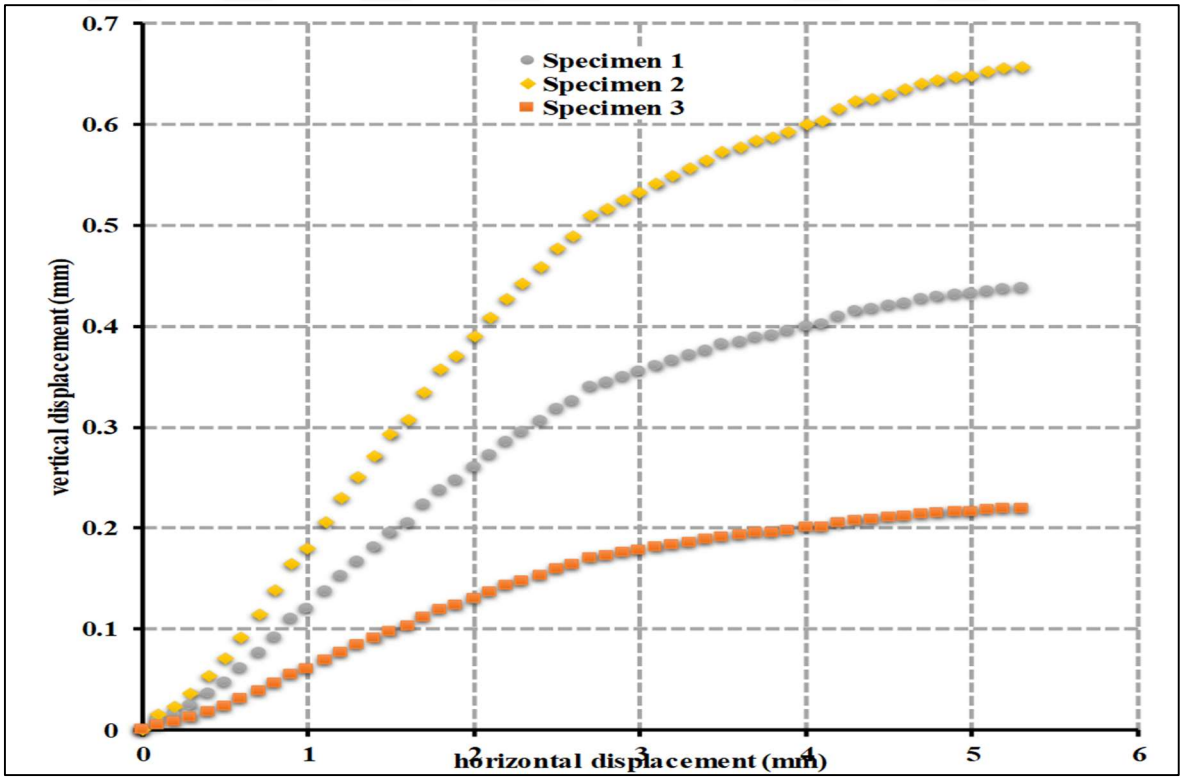

Figure 4.10. Vertical displacement - horizontal displacement curve for soil mix 2 (20% slag)

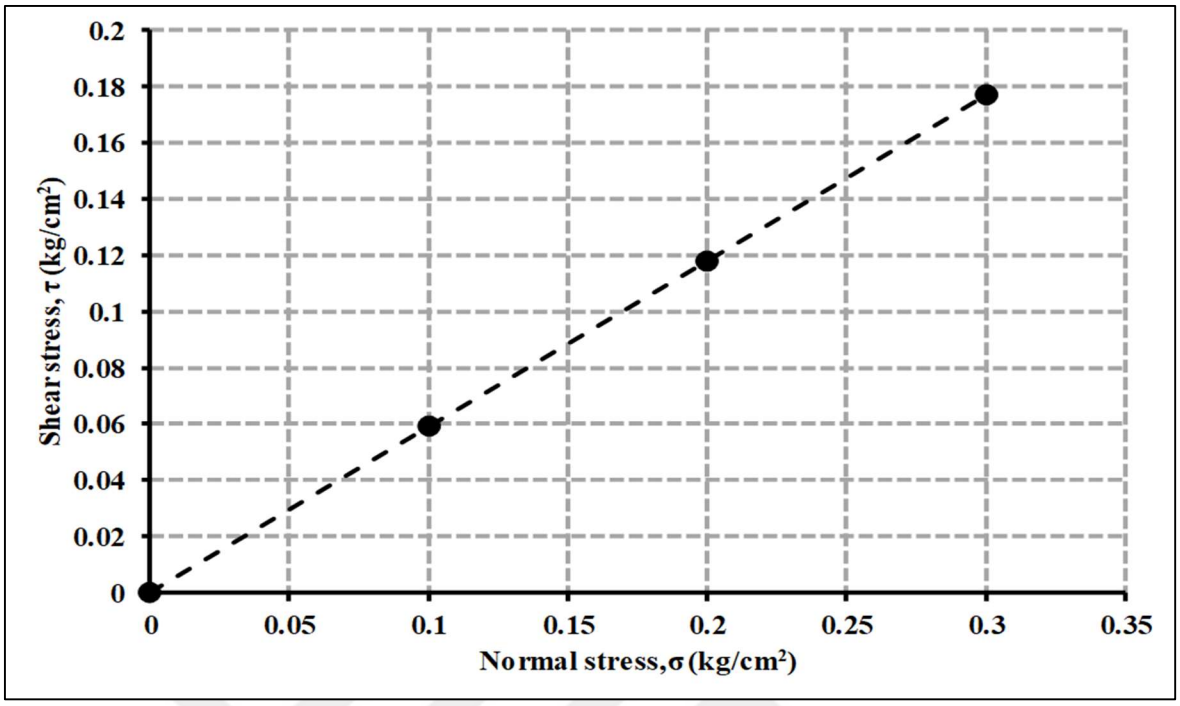

Figure 4.11. Shear stress – normal stress curve for soil mix 2 (20% slag)

Soil mix 3 with grading size of (0.85 mm - 0.6 mm- 0.425mm) showed a slight increase in the maximum shear strength to 0.13 kg/cm² and angle of friction of 46.62°, as shown in Figures 4.12,4.13 and 4.14.

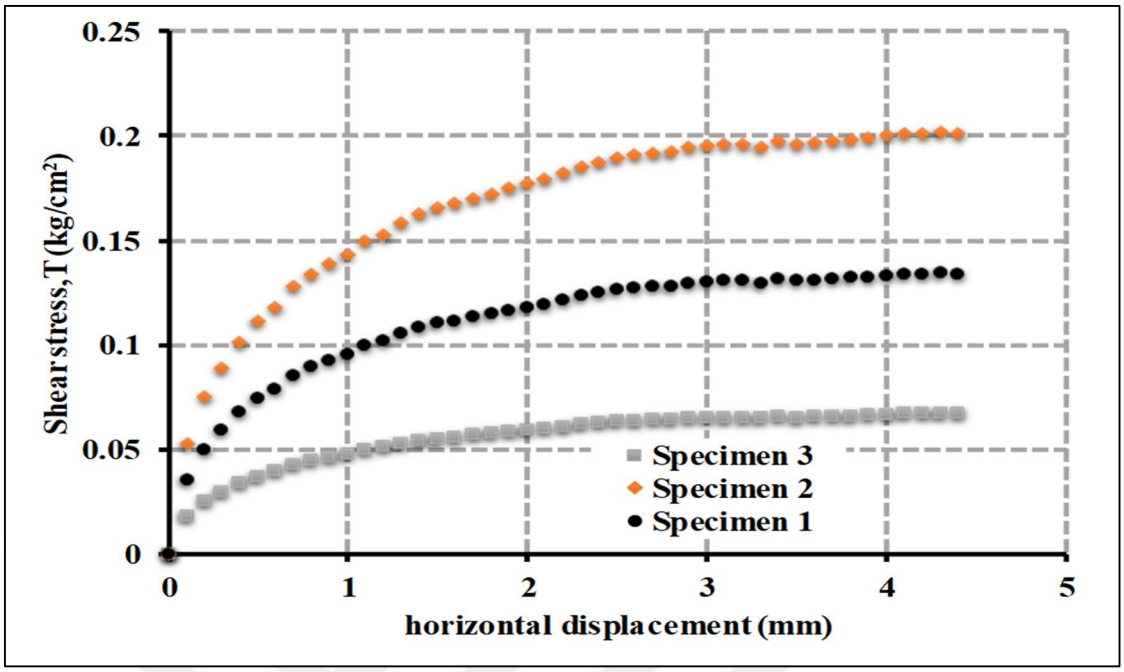

Figure 4.12. Shear stress – normal stress curve for soil mix 3 (20% slag)

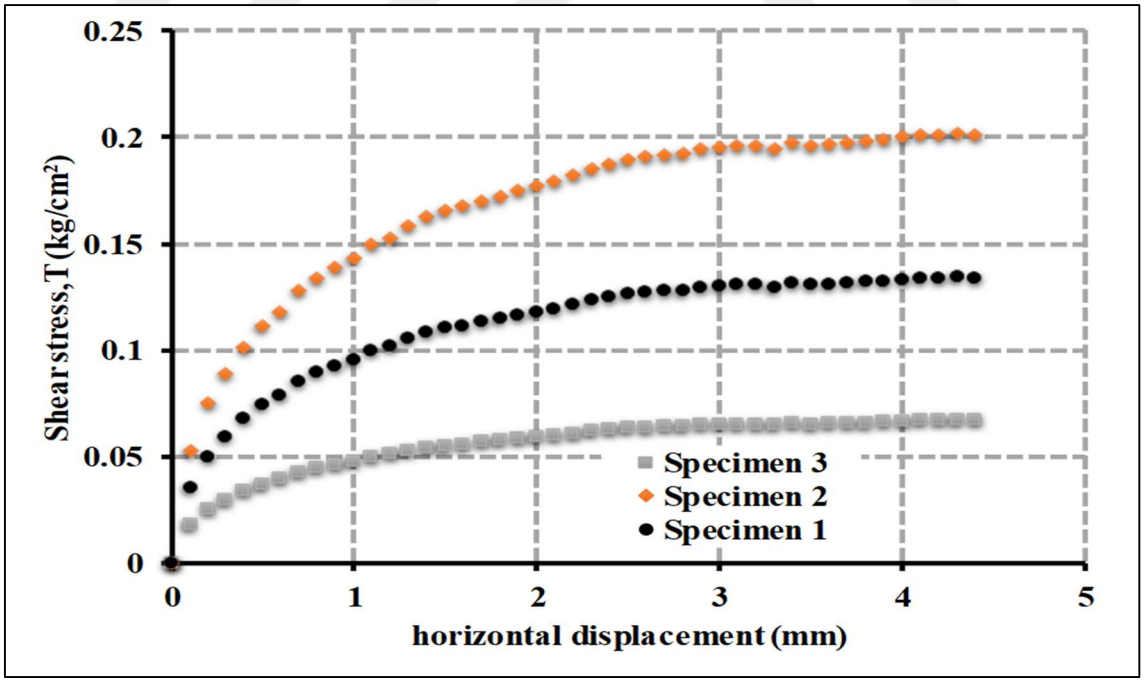

Figure 4.13. Vertical displacement - horizontal displacement curve for soil mix 3 (20% slag)

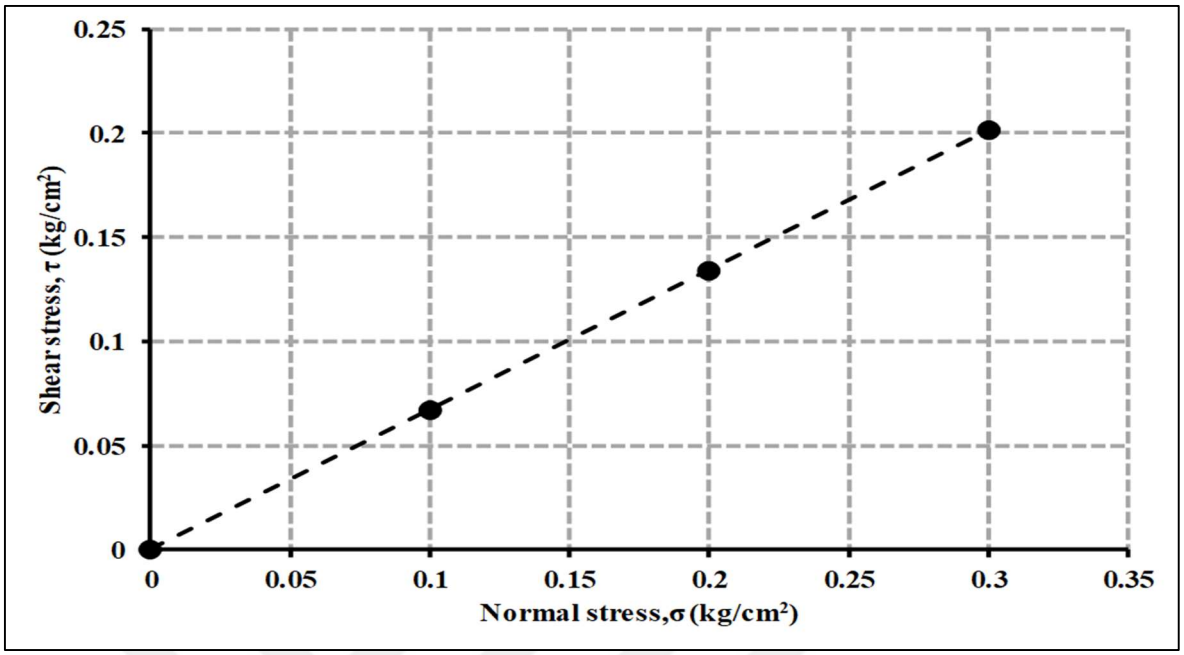

Figure 4.14. Shear stress – normal stress curve for soil mix 3 (20% slag)

Soil mix 4 showed the most stable particle arranging as can be seen in Figure 4.16 due to the tendency between the fine slag particles of grading size (0.25mm - 0.15mm - 0.075mm) and sand where they had a relative size which helped in decreasing the voids between the particles in the shear box. The maximum shear strength was measured as 0.15 kg/cm², identical to the soil mix 1, while the highest angle of friction with value to 57.97°, Figure 4.15, 16,17.

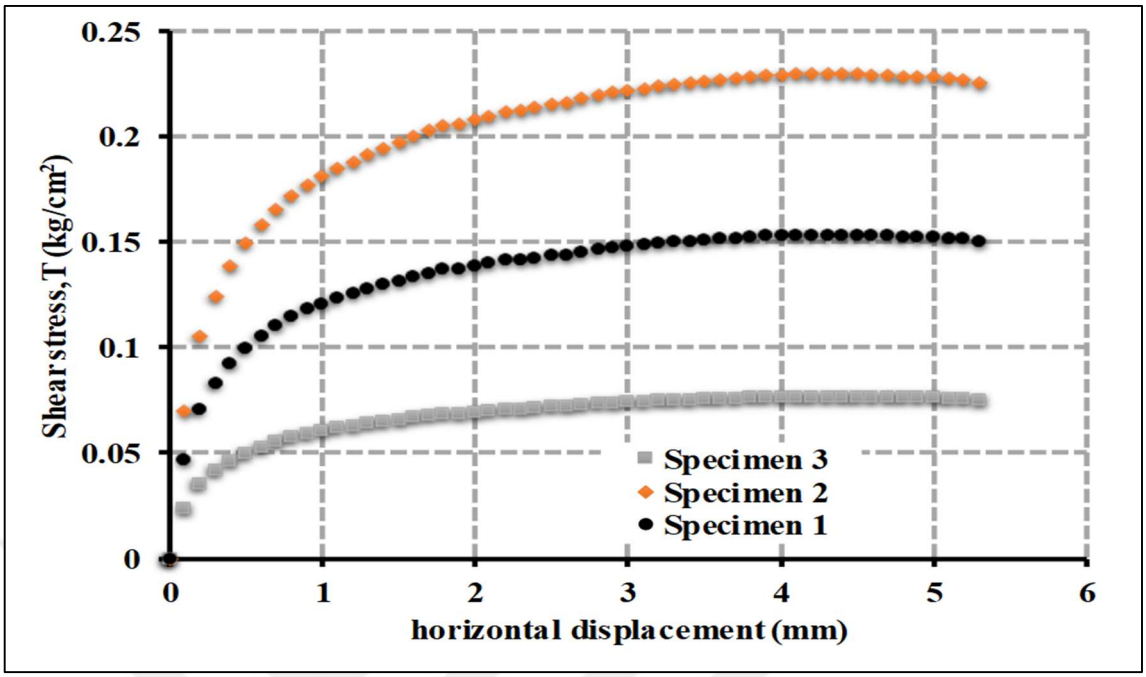

Figure 4.15. Shear stress-horizontal displacement curve for soil mix 4 (20% slag)

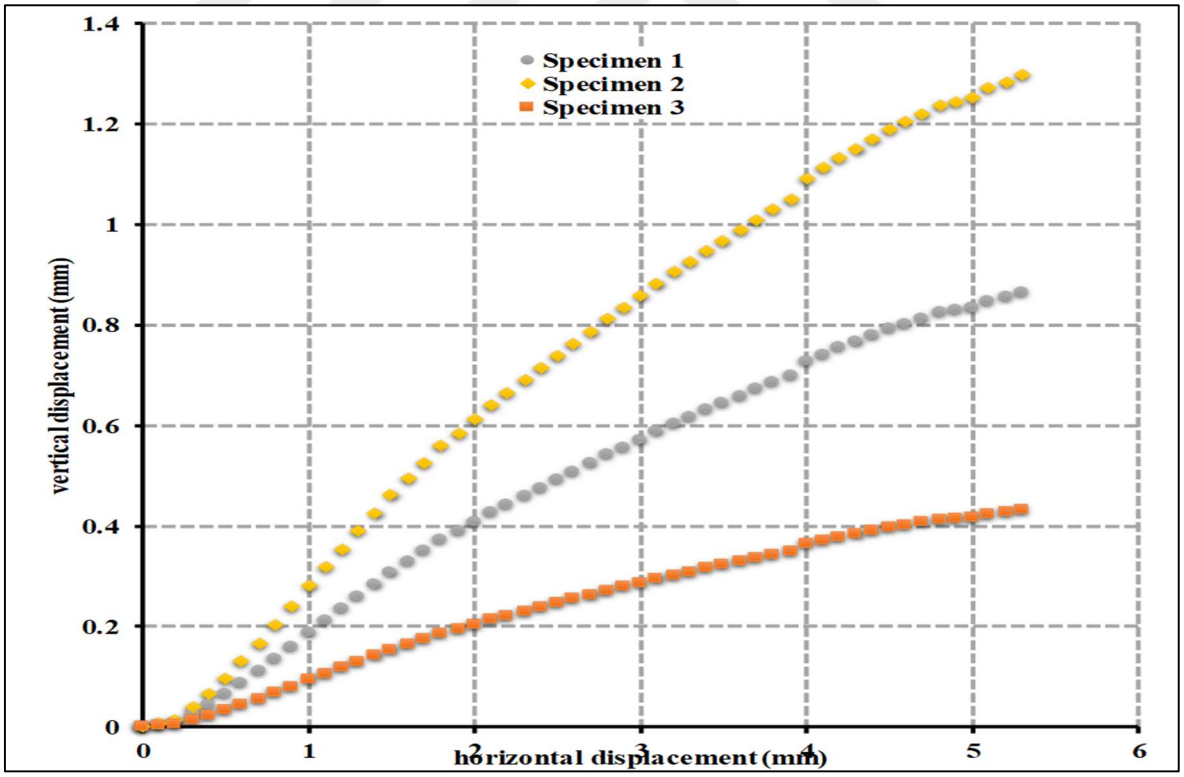

Figure 4.16. Vertical displacement -horizontal displacement curve for soil mix 4 (20% slag)

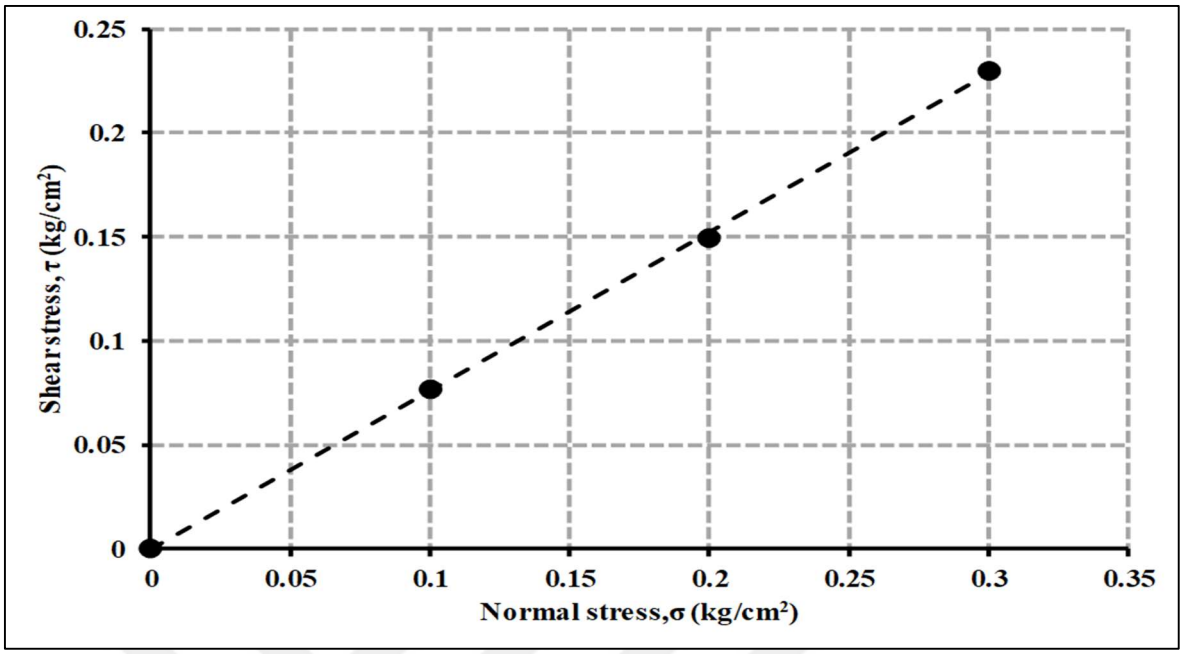

Figure 4.17. Shear stress – normal stress curve for soil mix 1 (20% slag)

The shear strength results showed a better performance for the soil mixes with 20 percent slag. Some mixes leaded to better results such as soil mix 1 and soil mix 4 while an intermediate improvement in soil mix2 and soil mix 3 was obtained . In the conclusion, the enhancement of using slag particles on the sand in terms of shear strength parameters was detected . Pisini et al. (2022) also observed improvement in the shear strength by using different percentages of slag.

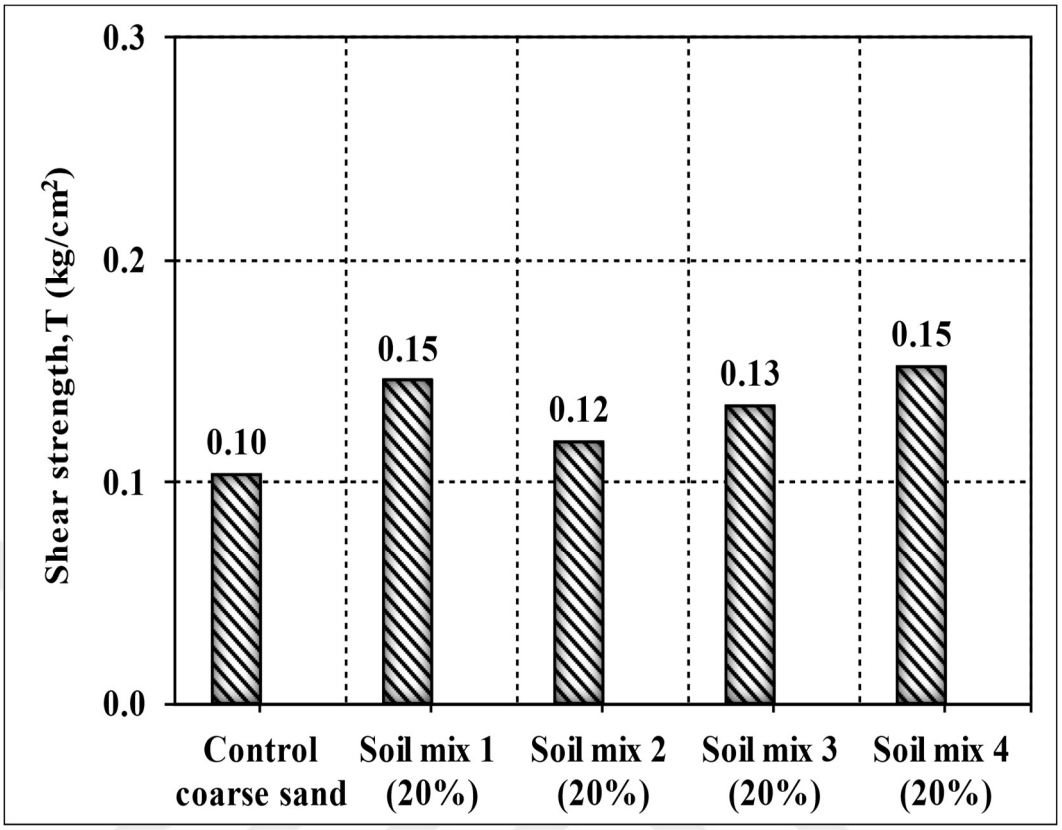

Figure 4.18. Results of shear strength (T) for different soil mixes (20 % slag)

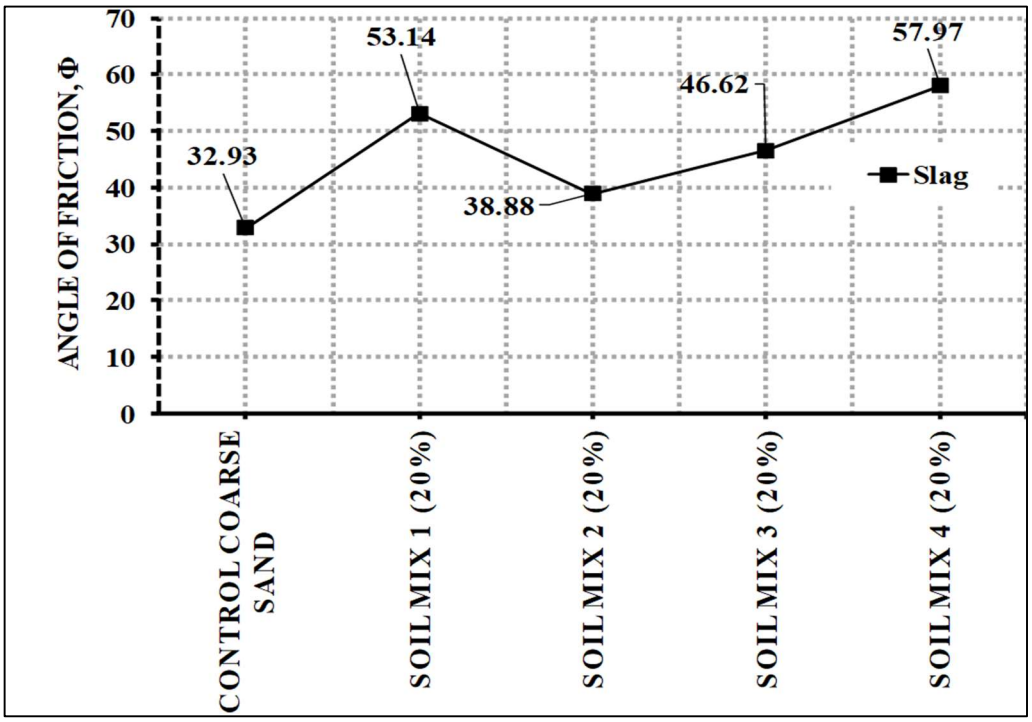

Figure 4.19. Results of internal friction angle (ϕ) for different soil mixes (20 %)

The relationship between the shear stress and the horizontal displacement was plotted previously for each specimen . The relationship between vertical and horizontal displacements was plotted previously for each specimen . The state of failure was defined as the peak of shear stress. In the horizontal and vertical displacement, the specimen dilatation was represented through a positive sign, whereas the negative sign represents a contraction of the specimen. After mixing the Slag with sand, a significant increase in the internal angle of friction was observed; this increase is inversely proportional to the size of the slag granules. The control specimen contracted and dilated from the vertical and horizontal displacement plots. Each soil mix was dilated from the vertical and horizontal displacement without any contraction, meaning the density of sand increased with slag. For calculation it was better to present the graph for different trials with concluding the average values.

Figure 4.20. Direct shear box test apparatus

4.3.2. Geogrid

4.3.2.1. Direct Shear Test

When shear strength is mentioned, the use of geogrid cannot be neglected; for that sake, a trial using geogrid was applied on the slag-sand mixture with the same slag percentage in order to determine the effect of using slag with geogrid on the shear strength. The same soil mixes were tested in order to keep the same experimental programming on track. First, the control sand with the addition of geogrid layer was evaluated as the reference with

maximum shear strength of 0.081 kg/cm² and angle of friction of 24.64°, Figures 4.21,4.22 and 4.23.

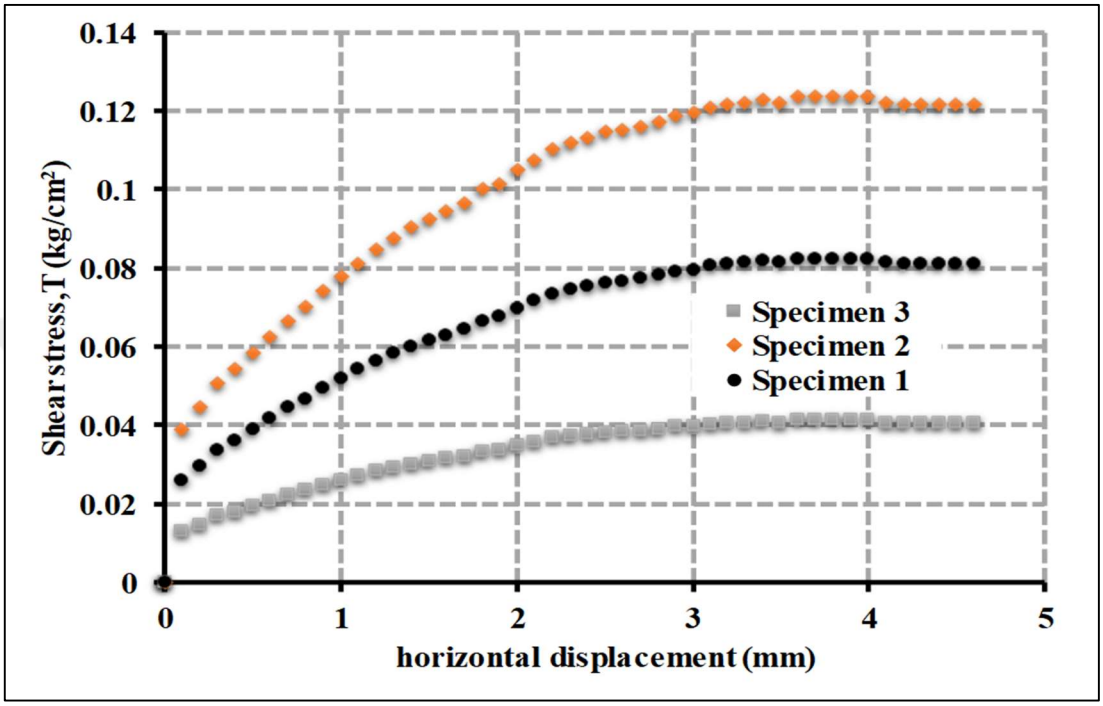

Figure 4.21. Shear stress- horizontal displacement for control sand

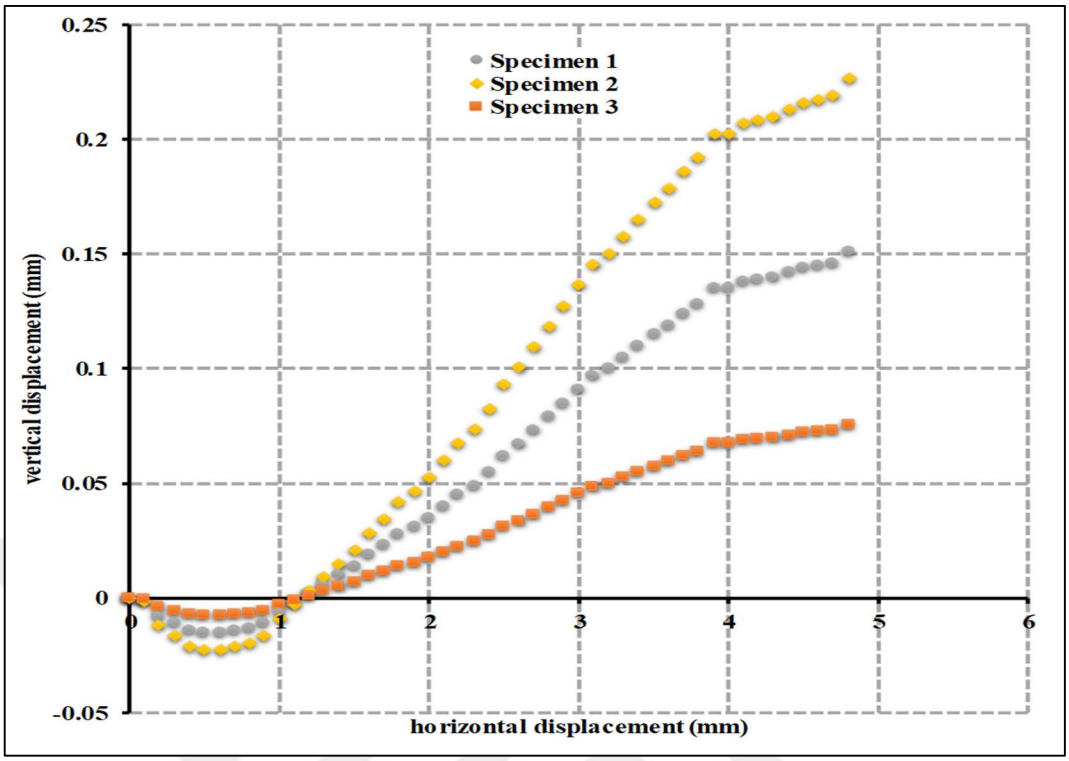

Figure 4.22. Vertical displacement - horizontal displacement curve for control sand

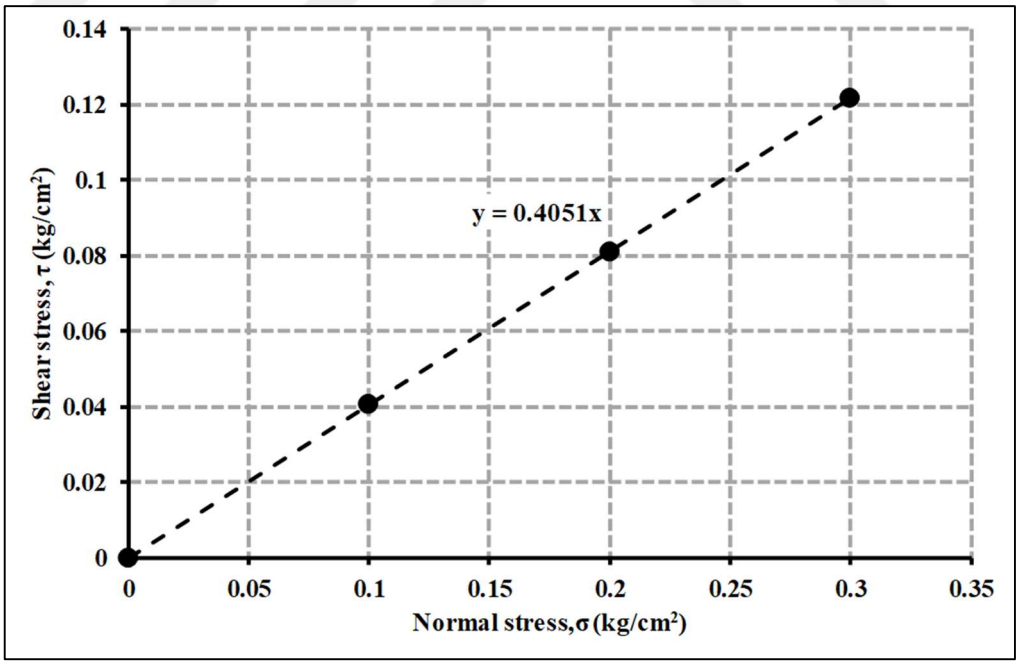

Figure 4.23. Shear stress – normal stress curve for control sand

Soil mix 1 had maximum shear strength of 0.081 kg/cm² and angle of friction of 24.48°which is nearly same as control sand see Figures 4.24,4.25 and 4.26, where the values are less than the same specimen without geogrid as the geogrid contributes additional friction to the soil

and the geogrid by the interface behavior . This interaction causes the shear strength and angle of friction to increase.

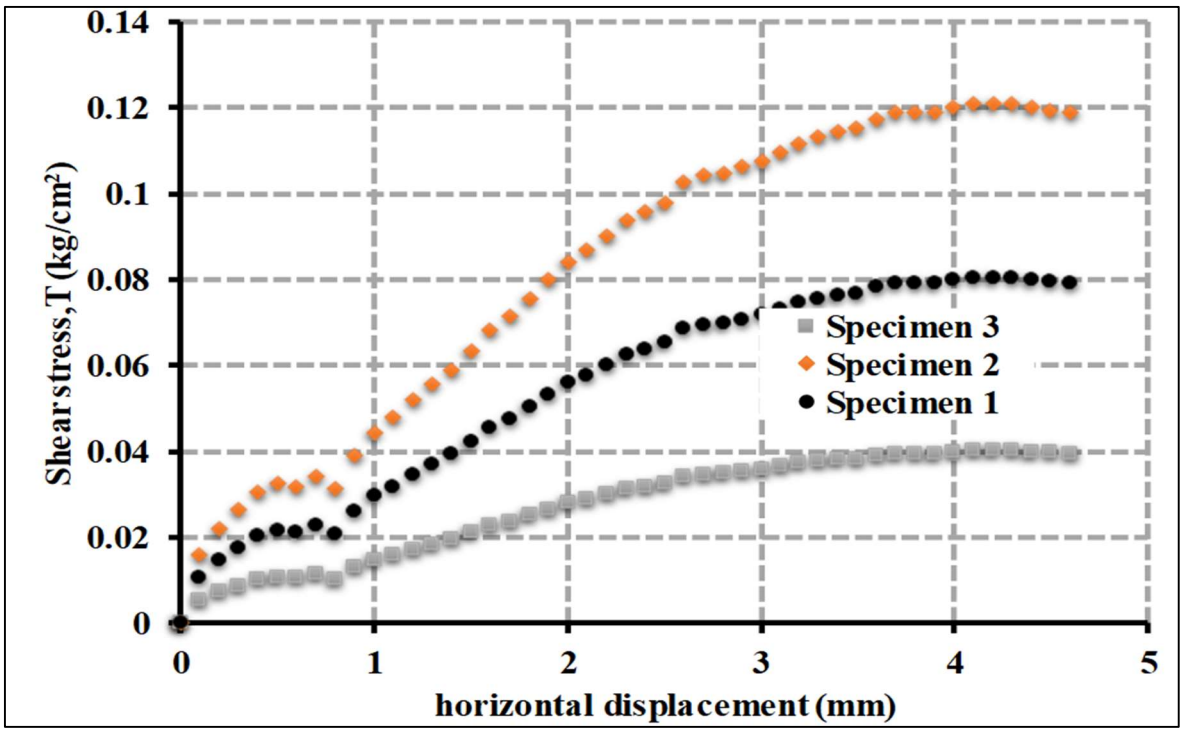

Figure 4.24. Shear stress-horizontal displacement curve for soil mix 1(20% slag)

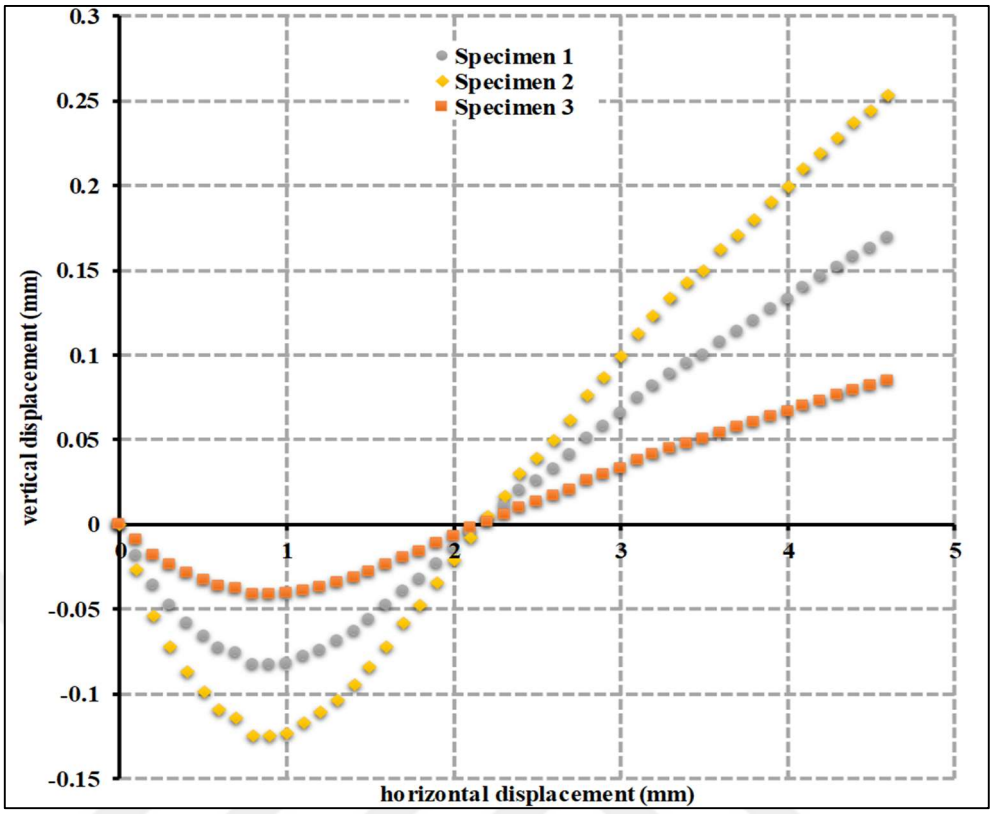

Figure 4.25. Vertical displacement-horizontal displacement curve for soil mix1 (20% slag)

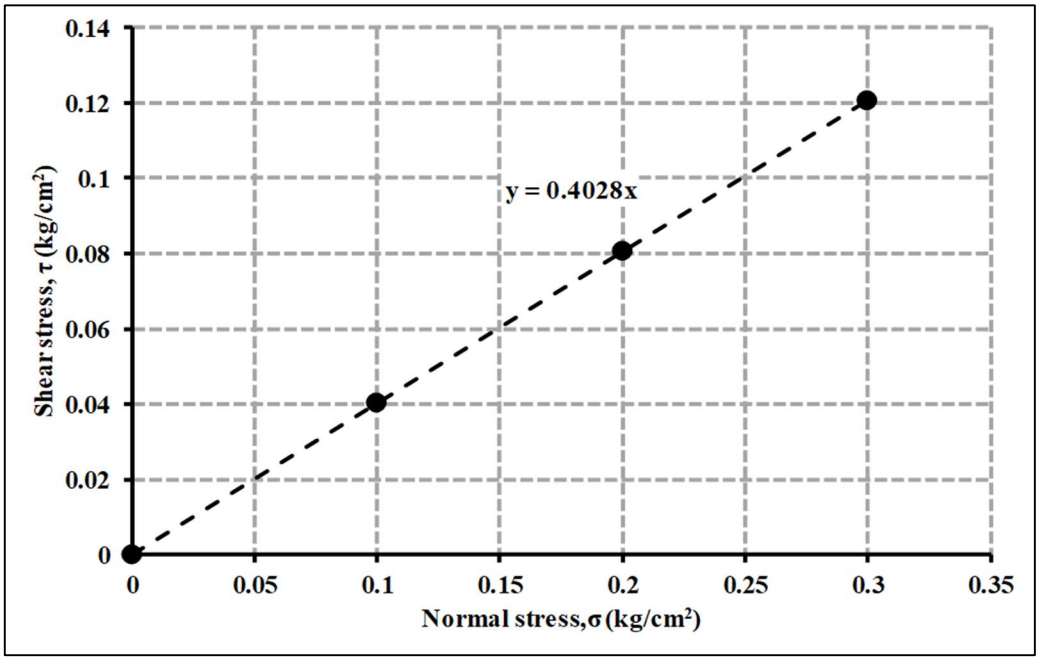

Figure 4.26. Shear stress-normal stress curve for soil mix 1(20% slag)

Soil mix 2 showed a significant increase in the shear strength by reaching up to 0.097 kg/cm² and causing an increase in the angle of friction by rising to 30.44°, as shown in Figures 4.27 , 4.28 and 4.29 . However , these values are still less than the results of the specimen without using geogrid but soil mix 2 indicates the second highest results.

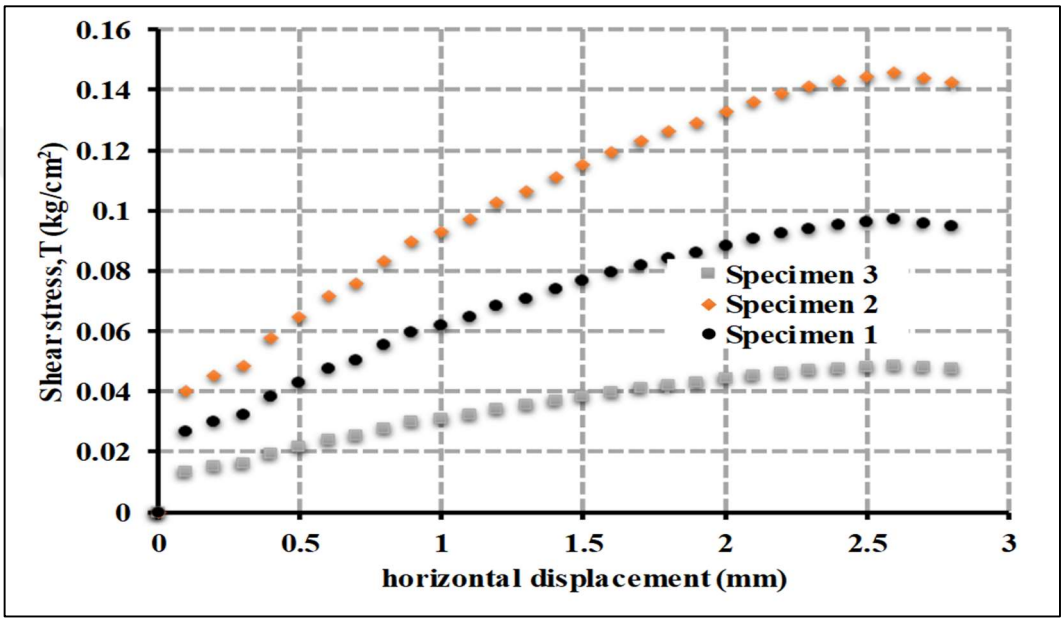

Figure 4.27. Shear stress-horizontal displacement curve for soil mix 2 (20 % slag)

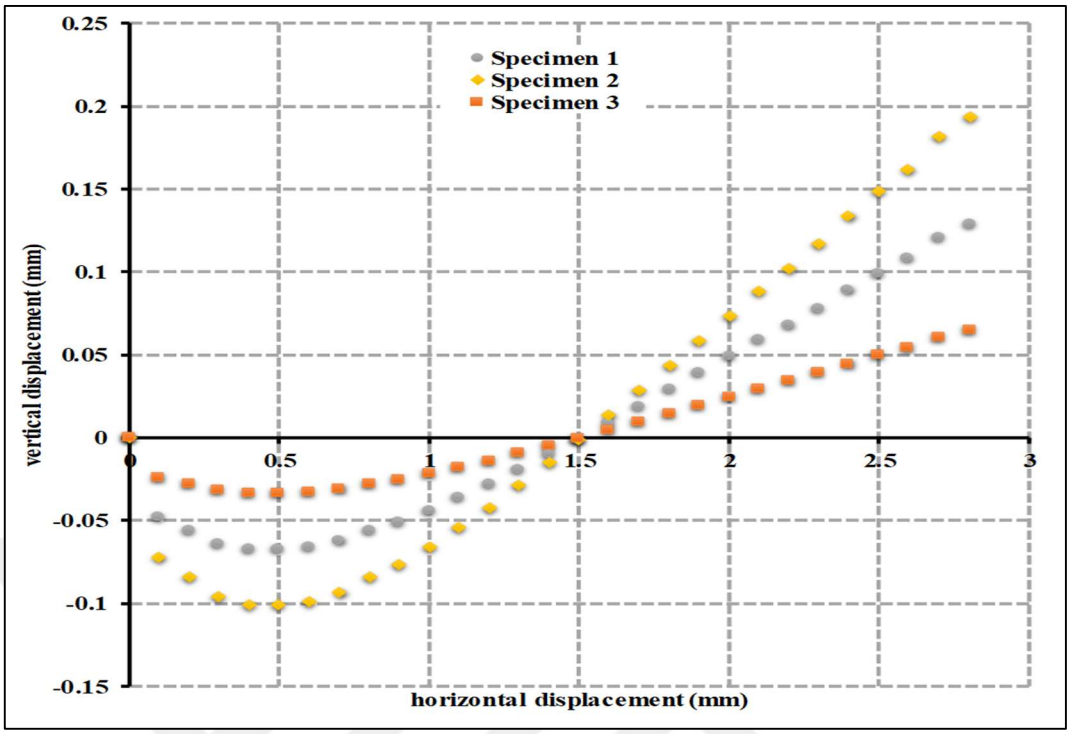

Figure 4.28. Vertical displacement -horizontal displacement curve for soil mix 2 (20 % slag)

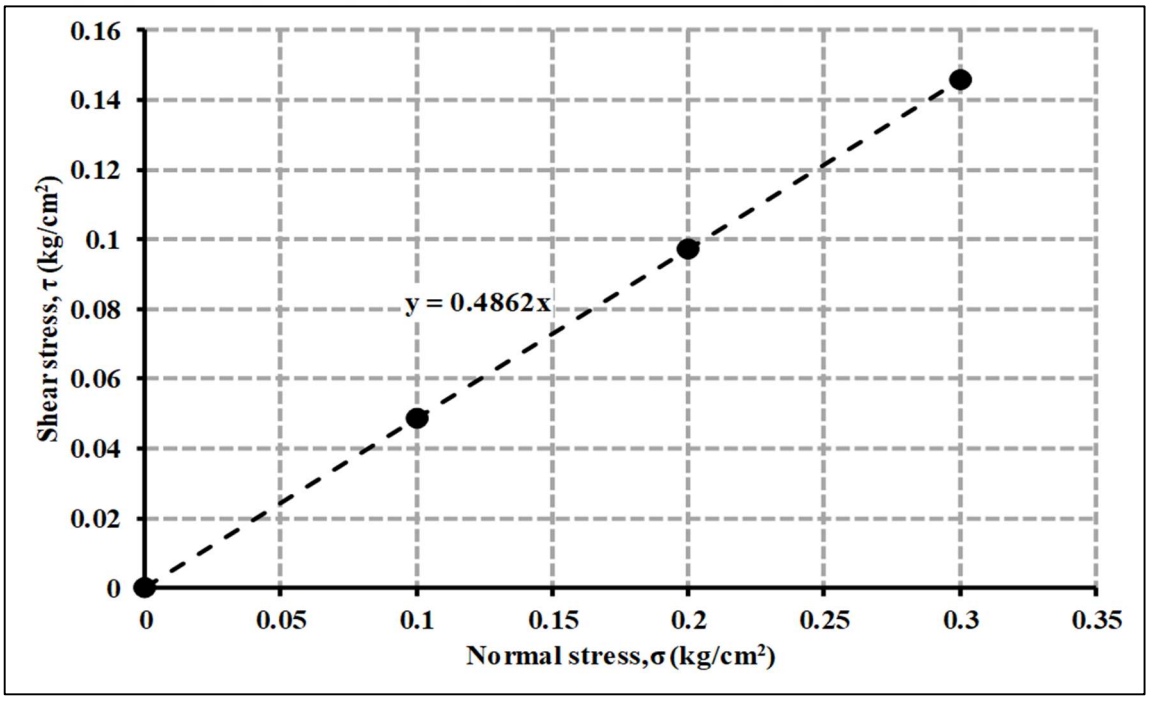

Figure 4.29. Shear stress-normal stress curve for soil mix 2(20% slag)

Soil mix 3 indicated a slight increase in the shear strength, reaching a value of 0.108 kg/cm² and the angle of friction of 34.58°, as shown in Figures 4.30,4.31 and 4.32, which is contrary to the results of soil mix 3 without geogrid where there was a slight decrease occurred between soil mix 1 and soil mix 4 during the previous experiment.

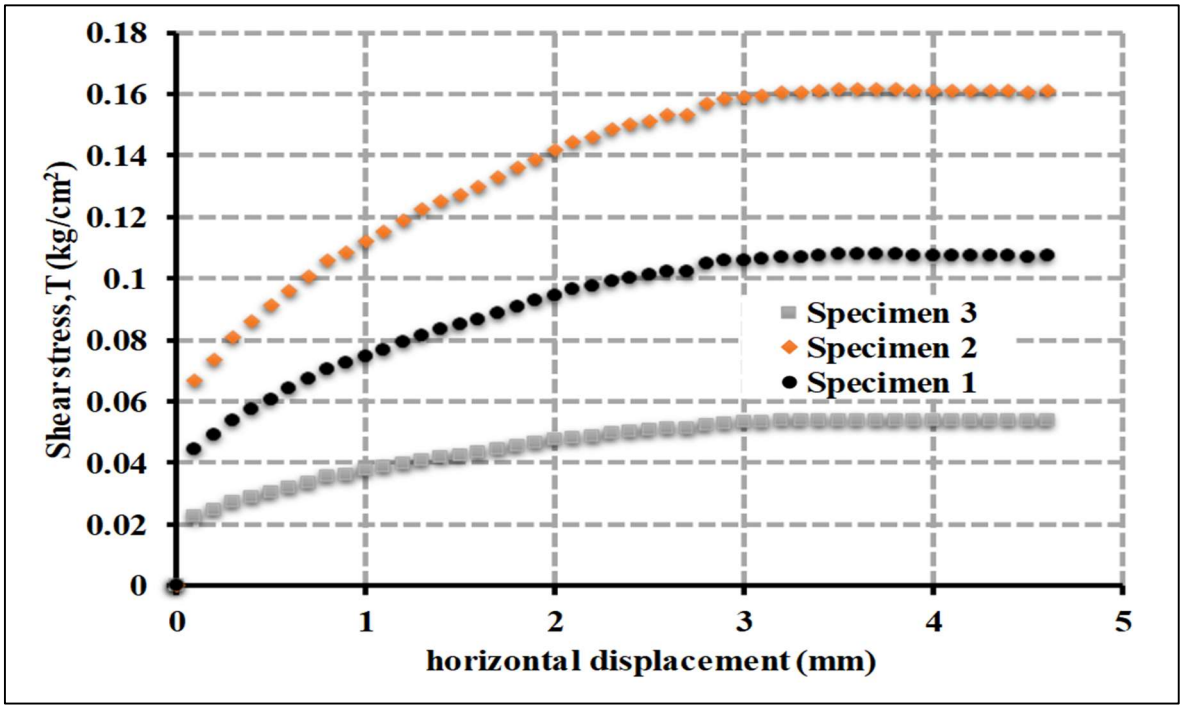

Figure 4.30. Shear stress-horizontal displacement curve for soil mix 3 (20 % slag)

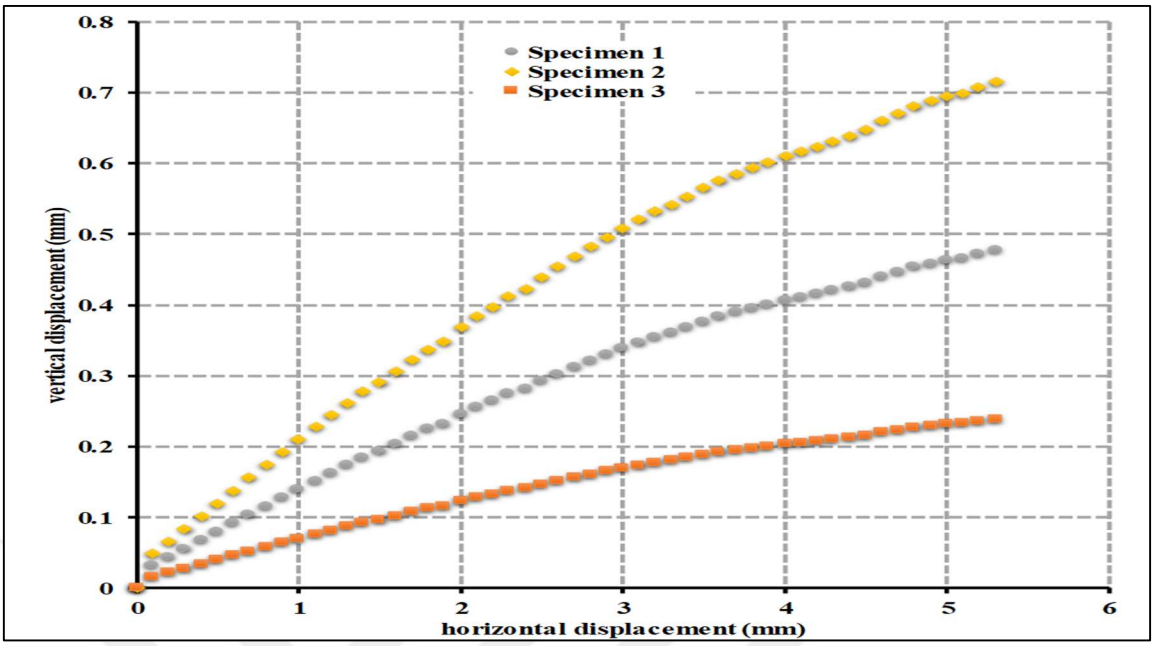

Figure 4.31. Vertical displacement - horizontal displacement curve for soil mix 3 (20 % slag)

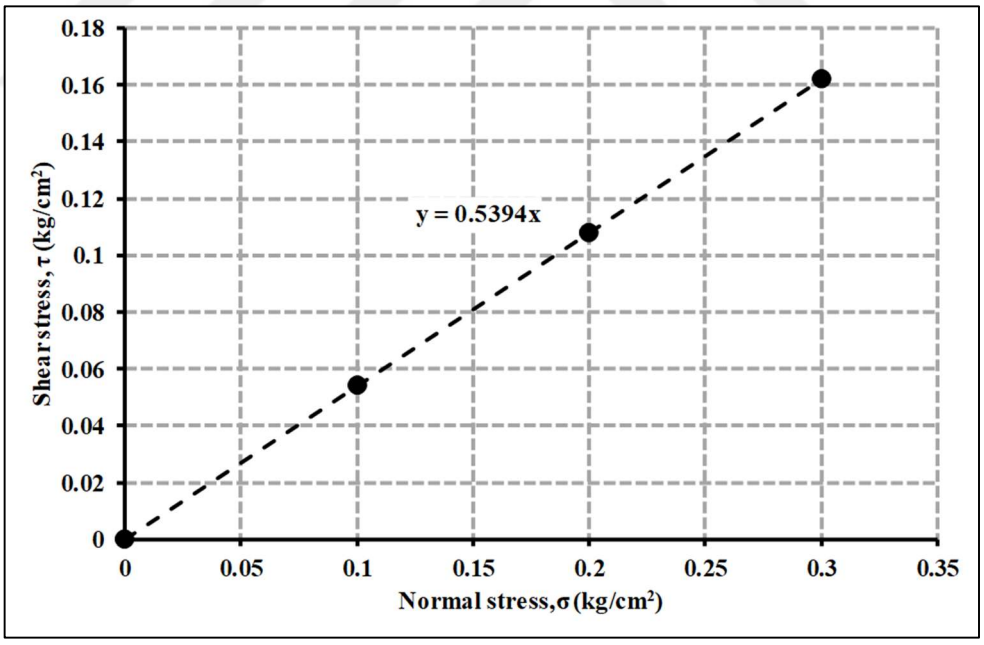

Figure 4.32. Shear stress-normal stress curve for soil mix 3(20% slag)

Results for soil mix 4 showed a decrease for both shear strength and friction angle, respectively down to 0.084 kg/cm², 25.92°, as observed in Figures 4.33,4.34 and 4.35. This decrease may occur due to the small grading size in this mix (0.25mm - 0.15mm - 0.075mm).

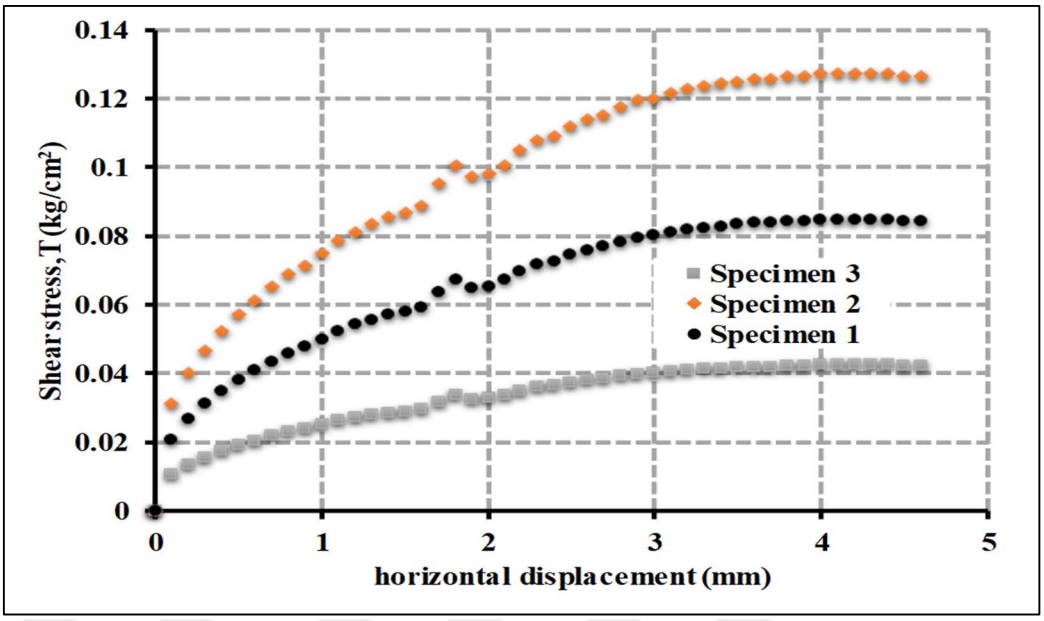

Figure 4.33. Shear stress-normal stress curve for soil mix 3(20% slag)

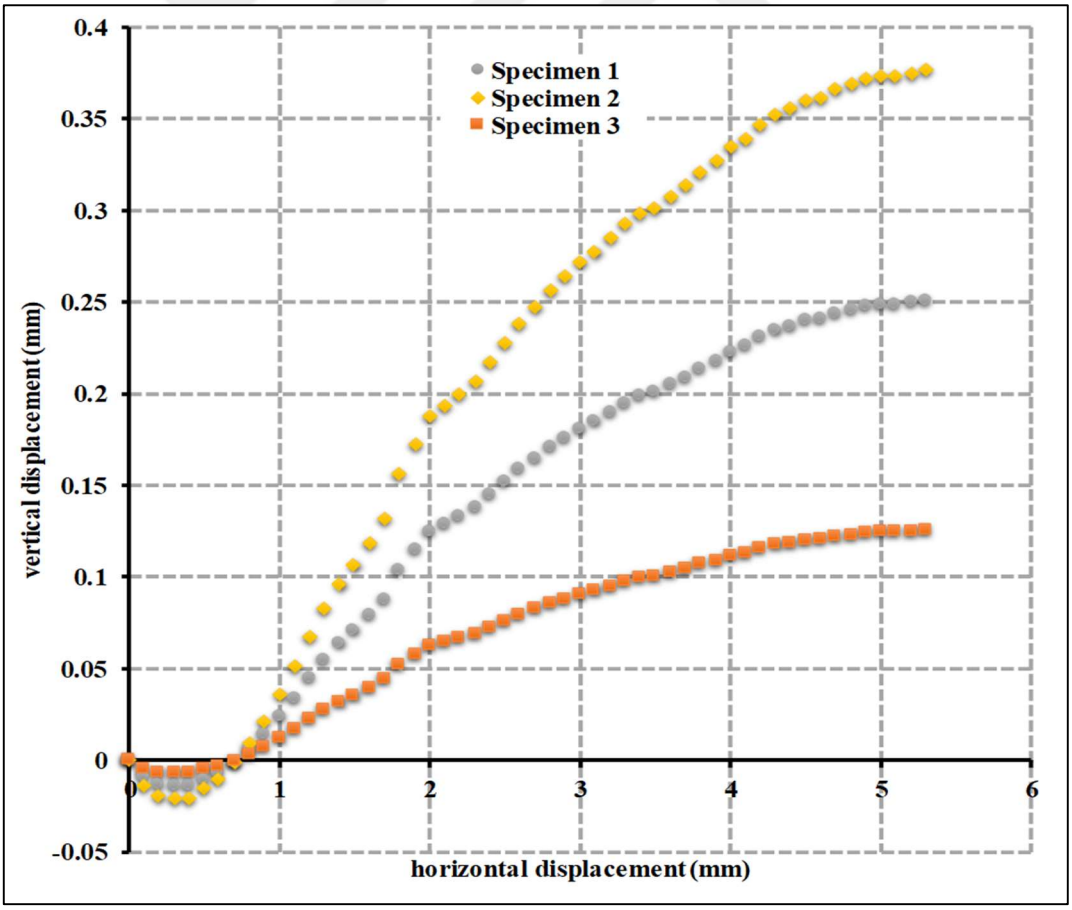

Figure 4.34. Vertical displacement - horizontal displacement curve for soil mix 4 (20 %)

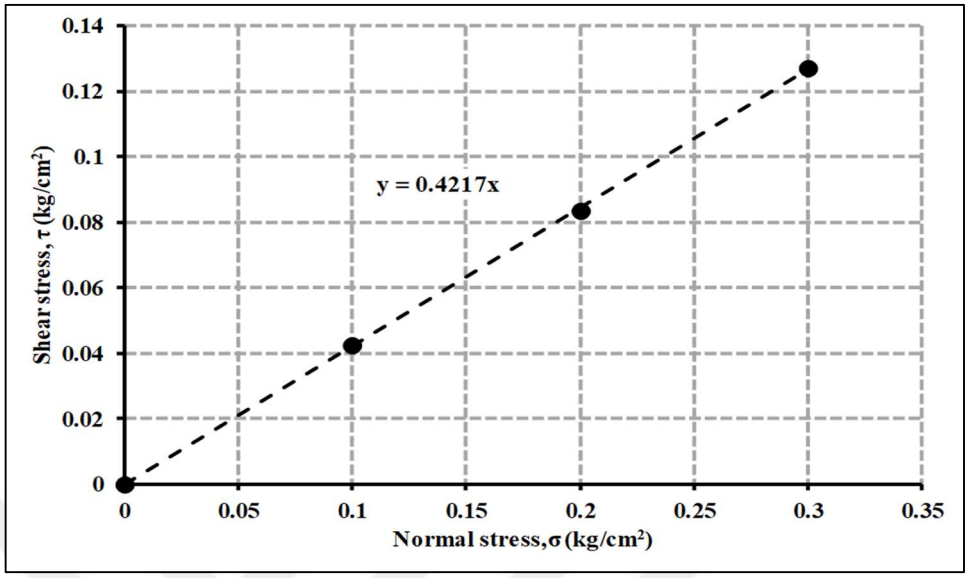

Figure 4.35. Shear stress-normal stress curve for soil mix 4(20% slag)

From Figures 4.36 and 4.37, the shear strength results for the geogrid-added slag-sand mixtures with the same grading sizes when compared with slag-sand mixtures without geogrid were found to be lower. This could be due to the rearranging of the slag particles underneath the geogrid layer with the existence of the slag that can might the arranging process during loading.

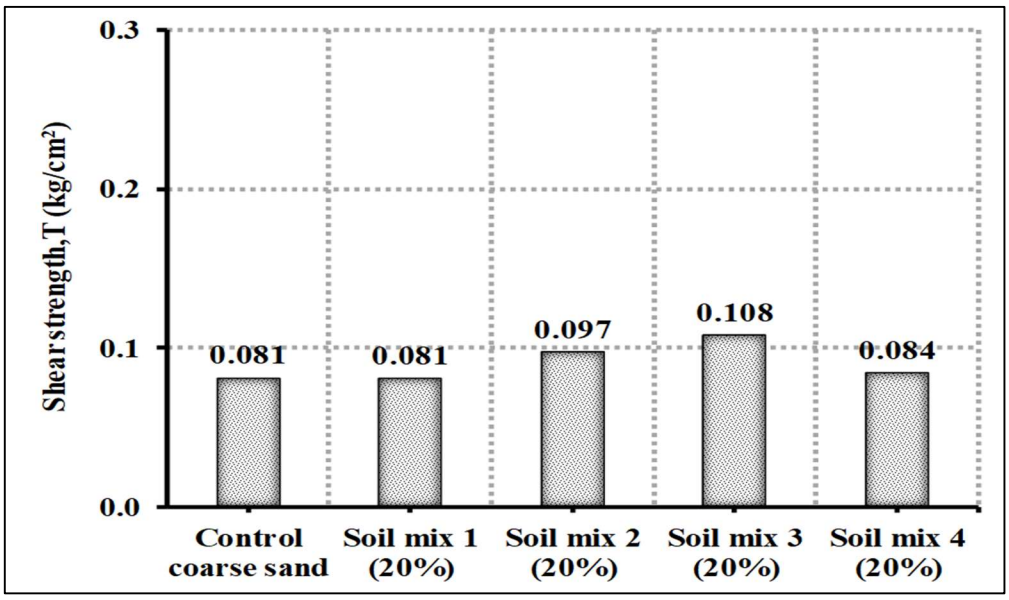

Figure 4.36. Results of shear strength (T) for different soil mixes (20 % slag)

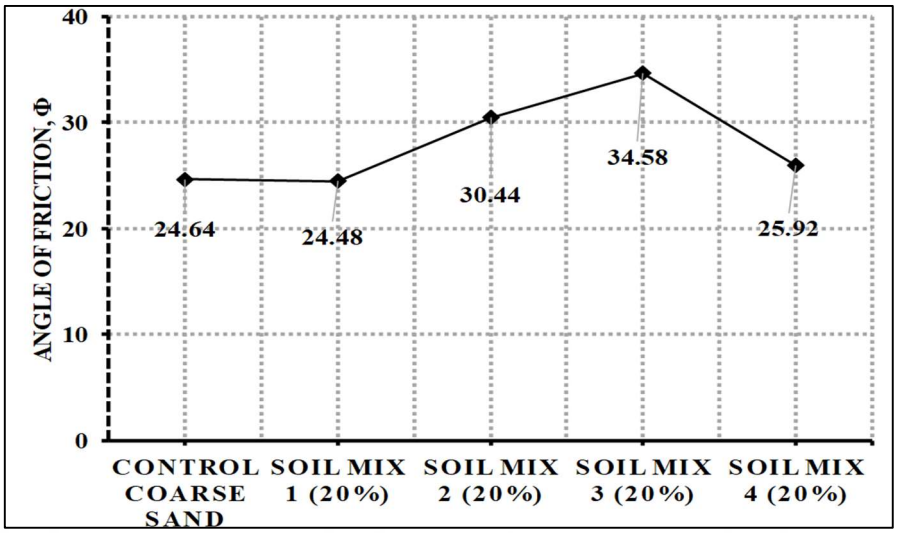

Figure 4.37. Results of interface friction angle (ϕ) for different soil mixes (20% slag)

Previous results showed that after mixing the slag with the sand, a significant increase in the average shear stress and interface friction angle were observed, but there was no pattern as fluctuation occured on the shear strength and interface friction angles values. All soil mixes initially contracted and then dilated as shown in the vertical displacement-horizontal displacement plots. Similarly, the control specimen initially contracted and then dilated from the vertical displacement-horizontal displacement plots.

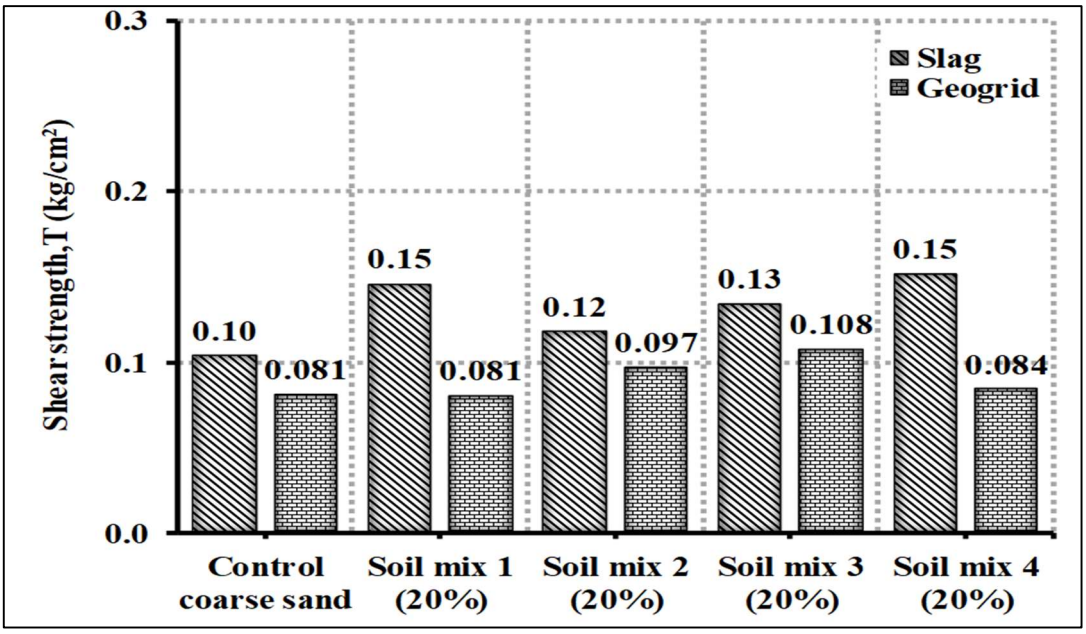

Figure 4.38. Results of shear strength (T) comparison for sand-slag specimen versus slag-sland with geogrid (20 % slag)

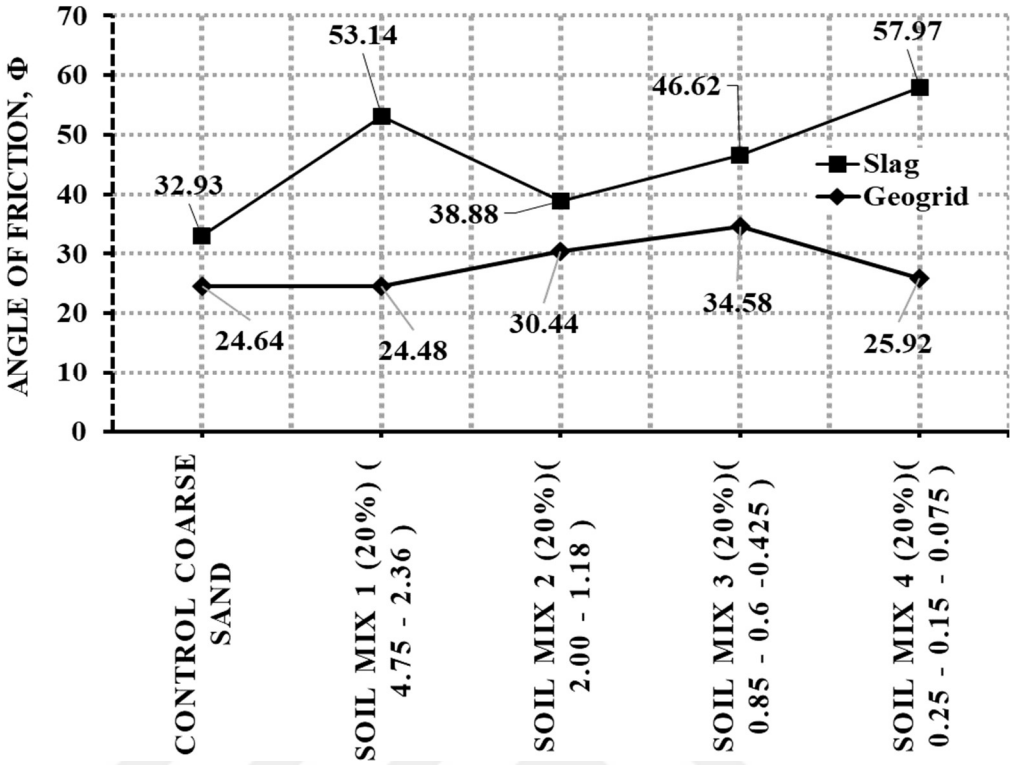

Figure 4.39. Results of internal angle of friction comparison for sand-Slag specimen versus slag-sand with geogrid (20 % slag)

Fluctations between results of internal angle of friction between sand-slag mixture and sand-slag mixture with geogrid occurred due to the presence of geogrid material at bottom layer which may cause pockets between geogrid layer and used soil with the particles.The arrangment of soil particles while conducting the test maybe one of the reasons . The highest value for soil mix 4 (0.25 - 0.15 - 0.075) due to its near particle size with sand which decreases the probability of voids .

4.3.3. Tires Chips

4.3.3.1. Standard Proctor Compaction

Tire chip might penetrate into the soil due to tire abrasion by the friction of the vehicles'tires with the roads or the shredding of tire waste when it reaches an expiration date. Many studies have discussed the percentage of tire abrasion with different aspects concerning a different way of gathering those particles. Tire chips particle appears to exist in soil as contaminated parts from car tire abrasion, which happen naturally between tires and asphalt on roads in different quantities and particle sizes depending on many factors like tire type, temperature, and vehicle speed.Tire chip particles which naturally exist from abrasion, differ in sizes but in most exact sizes, around 0.6nm – 700 nm, which is easy to be air born where studies take place on the Tire chips using many different collecting methods.Those studies have focused on different particle sizes according to the modeling ways.At first, the testing program took place on the optimum percent reached by Dierkes et al. (2019), which was 1000 mg/kg (i.e., 1 g/1000 gm), which means 0.1 percent as the optimum result of tire abrasion of the studied road. The latter can be artificially applied using that kind of waste during roads construction with determining the effect on soil parameters where the optimum dry unit weight and the optimum water content are the most important ones for many applications in order to achieve the goal of waste disposal technique serving a construction aspect without deterioration in soil parameter. In Proctor compaction test, all the specimens were oven-dried at a temperature of 105 °C . However, the tire chip particles are affected at temperatures higher than 200 °C. Figure 4.40 shows the existence of the tire chips particles after being dried, even proving the microplastic particles are not affected by temperature till the degree was approved by Kerekes et al. (2017), Juma et al. (2006), and Epic et al. (2021).

Figure 4.40. Oven dried sand specimen showing the tire chips particles

The standard Proctor compaction tests were initiated by using the control sand as the reference for the results. The control sand indicated a dry unit weight of 1.640 dry gf/cm³ with an optimum moisture content of 15 percent , as shown in Figure 4.41.

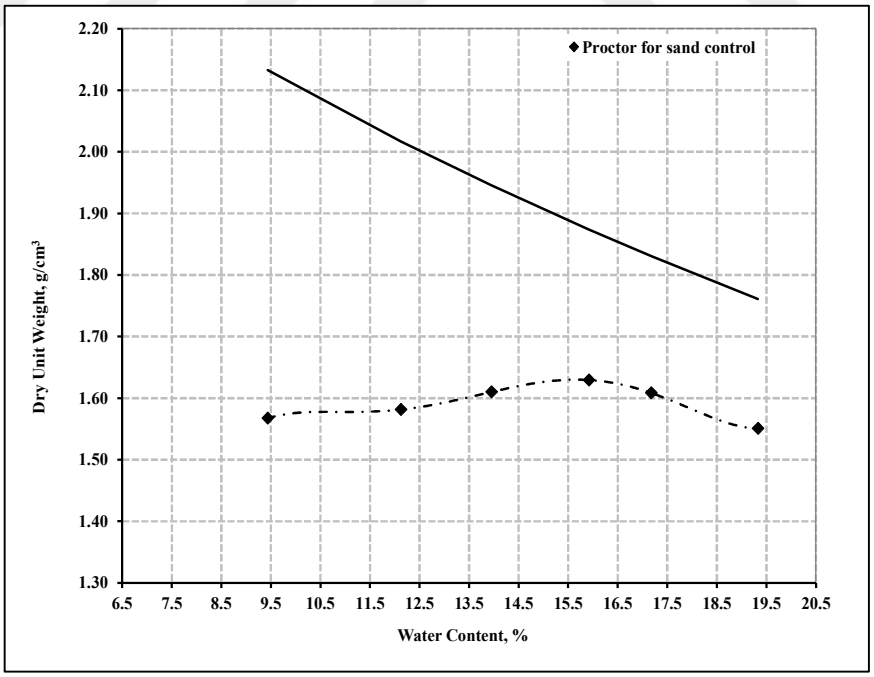

Figure 4.41. Compaction graph for control sand

The starting percentage was determined to be the same percentage taken from the previous study, which appears to be 0.1 percent of tire chips. As a results, the maximum dry unit weight and optimum water content were measured as 1.684 gf/cm³ and 14.93% respectively, as shown in Figure 4.42.

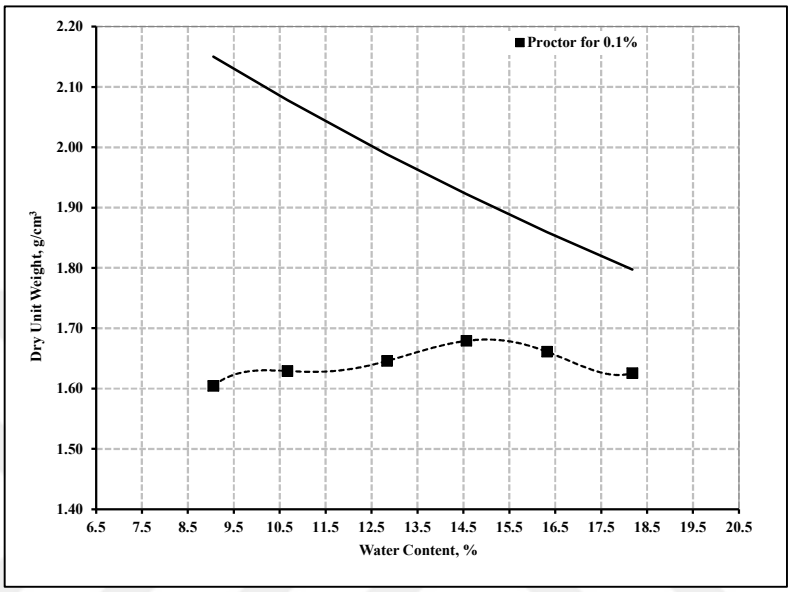

Figure 4.42. Compaction graph of sand-0.1% tire chips mixture

In order to determine the most purposive percentage to get rid of much tire chips waste without affecting the soil dry unit weight, a lower percentage of 0.05 was used, and gave a result of 1.661 gf/cm³ maximum dry unit weight with the optimum water content of 15.91%, as shown in Figure 4.43.

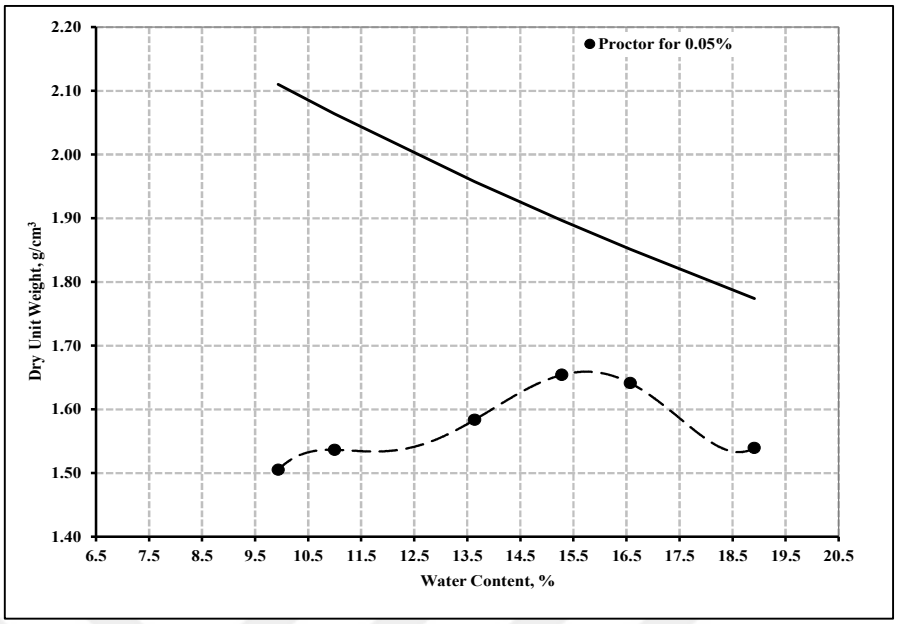

Figure 4.43. Compaction graph of sand-0.05% tire chips mixture

After testing a lower percentage which gave a lower result than the 0.1 percentage, more tire chip amounts were examined, starting with 0.2 percent, as its essential to use small amounts due to the fact that the tire chip particles are light material; therefore, the percentages should be increased gradually. The soil mix using 0.2 percent gave a better result with 1.705 gf/cm³ maximum dry unit weight and an optimum water content of 13.88 %, as shown in Figure 4.44.

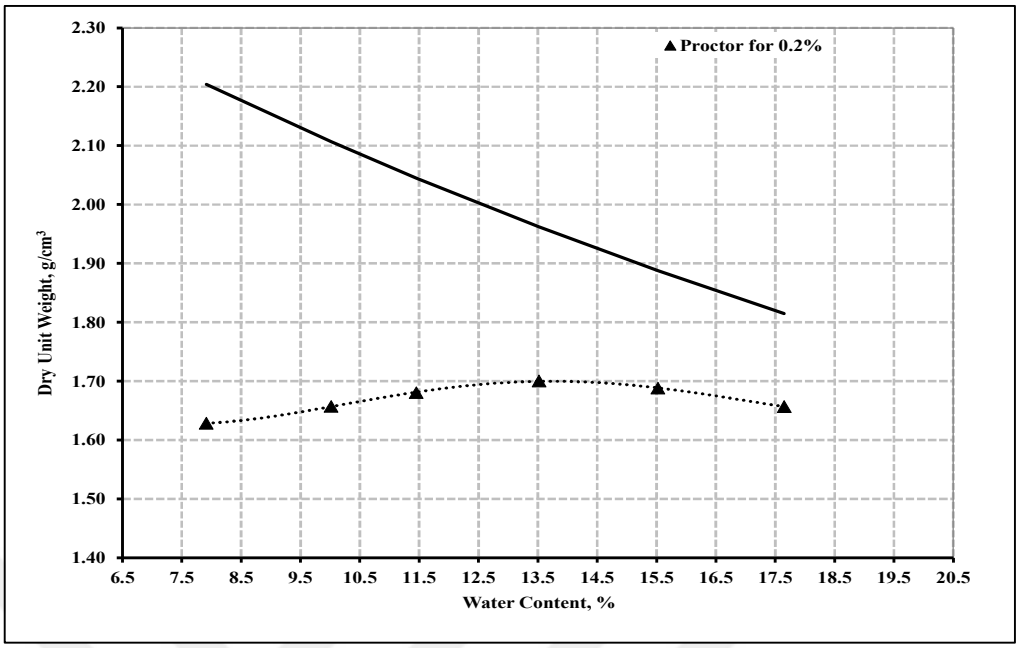

Figure 4.44. Compaction graph of sand-0.2% tire chips mixture

A percentage of 0.4 tire chips for another soil mix was applied for tracking the effect of tire chips on sand which showed a better result of 1.735 gf/cm³ maximum dry unit weight with 12.6% optimum water content, as shown in Figure 4.45.

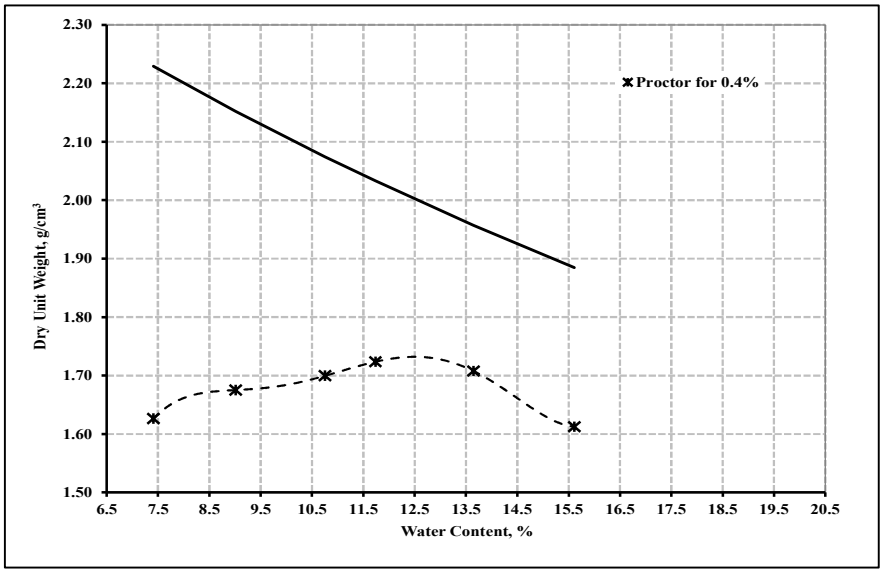

Figure 4.45. Compaction graph of sand-0.4% tire chips mixture

The percentage of tire chips was increased to 1 percent for a better determination of the tire chips effect, where a decrease in the compaction curve was observed by decreasing the maximum dry unit weight to 1.718 gf/cm³ with an optimum water content of 13.05%, see Figure 4.46.

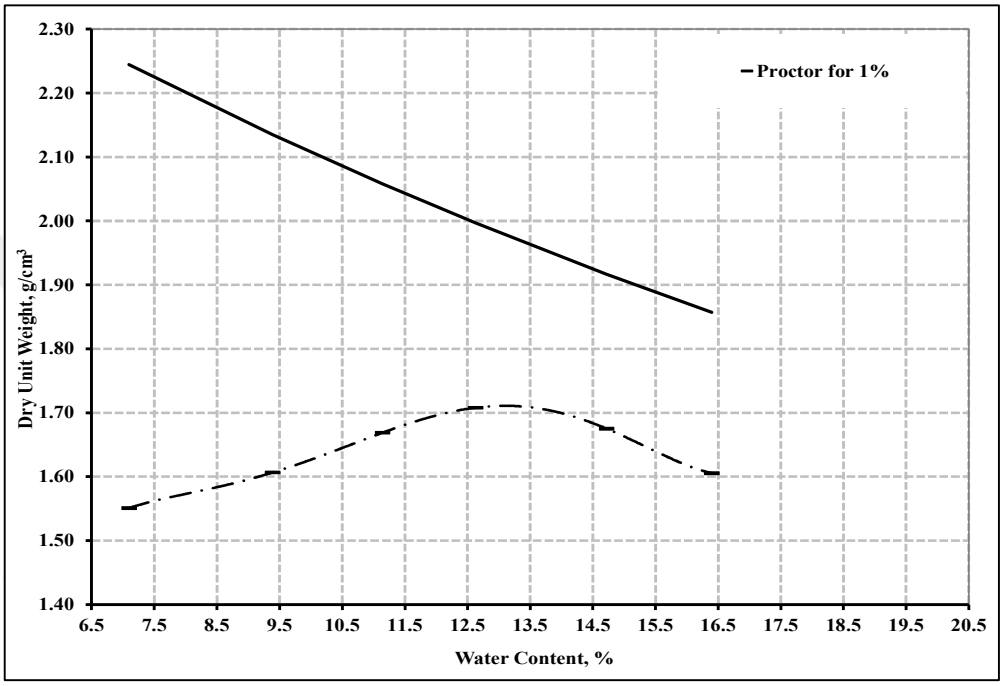

Figure 4.46. Compaction graph of sand-1% tire chips mixture

The final soil mix was conducted by using 2 percent of tire chips to ensure the tire chip's effect on soil dry unit weight, The results indicated a decrease to 1.676 gf/cm³ in the maximum dry unit weight with an optimum water content of 15.8% , as shown in Figure 4.47. These results indicated that the sand soil was improved by adding the tire chips up to a content of 0.4% by dry mass in terms of compressibility although there is a low-level risk for the contamination of the soil with the microplastics.

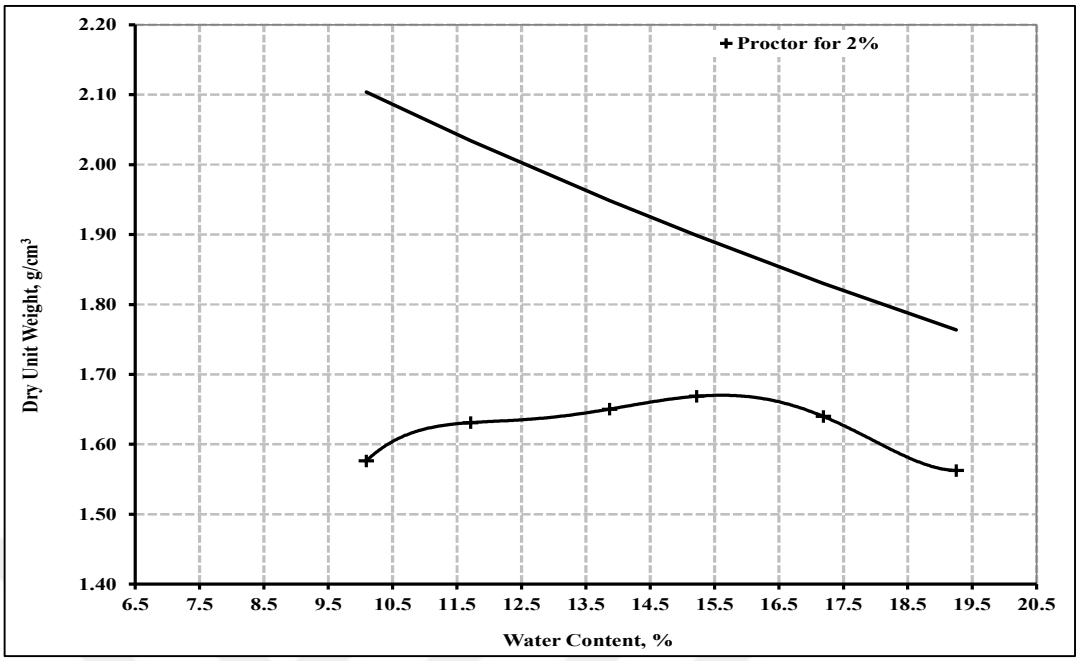

Figure 4.47. Compaction graph of sand-2% tire chips mixture

Actually, the tire chips that are in microplastics size are not artificially added to soil, however, they naturally exist through contamination of air-carried particles due to the abrasion between car tires and asphalt layer in roads and highways . Researchers have begun to discuss this contamination by focusing on the quantity, particle size, and effect of these materials through different ways of simulation by gathering these particles. This study was concerned with adding the same quantity discovered by Dierks et al. (2019) who found the concentration of 0.1percent as the optimum percentage of contamination that occurred in soil beneath roads . The addition of the tire chips that can be considered as a waste disposal technique and soil improvement method migh also cause environmental contamination . However , adding small amount (0.4 percent) of tire chips indicated an improvement in the dry unit weight for pure sand . By increasing and decreasing percentage differed from each other but are found to be higher than the maximum dry unit weight of the control sand which shows no bad effect in terms of the geotechnical aspect as shown in Figure 4.48.

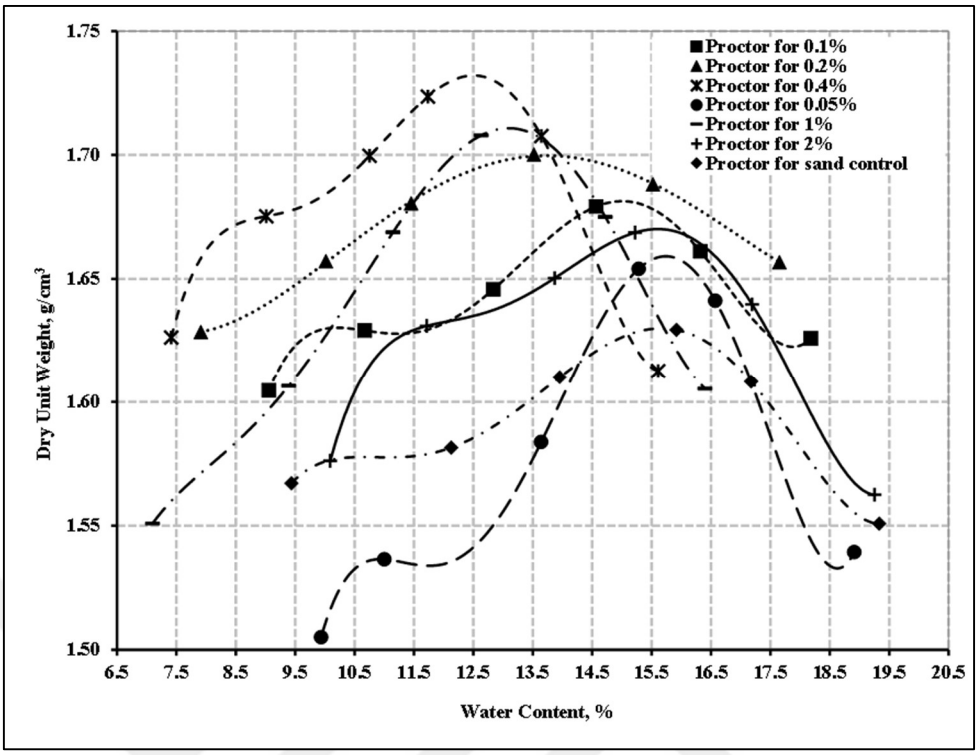

Figure 4.48. Comparison of maximum dry unit weight and optimum water content between control sand and sand -tire chips mixtures with different tire chip percentages

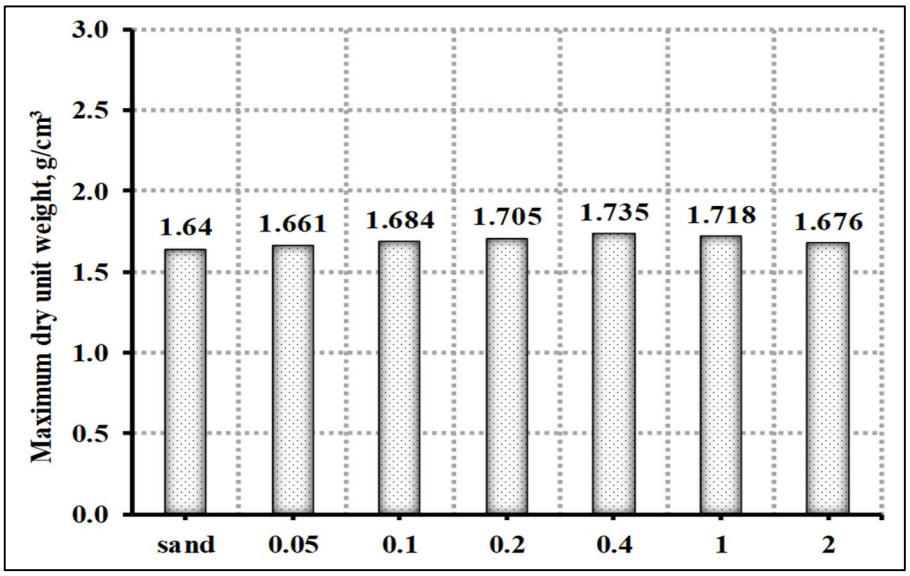

Figure 4.49. Bar chart showing maximum dry unit weight comparison between sand and sand-tire chip mixtures

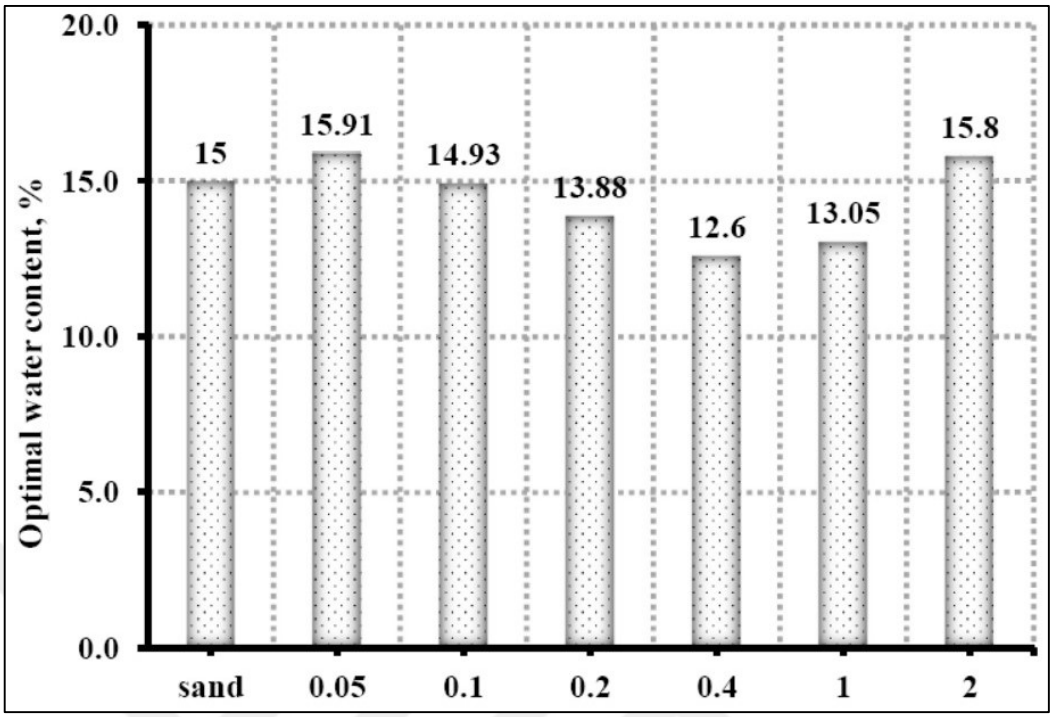

Figure 4.50. Bar chart showing optimum water content comparison between sand and sand-tire chip mixtures

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

In this thesis, the effect of using different environmental wastes that can be considered as soil improvement, are discussed through different aspects.

5.1.1. Slag

Slag material was prepared first by spreading and determining some physical properties like initial and final setting time and compressive strength, then sieve analysis to figure out more about the used material showing an excellent physical properties like durability, high hardening value, skin resistance and due to the presence of cementitious nature and lime particles. Slag particles indicated good interlocking behavior between sand particles due to the variation of slag particles' shape and size. Slag improved the strength of the sand used in this study and the soil improvement provided by the slag-sand mixture helped to get rid of a huge quantity of slag waste due to the high percentage used here in this study, 20 percent in the shear experiment while 50 percent in the Proctor compaction and sand cone tests.

1) The Proctor compaction test followed by a sand cone was conducted to show the effect of using slag in soil replacement application, which gave a good result compared to an entire sand specimen. It indicated two achieved goals either to be used instead of some sand or to be replaced with complete gravel or a percentage of gravel, which might help to improve the engineering properties of the sand by eliminating economic concern and getting rid of slag waste in huge quantities.
2) The maximum dry unit weight obtained from the Proctor compaction tests showed recognizable improvement from 1.640gm/cm³ for the control sand to 2.033gm/cm³ for sand-slag (1:1) specimen.
3) The sand specimen for sand cone shows an average of 1.81 gm/cm³ as dry density while addition of slag enhanced the dry to denisty in the both trials with value of 1.953 gm/cm³ and 1.967 gm/cm³ for dry denisty respectively .

4) Shear strength of sand-20 percent slag mixture was compared soil mixes depending on gradation size of the slag in the mixtures . The gradation size of slag in the mixtures is new and innovative in the experimental program, which might help to implement more waste disposal techniques depending on the particle size, which might differ from one country to another. The gradation size of the slag with the range of (4.75 mm- 2.36mm) and (0.25mm - 0.15mm - 0.075mm) leaded to the highest shear strength of 0.15 kg/cm² and internal friction angle of 53.14° and 57.97° respectively.
5) Shear results showed different pattern where all the mixes achieved an improvement in the shear strength and angle of friction but differed from gradation size to another as the improvement in the gradation size of (2.00mm - 1.18mm) was less than the improvement in both mixes containing slag with gradation sizes of (4.75 mm- 2.36mm) and (0.25mm - 0.15 mm- 0.075mm) .
6) Slag particles mixed with sand was well mixed with the addition of water and applied energy for the compaction as there was cementation on the surface of the tested area due to the slag cementation behaviour .
7) Shear strength was also evaluated by adding a geogrid layer as a secondary material to the same soil mixes by leading to lower values in some mixtures. The direct shear test was conducted with a geogrid layer showed that the gradation size of (0.85 mm- 0.6mm -0.425mm) leaded to the highest shear strength of 0.108 kg/cm² and internal friction angle of 34.58° which was higher without geogrid with shear strength of 0.13 kg/cm² and internal friction angle of 46.62°.
8) Change of results due to the addition of geogrid can be beneficially used according to the needed application as the available gradation size can be used as outlined in a project design procedure.
9) The highest value for soil mix 4 (0.25 - 0.15 - 0.075) due to its near particle size with sand which decreases the probalility of voids while the presence of geogrid may caused a higher void due to its place of installation which decreased the internal angle of friction .

5.1.2. Tire Chips

Microplastic wastes, especially tire chips, exist in huge quantities . The scientists have been concerned about that because of tmicroplastics' effect on the environment and marine life. So, it was necessary to mention a branch about the waste disposal ways for that waste in this study.

1) In this study , tire chips were manufactured by the disposal of waste tires where shredded into small particles in order to be easier for any waste disposal application trials.
2) Microplastic usage showed an enhancement and good effect on the control sand by performing the standard Proctor test where the sand had a maximum dry unit weight of 1.640 gf/cm³ . 0.05 percent tire chips addition resulted in a value of 1.661 gm/cm³ which is higher than that of control sand.
3) Adding 0.4 percent of tire chips caused the maximum dry unit weight to increase up to 1.735 gf/cm³ while adding 1 percent showed a slight decrease to 1.718 gf/cm³.
4) 0.4 percent of tire chips in the sand was found to be the optimum enhancement for the control sand, while increasing the tire chips amount to 1 and 2 percent leaded to decrease in the maximum dry unit weight .
5) The optimum maximum dry unit for sand-tire chip mixtures was located between 0.4 percent and 0.1 percent as those percentages were not tested .

5.2. RECOMMENDATIONS

5.2.1. Slag

1) Slag and sand mixtures can be examined in different contents to be used for more applications.
2) For further work, slag needs to be mixed with gravel by having different contents depending on its particle size variation.
3) The shear strength and compaction parameters obtained from this study can be compared with the results of problematic soils to discuss the improvement effect .

4) Examining higher and lower contents of slag with the same grading classification in various soil mixtures might help to grasp optimum content for soil improvement and waste disposal.
5) Slag has been proved to have a significant effect on control sand and is an excellent natural resource that mostly does not need improvement in some cases, so that enhancing effect can be examined through clayey and silty soils and this can be more beneficial for that study.
6) Consideration of specimen density used for shear strength test should be considered .

5.2.2. Tire Chips

1) For further studies, using more shredded tires for soil improvement is vital to eliminate enormous tire mass that might contaminate the soil naturally as being microplastics.
2) Other soil parameters such as hydraulic conductivity, swell index and shear strength have to be measured by performing laboratory tests on tire chip-added soils. Afterwards, the effect of adding tire chips to the soil can be evaluated in terms of soil improvement and also contamination by considering the related soil parameters.
3) Higher tire chip contents can be added to a sandy soil in order to evaluate the effect of tire chips on the compressibility of the sand that is used as the subsoil for roads.
4) Tire chips having the same contents can also be mixed with a gravely soil and the results can be compared to this study in which a sandy soil was mixed with the tire chips. A gravely soil can serve high performance as a subsoil beneath a road and its compressibility is significant for the usage beneath the road.
5) Direct shear test should be applied on tire chip-added sand mixturess in order to compare the shear strength of slag-sand mixtures with tire chips-sand mixtures.
6) Water can carry the small tire chips particles among the voids of the sand and this mechanism might cause contamination due to the microplastics. Because the microplastics might be carried to the deeper levels of the soil, there is the risk for the tiny particles to diffuse into the groundwater or to the rivers, lakes, etc. In order to evaluate this risk, hydraulic conductivity tests should be performed on the tire chip-added sandy soils as a future research.

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