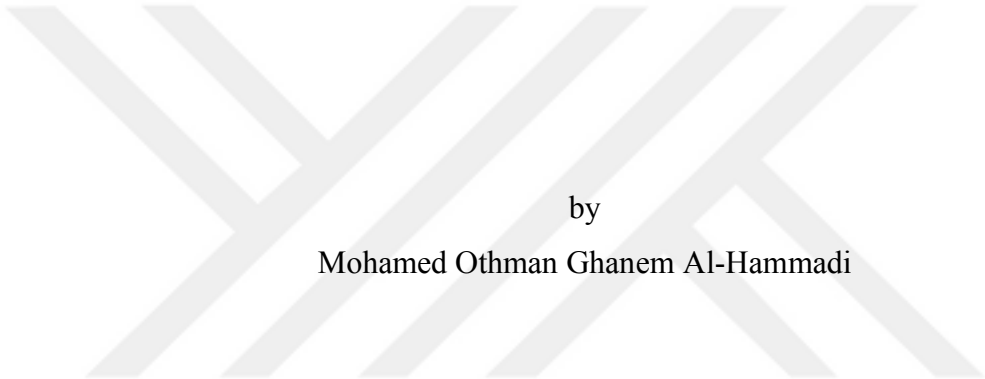


PLASTICITY AND COMPACTION CHANGE OF POLYACRYLAMIDE AND TIRE
CHIP-ENHANCED SAND-BENTONITE MIXTURES



by

Mohamed Othman Ghanem Al-Hammadi

Submitted to Graduate School of Natural and Applied Sciences
in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering in
Civil Engineering

Yeditepe University

2023

PLASTICITY AND COMPACTION CHANGE OF POLYACRYLAMIDE AND TIRE
CHIP-ENHANCED SAND-BENTONITE MIXTURES

APPROVED BY:

Assoc. Prof. Dr. Hakkı Oral Özhan
(Thesis Supervisor)
(Yeditepe University)

.....

Prof. Dr. Mehmet Murat Monkul
(Yeditepe University)

.....

Assoc. Prof. Dr. Mücahit Namlı
(Istanbul Medeniyet University)

.....

DATE OF APPROVAL .././20...

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Name, Last name Mohamed Othman Ghanem Al-Hammadi

Signature



ACKNOWLEDGEMENTS

I would like to start by giving gratitude to the Almighty God, who showered me with blessings during my study, allowing me to reach my goal and publish my findings.

Assoc.prof.Dr. Hakkı Oral Özhan, has been an inspiration as my research supervisor and has helped me tremendously. His energy, insight, honesty, and ambition have been really motivating to me. He instructed me in the proper procedure for conducting research and for presenting the results of that investigation in an understandable format. Working and learning under his supervision was an incredible honor. I appreciate his kindness, sympathy, and hilarious humor as much as I appreciate our relationship. I owe a great debt of gratitude to my parents for all they have done for me in terms of providing me with a solid education and setting me up for success in life. I owe a debt of gratitude of gratitude to my wife her constant encouragement and patience during the entirety of my study. I would like to thank my brothers and sisters for their support I am really grateful for that. I appreciate the backing from the administration Applied Science Institute. For being very helpful for me.

Finally, I'd want to express my gratitude to everyone who has helped me in any way throughout this study journey.

ABSTRACT

PLASTICITY AND COMPACTION CHANGE OF POLYACRYLAMIDE AND TIRE CHIP-ENHANCED SAND-BENTONITE MIXTURES

The present study aims to examine the impact of anionic and cationic polyacrylamide and tire chips considered as microplastics, on a sand-bentonite mixture consisting of 85% sand and 15% bentonite. The objective of this investigation is to assess the influence of different concentrations of polyacrylamide (0.5%, 1%, and 2%) and tire chips (0.05%, 0.1%, 0.2%, 0.5%, 1%, and 2%) on the engineering characteristics of soil, measured by Atterberg limits and Proctor tests. This thesis examines the effects of polyacrylamide and tire chip concentrations on the previously listed essential parameters by treating the sand-bentonite mixture. Additionally, the Proctor test is performed to evaluate the compaction properties of soil, with the aim of examining the ideal moisture content and maximum dry density of the modified sand-bentonite mixture. This examination facilitates the identification of optimal compaction parameters and the subsequent assessment of the soil's stability and strength. The experimental methodology consists of the preparation of diverse soil samples with varying proportions of polyacrylamide and tire chips. The mentioned specimens were subjected to Atterberg limits and Proctor tests in accordance with established procedures. The process of data analysis involves the comparison of outcomes derived from the altered mixtures with those of the control samples. Test results indicated that both anionic and cationic polyacrylamide and tire chip addition led to a decrease in maximum dry unit weight, an increase in optimum water content and plasticity index, and a decrease in liquid limit. The highest difference due to the additive addition was obtained with 2% anionic polyacrylamide by dry mass. When compared with no addition, maximum dry unit weight decreased from 1.76 to 1.65 gf/cm³, optimum water content increased from 16 to 18.2%, plasticity index increased from 14 to 19% and liquid limit decreased from 53 to 43% due to 2% anionic polyacrylamide addition. This study will clarify how polyacrylamide and tire chips influence the engineering properties of a sand-bentonite mixture. This study can help civil engineers and geotechnical engineers understand how suggested additives might improve soil quality.

ÖZET

POLİAKRİLAMİD VE LASTİK ATIĞI KATILMIŞ KUM-BENTONİT KARIŞIMLARININ PLASTİSİTE VE KOMPAKSİYON DEĞİŞİMİ

Bu çalışma, ayrı ayrı karıştırılmış (hem anyonik hem de katyonik) poliakrilamid ve mikroplastik olarak değerlendirilen araç lastik atıklarının %85 kum ve %15 bentonitten oluşan bir kum-bentonit karışımı üzerindeki etkisini incelemeyi amaçlamaktadır. Bu araştırmanın amacı, poliakrilamid (%0,5, %1 ve %2) ve araç lastik atığı (%0,05, %0,1, %0,2, %0,5, %1 ve %2) farklı konsantrasyonlardaki etkisini değerlendirmektir. Atterberg limitleri ve Proctor testleri ile ölçülen toprağın mühendislik özellikleri. Bu tez, kum-bentonit karışımını işleyerek poliakrilamid ve lastik talaş konsantrasyonlarının daha önce listelenen temel parametreler üzerindeki etkilerini incelemektedir. Gelişme, poliakrilamid ve mikroplastiklerin (lastik yongaları) eklenmesinin, toprağın plastiklik özelliklerini değiştirebileceği ve böylece mühendislik özelliklerini geliştirebileceği yönündedir. Ek olarak, değiştirilmiş kum-bentonit karışımının ideal nem içeriğini ve maksimum kuru yoğunluğunu incelemek amacıyla toprağın sıkışma özelliklerini değerlendirmek için Proctor testi yapılır. Bu inceleme, optimum sıkıştırma parametrelerinin tanımlanmasını ve ardından zeminin stabilitesinin ve dayanımının değerlendirilmesini kolaylaştırır. . Bu çalışmanın öngörülen sonuçları, poliakrilamid (hem anyonik hem de katyonik) ve araç lastik atıklarının bir kum-bentonit karışımının mühendislik özellikleri üzerindeki etkisinin anlaşılmasını artıracaktır. Deney sonuçlarına göre karışıma eklenen hem anyonik hem katyonik poliakrilamid, hem de araç lastik atıklarının maksimum kuru birim hacim ağırlığı azalttığı,. Karışımı hiç katkı malzemesi eklenmediği numuneye kıyasla en fazla değişim %2 anyonik poliakrilamid eklenmesiyle sağlanmış olup kuru birim hacim ağırlığı 1.76'dan 1.65 gf/cm³'e azalmış, optimum su muhtevası 16'dan %18.2'ye, plastisite indisi 14'den %19'a artmış, likit limit 53'den %43'e azalmıştır. Bu çalışmanın sonuçlarının, inşaat mühendisliği ve jeoteknik taahhütler bağlamında toprak kalitesinin artırılmasında belirtilen katkı maddelerinin olası kullanımlarının anlaşılmasına önemli katkılar sağlayacağı tahmin edilmektedir. Bu araştırmanın birincil amacı, yeni malzemeleri geoteknik mühendislik projelerine entegre ederek sürdürülebilir ve etkili toprak yönetimi metodolojilerini desteklemektir.

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LIST OF SYMBOLS/ABBREVIATIONS

SBM	Sand-bentonite mixtures
WCS	Waste containment systems
SBSW	Soil-bentonite slurry wall
CCLs	Compacted clay liners
GCLs	Geosynthetic clay liners
HDPE	High-Density-Polyethylene
PAM	Polyacrylamide
OWC	Optimum water content
LL	Liquid limit
PL	Plastic limit
k	Permeability, conductivity
Sr	Degree of saturation
1d C test	One dimensional consolidation test
CU	Consolidated undrained triaxial tests
PE	Polyethylene
MDD	Maximum dry density
PET	Polyethylene terephthalate
PS	Polystyrene
PVC	Polyvinyl chloride
FT-IR	Transformation function infrared
USCS	Unified Soil Classification System
SP	Poorly graded sand
SBR	Styrene-butadiene rubber
CL	Low-plasticity clays
CH	High-plasticity clays
Cu	Coefficient of uniformity
Cc	Coefficient of curvature
Ca	Calcium
Na	Sodium

GS	Specific gravity
Sr	Degree of saturation



1. INTRODUCTION

1.1. SAND-BENTONITE MIXTURES AS LINERS AND BARRIERS IN LANDFILLS

The installation of The presence of adequate liners is crucial in waste containment systems, such as landfills, and hydraulic containment systems, such as reservoirs, in order to effectively mitigate the infiltration of leachate into the surrounding soil and groundwater environment. To effectively carry out this task, engineers design compacted soil liners to demonstrate a low hydraulic conductivity, denoted as "k," typically considered to be a value less than 1×10^{-7} cm/s [1]. The utilization of bentonite as an additive in indigenous soils is a widely employed method to achieve hydraulic conductivity values that comply with global standards [4].

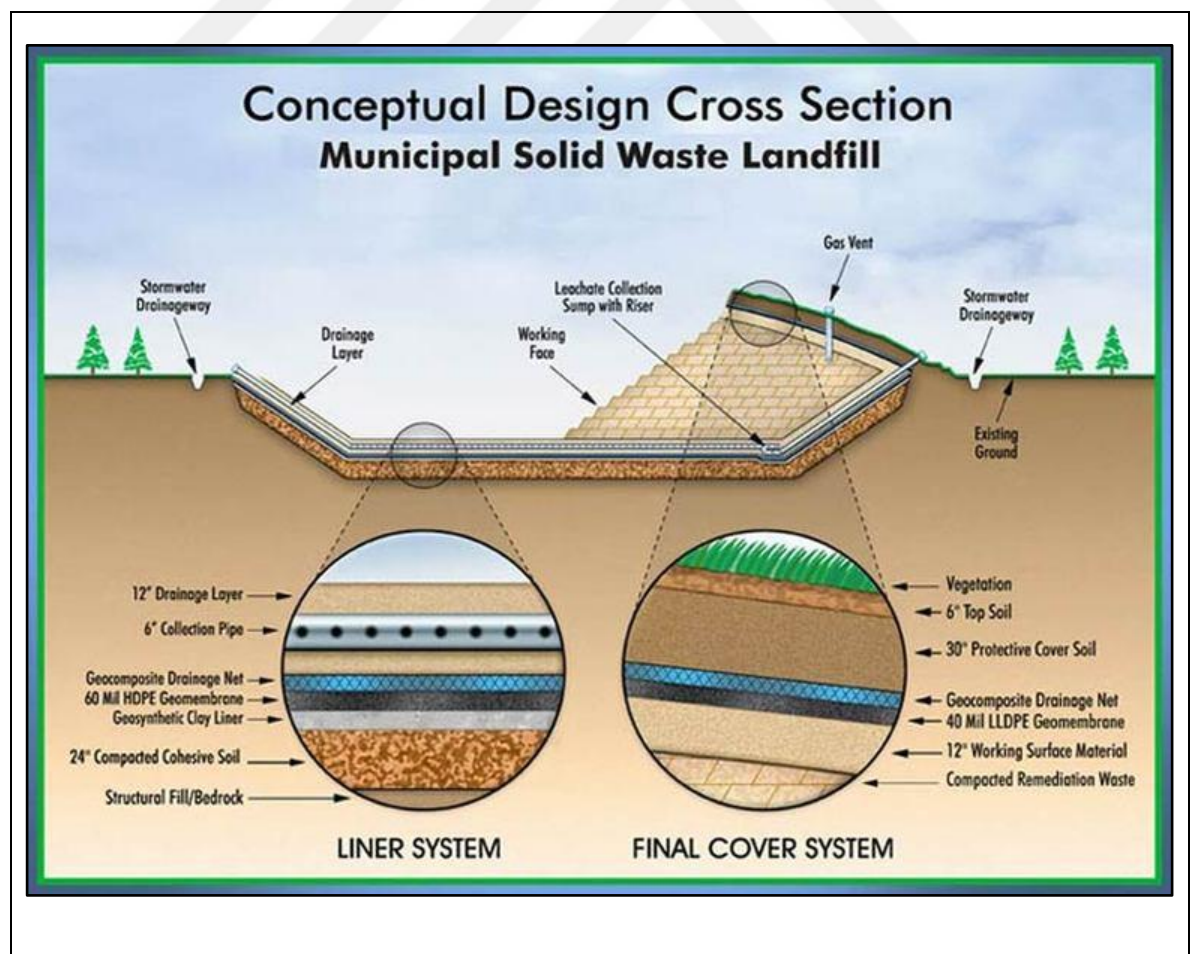


Figure 1.1. Conceptual design cross section of municipal solid waste landfill [2].

Landfilling persists as the most economically efficient method for managing solid waste. Under non-acidic conditions, it is not possible to eliminate leachate. The contemporary design of landfills necessitates the implementation of measures to contain leachate or permit its migration within acceptable limits. The application of a mixture of bentonite and sand which has been compacted, serves as liners and barriers in landfills, as well as a buffer and sealing agent for the containment of waste water and fresh water. The properties of bentonite play a crucial role in determining the behavior of compacted sand-bentonite mixtures. The behavior of a compacted mixture at a given composition (or bentonite level) is influenced by the qualities of sand, as stated by A. Samangan in 2005. Mixtures containing low levels of bentonite are impacted by the presence of sand. The load-deformation behavior of the sand has an impact on the properties of the composite material consisting of bentonite and sand, known as "bentonite-enhanced sand," under different levels of dry densities [5].

1.2. LINERS/ BARRIERS IN GEOTECHNICAL APPLICATIONS

Liners and barriers are materials with low permeability that are used in the design of engineering applications involve the analysis and evaluation of deposits and their respective sites [3].

These liners typically consist of a range of materials such as compacted clay, bentonite and dirt, geotextile, geomembrane, and cement. This security scheme shall consist of one or more of these types of liners, which have different dynamics in terms of pollutants and movement. Many types of liners have been developed in modern landfills, namely compacted clay liner(CCL), sand bentonite liner, geosynthetic clay liner(GCL), geomembrane(HDPE) [6]. On the other hand, polymers are either synthetic or organic substances that are added to various materials to enhance the mechanical or hydraulic performance of these materials. The polymers that are preferred to be added to various soils are generally water-soluble and have high molecular weight.

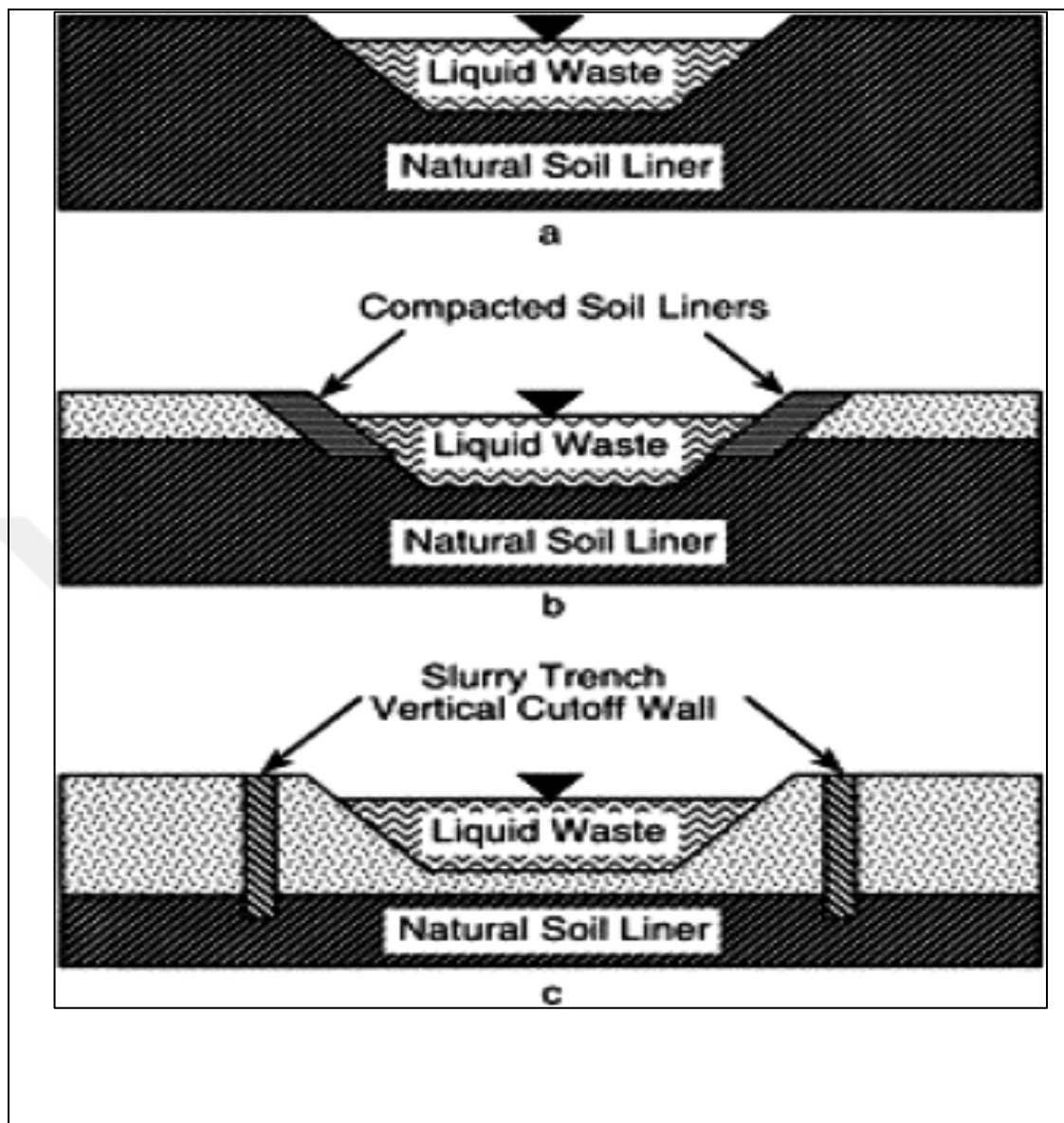


Figure 1.2. (a) First of multiple images, (b) Compacted soil liners (CSLs), (c) Slurry trench vertical cut-off wall [7].

1.3. POLYACRYLAMIDE (PAM) IN SOIL TREATMENT

Additional areas subject to erosion include development and construction zones. The construction of large cities, roads, and highways has a significant impact on the soil. Before regular vegetation can be re-established, these places are subject to soil erosion. Although polyacrylamide helps the stabilization of soil structure, however, it does not improve it. Polyacrylamide is widely used to maintain the structure of the soil in dry and Mediterranean regions around the world, resulting in enhanced infiltration, reduced water [8].

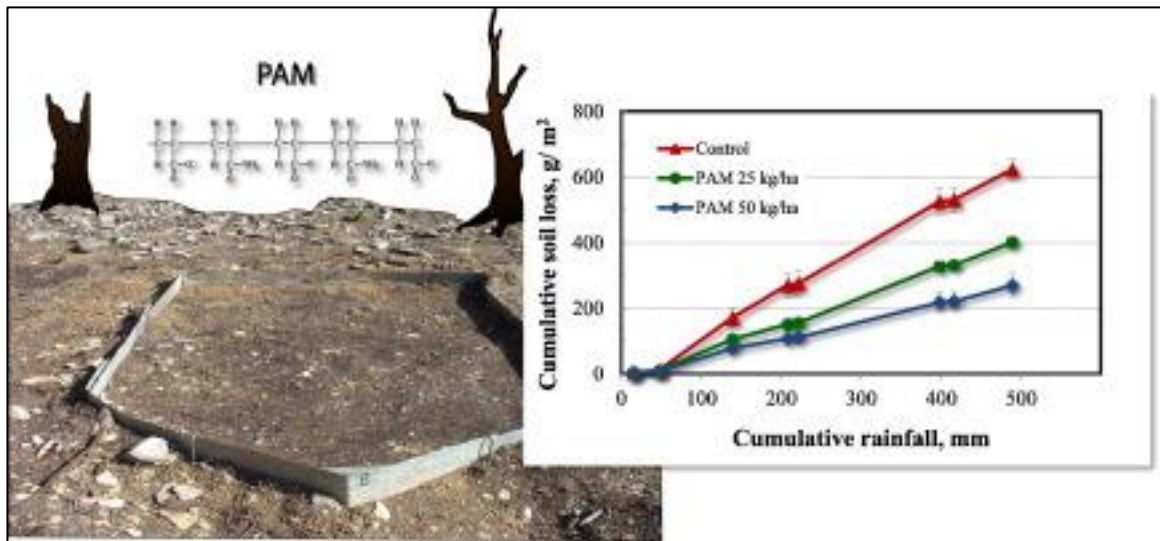


Figure 1.3. Rainfall against soil loss by using PAM [8].

1.4. STUDY PLAN

In this study, we plan to perform laboratory experiments such as Atterberg limit and Proctor compaction tests on sand-bentonite mixtures that will be enhanced by polyacrylamide and tire chips after that results will be investigated. The study's main aim is to determine the result of polyacrylamide and microplastic addition on some physical properties of the sand-bentonite mixture. Optimum water content (OWC), dry unit weight, liquid limit (LL) and plastic limit (PL) are the main parameters that will be measured and compared to assess how the additive materials affect the engineering characteristics of the soil mixtures that are used in many geotechnical projects such as liners and barriers in landfills, waste water and freshwater applications. The optimum polymer content that satisfies the related engineering properties will be determined according to the results. Moreover, correlations between the measured parameters will be tried to be found and the results will be discussed. The primary objective of this investigation is to investigate engineering performance, such as dry unit weight, optimum water content, liquid limit (LL) and plastic limit (PL), by measuring Atterberg limits and compaction parameters and one of our primary objective was the contribution to the permeability of sand-bentonite mixtures as barriers by evaluating their plasticity and compaction parameters.

2. LITERATURE REVIEW AND BACKGROUND

2.1. SAND-BENTONITE MIXTURE

Owing to their comparatively elevated level of strength, low compressibility, and extremely low hydraulic conductivity (k), mixes of bentonite and sand are commonly employed as barriers to prevent the transport of leachates in waste containment systems. To achieve these engineering properties, a combination of sufficient sand to preserve the compacted mixture's stability and fine Bentonite has been used as a means to occupy the empty spaces amidst the sand particles is applied [3]. Typically, the dry mass of bentonite in a combination should vary between 4% and 13% of the dry mass of sand. Greater concentrations of bentonite may result in increased flexibility, making it difficult to compress the mixture. In addition, the loss in hydraulic conductivity (k) is negligible and cost-effective for the construction of a waste containment facility [9] ,[10]. Due to the widening of the voids, a coarse-grained material with a high proportion of sand may have significantly more excellent conductivity than a fine-grained material [3].

In garbage disposal operations, mixtures of soil and bentonite are commonly applied as impermeable covers. Numerous laboratory permeability test results for bentonite-containing sands comprising up to 33 percent bentonite are provided. Different testing procedures that make it impossible to control some factors, such as the hydration duration, degree of saturation, and swelling under low confining pressure, were employed to get these data, making their interpretation challenging. However, hydraulic conductivity may be calculated using empirical formulae that account for the sand's bentonite content, porosity(ϕ), and degree of saturation(S_r) when measured at its optimal modified Proctor value using a permeameter. This first evaluation aids in determining which soil samples will be analyzed [11].

2.2. SAND-BENTONITE MIXTURE (SBM) USED AS A BUFFER

It is anticipated that a bentonite-sand combination will be the most suitable buffer material for high-level radioactive waste products when they are buried deep below. Consequently, it is crucial to design a technique for evaluating the in-situ mechanical behaviour of bulk

materials. In order to accomplish this, it is vital to clarify the stress-deformation behaviour of buffer materials under different situations. Individual subject-focused research projects have been conducted up until this point. For compacted bentonite-sand mixtures (CSMs) at high-stress levels, one-dimensional consolidation tests and consolidated undrained triaxial tests (CU) have been conducted Mitachi [12].

Komine (2001) and Komine and Ogata (2003) conducted swelling experiments. They provided equations for analyzing swelling features of bentonite-sand mixtures to quantify the swelling properties of bentonite buffer materials [13].

In addition, they conducted a series of model tests [14], to mimic the filling up of the gap between the buyer material and a wall of the disposal pit and between the buyer material and an overpack due to its expansion.

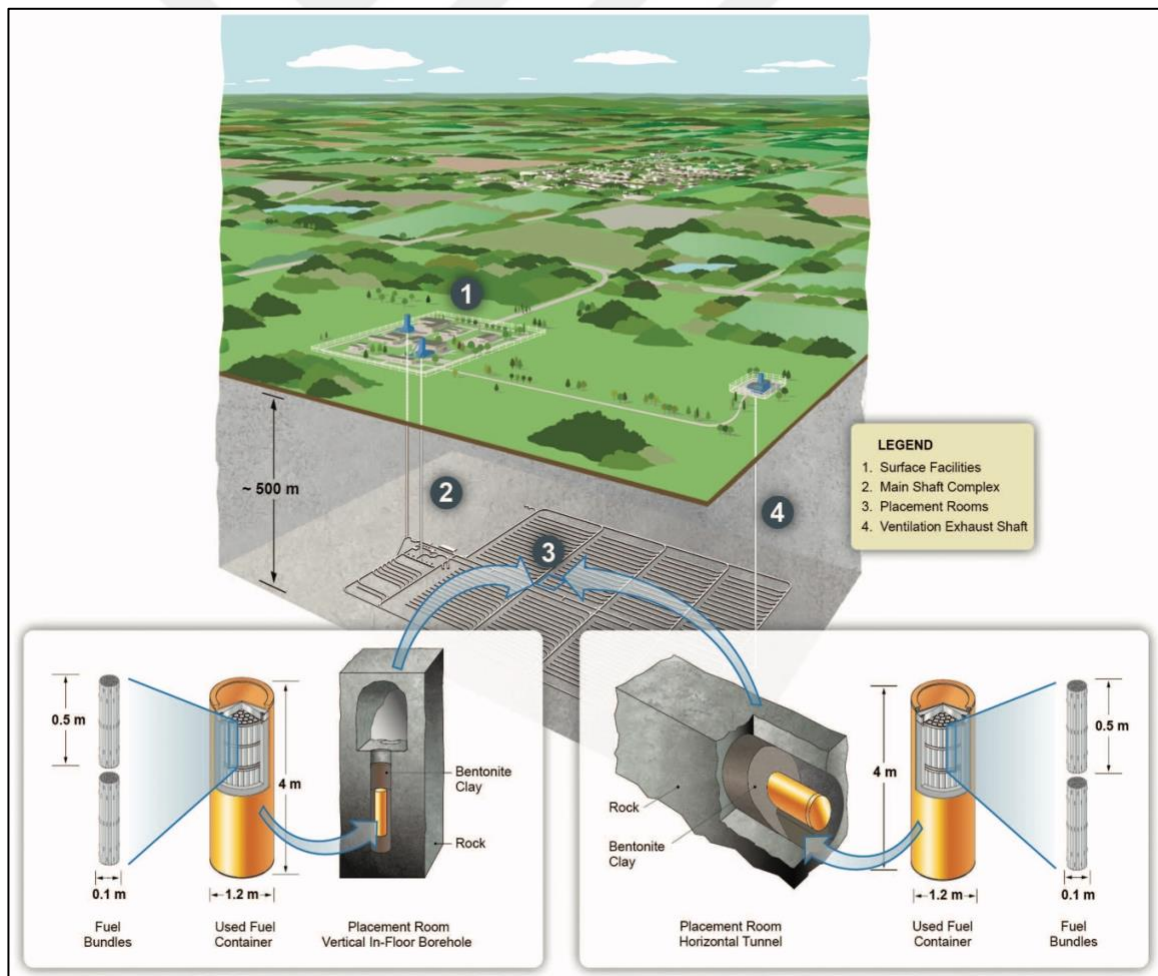


Figure 2.1. Two options for disposal according to the Canadian concept [15].

The containers shall be situated in either vertical boreholes that are drilled into the ground along the placement room's axis or horizontally within the boundaries of the placement room, contingent upon the geological properties and site-specific features [15].

2.3. BENTONITE MIXTURES APPLIED AS LINER AND ISOLATOR

Large quantities of hazardous waste will continue to be produced by humankind, requiring extended periods of retention, waste disposal, combustion, or treatments. The utilization of sodium-saturated bentonite is prevalent in the construction of compacted and geosynthetic liners and coverings for hydraulic isolation of hazardous waste in landfills. This is attributed to its favourable characteristics, such as low hydraulic conductivity, cost-effectiveness, extensive surface area, and remarkable adsorption capacity for contaminants.. According to its almost impermeable characteristics and a strong inclination to absorb pollutants, bentonite is typically utilized as a lining material to prevent subterranean contamination. Due to bentonite's desiccation, interlayer shrinkage, and differential settling, the landfill liner develops cracks. Commonly, fibers are added to sand–bentonite combination as a reinforcing material to prevent the formation of tensile fractures. The tire retreading process generates waste tire chips, which can be incorporated as short fiber in a sand–bentonite combination for material employed as a barrier in landfills. Albrecht BA, Benson CH. Effect of desiccation on compacted natural clays. Journal of [16].

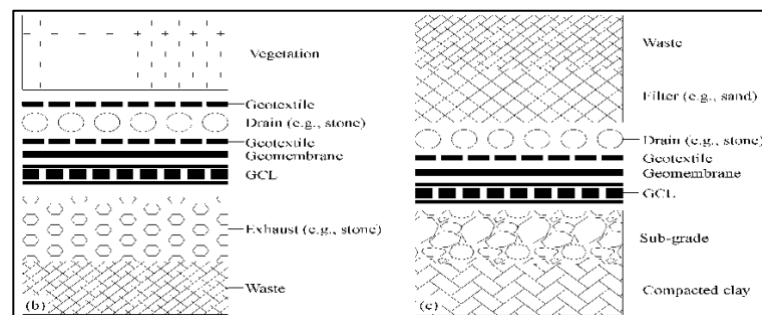


Figure 2.2. Typical structure of a landfill: (a) Schematic of a typical landfill (modified from du et al., 2009) (b) Covering liner structure; (c) bottom liners structure [17].

2.4. SAND-BENTONITE MIXTURE IN ROADS, HIGHWAYS

The usage of sand-bentonite mixtures has been widely applied in various applications. constructing roads due to their excellent mechanical properties and low cost. Bentonite is a natural clay mineral that swells when wet, providing good water resistance, while sand provides good drainage and stability.

The combination of these two materials results in a mixture that is ideal for use in road construction. According to a study, sand-bentonite mixtures with a ratio of 70% sand and 30% bentonite have been used successfully in the construction of various types of roads, including highways, rural roads, and urban roads. The study found that sand-bentonite mixtures had high compressive strength and shear strength, making them ideal for use as subgrade and subbase layers in road construction [18].

Another study by Fattah [19] investigated the use of sand-bentonite mixtures with a ratio of 70% sand and 30% bentonite in the construction of flexible pavements. The study found that the mixture had good resistance to moisture and provided good stability, resulting in reduced pavement deformation and improved pavement life.

In addition to road construction, sand-bentonite mixtures have also been used in other civil engineering applications, such as landfill liners, tunnel construction, and dam construction. Overall, sand-bentonite mixtures are an effective and low-cost material for use in road construction. The mixture has excellent mechanical properties, good water resistance, and good drainage, making it ideal for use as subgrade and subbase layers in road construction.

2.5. COMPARATIVE STUDY WAS DONE OF THE INVESTIGATION OF BEHAVIOUR OF SOIL AND SOIL-BENTONITE MIXTURE IN THE CONTEXT OF CONSTRUCTING IMPERMEABLE BARRIERS

Many researchers report differential amounts of bentonite additives. According to Gillham and Chapuis, the sodium bentonite displays a ratio that varies from 5% to 8%, while the calcium bentonite indicates a ratio that ranges from 9% to 15%. Previous studies have investigated the impact of various factors on the hydraulic conductivity of soil-bentonite, including grain size distribution, proportion of bentonite, consolidation pressure [20]. Three different types of soils were investigated nearby the Armenian region of Aragatsotn

using holes supported by a backhoe. Large polyethylene bags were used to collect and transfer the samples to the laboratory.

Table 2.1. Physical characteristics of the soil samples [20].

No	Sample name	Specific gravity	Atterberg limits			Proctor test		Permeability, m/sec.
			Liquid limit, %	Plastic limit, %	Plastic index, %	Max. dry density, g/cm ³	Optimum water content, %	
1.	Sample 1	2.66	21.0	17.4	3.6	1.73	16.5	$3.3 \cdot 10^{-7}$
2.	Sample 2	2.59	Non-Plastic			1.65	14.5	$5.30 \cdot 10^{-6}$
3.	Sample 3	2.59	Non-Plastic			1.76	16.5	$3.40 \cdot 10^{-7}$

Atterberg limit testing was conducted in accordance with ASTM D 845. Specific gravity testing was conducted in accordance with the ASTM D854 and standard Proctor compaction test was performed according to ASTM D698.

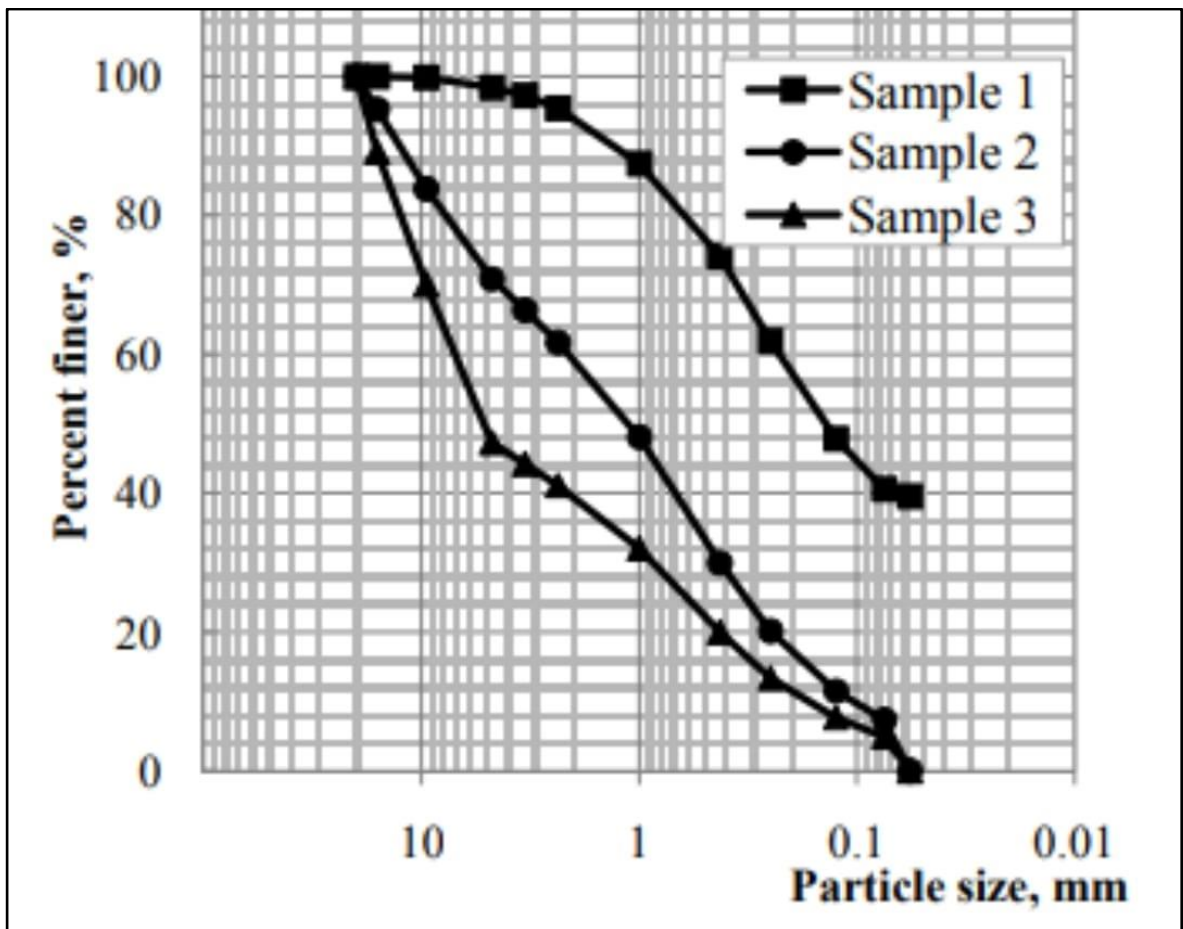


Figure 2.3. Particle size distribution of the soil samples [20].

The distribution of particle sizes of samples was determined using a dry and wet sieve test. Figure 1 depicts the results of sieve analysis on three types of soil. The minimum gravel fraction has Sample 1 (1.61%) and maximum Specimen 3 (52.74%). Specimen 2 contained the highest proportion of sand (63.57%) compared to Sample 3 (42.36%). The percentage of silt and clay was just high in Sample 1.

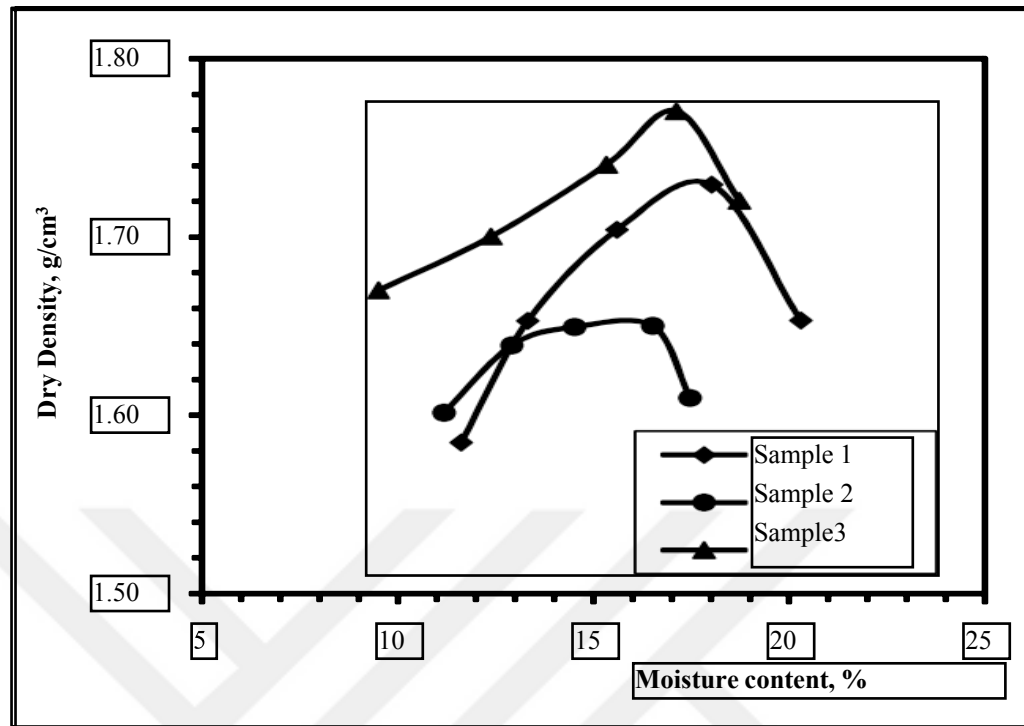


Figure 2.4. Standard compaction curve of the soil samples [20].

A compaction curve was utilized to evaluate the maximal dry density and optimal water content of compacted soil. Standard proctor compaction test: the maximum dry density and optimum moisture content were determined. A compaction test was performed to evaluate the results indicate that maximum dry density was greater for Sample 3 (1.76 g/cm³, with optimum water content-16.5%) and lower for Sample 2 (1.65 g/cm³, with optimum water content-14.5%).

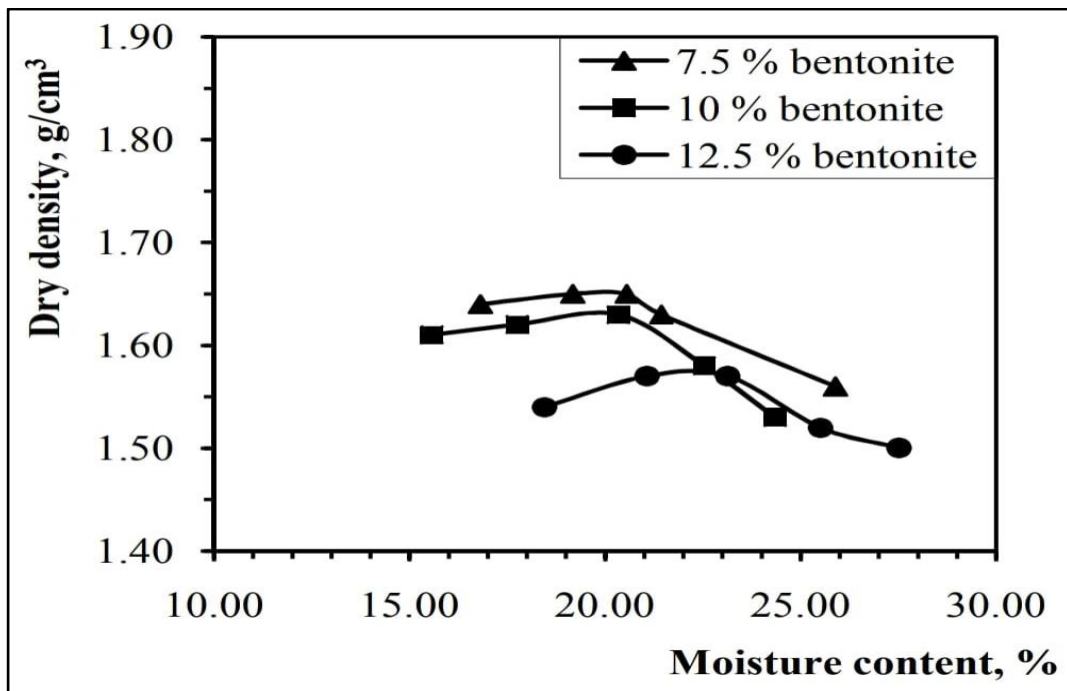


Figure 2.5. Compaction curves of the “sample 1 + 7.5, 10, 12.5% bentonite” mixtures [20].

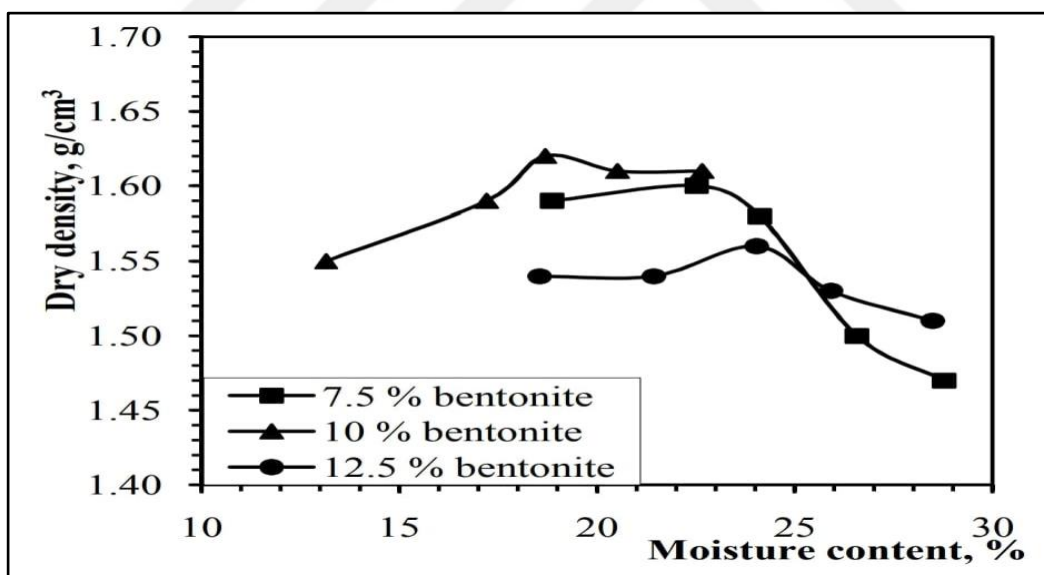


Figure 2.6. Compaction curves of the “sample 2+ 7.5, 10, 12.5% bentonite” mixtures [20].

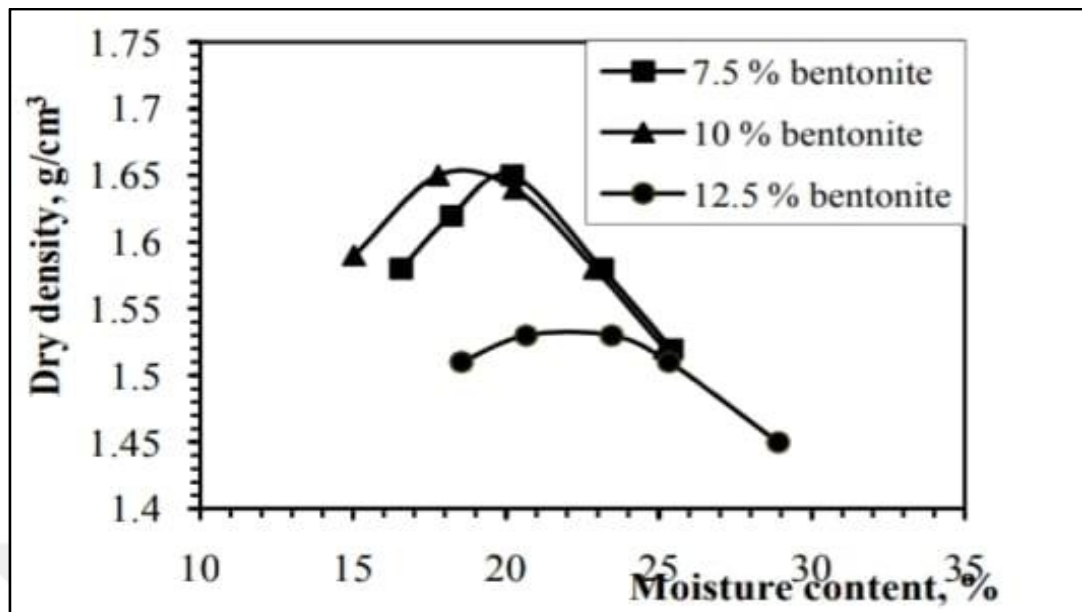


Figure 2.7. Compaction curves of the “sample 3 + 7.5, 10, 12.5 % bentonite” mixtures [20].

After examining all important points, three percentages of bentonite content were selected for each soil sample - 7.5%, 10%, and 12.5% - to examine soil stabilization mechanisms. Proctor compaction, permeability, Atterberg limit test results are listed in Table 2.2.

Table 2.2. Physical characteristics of soil-bentonite mixtures

Sample 3			Sample 2			Sample 1			Sample name
12.5	10.0	7.5	12.5	10.0	7.5	12.5	10.0	7.5	Bentonite content (%)
49.0	46.0	41.0	46.5	43.5	39.5	43.5	38.2	34.5	Liquid limit, (%)
40.6	39.3	39.0	45.0	42.2	39.2	18.4	17.4	17.0	Plastic limit, (%)
8.4	6.7	2.0	1.5	1.3	0,3	25.1	20.8	17.5	Plasticity index, (%)
1.57	1.63	1.65	1.56	1.62	1.61	1.53	1.65	1.65	Maximum dry density, g/cm³
23.0	20.3	19.2	24.0	21.2	21.0	23.0	20.3	20.2	Optimum water content, (%)
$1.88 \cdot 10^{-8}$	$1.36 \cdot 10^{-8}$	$3.06 \cdot 10^{-8}$	$2.48 \cdot 10^{-8}$	$6.98 \cdot 10^{-8}$	$2.24 \cdot 10^{-8}$	$2.88 \cdot 10^{-8}$	$1.72 \cdot 10^{-8}$	$1.80 \cdot 10^{-8}$	Permeability, m/sec.

Bentonite was found to increase the liquid limit values for all samples. Changes in the plastic limit levels were also caused by bentonite. However, they are not significant. The

addition of bentonite results in a linear increase in the LL but has a minor impact on the PL.

In Sample number one, increasing bentonite concentration led to a linear increase in the liquid limit but not in the plastic limit, and there were substantial disparities between PL and LL values. Sample 2's bentonite content increased plasticity, LL, and PL. LL and PL ratios are not significantly different for any bentonite concentrations. Bentonite turned Sample 3 plastic. As in Sample 2, LL increased linearly, while PL was essentially the same for all bentonite amounts.

The density of the compacted sample altered as a result of the bentonite's state altering as it accumulated water and time progressed. The testing of the mixture was conducted Promptly and at intervals of 1, 2, 5, and 12 hours subsequent to the preparation. The data indicate that the optimal results were attained during the compaction process during two hours of preparation because the material was more compacted. Table 2.2 summarizes the outcomes of the standard compaction tests conducted on the soil-bentonite mixtures. For soil-bentonite a mixture, typical compaction curves were obtained. Depending on the bentonite content of the soil samples, the maximum dry density of the soil-bentonite mixture dropped linearly as the water content increased. Upon the addition of a greater quantity of bentonite..., the optimum moisture content raised while the maximum dry density dropped. The third sample was found to have the highest maximum dry density. The permeability tests of soil-bentonite mixes were conducted on specimens that had been compacted in accordance with normal compaction testing techniques. After compression, the sample was left in the mold for three days before being inserted in the water tank for saturation. The permeability test results for the soil-bentonite combinations are reported in Table 2.2.

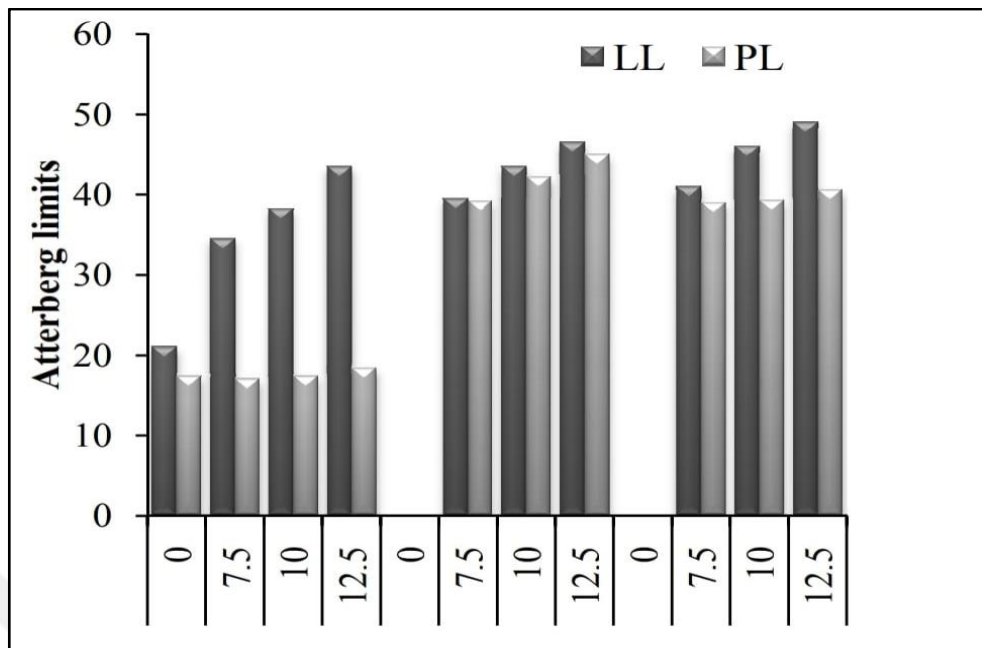


Figure 2.8. Atterberg limits of the soil samples and soil- bentonite mixtures. (LL-liquid limit, plastic limit) [20].

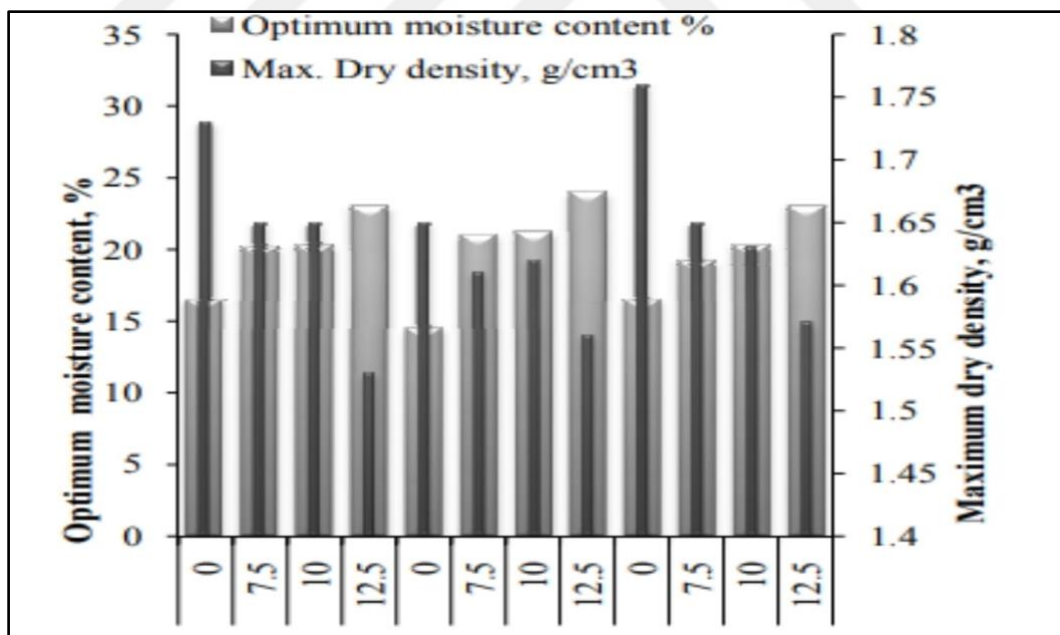


Figure 2.9. Results of the soil samples and soil-bentonite mixes' standard compaction tests [20].

According to the findings of the study, there was a decrease observed in the maximum dry density, and optimum moisture content increased with higher bentonite content in compacted soil-bentonite combinations. The investigation revealed that the configuration and examination of the behavior of the compacted soil-bentonite mixture in specific geo-environmental applications must examine the effect of at minimum two factors, particularly regarding the particle-size proportion and bentonite content, which are significant for decreasing the permeability of the soil-bentonite mixtures [20].

2.6. POLYMERS

2.6.1. Review About Polymers

The polymers are mainly polyethylene terephthalate (PET), polyolefins (polyethylene and polypropylene), poly(vinyl chloride) (PVC), and polystyrene (PS). Polymers have existed since the beginning of time and are the basic building blocks of life. Polymers make up all living things, including animals and plants. The term polymer is derived from the Greek words poly and meros, which respectively imply many segments. Instead of polymer, some researchers preferred to use the term macromolecule or colossal molecule.



Figure 2.10. Anionic polyacrylamide [21].

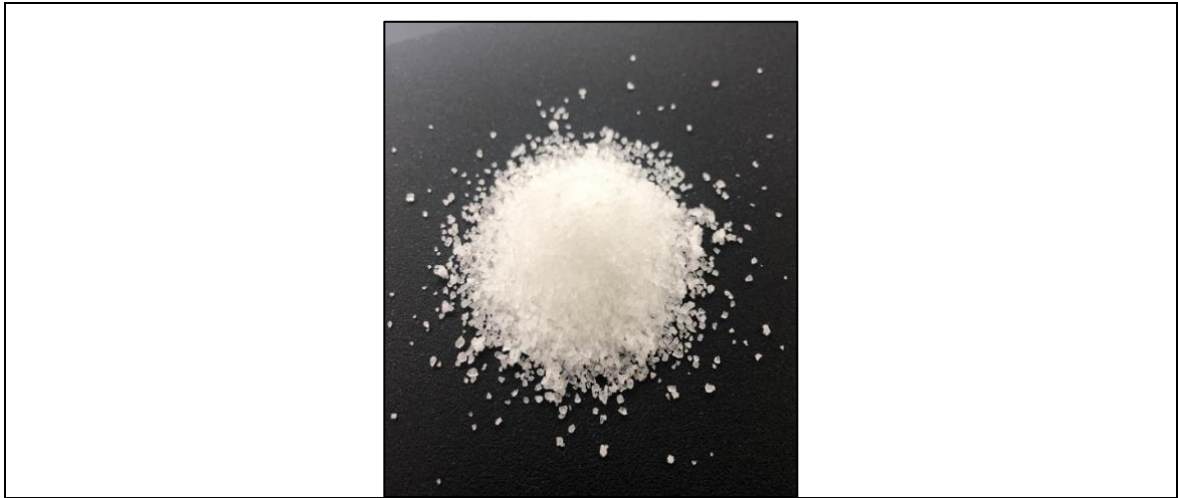


Figure 2.11. Cationic polyacrylamide [21].

2.6.2. Polymers Types

The polymers types are generally classified as polyethylene terephthalate (PET), polyacrylamide (PAM) polyolefins (polyethylene and polypropylene), poly(vinyl chloride) (PVC), polystyrene (PS), and polyacrylamide (PAM). Polymers cannot be easily categorized because they are complex materials.

The three main categories for polymers are natural, synthetic and semi-synthetic. Polymers have been categorized in other things based on their uses, origins, polymerization mechanisms, polymer structures, methods of synthesis, and temperature behaviors. Crystalline thermoplastics are distinguished from amorphous thermoplastics, categorized under synthetic polymers (i.e., non-crystalline). Due to its fundamental molecular structure-based foundation, this approach to categorizing polymers offers advantages over others. In general usage, the term "plastic" refers to thermoplastics, which are a class of polymers that can be either linear or branched and turn liquid when heated [22].

2.6.3. Polymers Application In Civil Engineering Aspect

The type of polymer that is typically used to enhance the sand-bentonite mixture is polyacrylamide.

Acrylamide is a chemical predominantly used to produce polyacrylamide and acrylamide copolymers. Polyacrylamide and acrylamide copolymers are utilized in several industrial processes, including the manufacturing of paper, dyes, and plastics, in addition to the treatment of drinkable water and wastewater, which encompasses sewage, purification is also carried out. They can also be found in various consumer products, including caulking, food packaging, and certain types of adhesives. It has been found that certain foods contain a chemical called acrylamide [23]. Studies have shown that the use of polymer treatment can improve the soil's ability to retain water. However, experiments on the impact of a cationic polymer on sodium bentonite have shown that increasing the polymer concentration from 1% to 2% by mass can lead to an increase in water flow through the bentonite [24]. The flow of water, on the other hand, did not vary much when the anionic polymer was introduced to sodium bentonite, even when the polymer concentration was doubled [25]. Furthermore, Liu et al. investigated the swelling index of sodium bentonite when treated with anionic or cationic polymers, discovering that the swelling index of bentonite treated with anionic polymer rose linearly with increasing polymer concentration. Conversely, the swelling index of bentonite treated with cationic polymer decreased with increasing polymer concentration [24]. Finally, Lam et al. (2015) found that at lower shear rates, a liquid modified with a polymer had a lower viscosity than bentonite sludge [10].

2.6.4. Changing Hydro-Mechanical Characteristics Of The Soil By Polymer Additive

Adding polymers to a combination of bentonite, sand, and other granular soils can have a significant effect on the hydro-mechanical characteristics of the soil. Studies have shown that when using an optimal blend of these materials as a barrier for leachate in landfills, it can lead to compressibility, shrinkage and swelling behaviors that are within an acceptable range. Also, the soil's mechanical parameters, like compressive and tensile strength, can be enhanced when the leachate is present on the surface of the bentonite-sand-tuff combination [25]. Additionally, incorporating bentonite into clay-sand mixes can result in a considerable rise in both the unconfined compressive strength and cohesiveness. Research conducted by Doley et al. (2016) on permeability and unreinforced pressure testing of clay-sand blends found that increasing bentonite concentration from 5 to 25% by

dry mass leads to a drastic drop in permeability and an increase in unconfined shear strength from 7.6 to 76.7 kPa [26].

The addition of polymers can alter the mechanical and hydraulic characteristics of clay. How a polymer interacts with clay can be influenced by the type of polymer and the way in which it binds to the clay. For example, anionic polyacrylamide can adhere to bentonite through cation bonding, while cationic polyacrylamide binds to bentonite through electrostatic forces [27]. As a result, anionic polymer addition causes the bentonite particles to flocculate, resulting in a more uniform distribution of pore size and narrowed pores between particles [30]. Conversely, cationic polymer treatment causes the bentonite particles to aggregate, leading to an uneven distribution of pore size [29]. The permeability of the bentonite-cationic polymer combination rises as a fluid passes through these non-uniform pores [25], [27].

Polymer affects the mechanical and hydraulic characteristics of sand. Research has shown that adding polymer to sandy soils can improve the soil's hydraulic performance. For instance, when anionic polyacrylamide fluids were put on a beach, Ejezie et al. (2020) [28], reported that the permeability was significantly reduced. This was attributed to the additional polyacrylamide clogging the pores between the beach particles, obstructing the inflow routes, and creating a four-fold decrease in permeability [28], [29].

Furthermore, when a water-responsive polymer mainly intended for soil stabilization in road building was applied to a beach and direct shear tests were undertaken, it was discovered, that the polymer treatment increased the beach's shear strength [30]. In addition, adding a polyurethane organic polymer and a polypropylene fibre to a beach soil mix improved shear strength performance, as reported by Liu et al. (2017) [31]. Including polymer also increased cohesiveness and decreased the internal disunion angle [32]. Research has found that as the amount of polymer added to a mixture of ground and beach soil increases, the cohesion of the mixture increases and the internal disunion angle decreases [25]. For example, a study found that when 0.1 percent polymer was added to 20 ground-beach mixtures, the cohesion of the mixture increased from 10.2 to 204.6 kPa and the inside disunion, the angle dropped from 39.1 to 33.6 degrees.

It's worth noting that the last sentence discusses a different subject matter than the first one, which is about Microplastics. *Microplastics* are defined as plastic elements minor than millimetres.

However, it should be noted that this size restriction is not universally agreed upon and some organizations, such as the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) includes nanoparticles in its definition as well [33].

2.6.5. Polyacrylamide Addition To The Soil

The addition of polyacrylamide (PAM) can improve the mechanical properties of sand-bentonite mixtures are commonly used in construction as a barrier or lining material. The study uses the Atterberg limits test and Proctor compaction test to evaluate the effect of PAM on the plasticity and compaction characteristics of the mixtures. The results suggest that the addition of PAM can enhance the plasticity and compaction characteristics of sand-bentonite mixtures, making them more suitable for construction applications where low permeability and high compressibility are required.

Polyacrylamide " A Type Of Synthetic Polymer ": Previous Studies Using Atterberg Limits And Proctor Tests [34]

In the Chinese province of Gansu, samples of the saline soils were taken from the soil layer and at a depth of 2.0–3.0 m. PAM mass ratios of 0.1% and 0.5% were chosen as the two concentrations. Numerous quaternary sediment deposits, including saline soil, are present in the Western region of China. The escalating soil salinity is a significant concern for land degradation globally. The presence of high levels of salts in soil can result in negative impacts on both its physical and chemical characteristics, including but not limited to soil

disintegration, erosion, and swelling [34].

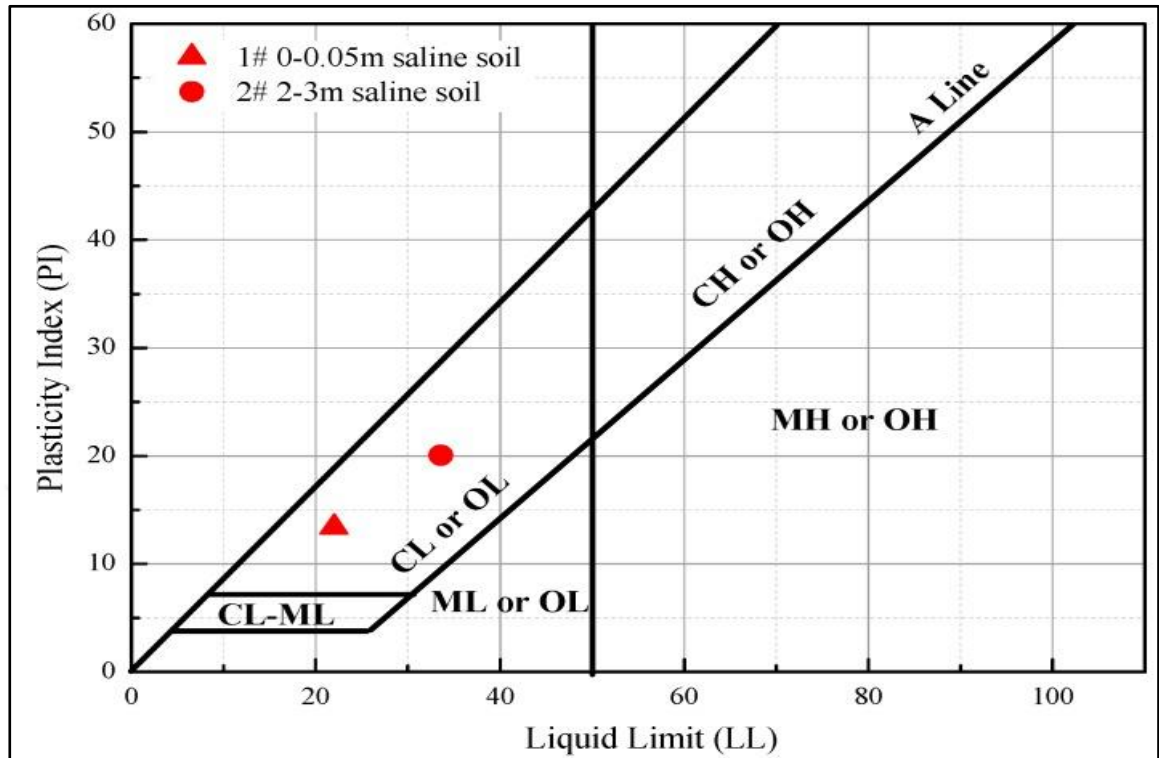


Figure 2.12. chart showing the plasticity of Sample #1 and Sample #2 [34].

According to GB/T 50123, the cone method was implemented to find the LL and PL of the samples of sediment that were chosen. The analysis is conducted in accordance with (USCS) System. ASTM-D2487, as illustrated in Figure 2.12, it can be inferred that the materials that underwent testing were categorized as low-plasticity clays (CL). The investigation employed an analytical grade commercial reagent of polyacrylamide (PAM). Table 2.3. This study examines the physical properties of a specific set of saline soil samples. [34].

Table 2.3. displays the fundamental physical characteristics of the soil, including its natural water content (w_0), dry density (d), and compression coefficient (a).

Soil Depth	Natural Water Content w_0 (%)	Wet Density (Mg/m ³)	Dry Density (Mg/m ³)	Saturation Degree S_r (%)	Void Ratio e	Compression Coefficient a
0–0.05 m	12.2	1.86	1.66	60.4	0.5	0.1
2.0–3.0 m	27.1	2.05	1.61	100.0	0.8	0.4

The findings demonstrate that the soil at a depth of 2-3 m had higher in-situ water content, void ratio, and compressibility than the soil at the surface.

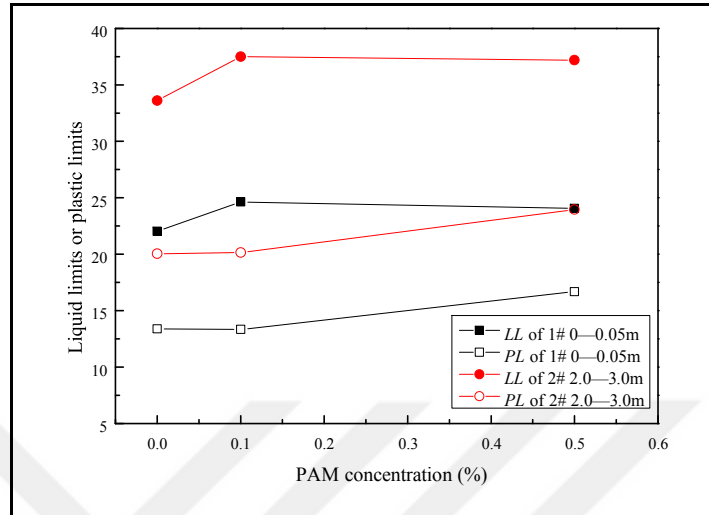


Figure 2.13. Liquid limits (LL) and plastic limits (PL) with a varying concentration of polyacrylamide (PAM) [34].

According to the results in Fig 2.13, the two saline soil samples behave similarly in terms of PAM concentration. As the amounts of Polyacrylamide in the pore water developed in the given sample 1 (0–0.05 m), the (LL) and (PL) increased from 22.0% and 13.4% to 24.6% and 16.6%, respectively. As PAM concentration increased, the levels of LLs (liquid limits) and PLs (plastic limits) in the saline soil samples obtained from the surface layer (0–0.05 m) and a subsurface layer at a depth of 2.0–3.0 m exhibited a statistically significant increase.

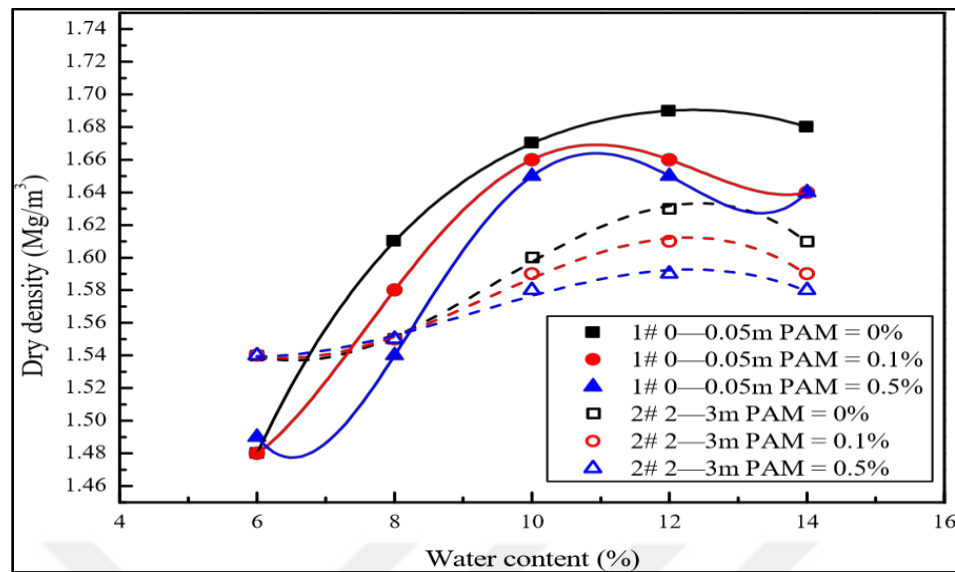


Figure 2.14. Compaction curves of Sample 1 and Sample 2 with polyacrylamide (PAM) addition [34].

Figure 2.14 displays the results of the samples' standard Proctor compaction curves.

The experimental results indicate that the maximal dry densities of Sample 1 were achieved with the use of purified water, 0.1% PAM, and 0.5% PAM, with values of 1.69, 1.67, and 1.66 mg/m³, respectively. The second sample, when treated with distilled water, 0.1% PAM, and 0.5% PAM, exhibited the highest dry densities of 1.63, 1.61, and 1.59 mg/m³, respectively. The maximal dry densities exhibited a negative correlation with the increase in both PAM content and plasticity.

2.7. MICROPLASTICS

2.7.1. Microplastic Definition

Microplastics are defined by Thompson et al. (2004) as synthetic particles or polymeric structures that have regular or irregular shapes, are between 0.0001 mm and 5 mm in size, and are moreover primary or secondary in manufacturing source, and do not dissolve in water [35].

This definition is used by the writers of this critical analysis. Microplastics are expressed as the fragmental plastic particles between 0.0001 mm and 5 mm, this is because some analytical techniques are more successful in detecting larger microplastic particles [35].

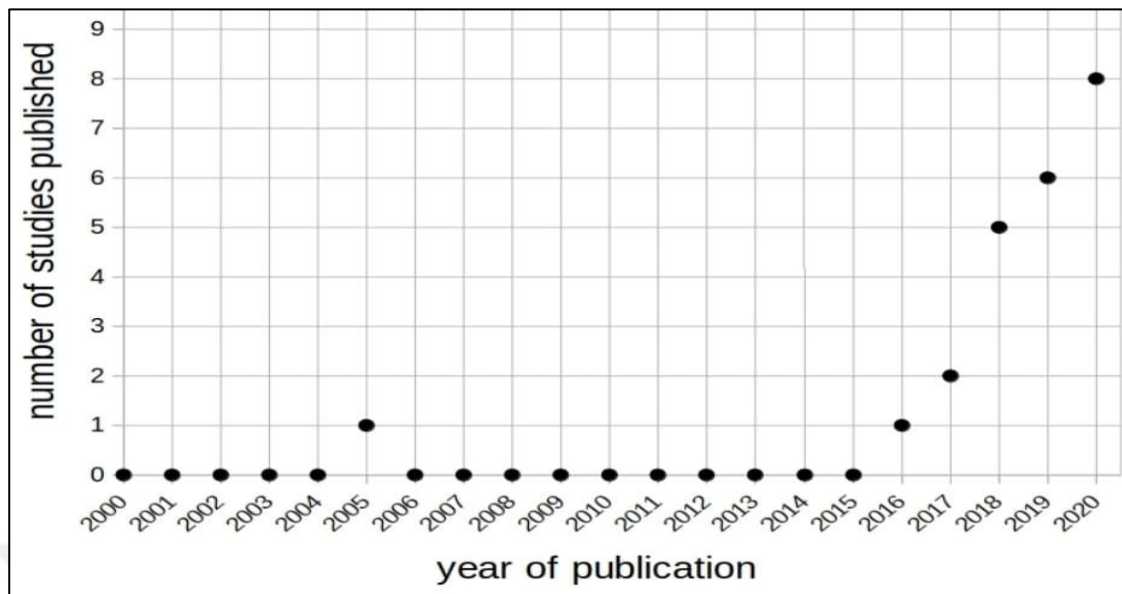


Figure 2.15. Number of studies on microplastic concentrations in terrestrial soils published since year 2000 [61].

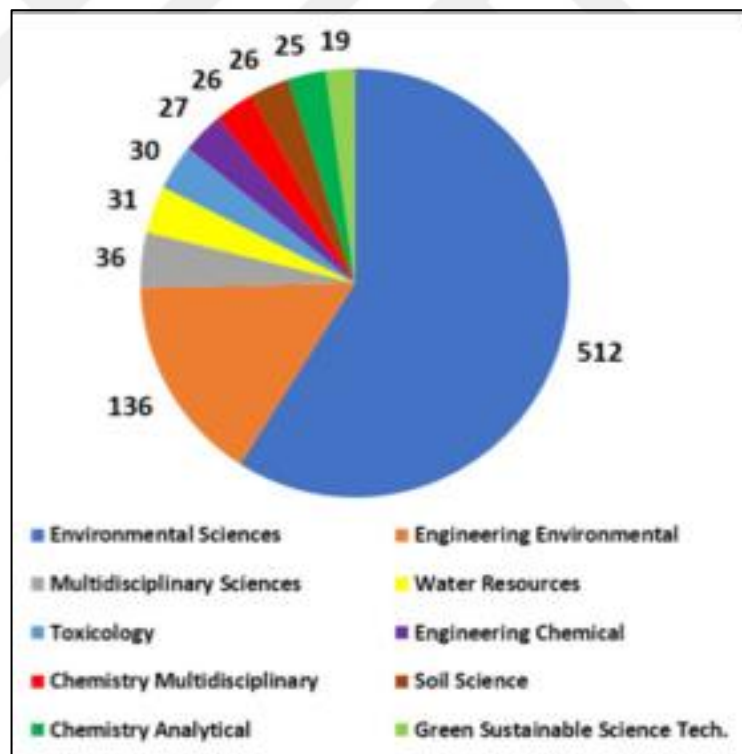


Figure 2.16. This study examines the distribution of research publications on microplastics and soils in the Web of Science Core Collection database from January 2016 to October 2021, focusing on the top 10 academic areas. The data was obtained from reference [61].

The investigation of microplastics in soil is a relatively uncommon research topic, and the existing studies may not be comparable due to different methods of collection, processing, and analysis. There is a lack of a well-suited and effective approach for analyzing microplastics in soil samples due to the complexity of soils. This review critically evaluates the published techniques for collecting, extracting, purifying, and detecting microplastics in multiple environmental matrices, focusing on their relevance to soil samples. Larger particles may be manually removed and validated by chemical analysis, but preparing samples for evaluating smaller particles is more complicated.

2.7.2. Detecting Microplastic Methods In Soil

Various methods for detecting and analyzing microplastics in soil samples have been studied, but none have been found to be entirely suitable. However, the authors suggest that by making minor adjustments and combining different approaches,

it may be possible to progress an actual method for analyzing microplastics in soil samples. [36]. Additionally, a comprehensive study of existing

literature on microplastics in soil was conducted, including an examination of detection methods, occurrence, classification, source, and potential dangers. The study findings indicate that microplastics are present in soil worldwide.

Investigating microplastics in the soil is difficult due to technical difficulties and challenges in detecting particles in a complex environment. Studies on the incidence and spread of microplastics in soil are not expected [37].

The investigation of microplastics in the soil is not yet familiar, and previous studies have faced challenges in identifying particles in the complex soil matrix. Microplastics are prevalent in soil, primarily in Africa, South America, and Oceania. Sources of microplastics may be shared between aquatic environments and soil. The properties and possible hazards of microplastics on soil ecologies are also being studied, with little evidence currently available on how microplastics interact with other contaminants and diseases in the soil, as well as the potential impacts on food chain migration. The characteristics of microplastics, including shape, chemical composition, and effects on soil, vary depending on environmental conditions.

There is a need for more research to understand the factors influencing the presence of microplastics in soil and the potential influences on soil strength and purpose, as well as microplastics masquerading as carbon storage [48].

2.7.3. Analysing Microplastic In Soil

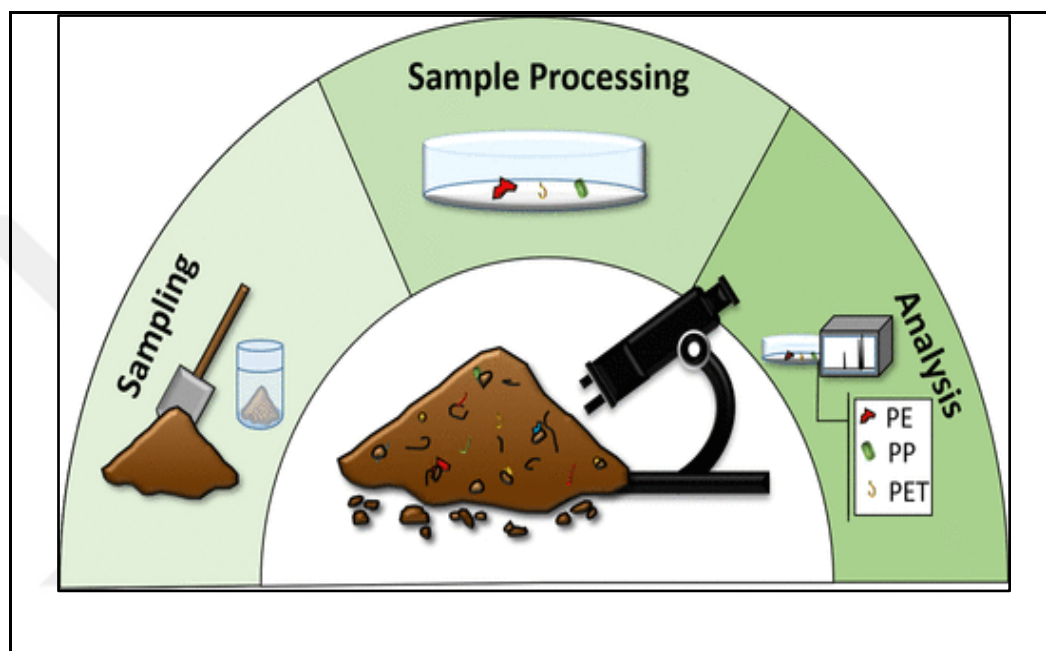


Figure 2.17. Analysing process of microplastic in soil [36].

Analyzing microplastics in soil samples poses different challenges compared to the established methods for marine ecosystems. The soil composition and the presence of organic materials can make it difficult to detect and identify microplastic particles [39], [40]. To overcome these challenges, the analytical procedures must be adapted to suit soil samples [36], these include drying and sieving the samples if necessary, removing the organic materials that are connected to the microplastic particles and the soil matrix, then using density separation to separate the microplastic particles from the remainder of the sample matrix [41], [42].

The likely microplastic particles can then be recognized underneath a microscope and confirmed using spectroscopy techniques like Transformation function infrared (FT-IR) and Optical spectrometry [43].

Conducting research on microplastics in the soil requires certain modifications to the established analytical procedures used in aquatic environments. However, the process can be hindered by the complexity of soil samples and the presence of microplastics in the air, which can lead to contamination of the samples during collection, processing and analysis. As a result, it is essential to take precautionary measures at every step of the process, such as using ultra-clean facilities, to avoid contamination by microplastics [44].

Proper cleaning of equipment using ultrapure water and heating them to high temperatures is a must to remove any microplastics which may be present before starting the analysis, as microplastics can contaminate the environmental samples during collection, processing and examination [45].

It is crucial to minimize the use of plastic in the analytical process. Additionally, it is necessary to conduct a test on a blank sample to ensure accuracy. Sample preparation and analysis should be done in such a way that exposure to air is minimized, for example, by covering the sample with aluminum foil. To reduce contamination, it is also recommended that researchers wear protective clothing, such as cotton jumpsuits and nitrile gloves, during the entire process [46].

Analyzing microplastics can also be difficult due to the lack of consistency among methods used and the quantity needed for accurate results (bulk). This poses a challenge as it relates to both the accuracy and the price of the analysis. This is an important choice that needs to be made after selecting the method, and it is also highly influenced by statistical and technical factors. Inadequate sample size may lead to inaccurate test results.

It is difficult to determine the optimal amount of soil samples needed for accurate analysis of microplastics due to the lack of information available [36]. The amount of soil samples analyzed in previous research on density separation ranges from 10g to 1kg [47]. However, many studies do not mention the sample mass used, or only a small number use volume as a measure. Additionally, there needs to be more consistency in the size of microplastics considered in environmental sample analysis, with variation in both upper and lower size limits. This phenomenon poses a challenge in terms of comparing findings across various research studies. In the initial stages of studying microplastics, sieves of varying mesh sizes are often used to remove scums and choice particles of a specific size series. The sifting process often targets smaller than 5mm microplastics, but 1mm and 2mm

microplastics are also being considered. However, it is worth noting that by definition, soils are typically sifted to a maximum size of 2mm and, in some cases, even smaller than 1mm [48].

2.7.4. The Negative Effect Of Microplastics Uses

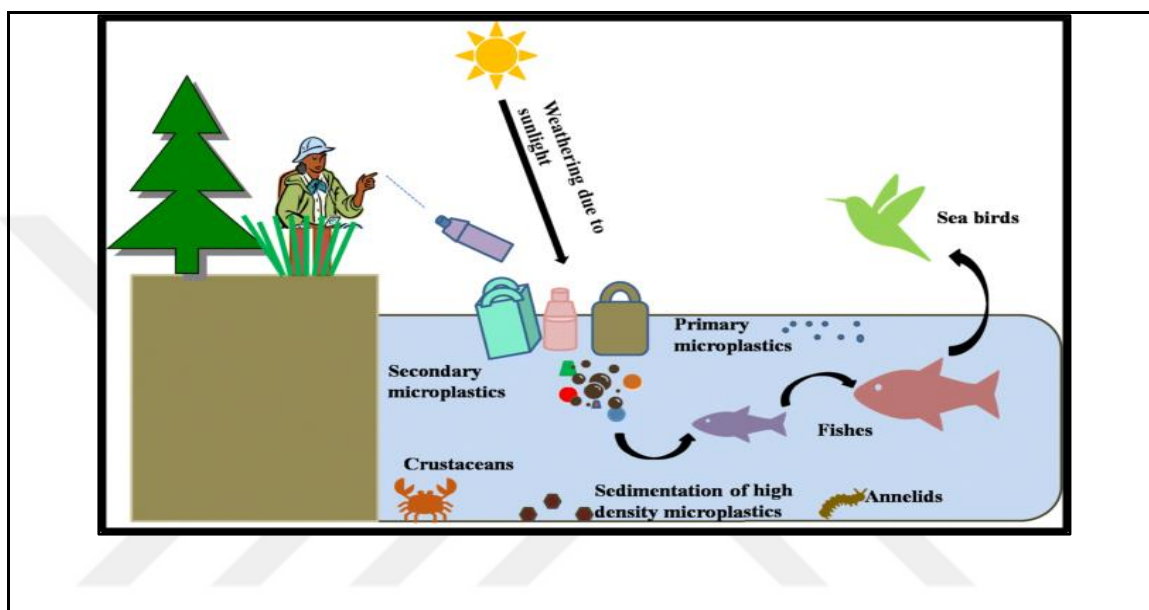


Figure 2.18. Microplastic pathway in organisms [49].

There is a growing understanding of the dangers posed by plastic trash and microplastic particles. Many studies have been conducted on microplastics in marine environments, and several nations have begun to monitor microplastics and marine plastic trash [50]. However, research on microplastics in soils has yet to be as advanced.

According to Wong et al. (2020) [50], controlling microplastic contamination in the soil also be achieved to a certain extent through better regulation and enforcement. The United Nations has reported that in 2018, out of 192 countries that were studied, 127 nations, or 66% of them, have put in place laws to regulate the use of plastic bags [51].

There are laws and regulations in place in many countries to try to reduce the amount of microplastic pollution in the Environment. These laws focus on plastic bags, other disposable plastics, and microbeads in personal care products. For example, some countries charge a fee for plastic bags or tax their manufacture and production. In some developed nations, using microbeads in personal care products is banned. These measures are

relatively simple and easy for people to comply with, and they can effectively decrease the number of microplastics entering the atmosphere. In addition, some countries promote the use of biodegradable plastics, and the use of disposable plastics is regulated. However, most plastic monomers are derived from fossil fuels, and their slow rate of biodegradation is a significant to microplastic pollution [52], [53], [50], [54], [55],[56].

Biopolymers are an alternative to traditional plastics, made using natural materials like starch and produced by microorganisms. They are considered more environmentally friendly since they are derived from renewable resources and can be a sustainable solution to reduce the use of traditional plastic. Bioplastics can be utilized as a substitute for traditional plastics.

Japan has established a strategy to promote bioplastics, which are made from natural resources like starch and are considered environmentally friendly. The goal of this strategy is to increase the production of polymers from renewable sources by 20% by 2010. Additionally, waste management and recycling are essential steps to reduce microplastic contamination. China also passed a law in 2017 that limits the importation of foreign waste, which aims to encourage sustainable waste management and increase recycling rates. This highlights the importance of promoting the use of bioplastics and effectively managing waste in order to reduce microplastic pollution [57].

The impact of tire powder on the stability and strength of road embankments has become an important issue due to the increase in vehicle traffic. As tire particles penetrate the soil, they can alter the soil's engineering properties. The use of tire waste in various industries and construction projects is a cost-effective solution, and tires can be processed into different particle sizes depending on the specific application.

The global population and industrial growth have led to an increase in the number of cars on the roads, which in turn increases the wear and tear of tires on the road surface. This results in tire particles entering roadside embankments and affecting the soil properties. Many governments now support the recycling of old tires to prevent adverse environmental impacts. The use of tires for other purposes, such as in building and industry, has also been implemented due to the economic benefits but road abrasions as a significant issue that needs to be addressed.

The influence of tire powder penetration on road embankment tension and stability was researched in a study published in 2015 by [58]. We will go through some of the specifics of their experiment here.

2.8. THE TIRE CHIPS AS MICROPLASTICS IN SOILS

Microplastics are a rapidly growing environmental concern due to their widespread distribution and persistence. The fragmentation of large-scale plastic products is a significant source of microplastics., such as tires. Tires contain a variety of synthetic polymers, such as styrene-butadiene rubber (SBR), which can break down into small particles over time and end up in the soil. Research has shown that tire chips can release microplastics into the soil, posing potential environmental and human health risks.

Furthermore, microplastics in soil can have negative impacts on soil properties, such as reducing water infiltration and affecting nutrient cycling. Microplastics from tires decrease soil microbial biomass and alter the composition of microbial communities, which can have significant impacts on soil health and productivity [59].

To mitigate the impacts of tire-derived microplastics in soil, there is a need for better waste management strategies and alternative materials for tire production. For example, a study by Fan et al. (2020) suggested that using biodegradable materials in tire production could reduce the amount of microplastics released into the Environment.

In conclusion, the fragmentation of tires can lead to the release of microplastics into the soil, with potential negative impacts on both the Environment and human health. More study is required to comprehend the issue's scope completely and devise practical solutions.

2.8.1. This study aims to investigate the impact of tire powder, also known as tire chips, on the geotechnical characteristics of clay soils through experimentation.

Davood Akbarimehr and EsmaelAflaki [62], did this experiments in 2018 to examine the soil with the addition of tire waste and can improve the geotechnical properties of the examined soil.



Figure 2.19. Tire Chips [60].

Table 2.3. The Atterberg limits of the clay soils utilized in this investigation [60].

High plasticity clay soil		Low plasticity clay soil	
Soil property	Water content (%)	Soil property	Water content (%)
Liquid Limit	75	Liquid Limit	33
Plastic Limit	28	Plastic Limit	17
Plasticity Index	47	Plasticity Index	16

The tire powder was procured from a commercial source. The powder is comprised of tire material that has been subjected to a No. 40 sieve. The soil specimens utilized in the experiment and the tire powder were subjected to the standard protocol of passing through sieve No. 40. The soil was classified into two distinct categories. The present study investigates the characteristics of clay with varying degrees of plasticity, specifically high and low-plasticity clay.

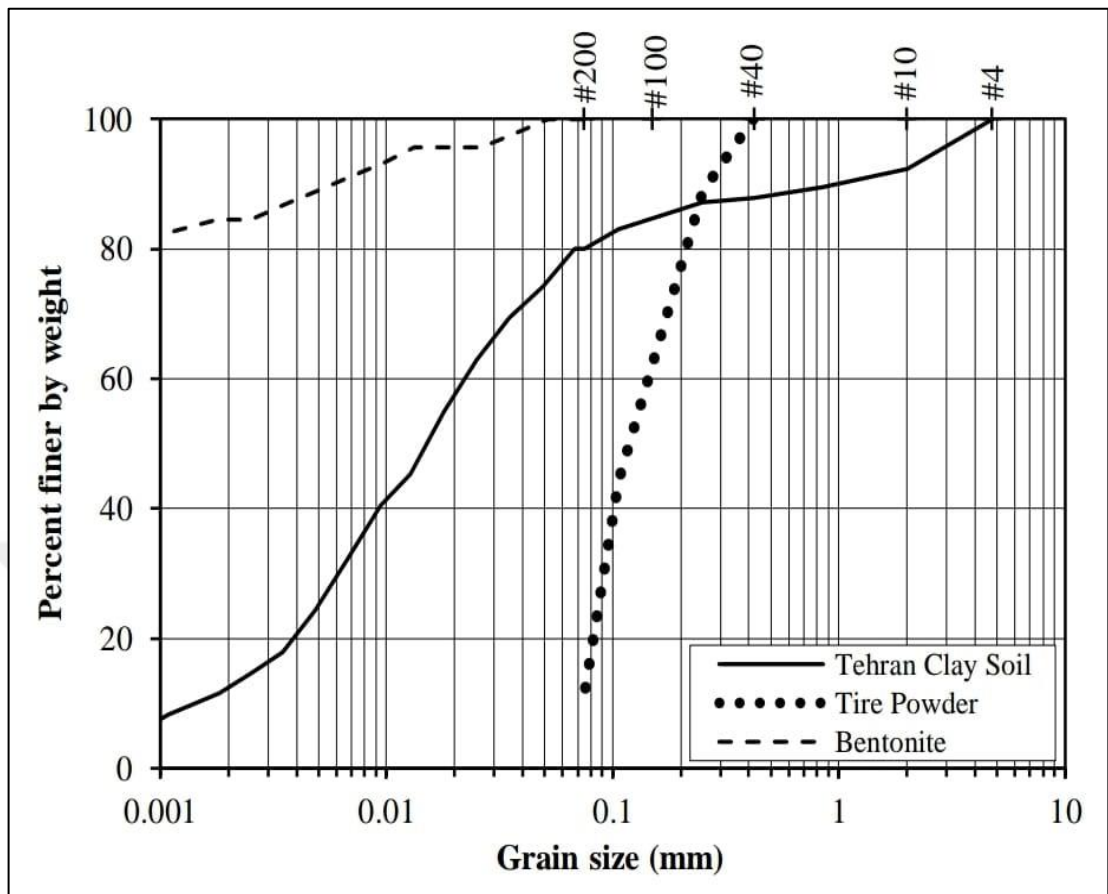


Figure 2.20. Gradation curve of clay and tire powder materials [60].

According to the test plan, CL and CH clay soils were created by combining a certain quantity of tire fragments, and the samples were then put through both liquid and plastic limits tests. These two combination parameters make it easy to calculate the plastic index.

Table 2.4. Weight composition of clay soils and tire powder [60].

Sample No.	Soil type	Tire Powder Percentage						
		0	5	10	15	20	25	30
1	CL	☒						
2			☒					
3				☒				
4					☒			
5						☒		
6							☒	
7								☒
8	CH	☒						
9			☒					
10				☒				
11					☒			
12						☒		
13							☒	
14								☒

Figure 2.21. depicts the impact or influence of adding tire powder on the Atterberg limits of low-plasticity clay soil. It demonstrates that the LL decreases in this sort of soil as the amount of tire powder increases. Obviously, the reduction is not particularly noteworthy. A 10 percent increase in tire powder results in a drop in LL; nevertheless, LL nearly selected at a 30 percent rise in tire powder.

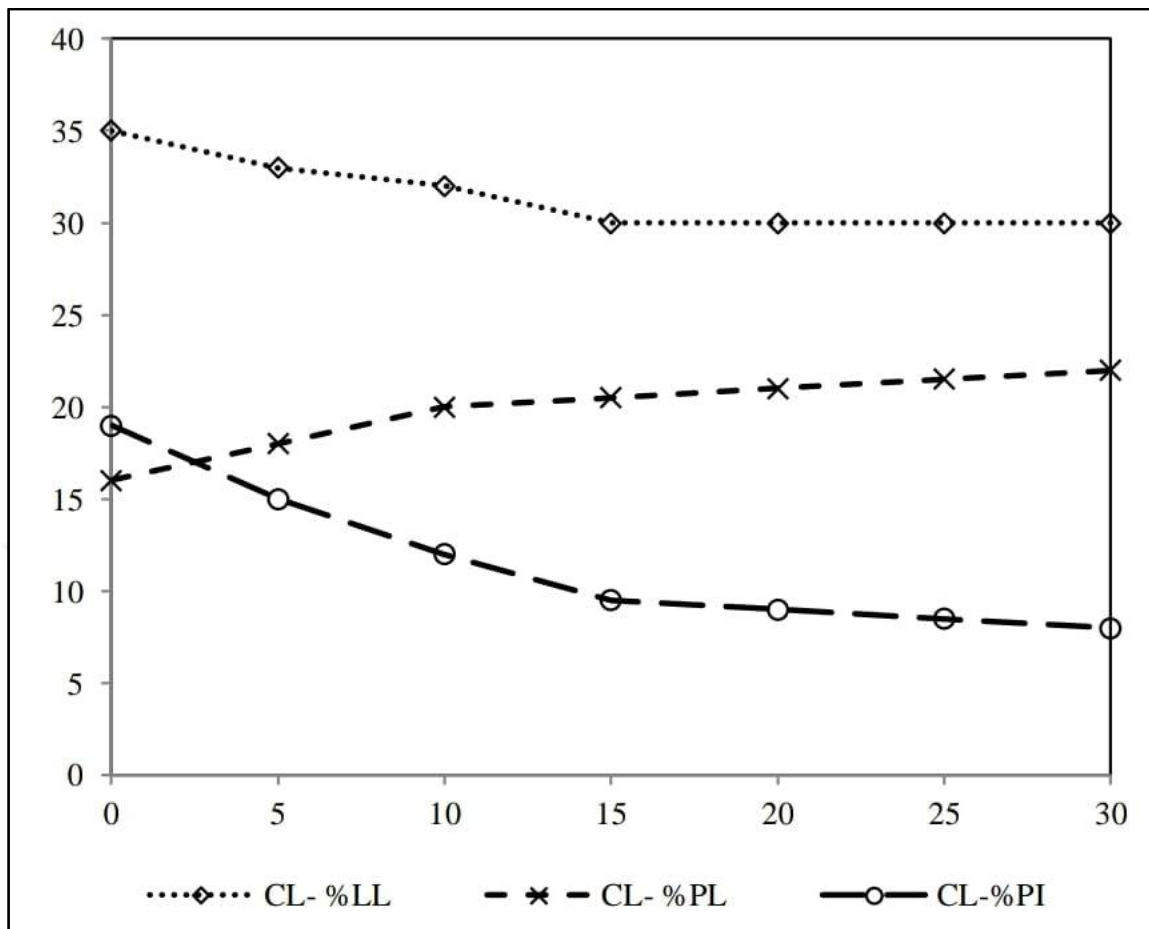


Figure 2.21. Variation of Atterberg limits of high-plasticity clay-tire powder mixtures [60].

Figure 2.22 below depicts how the addition of tire powder affects the Atterberg limits of high-plasticity clay soil. It demonstrates that an increase in tire powder Percent decreases the soil's liquid limit. Nevertheless, the reduction is enormous, with a roughly 30 percent increase in tire powder. Approximately 10 percent more tire powder has been added to the plastic limit, indicating an upward tendency. After that, a declining trend is noted in the diagram, with the percentage of tire powder in the combination the percentage is observed to have risen to 30%. With a 10 percent rise in tire powder, the plasticity index demonstrates a declining trend, as indicated by the plasticity index's alterations.

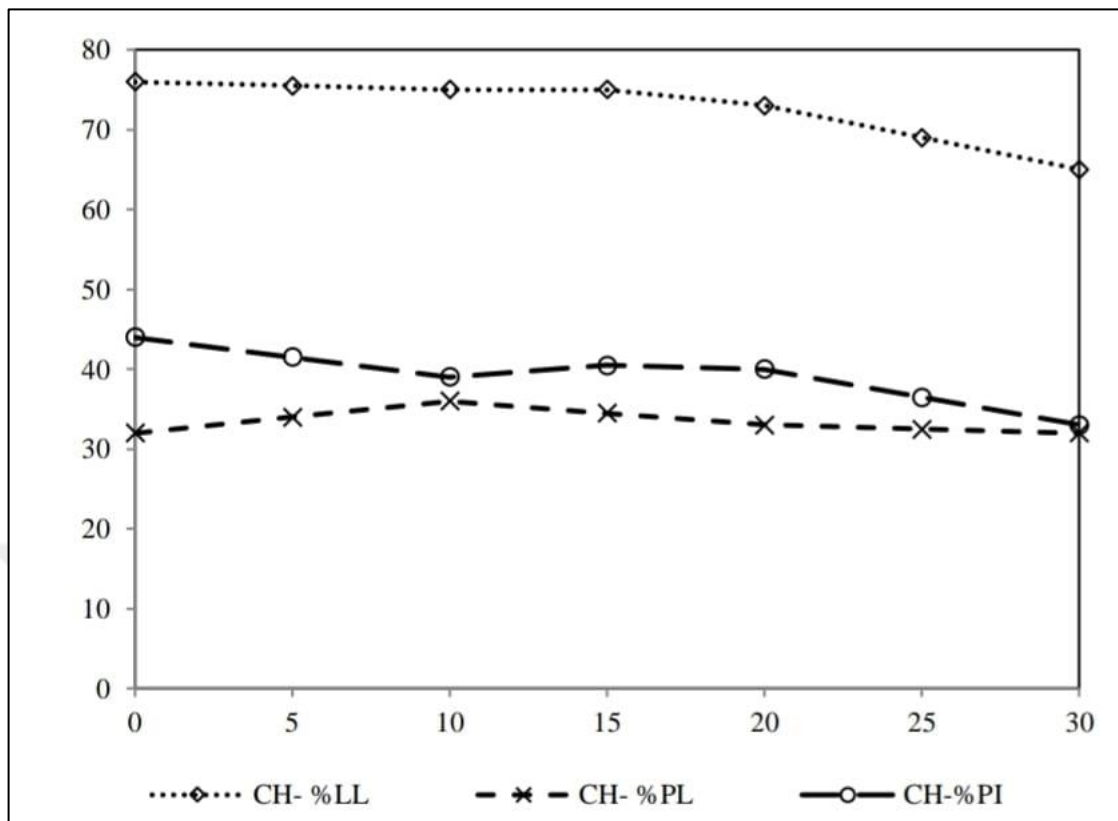


Figure 2.22. Variation of Atterberg limits of high-plasticity clay-tire powder mixtures [60].

In engineering applications, tire powder as a physical addition can increase the Atterberg limits of high- and low-plasticity clay soils, according to research findings. In both types of clay soils with varying plasticity a similar and entirely predictable process is observed, and the plasticity qualities of clay soil and tire powder can be generalized in similar situations [60].

2.8.2. Previous Studies About Tire Chips For Soil Improvement [62]

Tire chips have been proposed as a potential soil amendment to improve soil properties, such as Atterberg limits, Proctor compaction, hydraulic conductivity, and shear strength. Several previous studies have investigated the use of tire chips for soil improvement, and their findings indicate that tire chips can be a promising alternative to traditional soil amendments. Atterberg limits are important indicators of soil behavior and can affect soil compaction, stability, and erosion resistance.

A series of experimental tests were conducted on a mixture of sand and tire chips to analyze the properties of the sand and investigate the impact of adding tire chips on the engineering properties of maintained sand. Sand that had been disrupted was extracted from a depth range of 1 to 1.5 meters [62].

As per the Unified Soil Classification System (USCS), the soil type has been identified as poorly graded sand (SP), comprising 97% sand and 3% smaller particles, as evidenced by the results of the sieve analysis depicted in Figure 2.19 below.

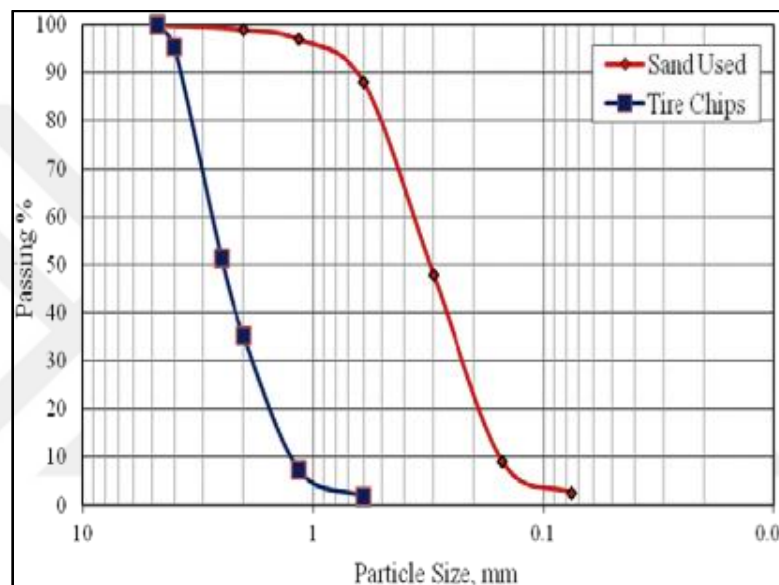


Figure 2.23. Sieve analysis of examined sand and tire chips [62].

Table 2.5. lists the distinguishing features of the sand utilized [62].

Soil Property	value
Specific gravity, GS	2.64
Coefficient of uniformity, Cu	2.55
Coefficient of curvature, Cc	0.79
Passing #200, O.M.C (%)	9.8
γ_{dry} Max. (kN/m ³)	19.6
Sulphate content, SO ₃ %	0.72
Gypsum Content %	1.55

Table 2.6. lists the Specific gravity affectation by tire chips [62].

Tire chips %	0	2	4	6	8
Gs	2.64	2.60	2.57	2.54	2.45

The sand-tire chips mixtures were subjected to a modified compaction test in accordance with IS-2720-Part-8 to determine the maximum dry unit weight (MDD) and optimum moisture content (OMC) [62].

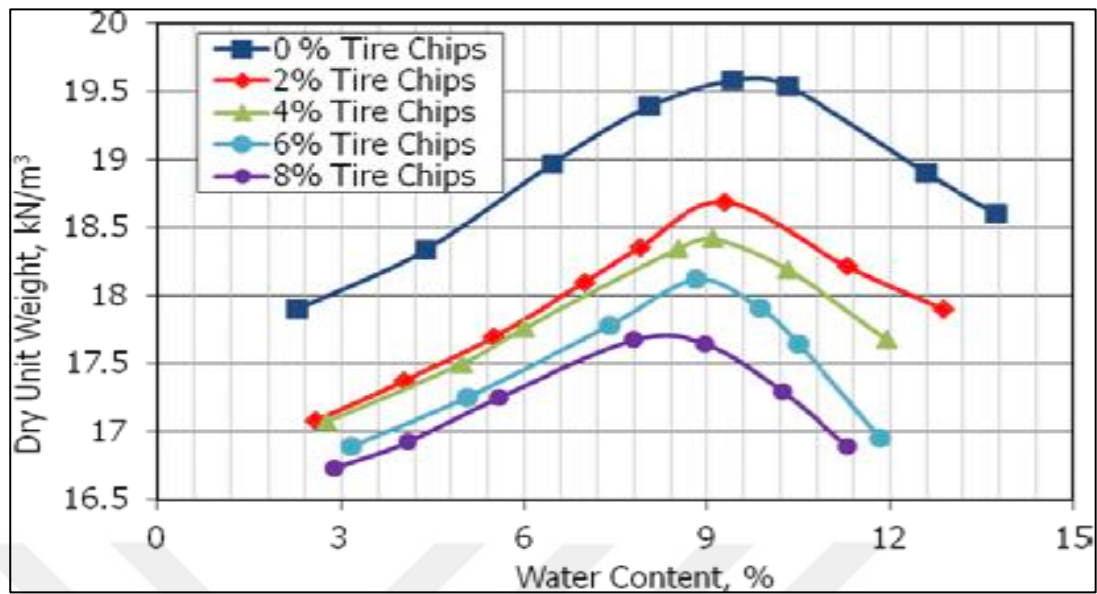


Figure 2.24. The compaction curves of mixtures containing sand and tire chips [62].

The results indicate that an increase in the proportion of tire chips in sand mixtures up to 8% leads to a reduction of approximately 10% in the optimum moisture content. However, it can be inferred that the influence of tire chips on the OMC is negligible [62].

The study involves conducting direct shear tests on mixtures of sand and tire chips, with the proportion of tire chips ranging from 0% to 8%.

The same previous study also found that adding tire chips to poorly graded sand (SP) increased the cohesion from 4 KPa to 9 KPa, indicating an improvement in soil stability.

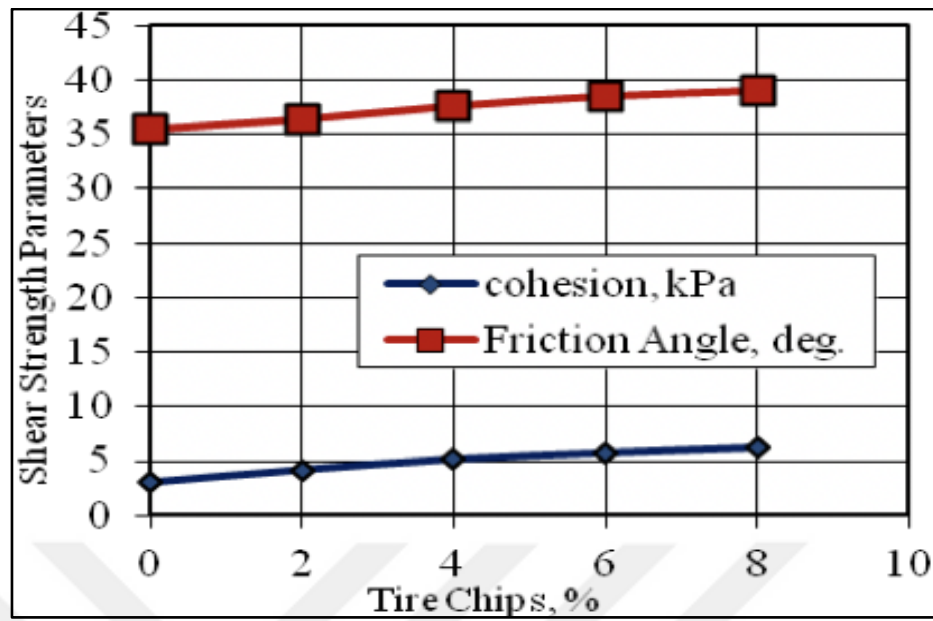


Figure 2.25. displays the outcomes of a direct shear examination conducted on a combination of sand and tire chips [62].

Overall, these studies suggest that tire chips can be a promising soil amendment for improving soil properties. However, further research is needed to fully understand the long-term effects of using tire chips in soil and to develop effective strategies for their application.

2.8.3. Previous study about expensive soil rubber ESR mixture compaction examination [67].

In a study conducted in 2007, The effect of integrating small fragments of tire rubber waste on the swelling potential of an expansive soil starting from Colorado was assessed by researchers. The primary aim of this study was to assess the index characteristics and compacting parameters of rubber, expansive soil, and a composite material consisting of expansive soil and rubber, which will be referred to as expansive soil-rubber (ESR) throughout the study. The experimental setup involved the utilization of a composite consisting of expansive soil and rubber (tire chips), with soil which includes 80% of the mixture and rubber tire chips containing the remaining 20%. The research revealed that the compaction parameter, specifically the dry unit weight, demonstrated a decrease upon the introduction of tire chips into the ESR mixture.

Enclosed within this correspondence is a pair of figures, each serving a distinct purpose. The first figure provides a visual representation of the sieve analysis, while the second figure presents the outcomes derived from the compaction tests.

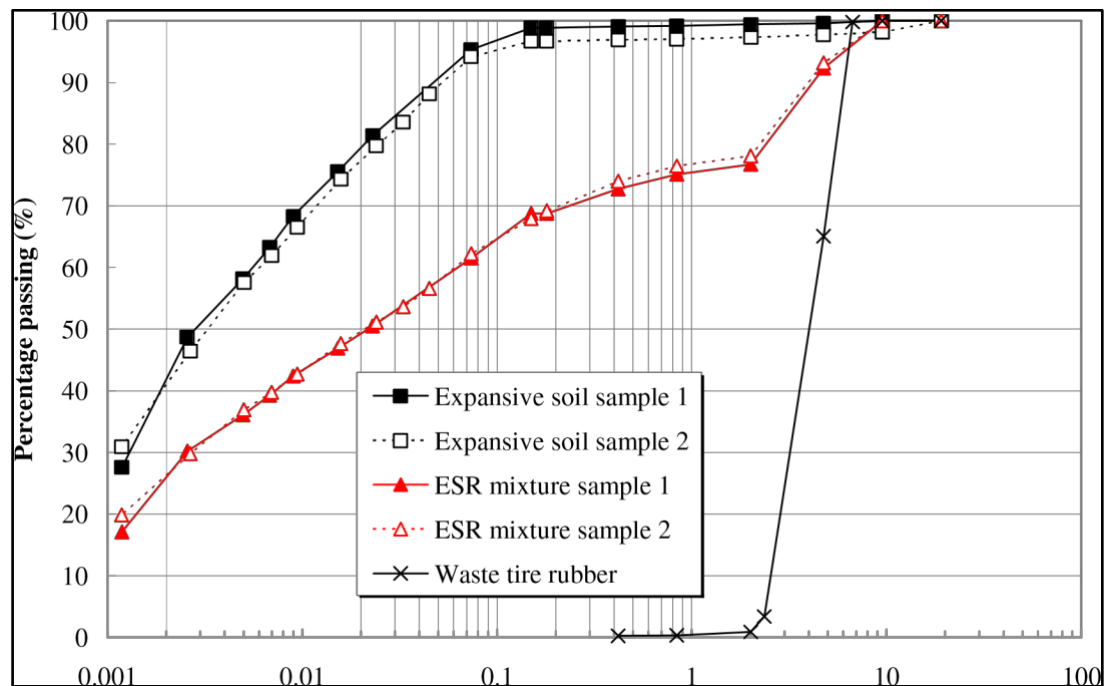


Figure 2.26. Particle size distributions for the expansive soil, waste tire rubber and ESR mixture [67].

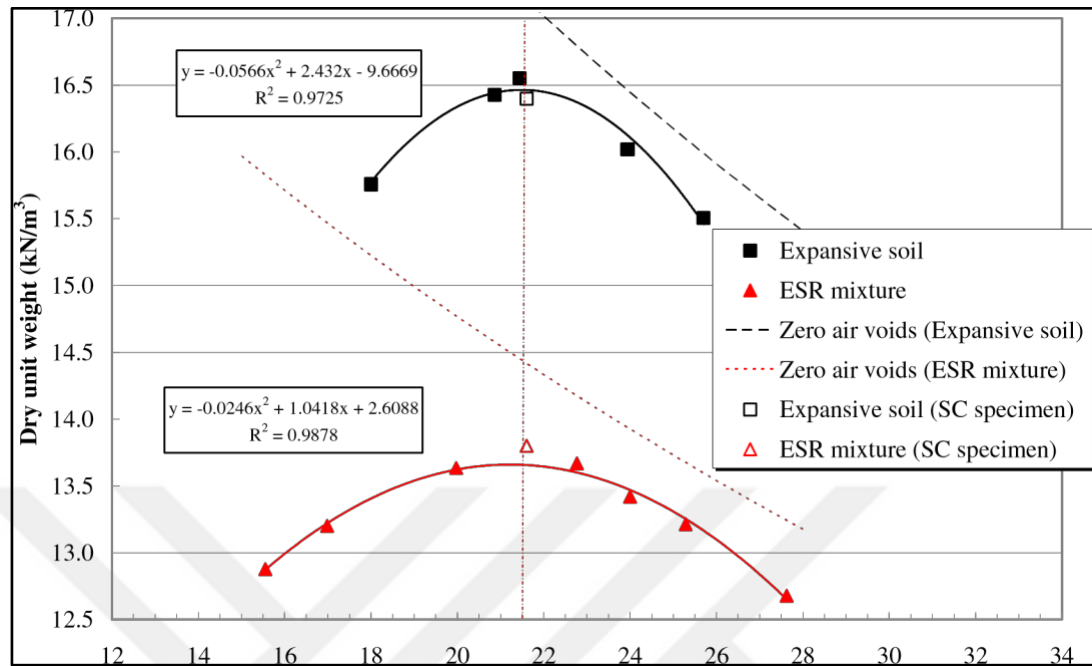


Figure 2.27. Water content vs. dry unit weight relationships of the expansive soil and ESR mixture [67].

3. MATERIALS AND METHODOLOGY

3.1. INTRODUCTION

The experimental program was implemented and tested in order to gather data and analyze its effectiveness.

The present chapter has been partitioned into three distinct parts. The first section presents an illustration of the materials used in the experimental procedure. The second part concentrates on the practical experiments conducted to demonstrate certain physical characteristics of the materials such as Atterberg limits and proctor tests. The third part of the document outlines the testing methodology for sand bentonite mixture with addition material using Atterberg limits and Proctor compaction tests. It provides an explanation for the specific percentages used in the testing process.

3.2. MATERIALS

3.2.1. Sand



Figure 3.1. Poorly Graded Sand

The name of used sand according to Unified Soil Classification System (USCS) is SP (poor-graded sand).

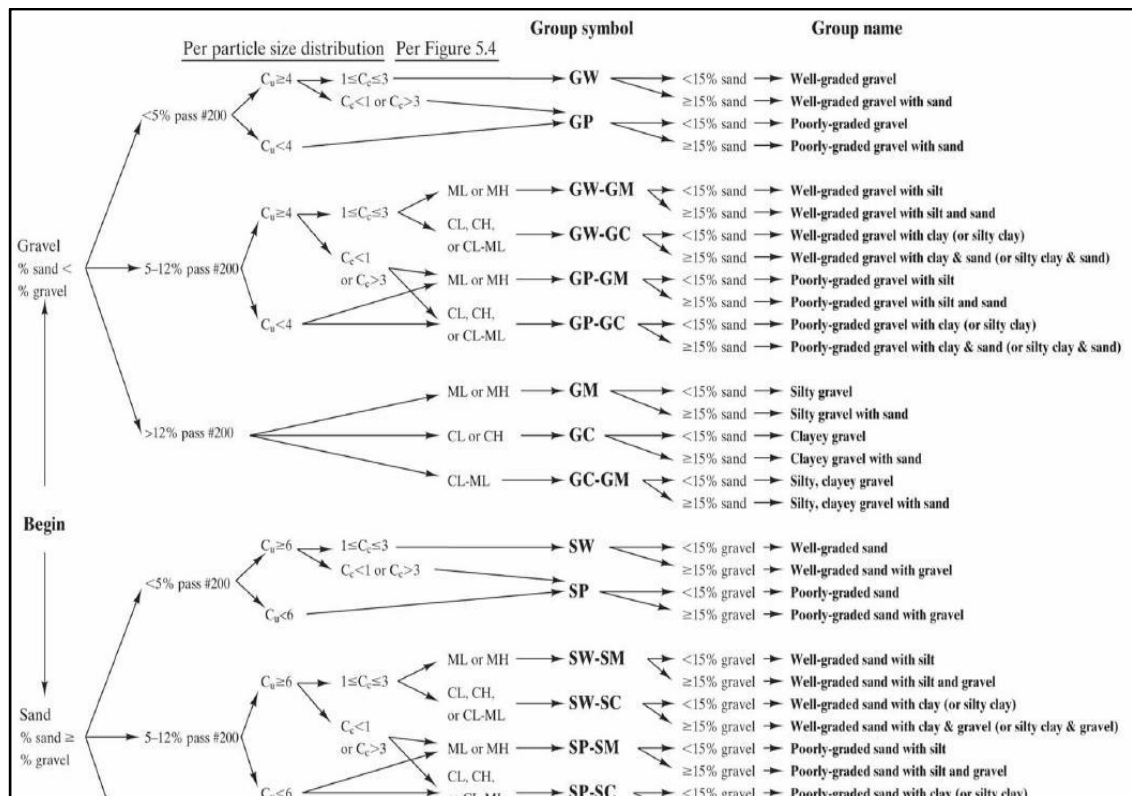


Figure 3.2. Unified Soil Classification System (USCS) Chart

Table 3.1. Sieve analysis (SA)table of the sand sample

*Sieve
Analysis*

Sieve No.	Opening (mm)	Weight retained	Weight retained %	% passing
7.00	9.52	0.00	0.00	100.00
4.75 mm	4.75	0.00	0.00	100.00
2.00 mm	2.00	6.98	1.37	98.63
1.00 mm	1.00	33.82	6.62	92.01
850 mic.	0.85	19.23	3.77	88.24
500 mic.	0.50	130.56	25.57	62.67
250 mic	0.25	238.77	46.77	15.89
125 mic.	0.13	60.79	11.91	3.99
106 mic.	0.11	5.06	0.99	3.00
75 mic.	0.075	15.07	2.95	0.04
PAN		1.73	0.34	

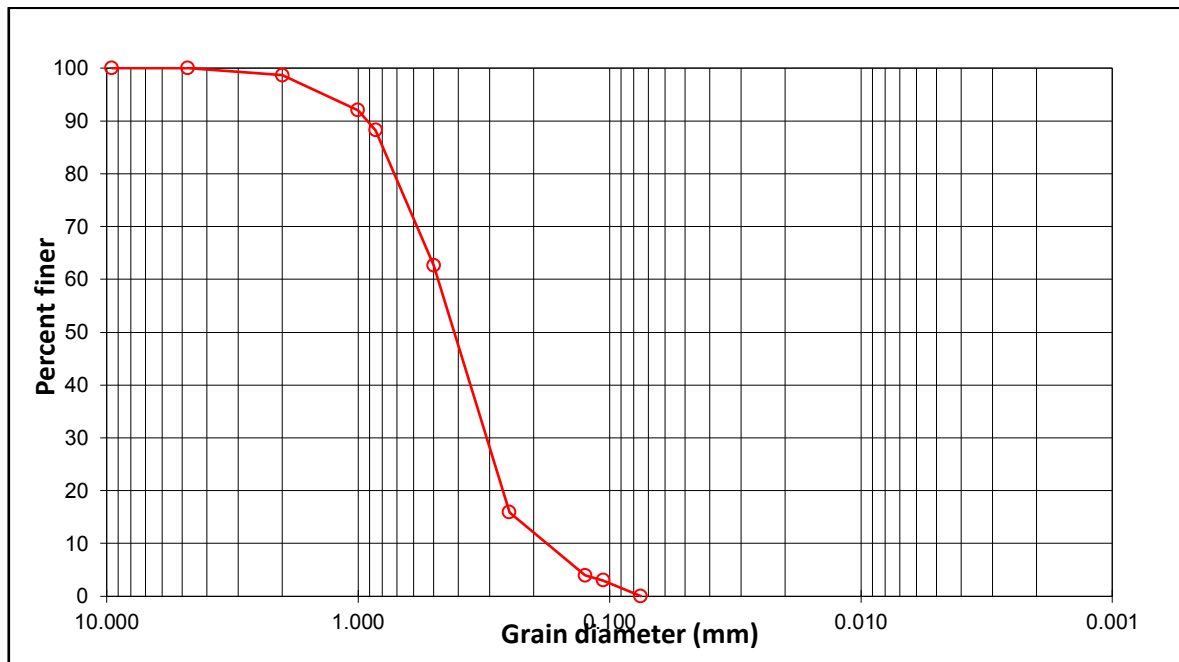


Figure 3.3. Sieve analysis graph of the sand sample

According to the sieve analysis graph, $D_{60}=0.48$ mm, $D_{30}=0.31$ mm, $D_{10}=0.17$ mm. C_u (coefficient of uniformity) $=d_{60}/d_{10}=2.82$, C_c (coefficient of curvature) $=(d_{30} \times d_{30})/(d_{60} \times d_{10}) = 1.18$. By using these values, we determine the used sand sample as SP based on USCS chart.

Table 3.2. Obtaining specific gravity using Pycnometer by 4 trials

	Test No:	1	2	3	4
Calibration of Pycnometer	Mass of Pycnometer, M_p	173,65	173,65	173,47	173,53
	Mass of Pycnometer and Calibration Water, $M_{pw,c}$	671,48	670,79	671,26	671,25
	Calibration Temperature of Water	20,7	20,5	21,9	22,9
	Density of Water, Calibration Temperature, $\rho_{w,c}$ (g/mL)	0,99823	0,99812	0,99780	0,99757
	Volume of Pycnometer, V_p	498,71	498,08	498,89	498,93
Calculation	Mass of Soil, M_s	100,00	100,00	100,00	100,00
	Test Temperature of Water	21,5	22,3	23	22,9
	Density of Water at Test Temperature, $\rho_{w,t}$ (g/mL)	0,9971	0,99768	0,99757	0,99757
	Mass of Pycnometer and Water at Test Temperature, $M_{pw,t}$	670,70	670,57	671,15	671,25
	Mass of Pycnometer, Water and Soil at Test Temperature, $M_{pws,t}$	732,62	732,89	733,54	733,92
	Specific Gravity at Test Temperature, G_t	2,626	2,654	2,659	2,679
	Temperature Coefficient, K	0,9997	0,9995	0,9993	0,9993
	Specific Gravity at 20°C, $G_{20^\circ C}$	2,625	2,653	2,657	2,677
Average of Specific Gravity of Solids, G_{avg}		2,662			

There are 4 trials. The first values, mass of pycnometers remain the same. We have to change the other values, in the end, we have to take the average of the four specific values as 2.67.

3.2.2. Bentonite

Bentonite, the prevalent type of clay, is formed through the process of devitrification and chemical alteration of glassy volcanic ash or tuff. Despite the fact that bentonite has been utilized for millennia, the majority of its contemporary applications were established subsequent to 1900. Currently, it serves as a crucial primary component in the manufacturing of energy and steel, as well as various other essential commodities and utilities that hold significant importance in the global economy.



Figure 3.4. Bentonite sample in the lab

3.2.2.1. Bentonite Properties

The bentonite is a powdered bentonite and the clay type is a mixture of calcium (Ca) and sodium (Na) montmorillonite. It was manufactured from the company Karakaya Bentonit. Engineering Properties of the Bentonite.

Table 3.3. Engineering Properties of the Bentonite

Parameter	Test Method	Value
Specific gravity (-)	ASTM D854	2.76
Liquid limit (%)	ASTM D4318	155
Plastic limit (%)	ASTM D4318	42
Plasticity index (%)	ASTM D4318	113

3.2.2.2. *Applications Of Bentonite.*

Bentonites primarily consist of minerals belonging to the smectite group. Calcium montmorillonite, which is one of the smectite minerals, is widely distributed across various regions of the globe. In comparison to calcium montmorillonite, the occurrence of sodium montmorillonite is relatively infrequent. Beidellite, an aluminium montmorillonite, exhibits a relatively infrequent presence. Smectite minerals are present in the form of submicron-sized particles, typically measuring 0.5 μm or smaller. The silicate layers are known to contain exchangeable cations, namely sodium, calcium, and magnesium, which usually interact with molecules of water. The interchangeability of these elements is determined through the measurement of their exchange capacity, expressed in milliequivalents per 100 grams.

3.2.2.3. *Sand-Bentonite Mixture.*

The utilization of sand and bentonite mixes as a lining material at waste disposal locations is a common practice. The addition of sand to bentonite is a method employed to increase its compacting density and decrease moisture shrinkage.

Despite the greater percentage of sand in the mixture, the influence of sand proportion and particle size on the mixture's properties remains uncertain due to the limited availability of knowledge on the subject.



Figure 3.5. Sand-Bentonite mixture

3.2.2.4. Sand-Bentonite Mixture Sieve Analysis

Table 3.4. Sieve analysis table of the sand-bentonite sample

Sieve Analysis

No.	Opening (mm)	Weight retained	Weight retained %	% passing
3/8	9.52	0.00	0.00	100.00
4	4.75	0.14	0.01	99.99
10	2.00	0.26	0.03	99.96
18	1.00	5.21	0.52	99.44
20	0.85	26.53	2.65	96.79
35	0.50	328.80	32.88	63.91
40	0.42	206.25	20.63	43.28
60	0.25	209.70	20.97	22.31
140	0.11	87.00	8.70	13.61
200	0.075	43.66	4.37	
PAN		94.35		

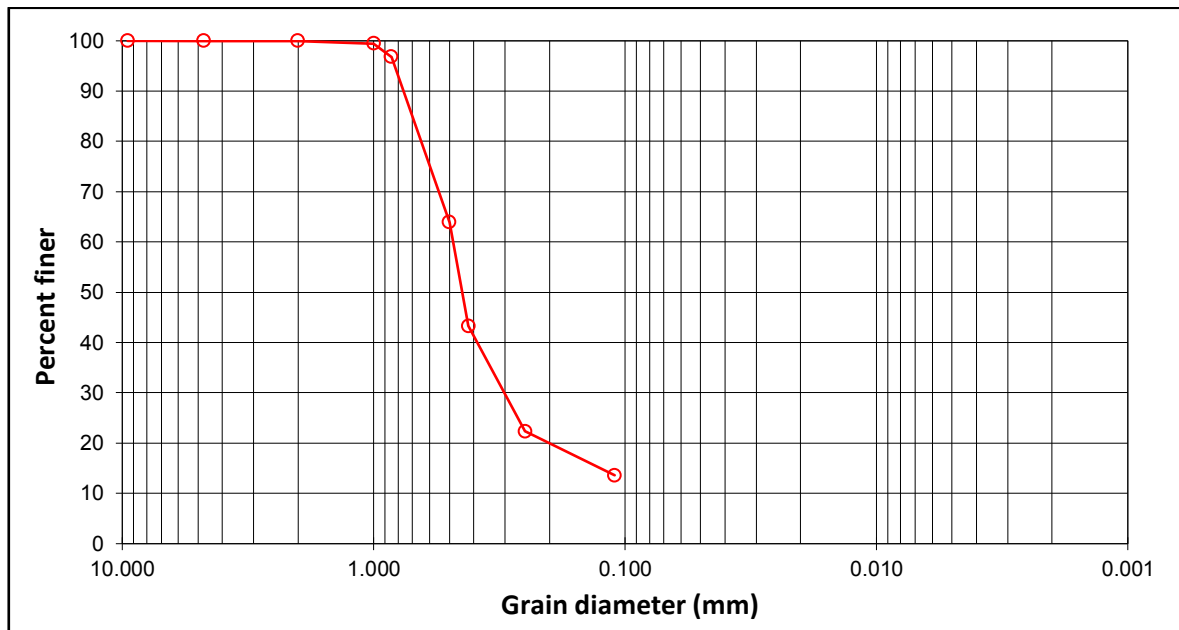


Figure 3.6. Sieve analysis graph of the sand-bentonite sample

3.2.3. Polyacrylamides

They are powdered polyacrylamides that have the chemical formula of $(C_3H_5NO)_n$ and the molecular weight within the range of 10^6 g/mol. They are formed by the copolymerization of acrylate and were manufactured from the company SNF Turkey. They are water-soluble polymers and when the anionic polyacrylamide is dissolved in water, the positive charges tend to move away and the polyacrylamide has only negative ions. Contrarily, the negative charges of the cationic polyacrylamide leave the polymer in water and the polyacrylamide contains only positive ions.

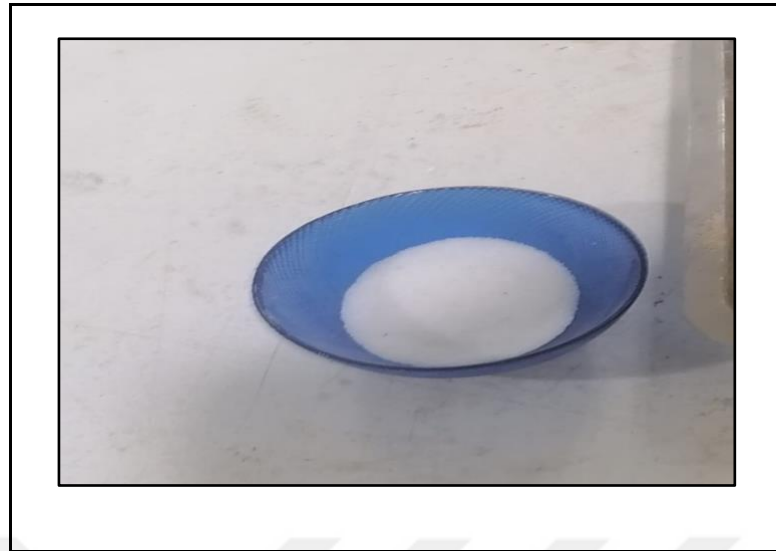


Figure 3.7. Polyacrylamide (CATIONIC) from lab

3.2.4. Tire Chips

The tire chips were manufactured from the company Lastik Sanayicileri Derneği (LASDER) and the main polymer of the tire chips is polystyrene, which is a synthetic polymer. The tire chips used in this study were obtained by the disintegration of the vehicle tires during the interaction of the tires with the roads or highways. They have the particle size smaller than 5 mm and considered as microplastics.



Figure 3.8. Tire chips that used in the experiments

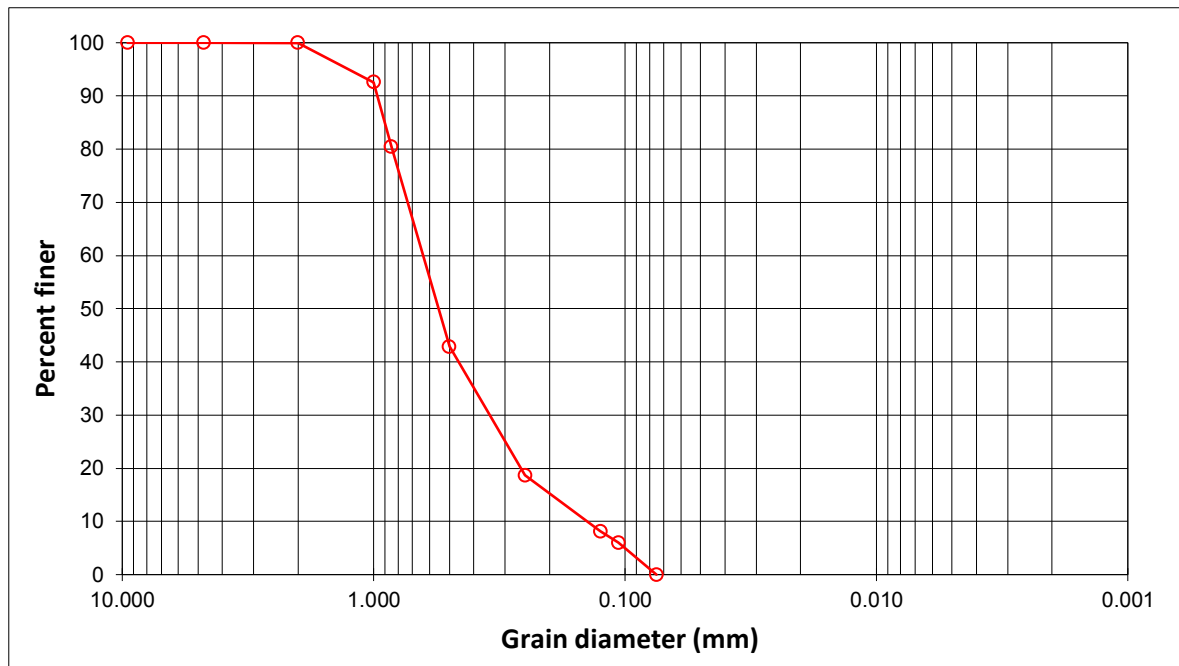


Figure 3.9. Sieve analysis of tire chips that used in the experiments

3.3. METHODOLOGY

In test procedure, different types of additive materials were mixed, polyacrylamides (Cationic and Anionic) and microplastics as tire chips with sand-bentonite mixture these mixtures were examined to observe the change of liquid limits. The sand percentage is 85 % and the bentonite is 15 % in sand bentonite mixture by the dry mass.

The first test was without addition and the following tests Polyacrylamide (cationic and anionic) and tire chips were added in each test the amount was varying in 0.5%, 1% and 2% by dry mass in polyacrylamide however in tire chips were 0.1%, 0.2%, 0.4%, 1% and 2% by dry mass.

3.3.1. Preparation Of Sand-Bentonite Mixture With Polyacrylamide Addition

Prior to preparing the bentonite-sand mixture, both the sand and the bentonite were dried in an oven at 105 °C. Then, mixing process was provided homogenously.



Figure 3.10. Mixing the dry sand with bentonite

Then, the polyacrylamide was added to the bentonite at concentrations of 0.5%, 1%, and 2% by dry mass, respectively. The polyacrylamide content was determined by dividing the mass of polyacrylamide by the mass of the bentonite and polyacrylamide mixture (100%). The bentonite and polyacrylamide were thoroughly mixed using a spatula to combine them.



Figure 3.11. Mixing the sand-bentonite mixture with polyacrylamide homogenously

The polyacrylamide-bentonite mixture was subsequently deposited in a polyethylene container and sealed to mitigate the risk of dehydration. In order to achieve a consistent distribution of polyacrylamide within the bentonite, the mixture was subjected to agitation for approximately five minutes and subsequently allowed to rest within the bottle for a duration of nearly 24 hours, as reported in reference [63]. Subsequently, the desiccated sand was blended with the polyacrylamide-bentonite mixture in the appropriate ratio. The soil mixture was then uniformly mixed with a spatula after the addition of the predetermined quantity of distilled water.

Selecting appropriate percentage of sand-bentonite mixture

According to a prior investigation conducted in 2016, the primary aim of this study was to examine the impact of integrating glass granule materials on the characteristics of low-strength soil and ascertain the need for soil enhancement in the eastern region of Mashhad. A total of 54 samples were collected from various locations within the designated area in order to ascertain the dominant soil type.

Consequently, the study put forth two experimental relationships in order to ascertain the strength parameters of the soil [64], the sand-bentonite mixture was employed with a composition of 85% sand and 15% bentonite. The findings of the study indicate that augmenting the quantity of bentonite in the amalgam led to a reduction in the dry unit weight. Hence, a proportion of 15% bentonite was selected for in order to achieve an appropriate balance between the targeted geotechnical characteristics and the preservation of an adequate dry unit weight. Furthermore, an investigation was conducted on the impact of bentonite concentration on permeability. The results revealed that a decrease in bentonite concentration may result in an elevation of permeability [65]. The cited references provide justification for the utilization of a sand-bentonite mixture comprising 85% sand and 15% bentonite, taking into account the dry unit weight and permeability properties.

3.3.2. Atterberg Limits Tests

The Atterberg limits are a bunch of tests that are used to figure out the amount of water in a fine-grained soil that causes it to change from one state to another. These limits comprise three measurements, which are the liquid limit (LL) and plastic limit (PL). The liquid limit is the quantity of moisture needed to close a 12.5 mm distance along the bottom of the groove after 25 blows.



Figure 3.12. Liquid limit machine and grooving tool (Casagrande cup)

First, tested mixtures samples were prepared and mixed in homogeneity. All samples of sand-bentonite mixture must go through sieve number 40 so the particles have to be smaller than 0.42 mm so before mixing the particles must go through sieve no 40 separately. Total sample was 200 gr. Casagrande cup technique was conducted in the lab. The soil paste is inserted in the Casagrande cup and a groove is formed in the middle. The limit is defined as the percentage of moisture content that is necessary to cover a distance of 12.5 mm. along the bottom of a crack in a liquid limit device after 25 blow. It can be difficult to modify the soil's moisture content to achieve the required 12.5 mm closure of the groove at 25 blows. Therefore, three tests were conducted on the same soil at various moisture contents, with the number of impacts, N , ranging from 12 to 38.



Figure 3.13. Mixing the sand-bentonite in homogeneity

The plastic limit (PL) is defined as the threshold water content level at which the soil undergoes a transition from a plastic state to a semi-solid state. The shrinkage limit refers to the specific water content level at which the soil undergoes a transition from a semi-solid state to a solid state. Based on the amount of water present in the soil, the soil can be in one of four states: solid, semi-solid, plastic, or liquid. Atterberg limits are utilized to classify fine-grained soils based on their consistency and behaviour.



Figure 3.14. Plastics limits tools

The Plastic limit test was conducted by repeatedly hand-rolling an ellipsoid-shaped mass of soil on an impermeable surface. Then water content was obtained. The test was repeated for all mixtures with all percentages.

The moisture content was conducted by putting the samples in the oven with 100 degree after weighting the sample then note the values before and after the oven.

The sample must be inside the oven at least 24 hours. Furthermore the weight of empty cup was measured . Subsequently, the moisture content was determined through the application of a mathematical formula involving the subtraction of the weight of the dry sample from the weight of the wet sample, followed by division of the result by the weight of the wet sample, and finally multiplying the quotient by 100.

$$w = \frac{W - W_d}{W_d} \quad (3.1)$$

w = Water content

W = The weight of wet sample

W_d = The weight of dry sample



Figure 3.15. Water content determination by putting the samples in the oven

3.3.3. Proctor Test

The optimum moisture content at which a particular type of soil becomes most compact and achieves its highest dry density has been determined using the Proctor compaction test.

The Proctor test is a laboratory method of determining the level of compaction achieved by earlier models of compaction equipment. Newer and heavier compaction equipment is now capable of attaining 100% or more of the standard Proctor compaction specifications with just a few passes [64].



Figure 3.16.' Proctor test equipment mold and hammer

Important for assuring the stability and durability of such initiatives is the level of compaction. Soil compaction reduces soil permeability, thereby restricting hydraulic conductivity and erosion. Consequently, the integrity of a roadbed (for example) will be less susceptible to subsurface water flow and subsidence.

For each sand-bentonite mixture polyacrylamide and tire chips were added separately with different amounts as stated above, water was added to the sample with the aim to determine the soil's moisture content. The addition of water was started by 10% increased to 12%, 14%, 16%, 18%, 20%. The water was added and mixed properly to be homogeneous with the sample. Each sample in total was 2000 gr in total.



Figure 3.17. Mixing the water with sand bentonite mixture



Figure 3.18. Taking weight the empty mold



Figure 3.19. Taking weight the wet sample with the mold

The mold has been cleaned and desiccated, and its weight without the base plate was determined. The mold was filled with moist soil from a tray in three equal layers, and each layer was compacted with 25 evenly distributed impacts from a standard hammer weighing 2.5 kg. The hammer's drop height should be 30.48 cm. After that in each water addition water content was taken as described above. Then the maximum dry unit weight was obtained by the maximum weight using the plots shown in next sections. Remove the soil from the mold and transfer it to the combining tray. Determine the moisture content of a representative specimen sample. Notate the relative moisture content "M". After each compaction procedure the compacted layers sample was shown as below:



Figure 3.20. The sample after the compaction processes

To obtain the moisture content more accurately two samples were taken. The water content of a representative sample of compacted soil obtained from the centre of the mold is determined. The remaining part of the sample soil was to be broken up and repeated mixing with the addition of a suitable amount of water.

For this, the average of water addition was 2%. A minimum of six determinations was performed, the amount of moisture should be adjusted to ensure that the optimum moisture content, which corresponds to the maximum dry density, falls within the specified range.



Figure 3.21. Crushing the remaining sample and remixing it by addition water

Obtaining the dry unit weight :

$$\gamma_m = \frac{W}{V_m} \quad (3.2)$$

W = Weight in g of mould + soil .

V_m = Volume of mould i.e. 944 cm³.

$$\gamma_d = \frac{100 \gamma_m}{(100 + M)} \quad (3.3)$$

γ_d = Dry density of soil in g/cm³.

M = Moisture content of soil .

γ_m = Bulk density of soil / cm³.

The dry densities, γ_d , derived through a series of measurements are depicted against the respective moisture content, 'M'.

Maximum dry density (M.D.D.) is determined by drawing a uniform curve through the resulting points and locating the maximum point on this curve. The corresponding moisture level is known as the optimum moisture content (O.M.C.).



4. RESULTS AND DISCUSSIONS

4.1. INTRODUCTION

This chapter discusses the results of the experimental work that were given in chapter 3 in detail. The examination and evaluation of soil properties are indispensable for determining the suitability and efficacy of soil enhancement techniques. In the case of soil enhancement utilizing polyacrylamide in a sand bentonite mixture, the Atterberg limits test and the Proctor test are frequently used.

These evaluations provide valuable insights into the soil's behavior and characteristics, allowing engineers and researchers to evaluate the efficacy of polyacrylamide in improving the soil's engineering properties. The Atterberg limits test is used to determine the moisture content at which a soil changes from a liquid to a plastic to a solid state. The liquid limit (LL) is the moisture content at which the soil starts moving, whereas the plastic limit (PL) is the moisture content at which the soil loses its plasticity. The difference between the liquid and plastic limits is known as the plasticity index (PI), which measures the compressibility and shear strength of the soil. On the other hand, the Proctor test is used for assessing the compacting properties of a soil.

It involves measuring the desiccated density and moisture content of a soil sample that has been compacted at various moisture contents. The results are used to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil, thereby identifying the optimal conditions for compaction. By applying the Atterberg limits and the proctor test to the sand-bentonite mixture, the impact of polyacrylamide on soil improvement can be determined. As a soil stabilizer, polyacrylamide seeks to improve the geotechnical properties of the soil, including its strength, workability, and permeability. The Atterberg limits test enables a thorough comprehension of the soil's behavior, including its sensitivity to moisture and plasticity, which can indicate the efficacy of the polyacrylamide treatment. In addition, the Proctor test reveals the compaction characteristics of the soil and evaluates the effect of polyacrylamide on attaining the desired density and moisture content.

This information is crucial for assuring the soil's stability and load-bearing capacity. In this discussion, we will examine the outcomes of Atterberg limits and Proctor experiments conducted on a polyacrylamide-treated sand-bentonite mixture. Due to the addition of polyacrylamide(Anionic and cationic) and microplastics (tire chips) the properties of the soil will change, including its liquid limit, plastic limit, plasticity index, maximum dried unite weight, and optimal moisture content.

The outcomes will cast a light on these changes. These findings will facilitate in the design and implementation of effective geotechnical engineering solutions by contributing to a comprehensive comprehension of the soil improvement potential of polyacrylamide and microplastics in the sand-bentonite mixture.

4.2. EXPERIMENTAL RESULTS AND DISCUSSION

4.2.1. Sand-Bentonite With Polyacrylamide Addition

4.2.1.1. Atterberg Limits

Atterberg limits tests were conducted on sand-bentonite mixture with a sand content of 85% by dry mass.

Then polyacrylamide (anionic and cationic) was added in different amounts (0.5%, 1% and 2%) by dry mass to determine the liquid limits and plastic limits after that the LLs and PLs were examined.



Figure 4.1. The liquid limits graph of the sand-bentonite mixture without addition

The graph shows an illustration of the soil's behavior regarding its sensitivity to moisture. The graph depicts the relationship between the soil's moisture content and its fluidity, demonstrating how the soil changes from a solid to a liquid state. The LL for this graph was 53% which is the water content represented the exact 25 blows number.

Table 4.1. PL of sand-bentonite mixture sample without any addition determination

Can, g	20.88	20.07
Sample+can , g	22.01	20.96
Dry sample+can , g	21.69	20.71
Dry soil, g	0.81	0.64
Wt. of water, g	0.32	0.25
Water cont., %	39.51	39.06

Two small sample were taken for plastic limit test then the average number was calculated to obtain the PL. The plastic limit for sand-bentonite mixture, 85% sand 15% bentonite without additional materials. Tested sample averages water content amount was 39 % which is PL as shown in table 4.1 . So easily we can obtain the plasticity index by subtracting (LL-PL) the result will be 14 %.

0.5% polyacrylamide (Anionic) addition by dry mass

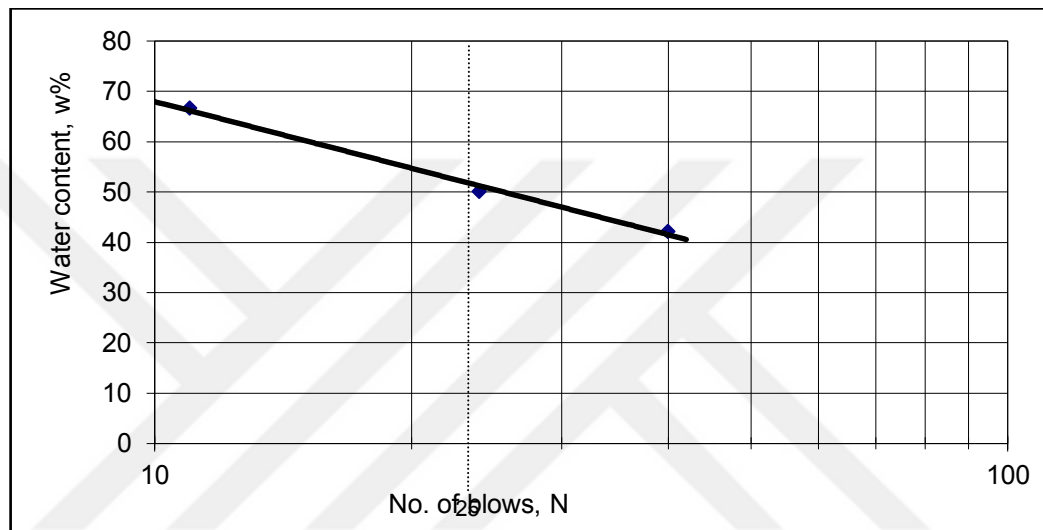


Figure 4.2. LL graph of the sand-bentonite mixture with 0.5% Anionic addition

Table 4.2. PL of sand-bentonite mixture sample with 0.5% anionic addition

Can, g	20.50	21.04
Sample+can , g	21.78	22.51
Dry sample+can , g	21.43	22.12
Dry soil, g	0.93	1.08
Wt. of water, g	0.35	0.39
Water cont., %	37.63	36.11

As shown in Fig 4.2 the LL is 50 % and in table 4.2 the PL is 37% , 0.5% anionic was added. So the PI is 13%. The liquid limit graph with a dose of 0.5% anionic material, which results in a slight rise in the plasticity index and a decrease in both the liquid limit and plastic limit values, reveals interesting insights into the soil's behavior. The modest decrease in the plasticity index may suggest a slight improvement in soil Stability.

These results highlight the subtle effects of the anionic addition on the engineering properties of the soil.

1% polyacrylamide (Anionic) addition by dry mass

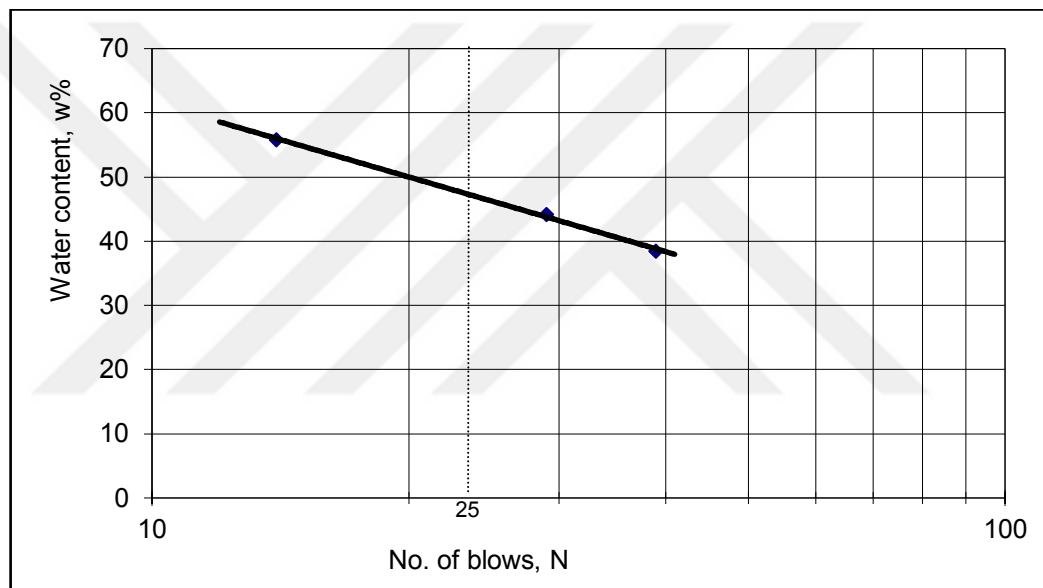


Figure 4.3. LL graph of the sand-bentonite mixture with 1% Anionic addition

Table 4.3. PL of sand-bentonite mixture sample with 1% anionic addition

Can, g	20.10	21.04
Sample+can , g	21.87	24.21
Dry sample+can , g	21.46	23.48
Dry soil, g	1.36	2.44
Wt. of water, g	0.41	0.73
Water cont., %	30.15	29.92

According to Fig 4.3, LL is 46% which is the water content in 25 blows and if we take a look at table we can realize the average water content (PL) is 30 % as discussed above. As it is observed the LL and PL dropped down, the PL decent rate is higher than in LL. But the plasticity index increased to 16 % which positively effects the shear strength and the soil deformity.

2% polyacrylamide (Anionic) addition by dry mass

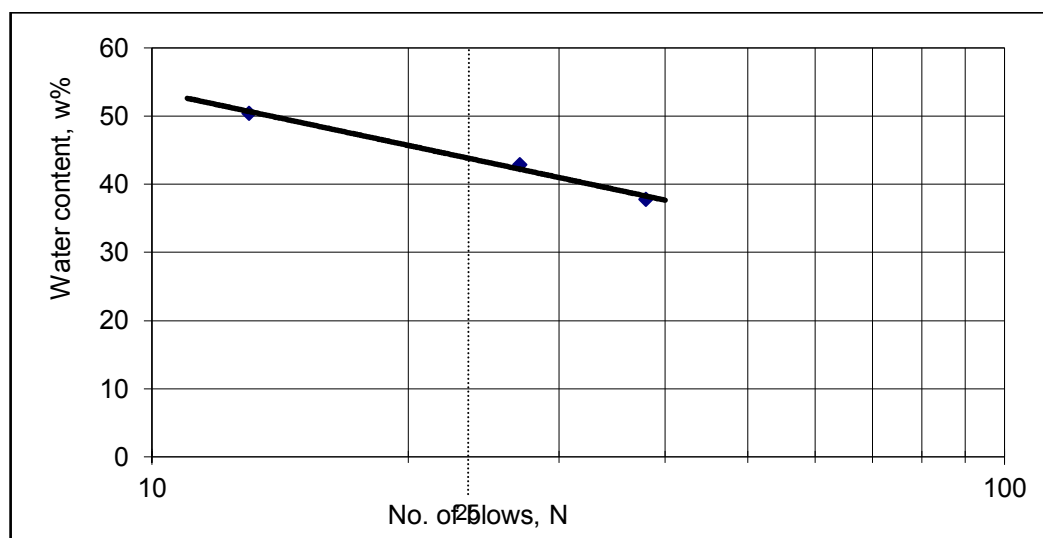


Figure 4.4. LL graph of the sand-bentonite mixture with 2% Anionic addition

Table 4.4. PL of sand-bentonite mixture sample with 2 % anionic addition

Can, g	20.00	19.40
Sample+can , g	21.11	21.51
Dry sample+can , g	20.89	21.11
Dry soil, g	0.89	1.71
Wt. of water, g	0.22	0.40
Water cont., %	24.72	23.39

In the case of Fig. 4.4, LL equals 43%, which is the water content in 25 blow, and an examination at the table reveals that the average water content (PL) is 24%, as previously described. The liquid limit graph with the addition of 2% anionic material, which results in an increase in the plasticity index to 19% and a decrease in both liquid limit and plastic limit values, provides useful information into the behavior of soil containing higher concentrations of anionic substances. the minor increase in the index of plasticity could indicate an enhancement in the soil's shear strength and deformation ability.

0.5% polyacrylamide (cationic) addition by dry mass



Figure 4.5. LL Graph of the sand-bentonite mixture with 0.5% cationic addition

Table 4.5. PL of sand-bentonite mixture sample with 0.5 % cationic addition

Can, g	20.04	23.12
Sample+can , g	22.90	25.85
Dry sample+can , g	22.11	25.10
Dry soil, g	2.07	1.98
Wt. of water, g	0.79	0.75
Water cont., %	38.16	37.88

The line graph in Figure 4.5 depicts the effect of adding 0.5% cationic material to a mixture of sand and bentonite on its liquid limit. LL in that case equal 52 %. The average of water content (PL) is 38%, as shown in the table 4.5. According to the graph number 4.5 and table 4.5, the incorporation of 0.5% cationic material into the sand-bentonite mixture had a significant impact on the liquid limit and plastic limit.

The graphical representations illustrates a reduction in the liquid limit and plastic limits upon the addition of cationic material in comparison to the mixture lacking any additive. The observed decrease in the liquid limit and liquid limits implies that the cationic substance exerts a stabilizing effect on the mixture. And the plasticity remains the same as no additive materials 14 %.

1% polyacrylamide (cationic) addition by dry mass

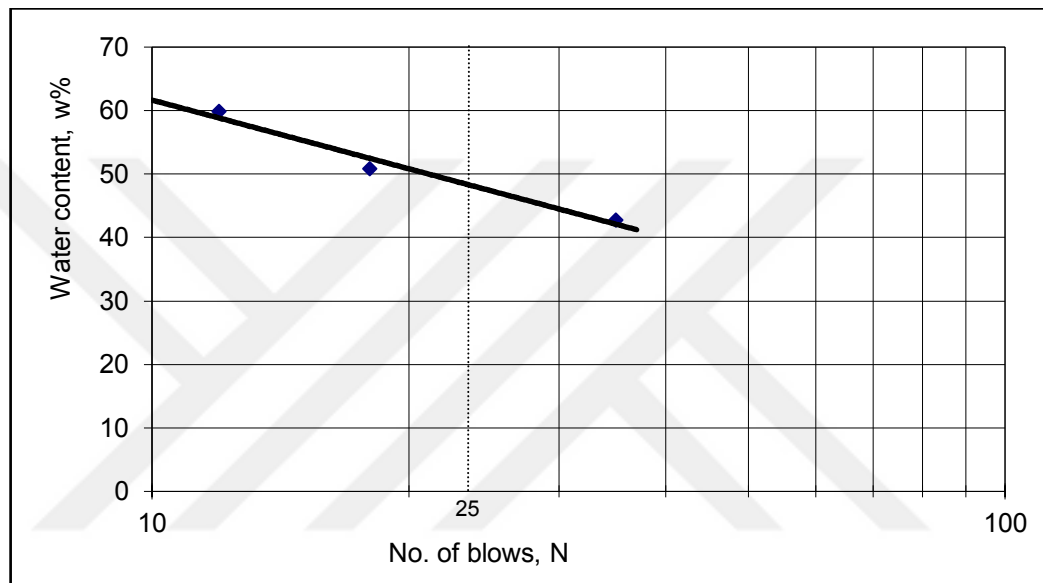


Figure 4.6. LL Graph of the sand-bentonite mixture with 1 % cationic addition

According to the data presented in Figure 4.6, the LL is 47%. Additionally, Table 4.6 indicates that the PL is 31%, the PI is 16 % and 1 % cationic was introduced , as shown below.

Table 4.6. PL of sand-bentonite mixture sample with 1 % cationic addition

Can, g	19.80	22.52
Sample+can , g	22.80	28.21
Dry sample+can , g	22.09	26.85
Dry soil, g	2.29	4.33
Wt. of water, g	0.71	1.36
Water cont., %	31.00	31.41

The graph depicting the liquid limit with a 1% cationic material quantity displayed noteworthy observations regarding the soil's characteristics. Specifically, there was a small increase in the PI, while both the LL limit and PL limit values decreased. The marginal elevation observed in the plasticity index could potentially indicate a minor enhancement in the soil's capacity to resist shear stress and experiences deformation.

The outcomes point out the diverse and complicated impacts of cationic supplementation on the soil's engineering characteristics.

2% polyacrylamide (cationic) addition by dry mass



Figure 4.7. LL Graph of the sand-bentonite mixture with 2 % cationic addition

Table 4.7. PL of sand-bentonite mixture sample with 2 % cationic addition

Can, g	20.89	19.10
Sample+can , g	31.27	33.06
Dry sample+can , g	29.10	30.15
Dry soil, g	8.21	11.05
Wt. of water, g	2.17	2.91
Water cont., %	26.43	26.33

The graphical representation and tabular data in Figure 4.7 and Table 4.7 respectively, illustrate the correlation between LL and PL of a sand-bentonite composite, on its addition of cationic material at a concentration of 2%.

The graph illustrates a significant reduction in the liquid limit and plastic limit, leading to a notable rise in the plasticity index when the cationic additive is absent. The aforementioned findings indicate that the LL and PL values are 43% and 26 %, correspondingly. By subtracting LL- PL the PI will be 17 % .

According to the graph's results, the incorporation of 2% cationic material has a significant impact on the sand-bentonite mixture. The observed reduction in the liquid limit and plastic limit indicates that the cationic material has a positive impact on the soil's water retention ability and a negative impact on its plasticity. This feature can confer benefits in geotechnical contexts where the reduction of settlement and enhancement of soil stability are of the utmost significance.

Moreover, the rise in the plasticity index indicates that the soil's cohesiveness and malleability are enhanced by the introduction of the cationic substance.

The aforementioned might produce practical outcomes in the field of construction projects, as it may enhance the process of compaction and simplify modifying of soil for shaping and molding purposes. It is imperative to acknowledge that although the graph offers significant insights into the conduct of the sand-bentonite mixture with the addition of 2% cationic material, additional investigation and experimentation are necessary to authenticate and comprehend the results comprehensively. In determining the ideal concentration of cationic material for soil stabilization purposes, it is imperative to consider project-specific factors and engineering requirements.

To summarize, the illustrations clarify the potential advantages of adding polyacrylamide (anionic and cationic) materials into a sand-bentonite mixture, leading to a reduction in both liquid and plastic limits, as well as an increase in the plasticity index. The aforementioned findings provide significant insights for geotechnical experts and researchers who aim to enhance the characteristics and functionality of sand-bentonite mixture for diverse engineering projects.

4.2.1.2. Proctor Compaction Test

The graph of compaction test obtained from the Proctor test offers significant insights into the compaction behavior of a sand-bentonite mixture in this case mixed with polyacrylamide.

Subsequently, varying concentrations of polyacrylamide (both anionic and cationic) have been added at various percentages (0.5%, 1%, and 2% for PAM by dry mass). The graph presented in this particular context depicts the correlation between the percentage of moisture content and the mass per unit volume of dry density in the sand-bentonite mixture, where in polyacrylamide has been incorporated. Polyacrylamide is a frequently utilized polymer additive that has the potential to augment the soil's characteristics and ameliorate its compaction behavior. Through an examination of the Proctor test graph, it is possible to evaluate the influence of polyacrylamide inclusion on the compaction properties of the sand-bentonite composite. The graph presented illustrates the relationship between moisture content and dry density, providing insight into the determination of the optimal moisture content and the corresponding maximum dry density.

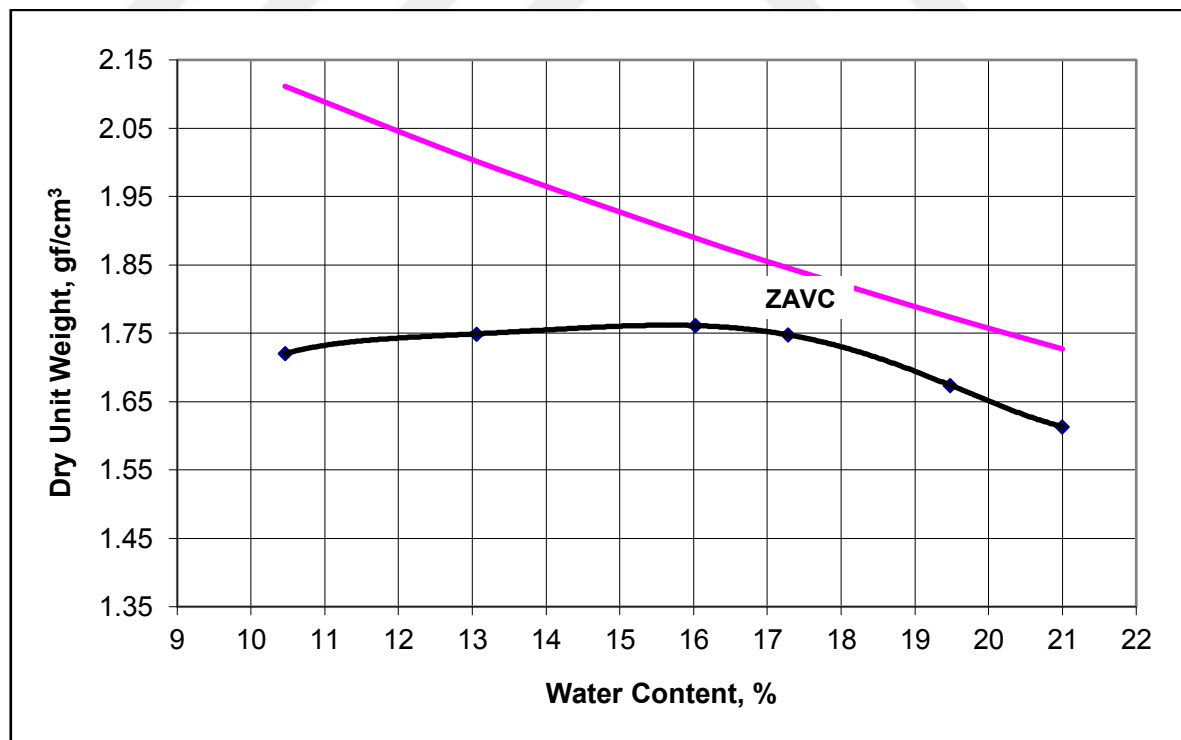


Figure 4.8. The sand-bentonite mixture without addition proctor test graph

Optimum water content, ω_{opt} : 16 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.760 gf/cm³

0.5% polyacrylamide (anionic) addition by dry mass

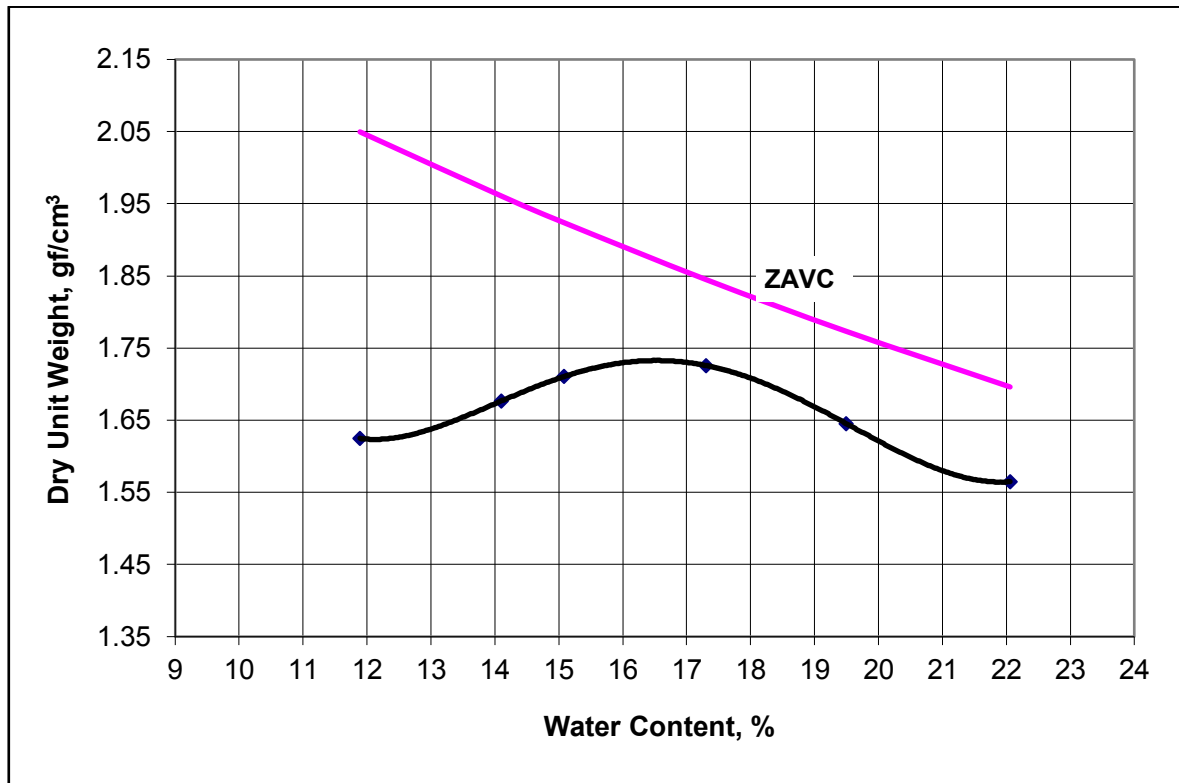


Figure 4.9. The sand-bentonite mixture with 0.5 % anionic addition proctor test graph

Optimum water content, ω_{opt} : 16.5 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.730 gf/cm³

Upon examination of the graph number 4.9, a discernible impact can be observed with the addition of 0.5% anionic material on the compaction characteristics of the sand-bentonite composite. The graphical representation indicates a reduction in the maximum dry unit weight and a rise in the optimal water content in comparison to the blend that lacks the anionic additive. The observed reduction in the maximum dry unit weight implies that the addition of 0.5% anionic material has an effect on the obtainable density during compression. The observed phenomenon may be attributed to various factors, including diminished particle interaction or rose lubrication, which could potentially impact the soil's compaction potential and result in lower densities.

It is noteworthy that the reduction in the maximum dry unit weight is not always associated with a disadvantageous consequence, as the particular engineering prerequisites and project discussion shall determine the preferred range of density.

Furthermore, the elevation in the optimal water content suggests that the presence of the anionic substance necessitates a greater level of moisture to attain the utmost dry unit weight.

The aforementioned observation implies that the presence of anionic material has an impact on the sand-bentonite mixture's ability to retain water, which could potentially result in modifications to the soil's compaction characteristics and workability.

1 % polyacrylamide (anionic) addition by dry mass

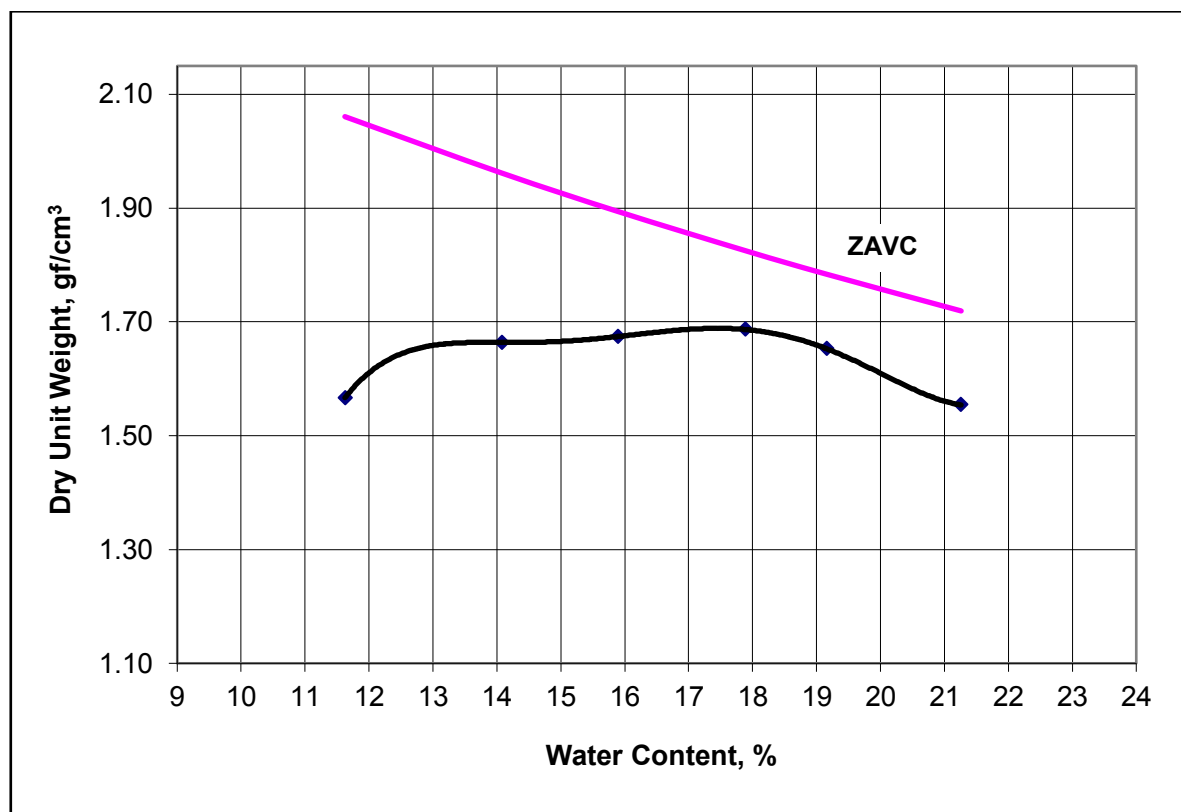


Figure 4.10. The sand-bentonite mixture with 1 % anionic addition proctor test graph

Optimum water content, ω_{opt} : 17.3 %, maximum dry unit weight, $\gamma_d \max$: 1.690 gf/cm³.

The graph number 4.10 illustrates a slight reduction in the maximum dry unit weight and a rise in the optimum water content in comparison to the mixture that doesn't have the anionic polyacrylamide. And there is observable change as we added the anionic gradually.

The insertion of 1 % anionic material into the Proctor test graph results in significant information regarding the compaction properties of the sand-bentonite composite.

The compaction behavior of the mixture appears to have been influenced by the anionic additive, as evidenced by the noticed reduction in maximum dry unit weight and increase in optimum water content.

2 % polyacrylamide (anionic) addition by dry mass

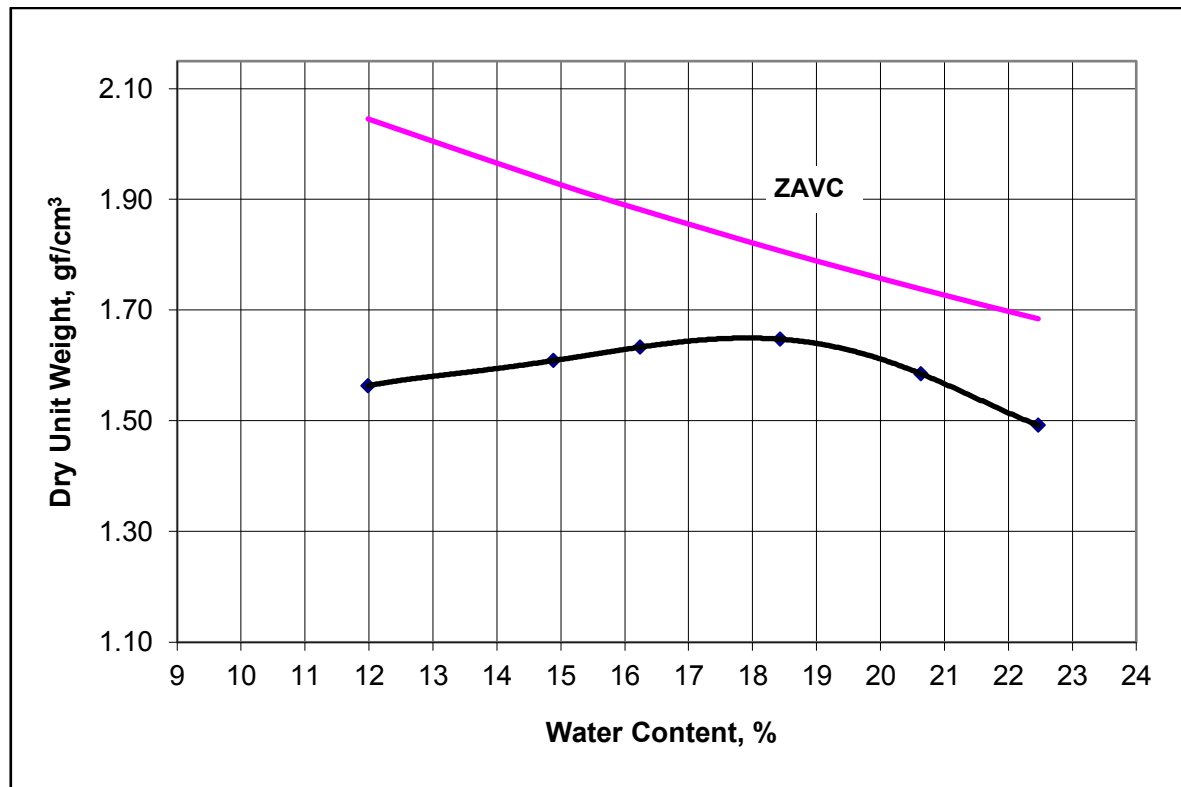


Figure 4.11. The sand-bentonite mixture with 2 % anionic addition proctor test graph

Optimum water content, ω_{opt} : 18.2 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.650 gf/cm³.

According to Fig 4.11, the minor drop observed in the maximum dry unit weight implies that the anionic material has an impact on the achieved density during the compaction process.

The observed phenomenon may be attributed to alterations in the soil's compaction pattern, adhesion, or resistance properties due to the inclusion of the anionic substance. It is noteworthy that a reduced maximum dry unit weight could potentially impact the comprehensive stability and load-bearing potential of the compacted soil. There was increase in optimum water content as well.

0.5 % polyacrylamide (cationic) addition by dry mass

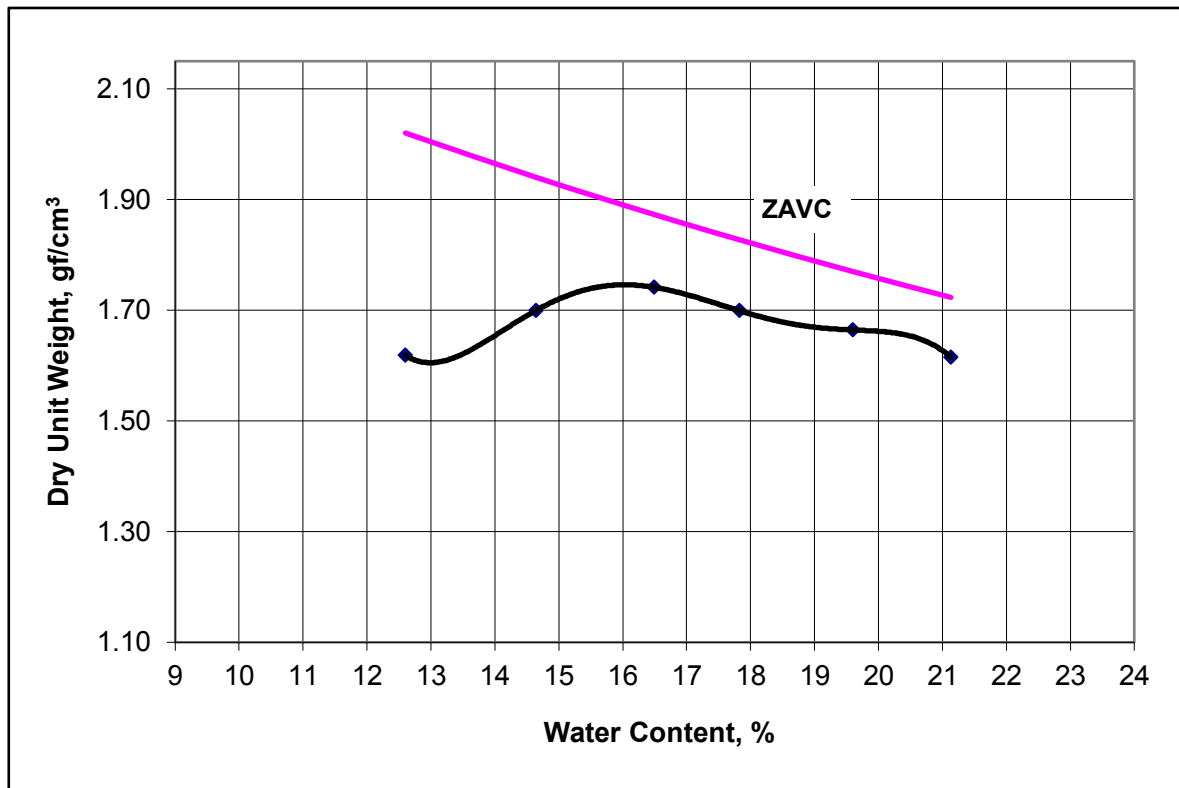


Figure 4.12. The sand-bentonite mixture with 0.5 % cationic addition proctor test graph

Optimum water content, ω_{opt} : 16.2 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.740 gf/cm³

The graph 4.12 obtained from the Proctor test depicts the compaction behavior of a mixture. Sand and bentonite, which has been supplemented with 0.5% cationic polyacrylamide material.

Upon performing an analysis of the graph, it is apparent that the inclusion of 0.5% cationic material in the sand-bentonite mixture yields significant impacts on its compaction characteristics. The graph indicates a decrease in the maximum dry unit weight and an increase in the optimum water content compared to the mixture without the cationic additive. The results revealed that the impact of anionic addition was almost the same.

1 % polyacrylamide (cationic) addition by dry mass

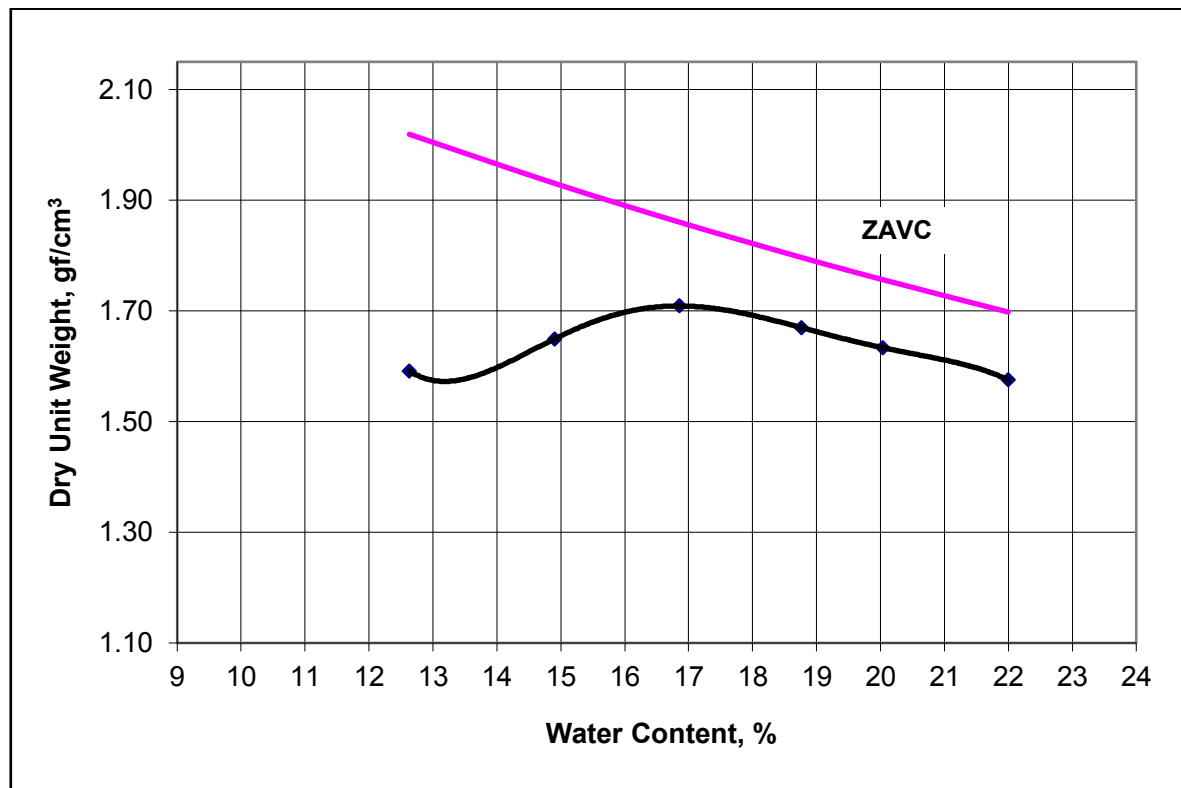


Figure 4.13. The sand-bentonite mixture with 1 % cationic addition proctor test graph

Optimum water content, ω_{opt} : 16.9 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.710 gf/cm³.

According to the Proctor test graph no 4.13, adding 1% cationic material to a sand-bentonite mixture reduces the maximum dry unit weight while increasing the optimum water content. These results emphasize the need for more research by indicating that the cationic component affects the mixture's workability and compaction properties.

2 % polyacrylamide (cationic) addition by dry mass

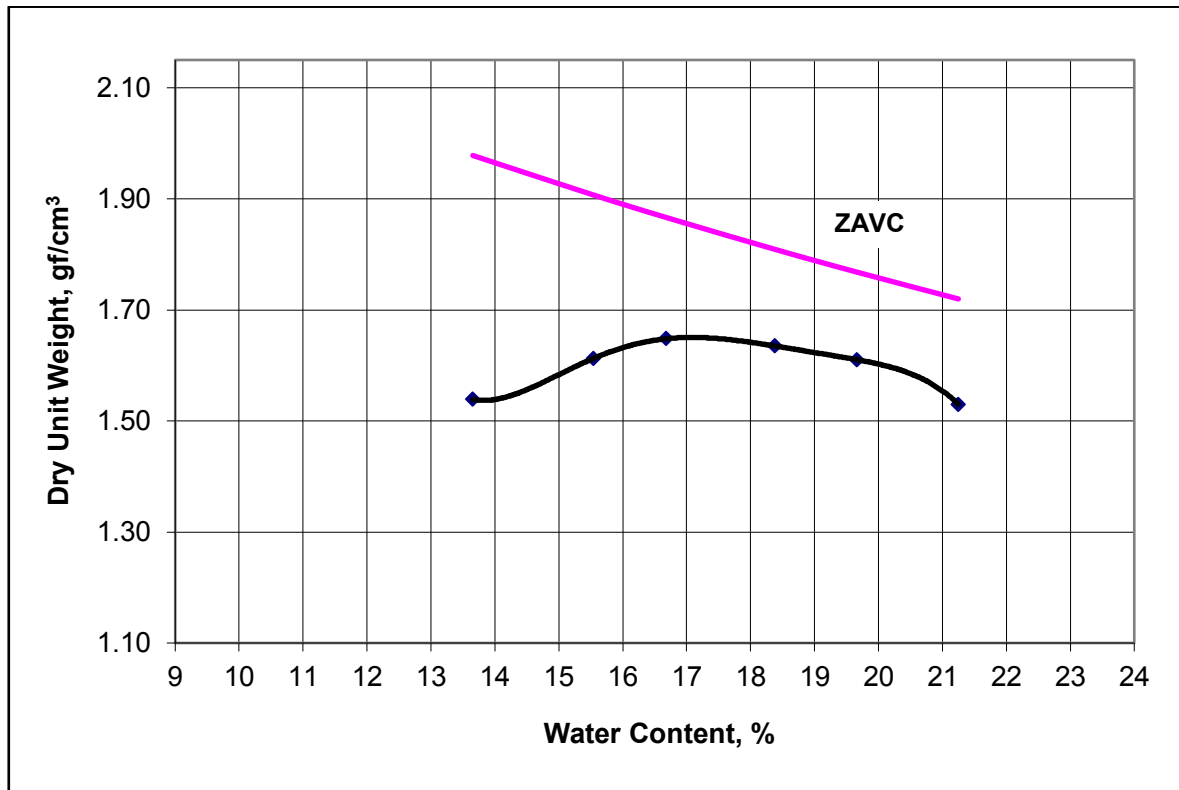


Figure 4.14. The sand-bentonite mixture with 2 % cationic addition proctor test graph

Optimum water content, ω_{opt} : 17.2 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.650 gf/cm³.

Figure 4.14 graph generated by the Proctor test reveals noteworthy observations regarding the compaction properties of a composite material consisting of sand and bentonite mixture containing 2% cationic substance. The graph demonstrates a drop in the maximum dry unit weight and an increase in the optimum water content in comparison to the mixture absence of the cationic additive. It suggests that the cationic material significantly influences the compaction features and workability of the mixture.

The observed decrease in the maximum dry unit weight can be attributed to alterations in the structure of particles and inter-particle forces caused by the presence of the cationic material. These changes may have significant implications for the soil's overall stability and load-bearing capacity.

Additionally, the higher optimum water content states modifications in the soil's plasticity and workability, as it is discussed earlier. Overall, the cationic polyacrylamide has a similar affection with anionic polyacrylamide added to the sand-bentonite mixture.

4.2.2. Sand-Bentonite With Microplastics (Tire Chips) Addition

4.2.2.1. Atterberg Limits

The examination of the liquid limits and plastic limits and sensitivity of soil was conducted in the geotechnical lab through the application of Atterberg limits tests on a sand-bentonite mixture containing tire chips with different amounts (0.05%, 0.1%, 0.2% and 0.5%) . This enables the evaluation of the influence of tire chips on the soil.

0.05 % microplastics (tire chips) addition by dry mass

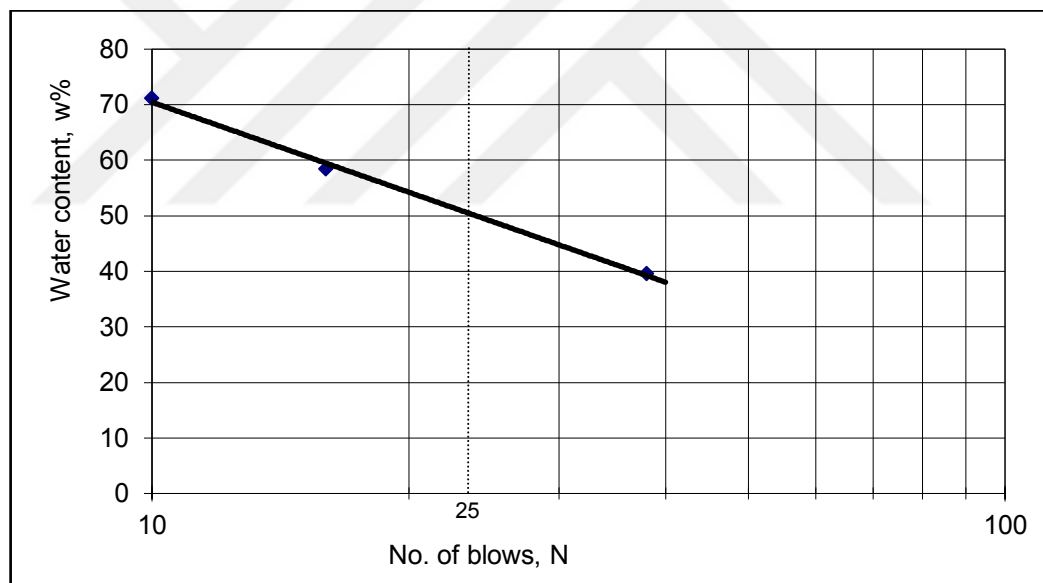


Figure 4.15. LL graph of the sand-bentonite mixture with 0.05 % tire chips addition

Table 4.8. PL of sand-bentonite mixture sample with 0.05 % tire chips addition

Can, g	27.57	30.80
Sample+can , g	29.86	32.90
Dry sample+can , g	29.28	32.37
Dry soil, g	1.71	1.57
Wt. of water, g	0.58	0.53
Water cont., %	33.92	33.76

The graph and the table number 4.15 show the correlation between a sand-bentonite mixture with 0.05% tire chips added and its liquid limit (LL) and plastic limit (PL). It's noteworthy that the graph shows the decrease in both the liquid and plastic limits in comparison with no adding additives, demonstrating a considerable impact of the tire chips on the soil's moisture plasticity. The LL is 49 %, as shown by the data provided by Figure 4.6 and Table 4.6 shows that the PL is 34 %.

0.1 % microplastics (tire chips) addition by dry mass



Figure 4.16. LL graph of the sand-bentonite mixture with 0.1 % tire chips addition

Table 4.9. PL of sand-bentonite mixture sample with 0.1 % tire chips addition

Can, g	20.03	22.13
Sample+can , g	22.51	25.06
Dry sample+can , g	21.91	24.35
Dry soil, g	1.88	2.22
Wt. of water, g	0.60	0.71
Water cont., %	31.91	31.98

The presented graph and table (4.15) depict the correlation within the liquid limit (LL) and plastic limits (PL) of a sand-bentonite mixture, afterwards the inclusion of 1 % tire chips. The findings suggest a marginal reduction in the liquid limit and plastic limit in relation to the mixture that has no tire chips the results were 48 % for LL and 32% for PL. The results indicate a minor reduction in the liquid limit of the sand-bentonite mixture upon the addition of 1 % tire chips, implying a negligible impact on the soil's liquid state. Although the alteration may not be substantial, a minor decrease in the liquid limit may result in practical consequences for the soil's performance, including enhanced drainage attributes and reduced susceptibility to fluctuations in moisture content.

0.2 % microplastics (tire chips) addition by dry mass



Figure 4.17. LL graph of the sand-bentonite mixture with 0.2 % tire chips addition

Table 4.10. PL of sand-bentonite mixture sample with 0.2 % tire chips addition

Can, g	20.03	22.13
Sample+can , g	22.47	25.06
Dry sample+can , g	21.91	24.35
Dry soil, g	1.88	2.22
Wt. of water, g	0.56	0.71
Water cont., %	29.79	31.98

The graphical representation and table 4.17 illustrates a minor reduction in the liquid limit (LL) and plastic limit (PL) of the sand-bentonite mixture upon adding an amount of 0.2 % tire chips. As shown in the results liquid limit (LL) is 47 % and plastic limit (PL) is 31%.

Although the alterations may appear minor, they offer significant perspectives for geotechnical engineers, emphasizing the possible enhancements in the soil's fluidity and plasticity.

0.5 % microplastics (tire chips) addition by dry mass

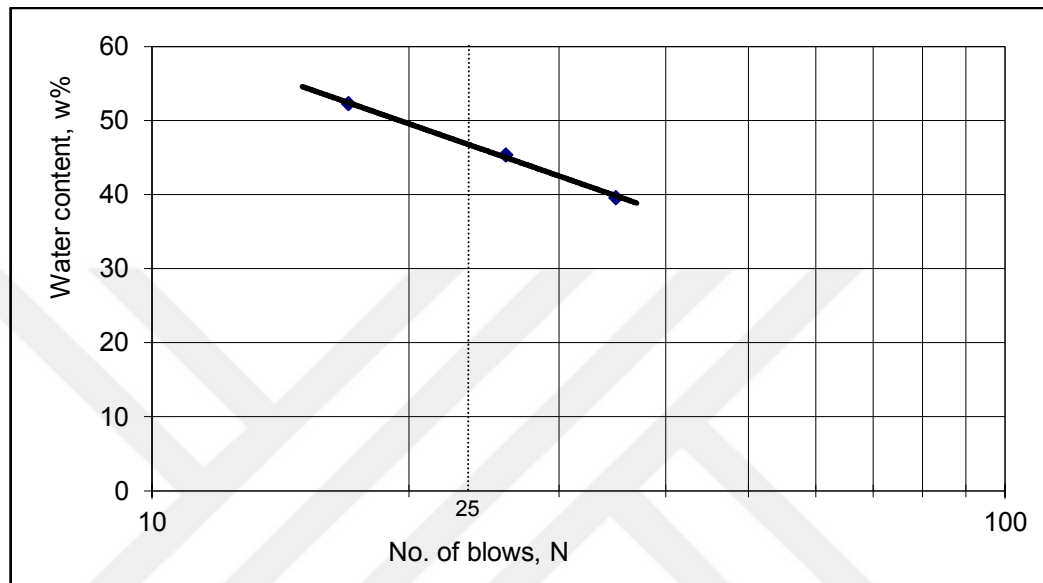


Figure 4.18. LL graph of the sand-bentonite mixture with 0.5 % tire chips addition

Table 4.11. PL of sand-bentonite mixture sample with 0.5 % tire chips addition

Can, g	30.81	27.81
Sample+can , g	34.30	31.03
Dry sample+can , g	33.51	30.28
Dry soil, g	2.70	2.47
Wt. of water, g	0.79	0.75
Water cont., %	29.26	30.36

The given tests results in the graph and table no 4.18 indicate a relationship between the liquid limit (LL) and plastic limits (PL) of a sand-bentonite mixture, applying an addition of 0.5 % tire chips. The results of LL and PL were 46 % and 30% respectively. The graph illustrates a limited reduction in the liquid limit and plastic limit in relation to the mixture that does not possess tire chips.

1 % microplastics (tire chips) addition by dry mass

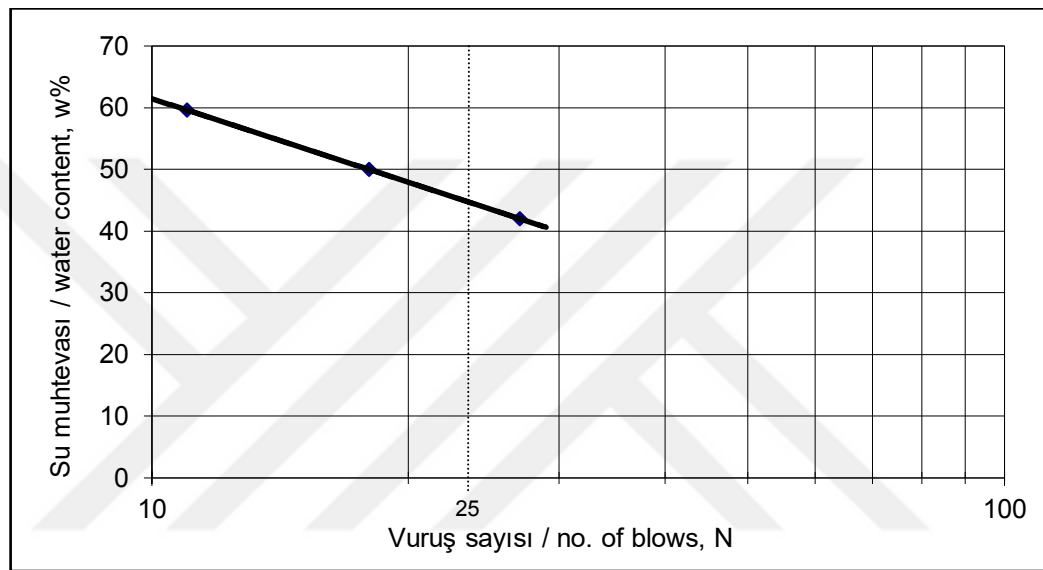


Figure 4.19. LL graph of the sand-bentonite mixture with 1 % tire chips addition

Table 4.12. PL of sand-bentonite mixture sample with 1 % tire chips addition

Can, g	19.81	20.89
Sample+can , g	22.01	22.96
Dry sample+can , g	21.55	22.54
Dry soil, g	1.74	1.65
Wt. of water, g	0.46	0.42
Water cont., %	26.44	25.45

The graphical and tabular representations in Figure 4.19 and table 4.12 demonstrate a correlation between the liquid limit (LL) and plastic limit (PL) of a sand-bentonite composite material, following the inclusion of 1% tire chips. The LL and PL yielded results of 44% and 26%, respectively.

2 % microplastics (tire chips) addition by dry mass

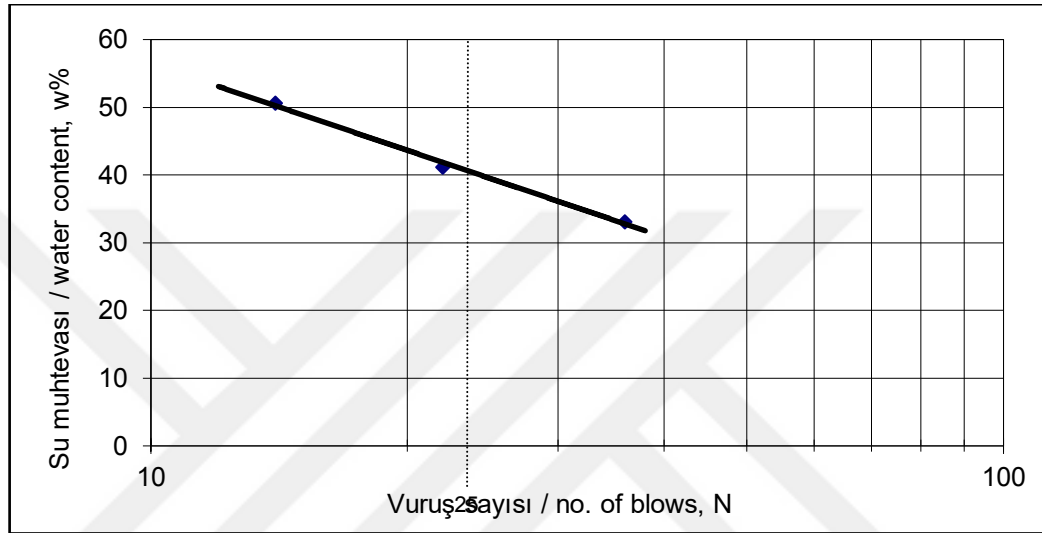


Figure 4.20. LL graph of the sand-bentonite mixture with 2 % tire chips addition

Table 4.13. PL of sand-bentonite mixture sample with 2 % tire chips addition

Can, g	29.91	20.46
Sample+can , g	31.04	22.39
Dry sample+can , g	30.84	22.06
Dry soil, g	0.93	1.60
Wt. of water, g	0.20	0.33
Water cont., %	21.51	20.63

The findings depicted in Graph 4.20 and Table 4.13 demonstrate a noteworthy correlation between the liquid limit (LL) and plastic limit (PL) of a sand-bentonite composite upon the inclusion of 2 % tire chips as an additive. The results indicate that the LL and PL values obtained were 40% and 21%, respectively, which were the minimum values observed among all the additive proportions tested.

It is important to highlight that the differences observed in the liquid limit and plastic limit are of a minor magnitude. Hence, further research is necessary for fully understanding the practical implications of these results. Furthermore, it is necessary to take into account the project-specific demands and engineering factors while determining the suitable proportion of tire chips in the sand-bentonite mixture.

4.2.2.2. Proctor Compaction Test

0.05 % microplastics (tire chips) addition by dry mass

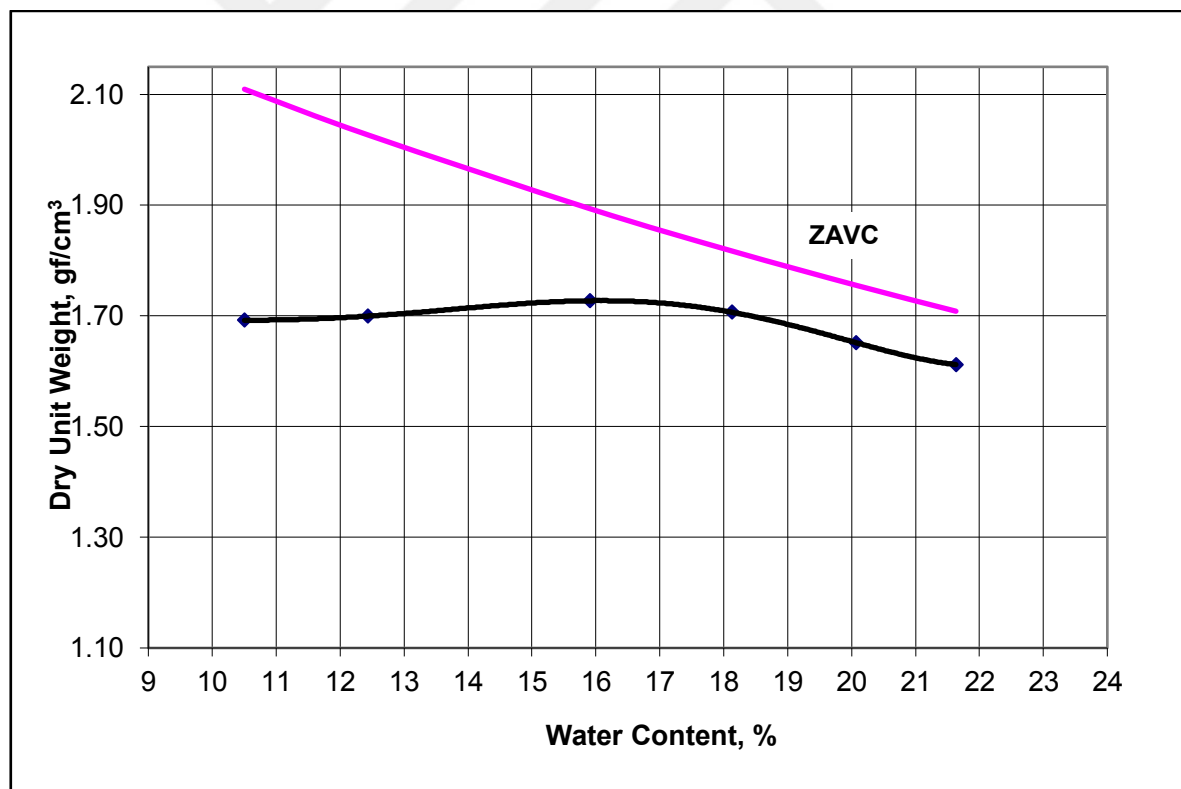


Figure 4.21. The sand-bentonite mixture with 0.05 % tire chips addition proctor test graph

Optimum water content, ω_{opt} : 16.3 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.730 gf/cm³.

The results obtained from the proctor test graph of the sand bentonite mixture, upon adding an amount of 0.05% tire chips, produced interesting observations.

The outcomes indicate a marginal reduction in the maximum dry unit weight, implying that the inclusion of tire chips leads to a slight drop in the overall compactness and density of the mixture.

It is important to note that there is increases in the optimum water content, pointing to that the presence of tire chips improves both the workability and moisture retention ability of the mixture.

0.1 % microplastics (tire chips) addition by dry mass

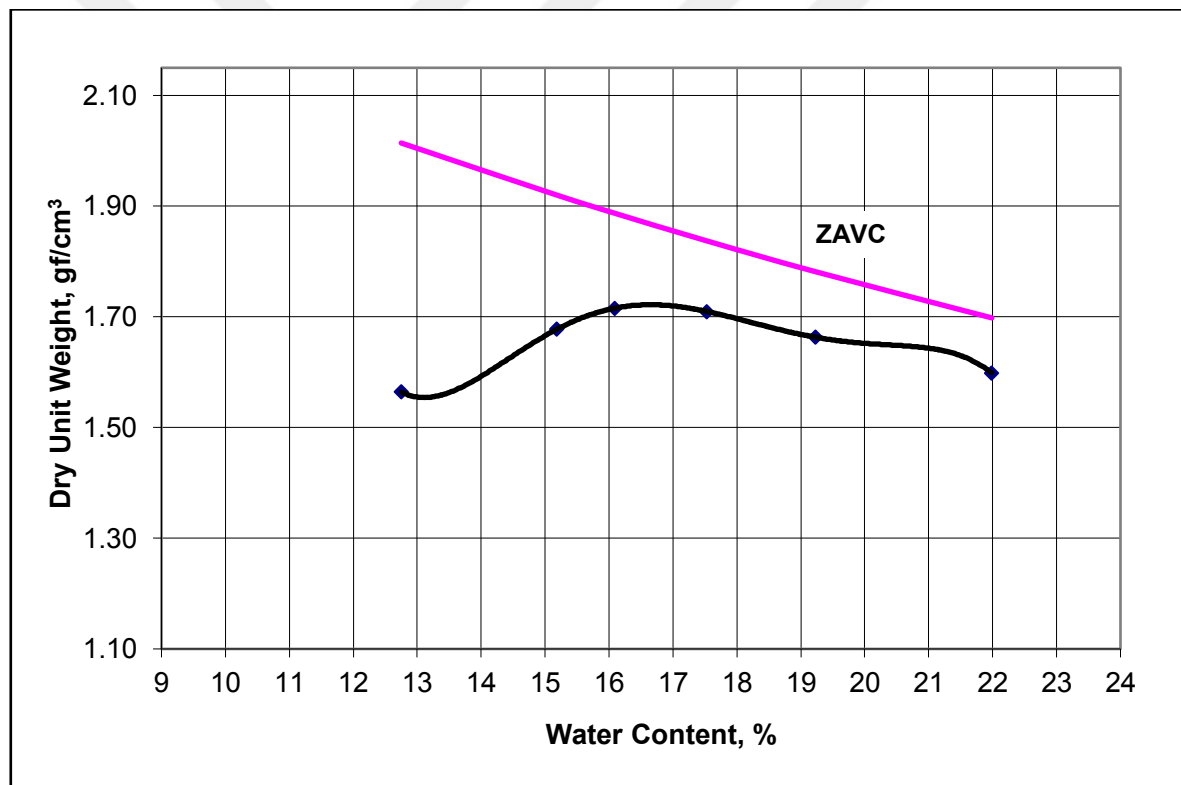


Figure 4.22. The sand-bentonite mixture with 0.1 % tire chips addition proctor test graph

Optimum water content, ω_{opt} : 16.7 %, maximum dry unit weight, $\gamma_d \max$: 1.720 gf/cm³.

As it is observed in figure 4.22 there still a small decrease in maximum dry unit weight and a slight increase in optimum water content notably the amount of tire chips is not much.

These findings suggest that adding an insignificant amount of tire chips may enhance the engineering qualities and performance of the sand bentonite mixture, providing up new opportunities for environmentally friendly and sustainable geotechnical applications. To determine the ideal tire chip content for obtaining specified technical properties, more research is necessary as mentioned earlier.

0.2 % microplastics (tire chips) addition by dry mass

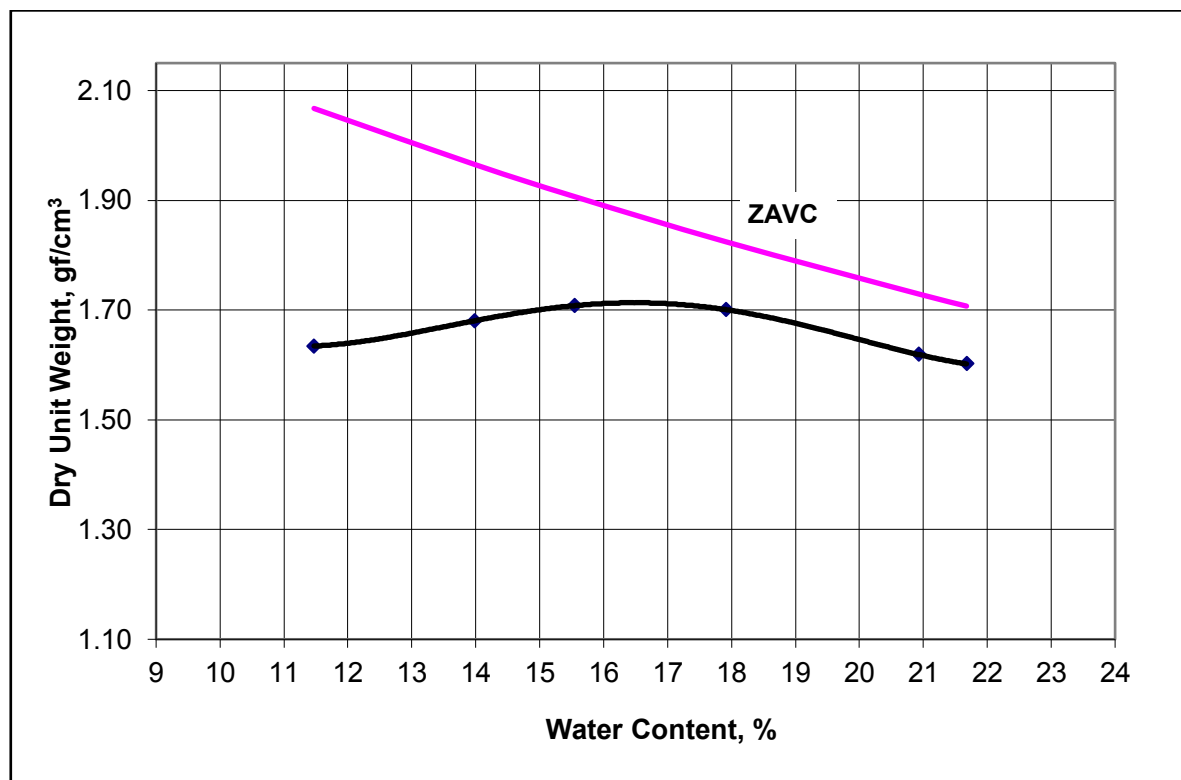


Figure 4.23. The sand-bentonite mixture with 0.2 % tire chips addition proctor test graph

Optimum water content, ω_{opt} : 16.8 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.710 gf/cm³.

The graph number 4.23 demonstrated a slight decrease in the maximum dry unit weight and an increase in the optimum water content as previous results so we may understand that the more we add tire chips the less maximum dry unit weight we will get and a small increase of optimum water content.

0.5 % microplastics (tire chips) addition by dry mass

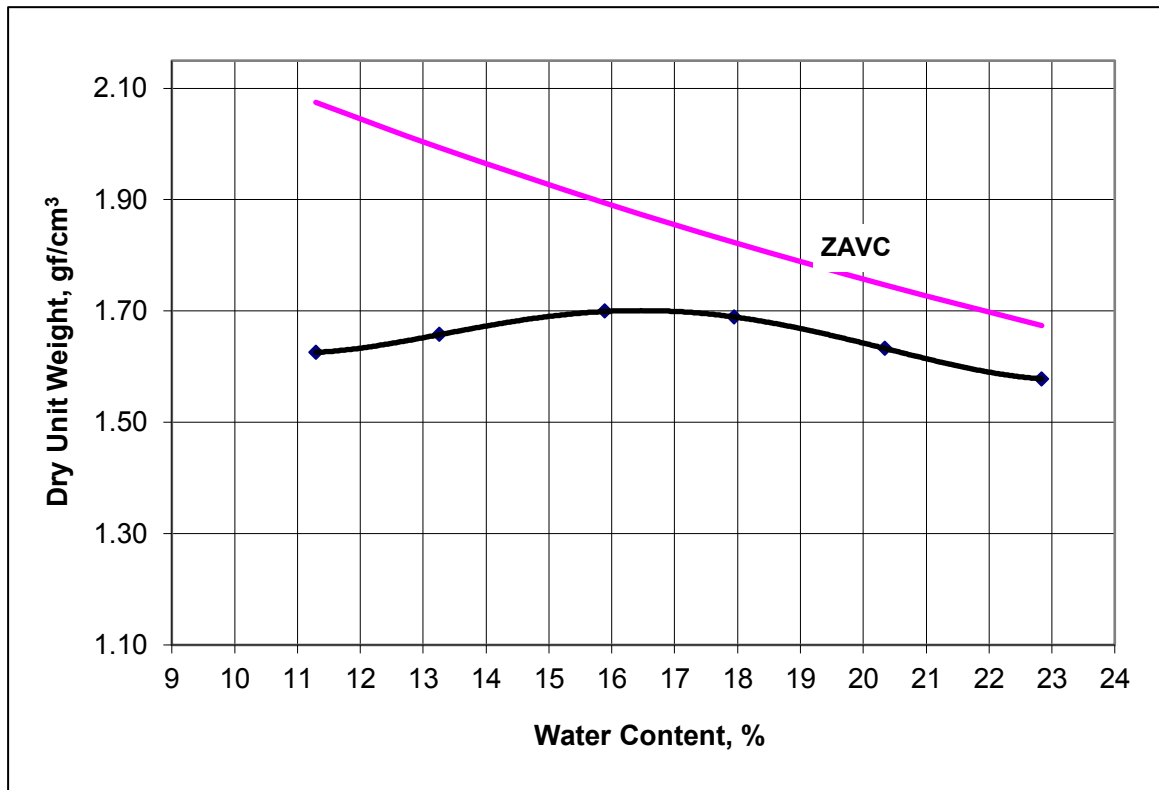


Figure 4.24. The sand-bentonite mixture with 0.5 % tire chips addition proctor test graph

Optimum water content, ω_{opt} : 17 %, maximum dry unit weight, $\gamma_d \max$: 1.700 gf/cm³.

The findings indicated a reduction in the maximum dry unit weight and a minor rise in the optimal moisture content. The same way with previous results.

1 % microplastics (tire chips) addition by dry mass

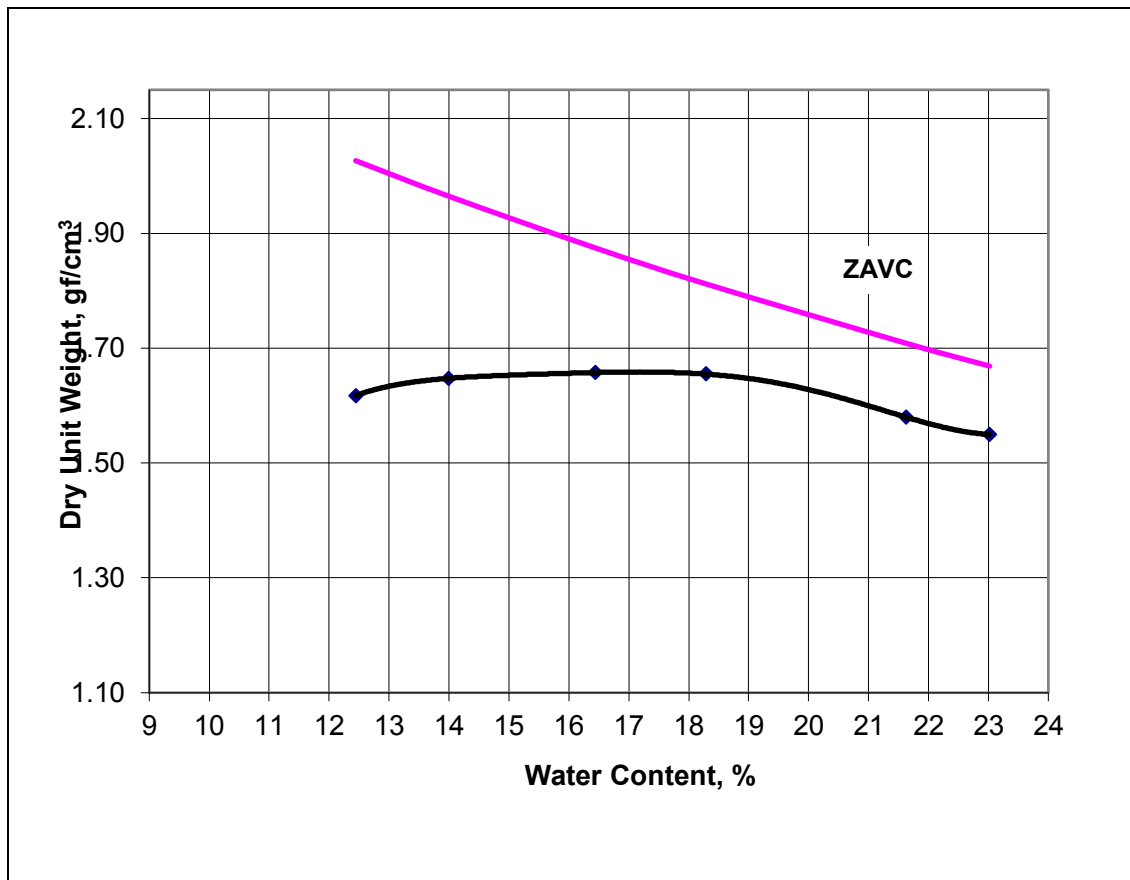


Figure 4.25. The sand-bentonite mixture with 1 % tire chips addition proctor test graph

Optimum water content, ω_{opt} : 17.3 %, maximum dry unit weight, $\gamma_d \max$: 1.660 gf/cm³. The proportion of tire chips has been increased to 1% in order to enhance the preciseness of the tire chips' impact assessment. As a result, a reduction in the compaction curve was noted, leading to a decrease in the maximum dry unit weight. The optimal water content was determined and still increasing as shown in Fig 4.25.

2 % microplastics (tire chips) addition by dry mass

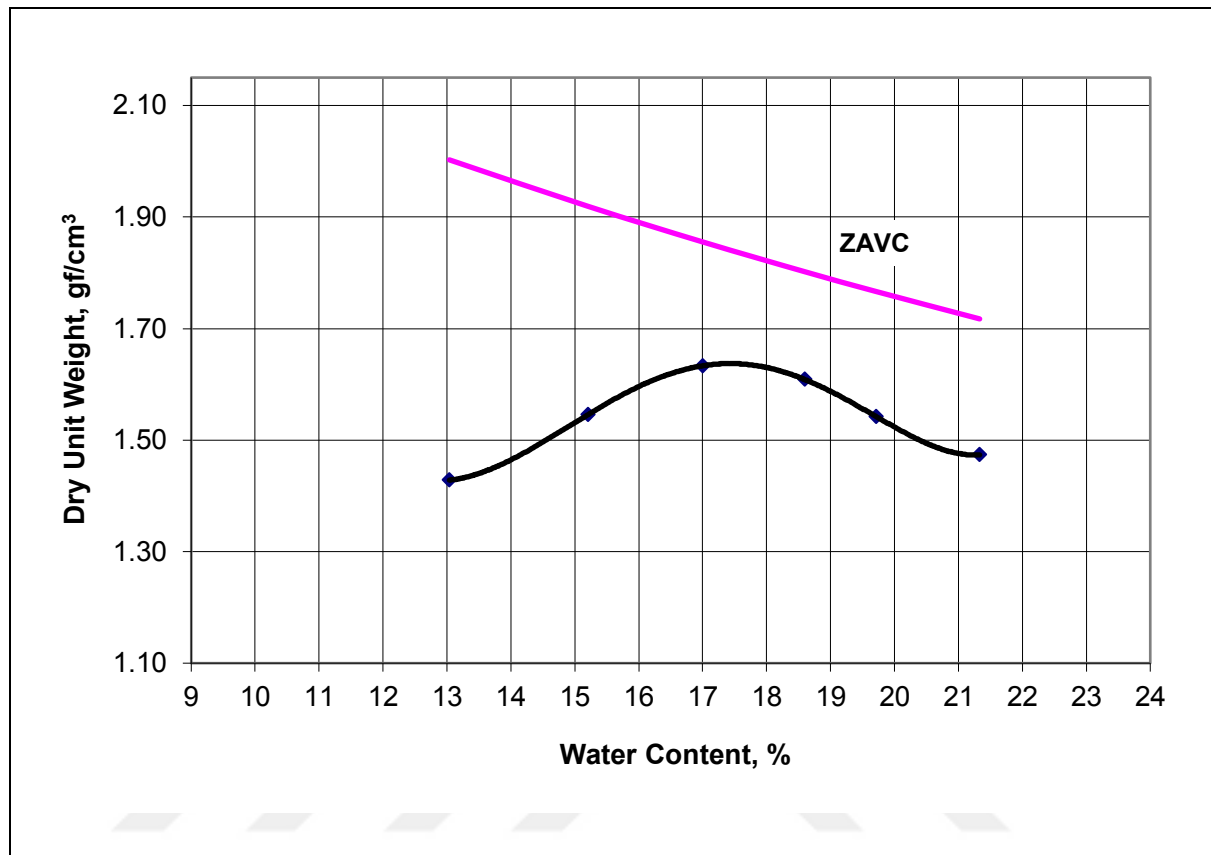


Figure 4.26 The sand-bentonite mixture with 2 % tire chips addition proctor test graph

Optimum water content, ω_{opt} : 17.5 %, maximum dry unit weight, $\gamma_d \text{ max}$: 1.630 gf/cm³ .

The soil mixture was finalized through an addition of 2% tire chips to evaluate their impact on the dry unit weight of the soil. The findings revealed a reduction in the maximum dry unit weight and the graphs obtained from the Proctor test conducted on a sand-bentonite mixture containing different proportions of tire chips (0.05%, 0.1%, 0.2%, 0.5%, 1 % and 2%) expressed interesting patterns. A consistent pattern was observed in every level of tire chip additions, wherein a slight reduction in the maximum dry unit weight and a corresponding increase in the optimum water content were noted. The aforementioned observation suggests that the inclusion of tire chips had an impact on the water retention ability of the mixture material. The reduction in the maximum dry unit weight implies a decrease in density, which could be attributed to the comparatively lower weight of the tire chips.

The augmentation of the optimal water content suggests an enhancement in water retention characteristics, plausibly ascribed to the porous structure of the tire chips.

The aforementioned results offer significant perspectives for geotechnical implementations that involve the utilization of sand-bentonite blends that have been altered with tire chips. Additional investigation is necessary to examine the most advantageous proportion of tire chips to meet particular engineering specifications.

4.3. DISCUSSION ABOUT THE RESULTS OF THE TESTS

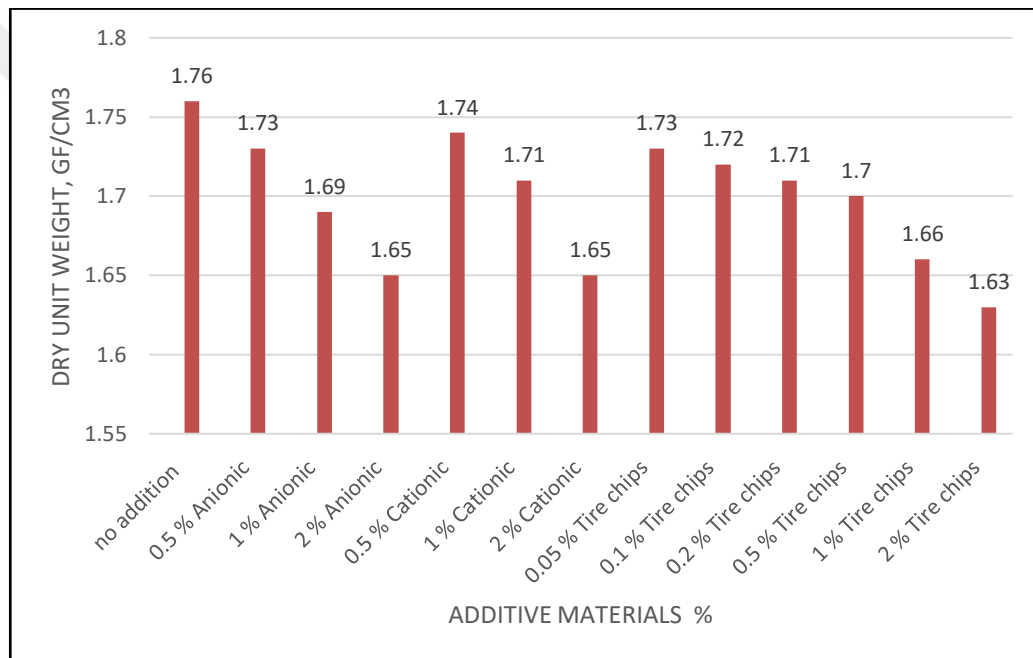


Figure 4.27. The combination graph of additive material content and dry unit weight

The combination graph depicting the dry unit weight as a function of varying percentages of tire chips and polyacrylamide (both anionic and cationic) reveals that the maximum dry unit weight is attained in the absence of any additive. In contrast, the minimum dry unit weight is observed at a concentration of 2% when incorporating tire chips.

The graphical representation illustrates that an increase in the concentration of additive materials results in a reduction in the dry unit weight of the sand-bentonite mixture. This observation is applicable to the incorporation of both polyacrylamide and tire chips.

As the additives are added to the sand-bentonite mixture, the added particles tended to clog the pores among the particles and led to a slight difficulty in applying compaction on the mixtures. Both of the polyacrylamides (either anionic or cationic) and tire chips behaved similarly by closing the voids and making it harder to compact the soil mixtures. The slight decrease in the maximum dry unit weights can be attributed to this mechanism where the increase in the amount of the additives caused more reduction in the voids.

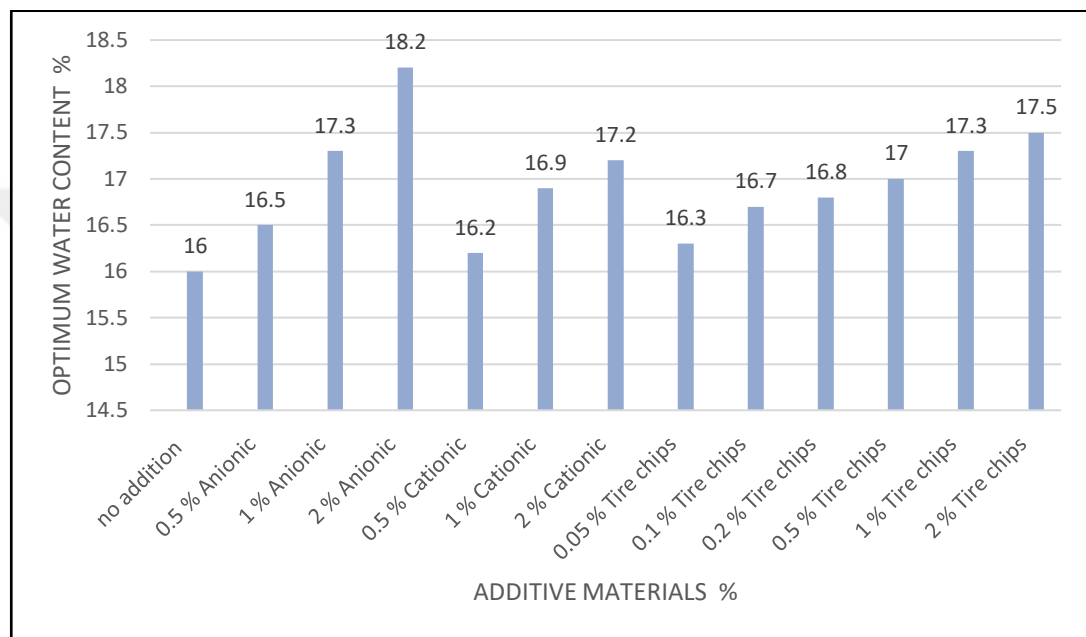


Figure 4.28. The combination graph of additive materials and optimum water content

The combined graph presenting the optimum water content as a function of varying percentages of tire chips and polyacrylamide (both anionic and cationic) additions illustrates that the maximum optimum water content has been achieved at a concentration of 2% anionic polyacrylamide. The smallest optimal water content can be achieved without any additional materials. Greater additive concentrations result in greater optimal water contents, which can be related to the interactions between the additions materials and the soil particles. In order to achieve maximum compaction and dry unit weight, these interactions may change the soil's structure and compaction behavior, necessitating a larger water content.

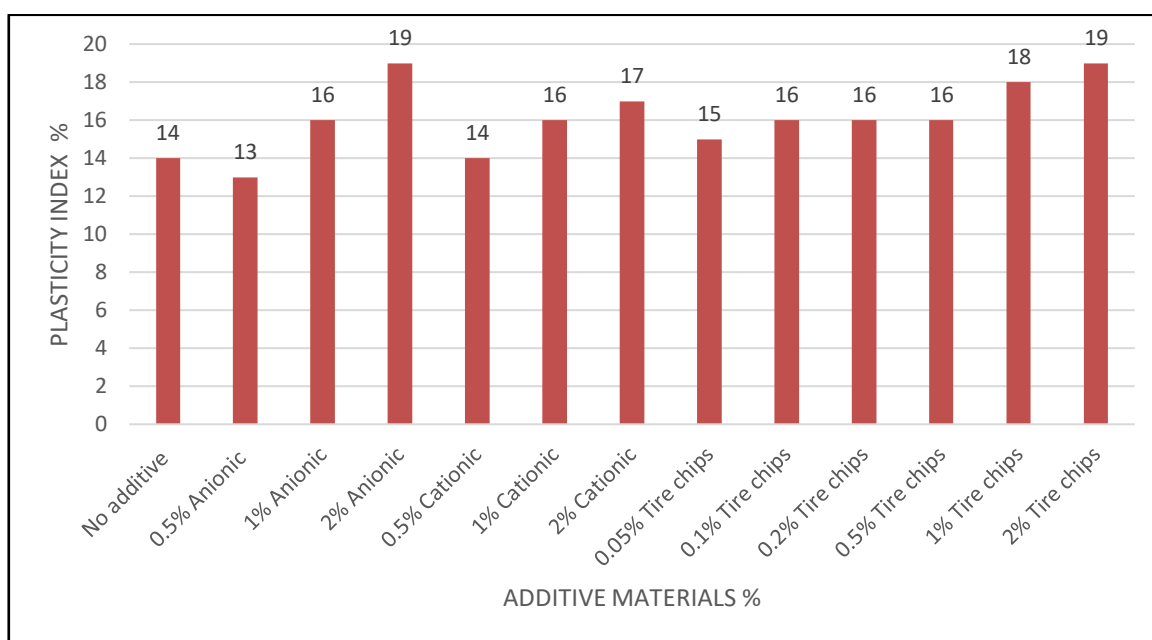


Figure 4.29. The combination graph of additive materials and plasticity index

The graphical representation depicting the relationship between plasticity index and varying proportions of tire chips and polyacrylamide (both anionic and cationic) demonstrates that the maximum plasticity index is obtained at a concentration of 2% anionic polyacrylamide and 2 % tire chips. In contrast, the plasticity index exhibits a comparatively lower value upon the incorporation of 0.5% anionic polyacrylamide. With respect to the inclusion of tire chips, the plasticity index exhibits minimal variation across varying proportions.

The results suggest that the inclusion of anionic polyacrylamide and tire chips have a notable impact on the plasticity index of the soil-bentonite mixture. Elevated levels of anionic polyacrylamide lead to a rise in the plasticity index, thereby signifying an increase in the plastic structure of the soil. The utilization of anionic polyacrylamide results in a modification of soil properties, ultimately resulting in an increased plasticity index.

Conversely, the incorporation of tire chips yields negligible effects at the beginning on the plasticity index, but it changed upward with 1 and 2% addition. The previously mentioned observation implies that the incorporation of tire chips into the soil-bentonite mixture has almost similar effect with polyacrylamide on examined sample in plasticity aspect.

The correlation between plasticity index (PI) and permeability in sand-bentonite mixtures is subjected to variation, dependent on a variety of factors such as the different properties of the individual components and the conditions of compaction. It is commonly observed in cohesive soil mixtures, such as sand-bentonite, that an increase in plasticity index results in a reduction in permeability [66].

The correlation between the plasticity index values and the clay content in the mixture is the foundation of this relationship. Elevated levels of clay content may lead to a denser soil arrangement, thereby reducing the availability of spaces between layers for fluid movement and ultimately causing a decrease in permeability.

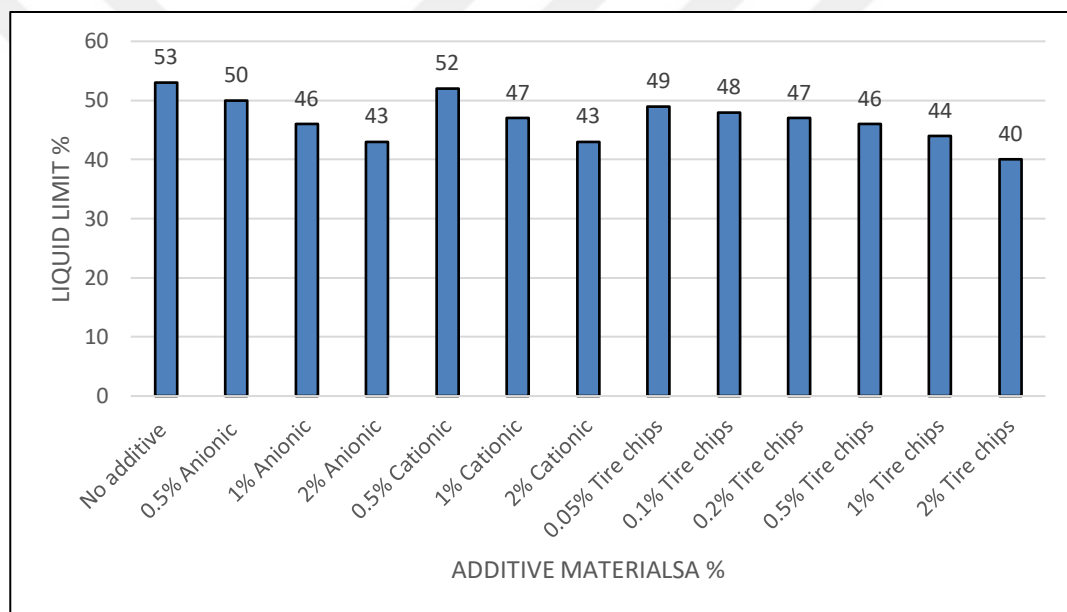


Figure 4.30. The combination graph of additive materials and liquid limit

The combination graph showing the relationship between liquid limit and varying percentages of tire chips and polyacrylamide (both anionic and cationic) additions reveals that not having any of any additives results in the greatest liquid limit. The liquid limit of the sand-bentonite mixture has a tendency to decrease as the level of additive materials rises.

The correlation between the concentration of additives and the reduction in liquid limit holds significant relevance in the context of geotechnical engineering. The incorporation of tire chips and polyacrylamide into soil has been observed to result in a reduction in the susceptibility of the soil to excessive deformation.

It is imperative to meticulously ascertain the ideal quantity and mixture of additives that achieve the intended engineering features, while simultaneously upholding acceptable liquid limits that correspond with the particular project requirements.

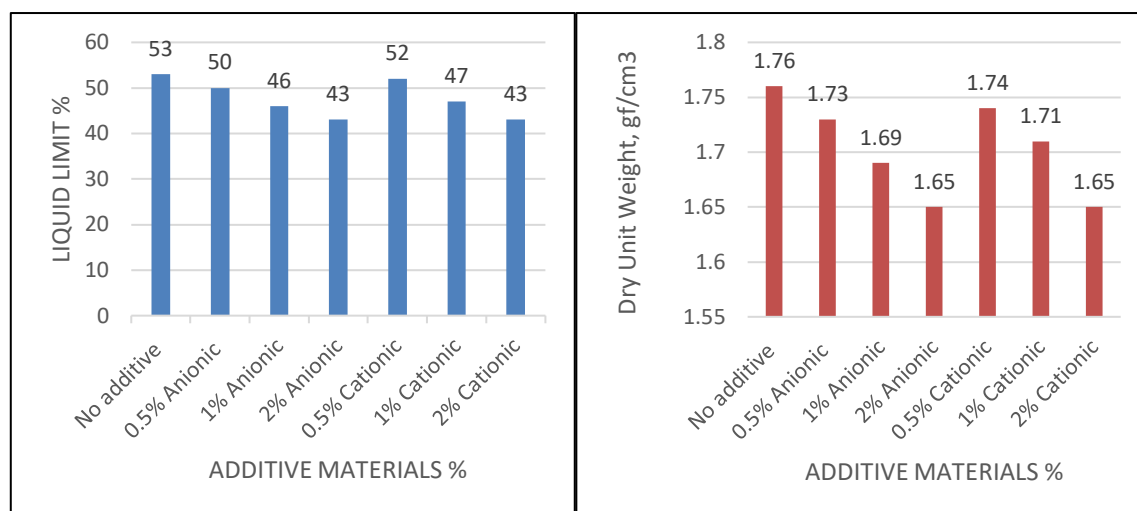


Figure 4.31. The combination graph of (Anionic and Cationic) in liquid limit and dry unit weight

The addition of anionic polyacrylamide results in a reduction in liquid limits and dry unit weight in contrast to the situation where no additive is present. A gradual decrease in liquid limits is observed as the concentration of anionic polyacrylamide is increased from 0.5% to 2%.

The addition of cationic polyacrylamide leads to a decrease in liquid limits and dry unit weight, although to a lesser degree when compared to anionic polyacrylamide. The liquid limits of cationic polyacrylamide demonstrate a relatively limited spectrum across varying concentrations.

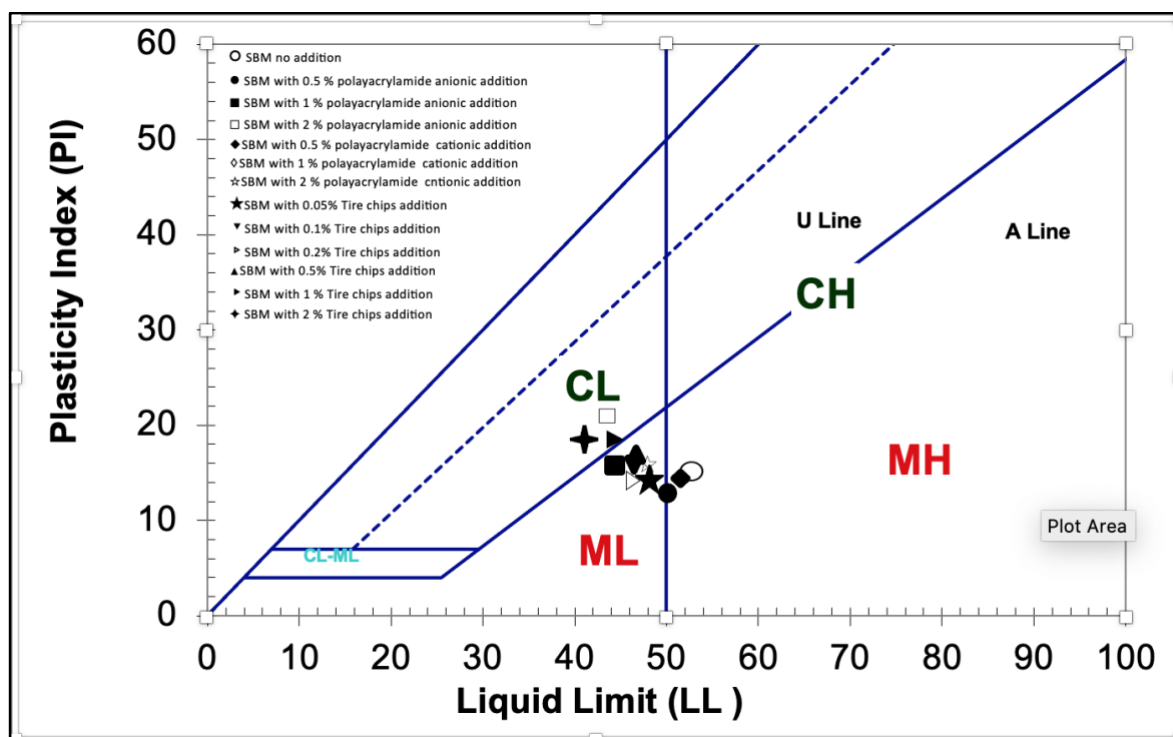


Figure 4.32. Plasticity Index-liquid limit graph of tested samples

The observed developments in the plasticity index and liquid limits graph in Figure 4.32 revealed noteworthy patterns for the examined soils, specifically a sand-bentonite mixture (SBM) that incorporated polyacrylamide (anionic and cationic) and tire chips as additives. The primary portion of the samples with 0.5 % cationic polyacrylamide addition exhibited characteristics consistent with the ML classification, suggesting the presence of silt with low plasticity. Nevertheless, it is important to highlight that the SBM samples containing 1% and 2% tire chips and the SBM sample containing 2% anionic addition were categorized as CL, signifying the presence of low plasticity clay. This observation implies that the inclusion of these additives has impacted the plasticity properties of the soil, causing it to exhibit behavior more akin to clay. In addition, the SBM sample, in its pure form, displayed a silt behavior with high plasticity, referred to as MH. The differentiation in plasticity categorization underscores the importance of additives in modifying the plasticity attributes of soil. In general, the findings mentioned above offer significant insights regarding the potential influence of polyacrylamide and tire chips on the plasticity index and liquid limits of the soil mixture. These insights contribute to the existing body of knowledge on soil behavior and have the potential to inform engineering and construction projects. The reduction in permeability of soils has been observed as a result of the

incorporation of polyacrylamide, as indicated by previous studies. In the present investigation, we have observed a notable enhancement in plasticity, which may probably be associated with the concurrent reduction in permeability. Nevertheless, it is crucial to acknowledge that a decrease in dry unit weight does not directly contribute to the reduction of permeability.

The results for the anionic polyacrylamide-added sand-bentonite mixture were found to be almost the same as those for cationic polyacrylamide-added sand-bentonite mixture in terms of plasticity and compaction. However, cationic polyacrylamide leads to aggregated structure whereas anionic polyacrylamide results in flocculated structure. Flocculation of the soil particles causes homogeneous void size and lower permeability. On the other hand, aggregation among the soil particles typically forms nonhomogeneous pore size that leads to an increase in the permeability of the soil [27]. This interpretation suggests that although the chemical interaction of the anionic and cationic polyacrylamides with the bentonite might cause significant changes in the hydraulic conductivity, their behavior in terms of plasticity and compaction do not differ from each other significantly. This behavior can be attributed to the high concentration of sand in the mixture.

It is imperative to emphasize that polyacrylamide has the propensity to occupy the empty spaces between soil particles, resulting in the formation of hydrogels. Although this particular structure impedes soil compaction, it concurrently functions as a lubricant within the soil's texture. This interaction leads to a reduction in both the permeability and dry unit weight of the soil.

5. CONCLUSION

In conclusion, the thesis has provided a comprehensive analysis of the topic at hand. The findings have shed light on the various aspects of the subject matter and have contributed to the current state of knowledge. The research has also highlighted the significance of further investigation in this area to enhance our understanding and inform future policy decisions. Overall, the thesis has successfully achieved its objectives and has made a valuable contribution to the academic discourse.

The aim of the present investigation was to examine the influence of polyacrylamide, encompassing both anionic and cationic forms, as well as microplastics, particular tire chips, on a sand-bentonite mixture characterized by a composition of 85% sand and 15% bentonite. The study analyzed the effects through the application of Atterberg limits and Proctor tests. In light of the findings, it is possible to infer the following conclusions:

1. Polyacrylamide: The sand-bentonite mixture experienced a reduction in its liquid limit (LL) and plastic limit (PL) as the concentration of anionic and cationic polyacrylamide were elevated. This suggests a decrease in the soil's capacity to hold moisture and its plastic deformation ability. The results indicate a slight increase in the plasticity index (PI), suggesting a greater level of plasticity in the soil.
2. Tire chips: The incorporation of tire chips at varying proportions exhibited a restricted influence on the plasticity index of the sand-bentonite mixture. The results suggest that the tire chips had a negligible impact on the plastic behavior of the soil, as evidenced by the consistent values observed for these parameters. The plasticity index exhibited minimal variation, indicating that the introduction of tire chips did not have a substantial impact on the soil's plasticity features. However, we have to mention that there is a decrement in liquid limits and plastic limits. The present study concentrated on investigating the application of smaller-sized tire chips for enhancing soil quality, in contrast to prior research endeavors.

Nevertheless, the findings unveiled various limitations linked to the utilization of tire chips in the context of microplastic dimensions. Initially, it is important to note that the contamination of soil with microplastics resulted in a substantial adverse environmental impact. This gives rise to apprehensions regarding the possible enduring impacts on the ecosystem and adjacent regions. Furthermore, the soil's compaction properties experienced a detrimental impact, as evidenced by a reduction in the maximum dry unit weight. The results of this study indicate that employing tire chips as microplastic particles may not be a viable strategy for enhancing soil quality, taking into account the potential environmental consequences and negative effects on compaction characteristics. It is imperative to conduct further investigation into alternative approaches and resources in order to guarantee the long-term viability and efficacy of soil enrichment practices.

3. **Maximum Dry Unit Weight:** A combination of polyacrylamide (both anionic and cationic) and tire chips led to a reduction in the maximum dry unit weight of the sand-bentonite mixture. This suggests a reduction in the density of the soil and its ability to compact.
4. **Optimum Water Content:** The inclusion of polyacrylamide and tire chips caused an increase in the optimum water content of the sand-bentonite mixture. This implies that more water was required to achieve the maximum dry unit weight during compaction. The sand-bentonite mixture's optimum water content experienced an increase due to the incorporation of polyacrylamide and tire chips. This suggests that a greater amount of water was necessary in order to attain the highest possible dry unit weight during the process of compaction.
5. There is no discernible distinction between anionic polyacrylamide and cationic polyacrylamide with regards to their physical characteristics of plasticity and compaction. The summary information indicates that the two variants of polyacrylamide additives demonstrate a comparable impact on the liquid limits and dry unit density of the sand-bentonite composite.

The alterations noted in the liquid limits and dry unit density exhibit almost similarity between anionic and cationic polyacrylamide at the concentrations subjected to testing. Hence, based on a physical perspective, the selection between anionic and cationic polyacrylamide may not have a substantial effect on the plasticity and compaction properties of the sand-bentonite mixture under investigation.

Based on the aforementioned results, a number of suggestions can be put forth for future investigation and real-world implementations:

1. Further investigation: Undertake further experimental procedures to investigate the enduring effects of polyacrylamide and tire chips on the geophysical properties of the sand-bentonite mixture, encompassing shear strength, permeability, and a long-standing durability.
2. The performance of the modified soil can be evaluated through field studies and monitoring under real-world conditions. This evaluation should take into account various factors, including environmental impacts, loading conditions, and weather variations.
3. The objective is to identify the optimal dosage and combination of anionic and cationic polyacrylamide and tire chips that can effectively achieve the desired. This study aims to investigate the engineering characteristics of numerous soil types and compositions and compositions. The proposed study aims to conduct a thorough Environmental Impact Assessment (EIA) of the utilization of polyacrylamide and tire chips. The assessment will primarily focus on the potential environmental implications of the mentioned materials, specifically on leaching, groundwater contamination, and the ecological effects of microplastic additives.

Through the implementation of these suggestions, forthcoming research endeavors can augment our comprehension of the impacts of polyacrylamide and tire chips on soil characteristics, and supply significant perspectives for their suitable and enduring application in geotechnical engineering projects.

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