Reuse of Recycled Plastic for Subgrade Treatment

By

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ABSTRACT

REUSE OF RECYCLED PLASTIC FOR SUBGRADE TREATMENT

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Disposal of solid waste becomes a global issue due to it contains a large amount of non-degradable polymers and may lead to many environmental issues. With the scarcity of space for landfilling and due to ever increasing cost, finding ways to handle these wastes without endangering the environment is crucial. One of these methods is to use plastic wastes as one of the pavement materials. In this study, a new method of subgrade soil stabilization of pavement is proposed where soil will be stabilized by mixing only plastic with soil for the treatment of subgrade.

In order to demonstrate and quantify the benefit of plastic in improving subgrade soil, HDPE, PET and PP have been shredded and mixed with soil. Standard laboratory tests were conducted to assess the stabilization's impact. These tests were carried out on four plastic contents of 2%, 3%, 4%, and 5% of the soil weight in natural and stabilized soils. The tests were the standard compaction test, unconfined compressive strength (UCS) test, hydraulic conductivity test and swelling tests.

According to laboratory test results, the presence of plastics reduces the stabilized soils' maximum dry density (MDD) and optimal moisture content (OMC), both of which are necessary for the construction of lightweight embankments. Additionally, the UCS of soils significantly improved by up to 88%, 75%, and 57% for HDPE, PET, and PP, respectively. The findings of the laboratory tests also showed that plastic treatment enhanced the soil's hydraulic conductivity, and that the degree of this increase was more significant at larger dosages. PET showed the best result regarding increasing the hydraulic conductivity of plastic treated soil. By mixing plastics with soil, the hydraulic conductivity was increased by 100 times approximately. Similarly, when the soil is mixed with plastic, the swelling behavior of soil is reduced significantly. Soil showed 73%, 71% and 67% improvement regarding swelling when the soil was treated with 5% of HDPE, PET and PP, respectively.

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CHAPTER 1

INTRODUCTION

1.1 Background

The strength of the unbound subgrade materials is the main geotechnical component in many pavement distresses. Almost all evaluations of the performance of an existing pavement are based on observations made at the pavement's surface, such as surface rutting, deformation, cracking, freeze/thaw, and failure. Serviceability and riding quality are also impacted by this. These surface distresses can sometimes be directly attributed to deficiencies in the asphalt or concrete surface layers, but they are frequently at least partially the result of deficiencies in the underlying subgrade (figure 1-1). It is critical to comprehend how geotechnical issues affect these distresses since the ultimate goal of pavement design is to reduce potential future pavement and bridge distresses and, as a result, maximize the performance. To check the performance of an existing bridge, the dynamic impact factor was calculated by Shuvrodeb et al. (2021) using vehicle-bridge interaction modeling, and potential damage was then recognized by Shohel et al. (2022) to prevent the bridge from failing suddenly and without warning.

Pavement failures may occur due to inadequate drainage and reduced stability. Excessive stresses that result in a shear failure in the subgrade, base course, or surface can potentially cause distress. Pavement distress can also result from subgrade soil volume changes brought on by wetting and drying, freezing and thawing, swelling, or poor drainage. One of the main causes of pavement issues that affects performance in the future is inadequate drainage of water from the base and subgrade.

On the other hand, the numerous applications of plastics in our daily lives, such as packaging, building and construction, automotive, electric, and electronic applications, result in a sizeable amount of solid rubbish being produced every day throughout the world (Gawande et al. 2012). They can remain on land and in the ocean for years before decomposing due to their high decomposition temperature, strong resistance to ultraviolet radiation, and lack of biodegradability. This pollutes the ecosystem. Due to population increase, urbanization, construction activities, and frequent changes in lifestyle, it has been challenging to dispose of plastic (Venkat, 2017). They are either burned or dumped into landfill, both of which are unfriendly to the environment and pollute the land and air (Prasad et al. 2012). Since China began to forbid the import of foreign waste from numerous nations, including the United States, on January 6, 2018, the rate of plastic recycling is decreasing day by day. Also due to Covid-19 pandemic, plastic waste generation has been increased rapidly (Sehneela 2021). As a result, previously recycled plastics are now being dumped in landfills, where they will take up a lot of room for a very long time. Due to the fact that the majority of plastics are not biodegradable and have a long lifespan, several nations are implementing plans to effectively recycle and reuse plastics in a variety of industries in order to lessen or minimize the impact of plastic materials.

In order to protect the environment from the pollution of plastic waste materials, many researchers have conducted studies to find efficient ways to limit the pollution of these materials, including recycling and reusing these materials in civil engineering applications. Utilizing these materials as a soil stabilizer during road construction is a practical way to do so (Tatone et al. 2018). Cement and lime, two conventional soil stabilizers, are frequently utilized to enhance the geotechnical characteristics of poor soils (Sherwood 1993). Several researchers have confirmed that these compounds can improve soil characteristics (Bell 1996; Little 1995; Rout et al. 2012;

Rasul et al. 2015; Rasul et al. 2016; Yadav and Tiwari 2017; Rasul et al. 2018). However, due to their extensive use, these materials are not cost-effective (Obo and Ytom 2014). Because of this, several researchers look for cheaper alternatives to traditional soil stabilizers, like plastic, tire chips, and rice husk. Pavement foundation layers can be improved by stabilizing soil using plastic debris (Khattab et al. 2011).

To improve the necessary engineering properties of soil, soil stabilization is a technique in which finer soil particles are changed or substituted for coarser soil particles. This results in a mixture of soil that, when properly mixed, placed, and compacted at the site, has high load carrying capacity as well as cohesion and friction factors. Depending on how the soil is being used, stabilized soil has various advantageous qualities. In general, stabilized soil reduces the thickness of the pavement, avoids the handling and transporting of excavation debris, provides more resilience, and lessens the clayey soil's swelling qualities and fluidity.

By minimizing the number of materials produced and reusing the materials to improve soil qualities, using plastics with soil helps address the issue of waste. Because when plastic materials are combined with soils, they behave similarly to fiber-reinforced soil, one way to employ plastic to stabilize soil is to use the plastic in the form of discrete fibers (Yetimoglu and Salbas 2003). The impact of discrete fibers made from plastic waste on the characteristics of soils has been the subject of several studies (Ziegler et al. 1998; Babu and Chouksey 2011; Mondal 2012; Ahmadinia et al. 2012; Modarres and Hamedi 2014; Rawat and Kumar 2016; Peddaiah et al. 2018; Salimi and Ghzavi 2019). These researchers have found that employing plastic waste products for soil stabilization can enhance the characteristics of weak soils, including an increase in UCS, CBR, a decrease in the soil's plasticity and swelling.

In this research, the geotechnical properties of soils are analyzed in relation to the use of shredded plastic waste. To determine the impact of plastic content, a series of conventional geotechnical laboratory tests were carried out. These tests included soil index properties, the proctor test for standard compaction, the unconfined compressive strength test, hydraulic conductivity test and swelling test.

Figure 1-1 Premature failure caused by poor subgrade (roadwurx.com)

1.2 Problem Statement

Most nations around the world are finding that disposing of waste is a major problem. Large-scale buildup of these waste products is having negative environmental and financial effects. Awuchi (2019) estimates that 15.4 billion pieces of plastic waste are produced per day on average. Plastic waste is the waste type that is most common. In our daily lives, these materials are the mostly used. Massive amounts of plastic wastes are produced, such as that from polyethylene terephthalate (PET) plastic bottles; from polypropylene (PP) plastic bags and rugs (PP) and milk containers, motor oil, shampoo and conditioner bottles made from High Density Polyethylene (HDPE). Although it has many uses in daily life, plastic has detrimental effects on the environment and human health. Many countries are putting plans into action to successfully recycle and reuse plastics in a range of industries due to the fact that the majority of plastics are not biodegradable and have a long lifespan in order to diminish or eliminate the impact of plastic materials.

Previously recycled plastics have been used for asphalt pavement and the effects of recycled plastics have been investigated while using recycled aggregate such as recycled asphalt pavement (RAP) instead of virgin aggregate (Tahsina Islam, 2022). Again, recycled plastics have also been used with cement for pavement base and sub-base treatment. According to a study conducted by (Shruti Singh, 2022) Hamburg Test results clearly shows that inclusion of plastic has an added advantage in improving the deformation and moisture resistance of HMA design. This will extend the service life of pavement with improved performance and will help in reducing the legacy plastic waste at the same time. But the plastics are not commonly used for subgrade treatment. In our research, we are going to use recycled plastic as pavement subgrade in order to alleviate the problem of disposing of plastic. Instead of using conventional lime or fly ash, recycled plastic has been employed in the proposed pavement construction to maintain sustainability. This experimental study may not only provide a solution to the global issue of how to dispose of plastic garbage, but it may also contribute to improving the health of pavement subgrade.

1.3 Research Objective

The objective of this research is to evaluate the potential reuse of recycled plastics for subgrade treatment of pavement. The following task will be performed to accomplish the objective of this study:

- Collection, sorting, cleaning, and shredding of recycled plastic
- Collection of soil

- Development of experimental program for determining optimum plastic content
- Classification of soil
- Evaluation of Optimum Moisture Content and Maximum Dry Density for sample preparation
- Determination of Unconfined Compressive Strength (UCS), hydraulic conductivity and swelling of control soil sample and plastic mixed soil sample and comparing the results.

1.4 Thesis Organization

The research report is organized into total six chapters. The summary of each chapter is presented as follows:

Chapter 1 begins with a description of the background of the study, identifies the issues, sets goals to better the situation, and concludes with an organization of the thesis.

Chapter 2 comprises a literature review on previous studies conducted on subgrade course of pavement and recycled plastic materials. A brief overview of recycled plastic situation in the world. It also provides a glimpse of the performance of plastic mixed with clayey type of soil and test results of unconfined compressive strength, swelling and permeability in case of plastic mixed with soil.

Chapter 3 describes the experimental program and preparation of recycled plastic; several sample preparation and test procedures, such as optimum moisture content (OMC), maximum dry density (MDD), unconfined compressive strength (UCS), swelling and permeability.

Chapter 4 presents test results, analysis, and discussions of the results.

Chapter 5 summarizes the major conclusions from laboratory test results. Finally, recommendations for further studies are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will provide a quick overview of pavement structure, subgrade soil strength, swelling, and permeability testing, and current research findings on subgrade material development methods. Following a brief introduction to pavement layers, various conventional and recycled materials utilized in pavement subgrade construction are discussed. There will be a brief review of the qualities of strength, swelling, and permeability. The earlier research that served as the theoretical basis for the current experimental study are compiled in the chapter's literature review. Numerous books, journals, conference proceedings, and online resources contained these works.

2.2 Pavement Structure

The primary purpose of a pavement is to lower the stress on the subgrade to a manageable level. A typical pavement construction is made up of numerous layers (figure 2-1), each of which transfers weight from the upper layers to the lower layers. The main goal of the higher layers is to make sure that the transmitted stresses brought on the wheel load do not exceed the sub-grade's capability. Pavements can be categorized from a structural standpoint according to their load distribution characteristics. There are three different kinds of pavement: composite pavement, flexible pavement, and rigid pavement. A prepared or stabilized sub-grade, a base or sub-base course, and a surface course make up flexible pavement. The deflection of flexible pavement is greater at the borders and less in the middle. A prepared sub-grade, base or sub-base course, and a pavement slab make up rigid pavement. A concrete slab that settles equally when loaded typically serves as a pavement slab. Flexible and rigid pavement are combined to create composite pavement.

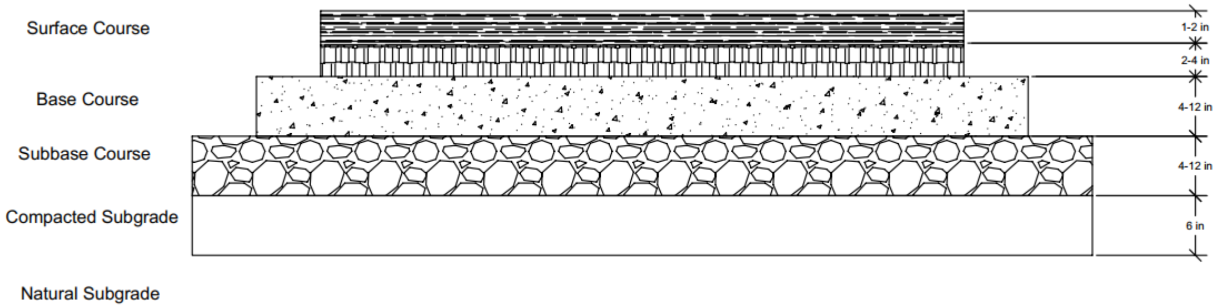


Figure 2-1 Typical pavement structure

2.2.1 Surface Course

The surface course is the pavement's topmost layer. This layer, which is built on top of the base course, is in direct contact with the wheels of the vehicles. As a result, this layer is designed to support the traffic volume, provide proper drainage, prevent sliding and traffic abrasion, and withstand the degrading impacts of the environment.

2.2.2 Base Course

In order to create a stable structural support, the base course is built directly on the sub-grade, just below the surface course, and above the sub-base if there is one. The main components of this layer are virgin aggregate, crushed limestone, recycled crushed concrete aggregates (RCCA), and recycled asphalt pavement treated with lime, Portland cement, or other binder materials. According to the specifications, base materials are chosen.

2.2.3 Sub-base Course

To support the surface and base course, this layer is typically built beneath the base layer. It generally comprises of stabilizer-treated or untreated compacted granular materials. It prevents sub-grade particles from entering the base layer. Given that it requires less strength than the base layer, the sub-base typically has lesser material properties. If the base layer's strength is high enough to withstand the weight of the wheels, the sub-base layer can be disregarded for financial reasons. To ensure the most cost-effective and environmentally friendly design, it is crucial to take traffic load into account while planning a pavement as well as the sort of materials to be utilized.

2.2.4 Subgrade Course

Native soil that has been compacted to sustain the stresses above it makes up a subgrade. It is a layer that is necessary for many construction types, including pavement and slabs, but it must have specific properties. If the subgrade is made of impermeable soil, specific drainage structures may be required, and the subgrade should be graded to within plus or minus 1.5 inches of the designated elevation. A subgrade needs to be strong enough to support the weights placed on it. Subgrades up to 12 inches thick and even more are possible, usually for highways, therefore the stronger the loads, the thicker the subgrade should be. However, the subgrade material can keep water from rising to the surface and is typically less expensive than the surface material.

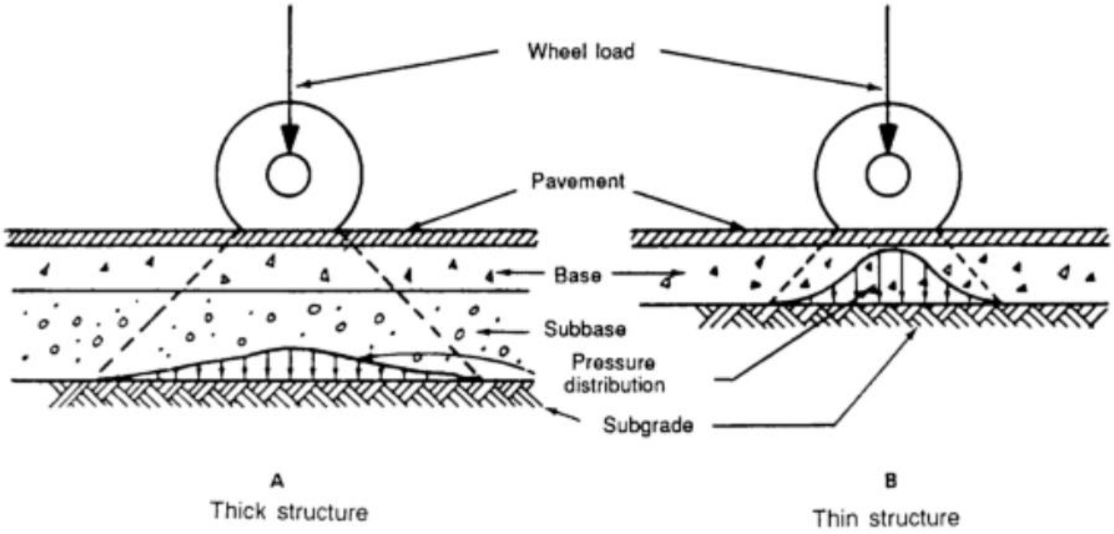


Figure 2-2 Load distribution of thick of different types of roads

2.3 Pavement Design Criteria

To distribute the stress generated on by the weight of the wheels in a way that keeps the stress on the natural soil within its capability, a pavement layer of sufficient thickness is required. The imposed load on the pavement as well as the strength and stiffness of the sub-grade serve as design parameters to determine the pavement layer's thickness.

Table 2-1 Property analysis for soil subgrade

Test Name	Property	Code
Liquid limit, Plastic limit and Plasticity index of soil	Atterberg limit	ASTM D4138-17
Gradation of soil using sieve analysis	Particle size distribution	ASTM D6913/D6913M-17
Unconfined Compressive Strength of Cohesive Soil	Durability and Strength property of soil	ASTM D2166/ D2166M-16
Falling Head Permeability	Water flow	ASTM D 2434

One-Dimensional Swell	1-D ground surface heave or settlement	ASTM D4546-21

2.3.1 Subgrade Performance

The performance of a subgrade is typically influenced by two interlinked qualities:

- Load bearing capacity- The subgrade must be capable of supporting the loads that the pavement structure transmits. The degree of compaction, moisture content, and soil type all frequently have an impact on this load bearing capacity. A good subgrade is one that can withstand significant loading without experiencing too much distortion.
- The volume change- When exposed to extreme moisture or freezing temperatures, the majority of soils experience some degree of volume change. Depending on their moisture level, some clay soils can shrink and swell, whereas soils with too many fine particles may be vulnerable to frost heave in colder climates.

2.4 Common Problems Due to Poor Subgrade

If the subgrade soil is poor, it can directly cause damage to the surface of the road or embankments. Figure 2-3, 2-4, 2-5 show the road pavement defect because of expansive subgrade soil, and figure shows slope failure of embankment which is caused by poor subgrade soil.

Figure 2-3 Road pavement defect duo to poor subgrade (U.S. Department of Transport).

Figure 2-4 Typical longitudinal crack developed on pavements over expansive clays (Zornberg and Gupta, 2015).

Figure 2-5 Slope failure of embankment caused by expansive soil (Jalal et al., 2020).

The following issues could arise from poor subgrade:

- Massive shear failure caused by the sub-grade material's low shear strength

- General sub-grade failure or progressive shear failure as a result of the axle loads' progressive squeezing out of the overstressed sub-grade clays.
- Attrition or localized sub-grade failure, where the sub-grade is repeatedly loaded and becomes sludge that can "pump" to the surface, especially when there is water present.
- Subgrade settlement brought on by consolidation, changes in moisture content, or gradual deformation brought on by continual traffic stresses.

It is also necessary to evaluate the slope stability of embankments and cuts and to rule out the risk of a catastrophic shear failure. For the majority of projects, residual soil fill material that has been well-compacted and possesses a high shear strength and resilience modulus is used as the sub-grade material, preventing the possibility of progressive shear failure.

2.5 Subgrade Treatment Methods

When the subgrade material is insufficient to withstand the required loads, more work should be done to make the material appropriate for the building.

2.5.1 Removal/ Replacement & Fill

Simple excavation and replacement with better-quality fill can fix poor subgrade problems. This technique, sometimes known as "undercut and backfill," is straightforward and doesn't call for any specific tools. However, removal and replacement are typically far more expensive than the use of additives unless a suitable backfill material is accessible close to the construction site. Because of this, removal and replacement are most frequently utilized in metropolitan areas, where the use of additives is less desired due to dust and other environmental factors. In regions where deep deposits of peat and muck cannot be managed with the use of chemicals, removal and replacement may also be the best solution.

Figure 2-6 Removal of soil for subgrade treatment

2.5.2 Traditional Compaction

The simplest and most used technique for subgrade improvement is compaction. The three types of rollers that are most frequently used for subgrade stabilization are pneumatic, static steel wheel, and vibratory steel wheel. Rolling a material has the advantages of increasing its strength and density while lowering its permeability and compressibility. However, field compaction testing (Proctor testing) and moisture-density management are required for this approach.

Figure 2-7 Traditional compaction method for subgrade treatment

2.5.3 Use of Geosynthetics

Using geosynthetics is another technique for soil stabilization that is becoming more and more well-liked across the commonwealth. Geotextiles, geogrids, and geo-composites are the geosynthetic product types that are most likely to be employed for stabilization.

Geotextiles are constructed of synthetic fibers that have been randomly matted together to create nonwoven fabrics that are flexible and porous. Plastics shaped into an open, grid-like arrangement are called geogrids. Geo-composites are a mixture of geosynthetic materials, such as a geotextile bonded to a geo-grid, or a geotextile attached to a dimpled plastic sheet used for pavement drainage. Because the characteristics of different types will affect how well the structure functions as a whole, it is critical to implement the right geotextile in the right position.

Figure 2-8 Use of geo-grid for subgrade treatment

2.5.4 Use of Additives

There are several types of additives available to improve the subgrade soil. One of them is reactive, such as lime; and another is self-cementing, like Portland cement and fly ash. Chemical reactions between reactive additives and the soil's clay fraction affect the soil's engineering qualities in ways that are beneficial. Lime can often enhance the plasticity, workability, shrink-swell potential, and strength of fine-grained soils.

The amount of improvement relies on several variables, including the kind of soil, the type and concentration of lime, the length of cure, the soil temperature, and the soil moisture levels at the time of curing. Typically, when used for modification, lime does not require a curing period for the treated subgrade to reach the necessary stability. Lime needs seven days of curing time before it can be utilized for stabilization.

Fly ash was shown to need two to three times the application rate of lime for modification with self-cementing additives for clayey soils. These types of applications may not be economical in practical use.

Figure 2-9 Mixing additives for subgrade treatment

2.5.5 Others (Deep Stabilization)

Other soil stabilization methods that are now being introduced are Deep Stabilization and Intelligent Compaction. For deep stabilization method, Phenolphthalein spray is used, and some tests are performed afterwards. Typically, compaction test (density and moisture content), strength test is performed, and grade is checked so that smooth, uniform pavement starts at the subgrade.

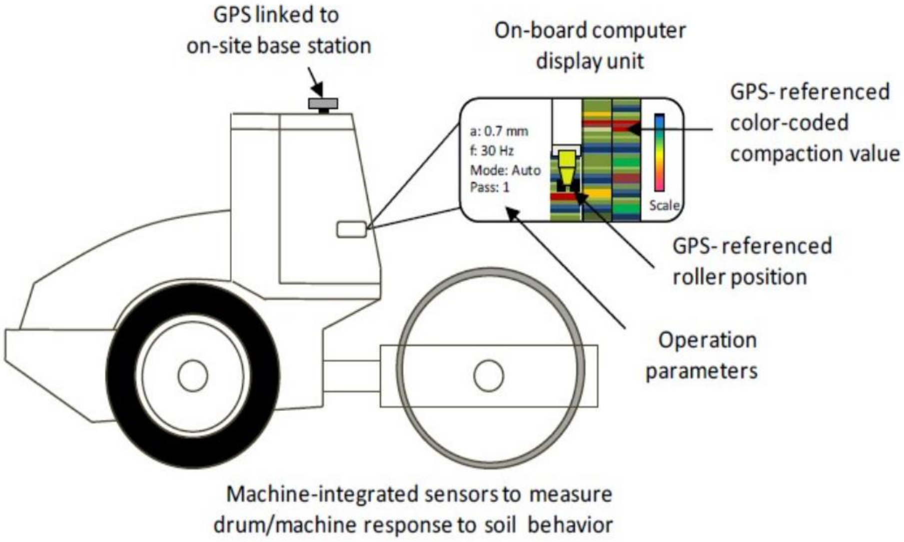


Figure 2-10 Intelligent compaction for subgrade treatment

2.6 Plastic and Plastic Waste

Our lives now revolve around plastic in one way or another. Plastic consumption has been rising steadily every year. The use of plastic in road building would offer a technique to recycle plastic and minimize the environmental risk associated with its disposal in landfills. Numerous researchers are examining the ecological stability and practicality of recycled materials in various construction scenarios, and there is little doubt that using the plastic waste in flexible pavement construction will hasten the removal of enormous volumes of plastic from landfills.

2.6.1 Plastic waste in USA

A large amount of solid waste is produced globally because of the usage of plastics in a variety of areas, including packaging, construction, automotive, electric and electronic devices, and automobile. These are man-made substances mostly made of hydrogen, carbon, and oxygen. They are often not biodegradable in addition to having a high decomposition temperature, high UV resistance, and being non-biodegradable. They can stay for years on land or in the water, which pollutes the ecosystem. It has become increasingly challenging to dispose of plastic since plastic usage has increased as a result of population growth, urbanization, development activities, frequent changes in lifestyle [4] and COVID 19 pandemic [5]. These materials can be disposed of in two ways: either by burning, which pollutes the atmosphere and land, or by land filling.

The EPA estimates how much plastic is produced, recycled, composted, burned with energy recovery, and disposed of in municipal solid waste landfills. In 2018, the United States produced 35.7 million tons of plastic, or 12.2 percent of MSW (Figure 1.2). Only 8.7% of the plastic produced in the US in 2018 was recycled. There were 3.1 million tons of plastic that were recycled. In 2018, 5.6 million tons of plastics were burned in MSW. This amounts to 16.3% of the total amount of MSW burned in that year. Additionally, in 2018, 28 million tons of plastic were disposed away in landfills. This method of disposal was used to get rid of 18.5% of all MSW. The management of plastic garbage in the USA is shown in Figure 1.3.

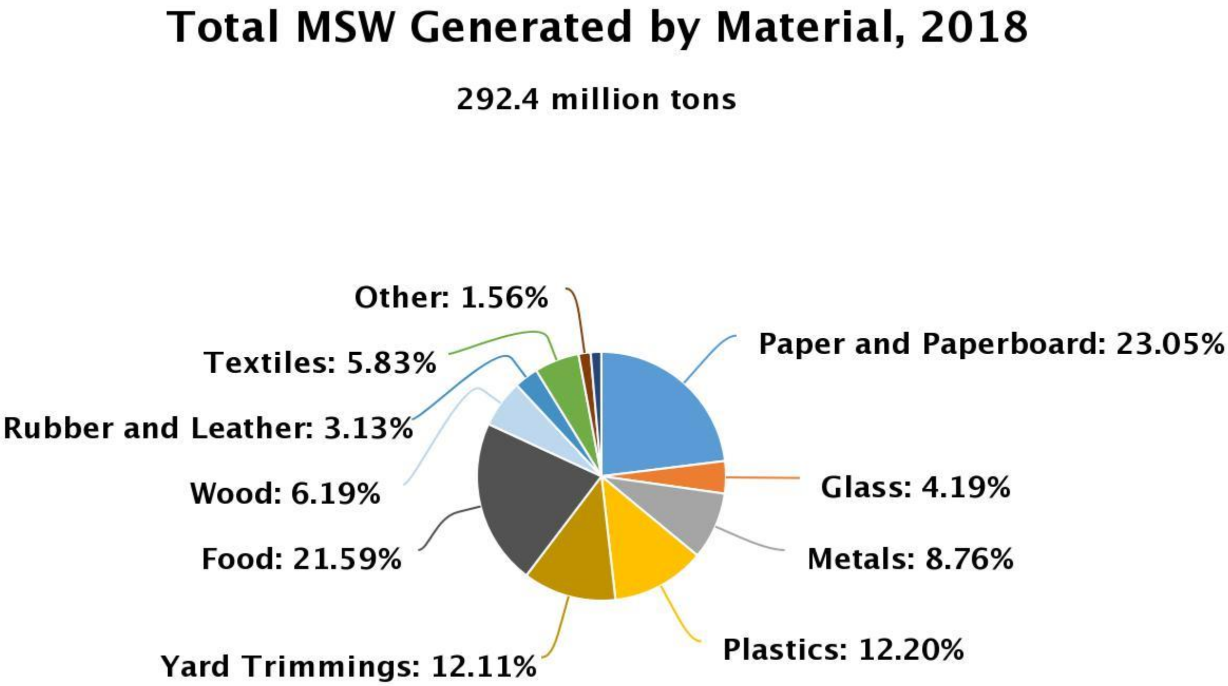


Figure 2-11. Total MSW generation in USA, 2018 (Environmental Protection Agency)

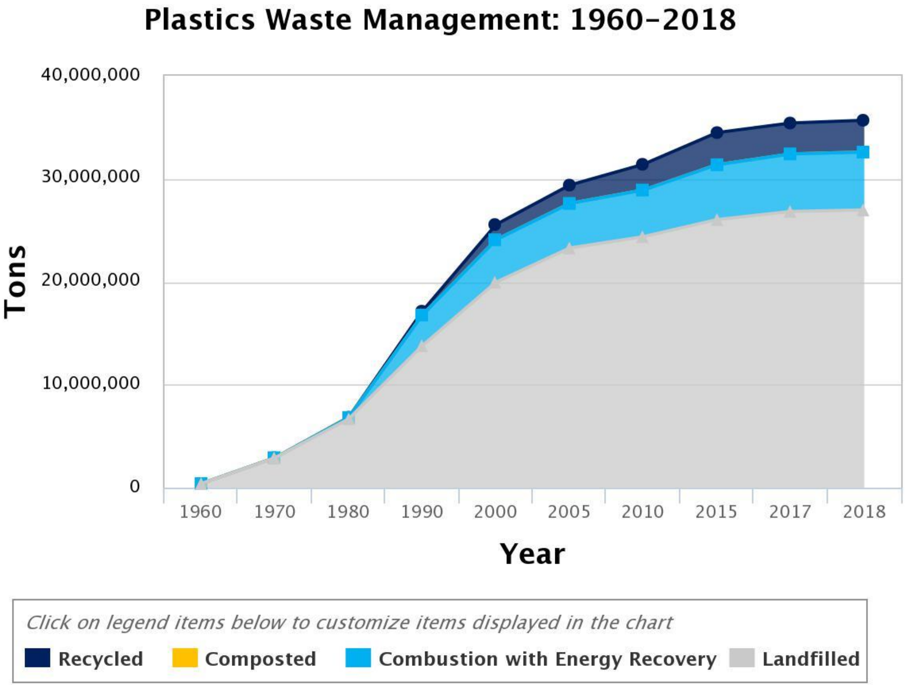


Figure 2-12. Plastic Waste Management (American Chemistry Council)

One of the fastest growing types of municipal solid waste (MSW) is waste plastic. Of all the major MSW categories, containers and packaging had the largest plastic tonnage in 2015, totaling almost 14 million tons. This category includes bags, sacks, and wraps, as well as other packaging, PET bottles and jars, high-density polyethylene (HDPE) natural bottles, and other containers. Although the number of recycled plastics is very little (3.1 million tons for an 8.7 percent recycling rate in 2018), the amount of recycled plastic containers is much larger. For instance, PET bottles and jars made up 29.1% of recycling in 2018, whilst HDPE natural bottles made up 29.3%. However, there are either few or no LDPE recycling facilities available.

According to the USEPA, the total amount of plastic garbage produced in the United States increased by 3.8 percent year between 2015 and 2014, going from 34.5 million tons in 2015 to 38.5 million tons in 2018. Chemical engineer Jan Dell (2018) estimated the United States' plastic recycling rate using information from the Environmental Protection Agency (EPA) and the industry and discovered that it will decline more sharply from 2018. If more Asian nations enact import bans on plastic garbage, Dell, 2018 predicted the recycling rate could go as low as 2.9% in 2019. The generation and recycling rates of plastic garbage in the US are summarized in Table 2.1.

Our seas' health and the health of wildlife are both being negatively impacted by plastic pollution. Numerous cases of marine impacts have occurred. By weight, trash will outweigh fish in the oceans by 2050. (Jambeck et al, 2015). With an estimated 88 to 242 million pounds of marine debris produced from plastic annually, the United States is ranked 20th among the nations that contribute to ocean plastic pollution. In 2017, when more than 3.7 million pounds of trash, the majority of it plastic, were collected by 209,643 people in a single day, the annual International Coastal Cleanup verified the evidence of plastic pollution on American coasts.

Table 2-2. Summary of US Plastic Waste Generation and Recycling Rates (Dell, 2018)

Plastic Waste	2015 (million tons) USEPA	2015 Actual % USEPA	2018 Projected (million tons)	2018 Projected %	2019 Projected (million tons) (Basel Convention enacted)	2019 Projected % (Basel Convention enacted)
Total Generated	34.5		38.5		40	
Recycled	3.14	9.1	1.68	4.4	1.14	2.9
Composted	0	0	0	0	0	0
Combusted-Energy Recovery	5.35	15.5	5.35	13.9	5.35	13.4
Landfilled	26.0	75.4	31.5	81.7	33.5	83.7

All of the negative consequences of plastic lead to the conclusion that they must be disposed of in order to prevent harm to the environment and nature. Therefore, melting these plastics and using them in the construction of bituminous roads is one of the finest ways to dispose of them. Several academics are conducting numerous investigations on the performance and environmental compatibility of recycled materials in high building. Large amounts of plastic garbage can be disposed of with the help of bituminous road construction.

2.6.2 Classification of Plastics

There are seven different kinds of plastic [3], according to the Society of the Plastics Industry (SPI). For consumers and recyclers to identify between various forms of plastic, SPI developed a classification system in 1988. An SPI code is included on every plastic item and is typically molded into the bottom. The sorts of plastics connected to each of the code numbers listed in this guide are briefly defined in the following section.

Figure 2-13 Plastic grades

Grade 1. Polyethylene terephthalate (PET or PETE)

PET, commonly found in bottles of soft drinks, is transparent, durable, and has effective gas and moisture barriers. Sometimes, the odors and flavors of the foods and beverages that are stored in them are absorbed by polyethylene terephthalate. This plastic is used for a variety of household goods and necessities. In the US currently, recycling accounts for 25% of PET bottles.

Figure 2-14 Grade 1. Polyethylene terephthalate (PET or PETE)

Grade 2. High Density Polyethylene (HDPE)

The recycling of HDPE products is frequent. Containers for milk, motor oil, shampoo and conditioner bottles, soap bottles, detergents, and bleaches are among the products created from this plastic. However, if an HDPE bottle did not initially contain any sort of edible ingredient, it is unsafe to use it as a container for food or drink due to the possibility of contamination. Every year, 30-35% of the HDPE plastic used in America is recycled.

Figure 2-15 Grade 2. High Density Polyethylene (HDPE)

Grade 3. Polyvinyl Chloride (PVC)

Although PVC is mostly used in the plumbing and building industries, it is found in many everyday items. Along with the construction industry, where it is extensively used in pipes and fittings, there are sizable rigid markets for bottles and packaging sheets. This plastic should not be used for food since it contains a hazardous, poisonous chemical. Recyclable PVC content is extremely rare—less than 1%.

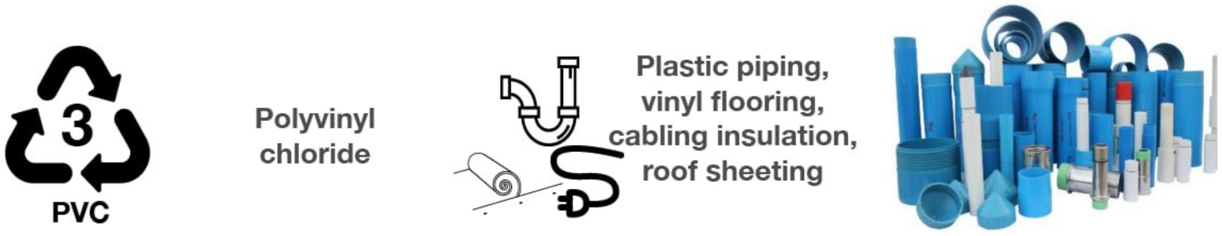


Figure 2-16 Grade 3. Polyvinyl Chloride (PVC)

Grade 4. Low Density Polyethylene (LDPE)

Due to its production from ethylene monomers, polyethylene is the most prevalent polymer in plastics. Polyethylene plastics are strong and flexible. It does not release dangerous compounds;

therefore, food can be stored with it safely. Plastic sandwich bags, supermarket bags, squeezable bottles, and cling film are just a few everyday things produced of LDPE.

Figure 2-17 Grade 4. Low Density Polyethylene (LDPE)

Grade 5. Polypropylene (PP)

Polypropylene has a high melting point, is chemically resistant, and is strong, making it suitable for liquid hot-filling, as well as packaging for catchups and margarine. There are many uses for it, such as lunch boxes, yogurt pots, syrup bottles, prescription bottles. PP is typically used for plastic bottle caps. PP is a durable plastic that frequently withstands greater temperatures. In the US, recycling of PP products now accounts for about 3%.

Figure 2-18 Grade 5. Polypropylene (PP)

Grade 6. Polystyrene (PS)

Depending on its structure, polystyrene can be stiff or foamed. A hard, transparent material that is fragile and hard is polystyrene. It has a rather low melting point. Protective packaging, containers, lids, cups, bottles, and trays are examples of common usage. PS can be recycled, but it can't be done well; it requires a lot of energy to recycle, so few places accept it.

Figure 2-19 Grade 6. Polystyrene (PS)

Grade 7. Other

Code 7 is used to identify various plastic types that are not covered by the other six codes. This group include polycarbonate and polylactide. Recycling these polymers is challenging. Baby bottles, CDs, and storage containers for medical supplies all use polycarbonate (PC).

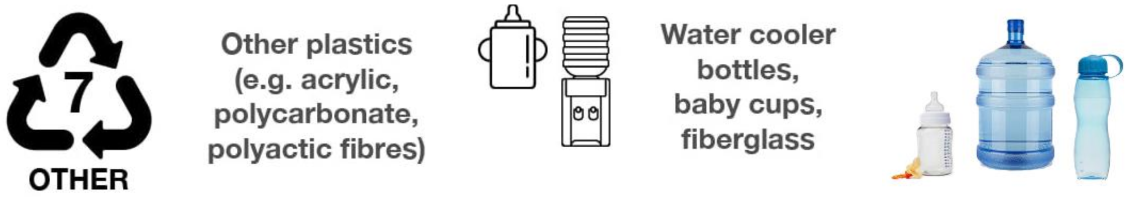


Figure 2-20 Grade 7. Other Plastic type

2.7 Recycled Plastic as Construction Material

The proper disposal of waste is increasingly important for the majority of nations worldwide. Despite its usefulness in daily life, plastic has detrimental effects on the environment and human health. Many countries aim to lessen or eliminate the impact of plastic materials by proper recycling and reusing these materials in a number of industries because the majority of plastics are not biodegradable and can last for many years. Researchers are concentrating on utilizing plastic waste as different construction materials due to the overproduction of plastic garbage. Some of the plastic wastes utilized as unusual materials in lightweight concrete include

High Density Polyethylene (HDPE), polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), and polystyrene (PS) (Akçaözoğlu, 2010).

2.7.1 Use of HDPE

High-density polyethylene (HDPE), which is stiffer, has a higher tensile strength, and is better at withstanding heat, is produced in large quantities by the plastics industry. According to Meran et al. (2008), the mechanical characteristics of HDPE, such as elongation and tensile strength, have been described. Benson and Khire (1994) reinforced sand with HDPE strips and assessed the geotechnical qualities of the reinforced mixtures in their early 1990s research on HDPE's use as a reinforcement material for civil engineering materials. The California Bearing Ratio (CBR), secant modulus, resilient modulus, and shear strength of the sand have all been found to be improved by reinforcement. The use of HDPE as reinforcement for pavement materials in the sub-base layer and sub-grades in the form of strips has been studied (Choudhary et al 2014).

The specimens reinforced with HDPE strips demonstrated improved geotechnical qualities throughout testing, including bearing capacity and secant modulus. Another study by Jha et al. (2014) shown that adding HDPE strips to pavement improved its ability to support industrial waste in pavement.

2.7.2 Use of PP

Incredibly tough and resistant to cracking and stress, Polypropylene (PP) is a thermoplastic polymer that can survive regular use. Only a few of the building and construction uses for polypropylene include siding, air and moisture barrier membranes, carpet textiles, films and sheets used in insulating building wraps, industrial adhesives and tapes, and plastic components used in pipes. Many researchers have ensured the efficiency of PP in stabilization of soil and production of construction materials (Al-Bared 2018, Appiah 2017).

2.7.3 Use of PET

Consumption of packaged goods has increased the amount of solid plastic garbage generated globally, making landfill disposal more challenging. In particular, there is a propensity for PET-based soda bottles, water bottles, food packaging, and other items to produce plastic garbage at an exponential rate (Albano 2009). The problem of solid waste is growing globally due to the rapid increase in PET bottles. However, the issue is made more urgent by the prolonged rate of deterioration of PET bottles in nature (more than 100 years) (Silva et al 2014). Melting fusion had been used to convert used PET bottles into drinking bottles, but the process was too expensive (Choi et al 2005). Therefore, employing these wastes in other industrial regions is one of the reasonable options for getting rid of PET wastes, which cause environmental contamination.

2.8 Current Research Findings on Use of Recycled Plastic with Clay

Numerous researchers have looked at practical ways to stop the pollution of these materials, such as recycling and reusing these materials in civil engineering applications, in an effort to save the environment from the polluting impacts of plastic waste materials. A practical approach to do this is to use these materials as a soil stabilizer when building roads (Tatone et al. 2018). The geotechnical properties of poor soils are usually improved by using lime and cement, two conventional soil stabilizers (Sherwood 1993; Yadav et al. 2018 and Yadav and Tiwari 2016). Numerous studies have demonstrated how well these minerals work to improve the characteristics of soils (Bell 1996; Little 1995; Rout et al. 2012; Rasul et al. 2015; Rasul et al. 2016; Yadav and Tiwari 2017; Rasul et al. 2018). But because they are used so frequently, these materials are not economical (Obo and Ytom 2014). Many researchers therefore hunt for less expensive substitutes for conventional soil stabilizers including plastic, tire chips, and rice husk.

Pavement's subgrade layers can be strengthened by stabilizing soil with plastic wastes (Khattab et al. 2011). So, by reducing the amount and reusing the materials to improve the qualities of soils, this can address the waste problem. Because plastic materials behave like fiber-reinforced soil when combined with soil, one way to employ plastic to stabilize soil is to use it in the form of discrete plastic waste (Yetimoglu and Salbas 2003). Numerous studies have been carried out to examine the effects of discrete fibres made from plastic waste on the characteristics of soils (Ziegler et al. 1998; Babu and Chouksey 2011; Mondal 2012; Ahmadinia et al. 2012; Modarres and Hamedi 2014; Fauzi et al. 2015; Changizi and Haddad 2015; Rawat and Kumar 2016; Peddaiah et al. 2018; Salimi and Ghzavi 2019; Hassan 2021; ELTAYEB 2021).

2.8.1 Standard Compaction

Hassan et al (2021) used polyethylene (PE) bottles and polypropylene (PP) with four different percentage (1%, 2%, 3%, and 4%) and found that plastic content decreased maximum dry density (MDD) and optimum moisture content (OMC) compared with soil that is not mixed with any plastic. This criterion is required for the construction of lightweight materials. They mixed plastic of two lengths, which are 1.0 cm and 2.0 cm and found the similar characteristics for both lengths (figure 4 & 5).

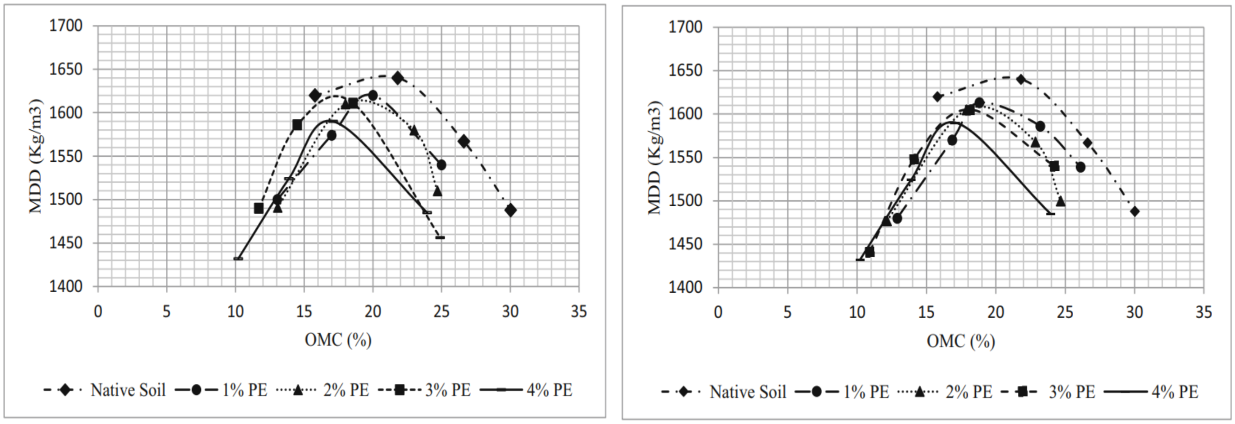


Figure 2-21 Compaction test result for 1.0 and 2.0 cm of PE (Hassan 2021)

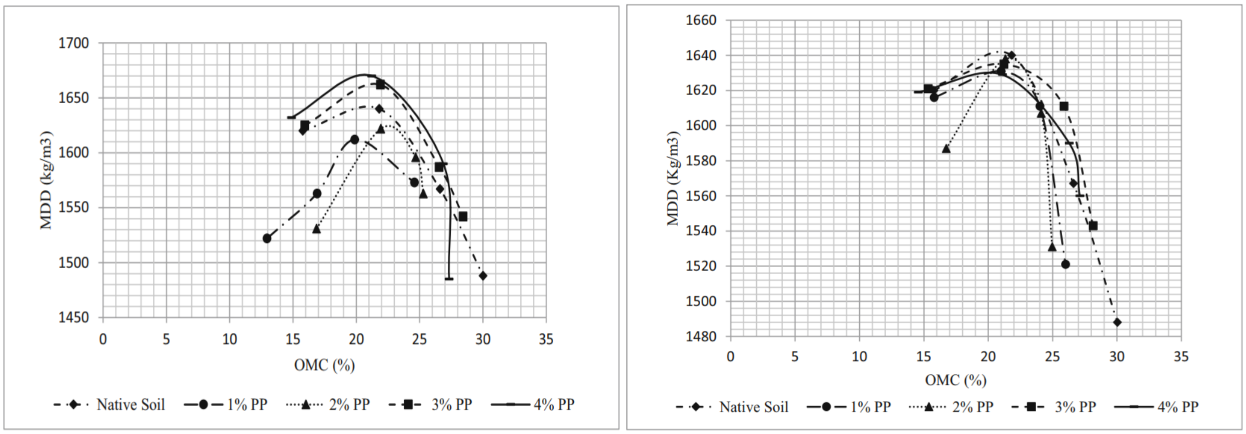


Figure 2-22 Compaction result for 1.0 and 2.0 cm of PP (Hassan 2021)

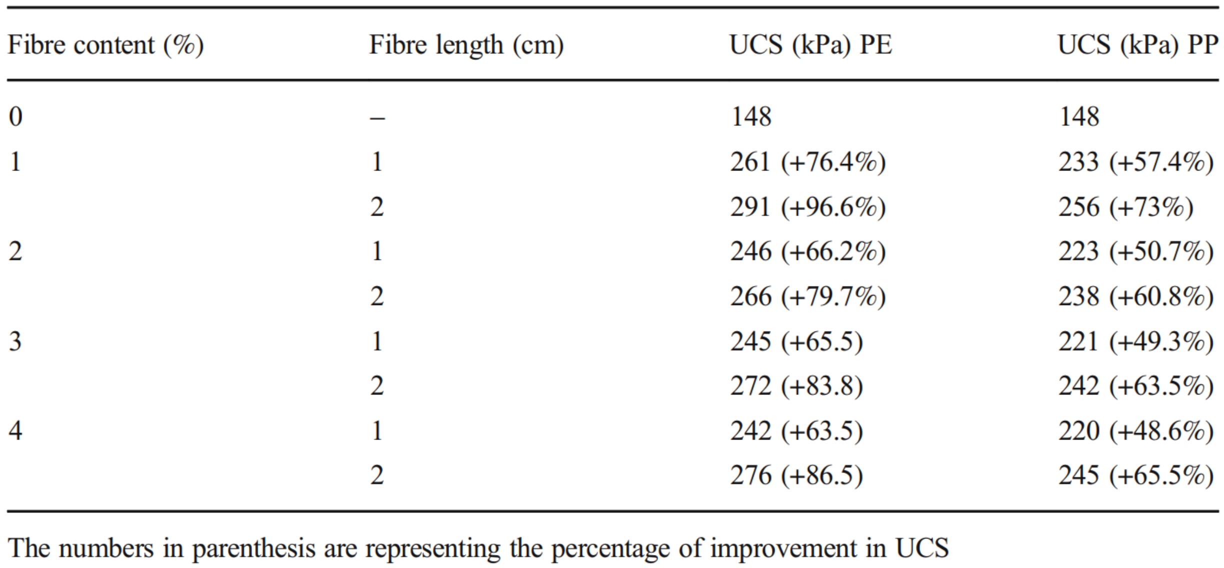
ELTAYEB et al (2021) also used shredded plastic bottles of six different percentages 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0%) and conducted standard compaction test. They conducted the tests with two types of clayey soils and the test result revealed that the addition of shredded plastic reduced both the maximum dry density and optimum moisture content for both types of soils. They found the minimum MDD and OMC for 3% of plastic addition with clay.

2.8.2 Unconfined Compressive Strength

According to the study conducted by several researchers (Tang et al. 2007a, b; Muntohar et al 2009; Muntohar et al 2013; Zukri et al. 2017; Ghorbani et al. 2018; Oliveira et al. 2018; Zukri et al. 2017; Hassan et al 2021), when soil is mixed with shredded plastic, it gains strength by a large amount. AlAfandi (2015) combined cement and waste polyethylene (from water bottles) in the form of fibers to increase the tensile and compressive strength of clayey soils. The fiber lengths were 1.0 cm, 2.0 cm, and 3.0 cm, while the fiber concentrations were 0.4 percent, 0.8 percent, and 1.2 percent of the soil's dry weight. He discovered that fiber-stabilized soil has a higher unconfined compressive strength (UCS) than tensile strength. The ideal fiber length and content were 2.0 cm and 1.2 percent, respectively.

Hassan et al. (2021) performed the studies on four different types of stabilized and natural soils with fiber levels of 1, 2, 3, and 4% of the soil weight. Two lengths of fiber, measuring 1.0 cm and 2.0 cm, were inserted. According to the results of the UCS test, the addition of PE and PP fiber significantly increased the soil strength compared to the native soil strength, which was 148 kPa. The ratio of plastic content determines the maximum increase in UCS; after that, the curve flattens and remains at the same strength with the increase in fiber content.

Table 2-3: UCS result for PE and PP content (Hassan et al. 2021)



Fibre content (%)	Fibre length (cm)	UCS (kPa) PE	UCS (kPa) PP
0	–	148	148
1	1	261 (+76.4%)	233 (+57.4%)
	2	291 (+96.6%)	256 (+73%)
2	1	246 (+66.2%)	223 (+50.7%)
	2	266 (+79.7%)	238 (+60.8%)
3	1	245 (+65.5)	221 (+49.3%)
	2	272 (+83.8)	242 (+63.5%)
4	1	242 (+63.5)	220 (+48.6%)
	2	276 (+86.5)	245 (+65.5%)

The numbers in parenthesis are representing the percentage of improvement in UCS

Comparing PE and PP reveals that for fiber lengths of 1.0 cm and 2.0 cm, the former has higher UCS values than the latter. The results for fibers with a 2.0-cm length are consistently better than those for fibers with a 1.0-cm length. Overall, the UCS of soils significantly increased by 76.4 and 96.6 percent for both lengths of PE fibers and by 57.4 and 73.0 percent for both lengths of PP fibers, respectively.

Taha et al. (2020) also investigated polypropylene reinforcement's impact on the mechanical properties of clay soil. They used a series of soil samples with 0%, 1.5%, 2.25%, and 3% plastic content by soil weigh and conducted different tests. The result indicated improved strength with the increase of plastic content. The optimum plastic content was obtained to be 3% of plastic mixed with soil as it showed better strength behavior than others.

2.8.3 Swelling

Expansive clay soils are a particular type of soil that significantly fluctuates in volume when exposed to moisture. When exposed to excess water, they expand, and when there is not enough water available, they contract in hot temperatures. Expanding and contracting expansive clay soils have a negative impact on the stability of structures placed on top of them, which poses a major risk. By uplifting as they swell, it significantly reduces the bearing capacity and strength of foundations and may result in cracks, differential movements, or structural failures (K. S. Gandhi et al. 2012). Expanding soils must be stabilized to lessen their swelling and increase their mechanical capabilities before construction can begin.

To improve expansive subgrade soil, Zumrawi & Hamza (2014) used Lime and fly ash mixed with soil at ranges 0-15% and 0- 40% respectively and conducted free swell test on natural and treated soil. For the investigated admixture lime-fly ash; the amount of lime added were 5% and 8% combined with the fly ash content 0%, 5% and 10% and they were compared with the swelling of natural soil. The free swell of the natural soil that was used for the test was found to be 195% which indicates that the soil is highly expansive clay. The variation of free swell index with percentages of fly ash for lime-stabilized clay is shown in figure 2.8-3.

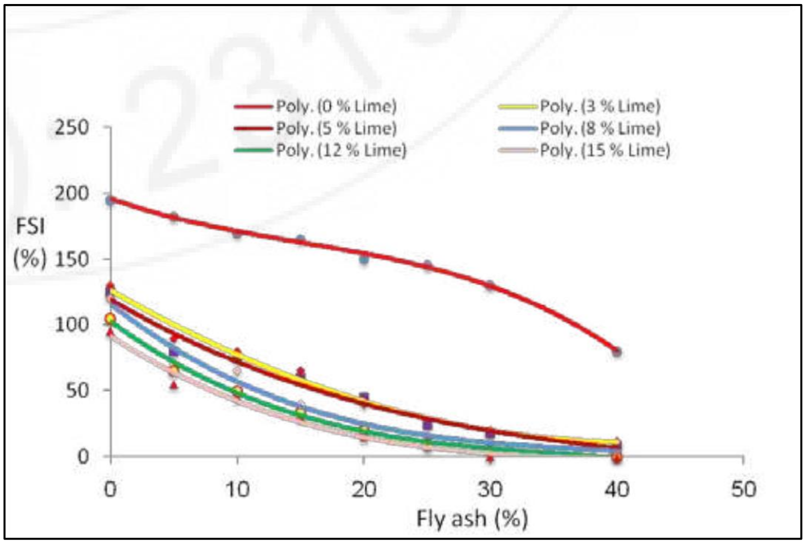


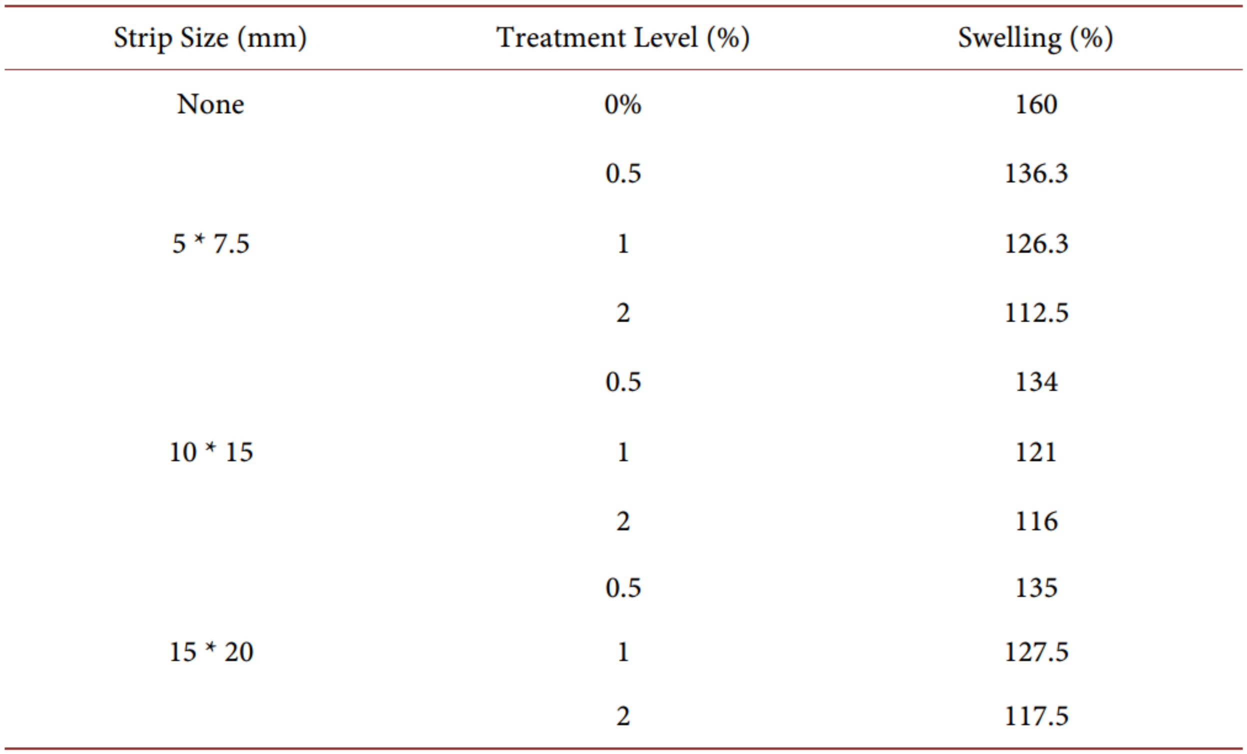
Figure 2-23 Free Swell Index versus Fly Ash for clay-lime (Zumrawi & Hamza 2014)

From the figure 2.8-3, the Free Swell Index (FSI) is shown to decrease non-linearly when fly ash percentage increases. The reduction in FSI caused by the addition of a little amount of lime is significant. Untreated soil has an FSI value of about 195 percent, which is reduced to about 80 percent by adding merely 40 percent fly ash. There will be a greater reduction in FSI when lime is added along with fly ash. The optimal lime-fly ash admixture level, which is 8 percent lime and 20 percent fly ash, reduces the FSI from 195 percent to roughly 20 percent, or a reduction of about 175 percent of the untreated swell value.

Additionally, R. B. Kassa et al. (2020) conducted tests on expansive clay soils of Ethiopia by adding plastic strips with soil at different mixing ratio (0.5%, 1% and 2%) by weight and in three different aspect ratios (5 mm × 7.5 mm, 10 mm × 15 mm, 15 mm × 20 mm). In the experiment, unreinforced soil (soil without plastic) has a free swell of 160 percent, which is categorized as very highly expansive soils by ASTM. The inclusion of plastic strip causes a significant decrease in the soil's free swell. At a strip size of 5mm x 7.5 mm and a strip content of

2%, the swell is reduced by 30%. The swelling test findings are described in Table 3 for each plastic strip size and treatment level.

Table 2-4: Free swell test result (R. B. Kassa et al 2020)



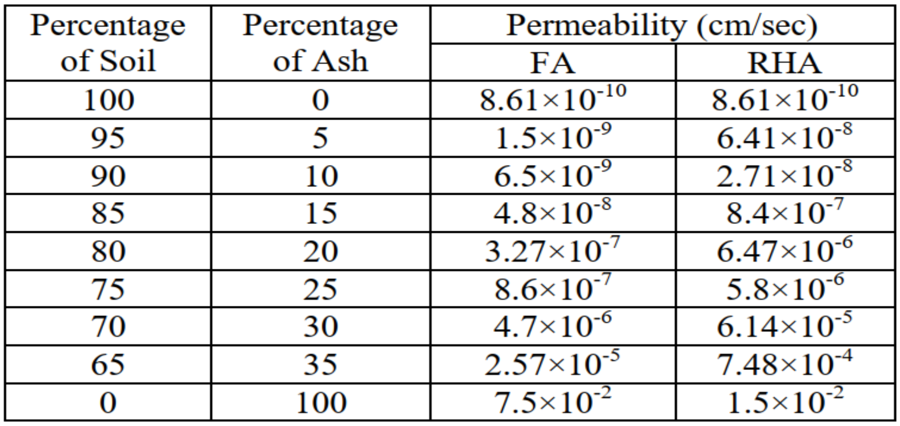
Strip Size (mm)	Treatment Level (%)	Swelling (%)
None	0%	160
5 * 7.5	0.5	136.3
	1	126.3
	2	112.5
10 * 15	0.5	134
	1	121
	2	116
15 * 20	0.5	135
	1	127.5
	2	117.5

2.8.4 Hydraulic Conductivity

Water flow across a volume of soil is characterized by its hydraulic conductivity or permeability. It is one of the most crucial geotechnical characteristics. But determining it is arguably the most challenging part. It significantly affects how strong and deformable soils are. It immediately influences the amount of water that will flow toward an excavation, the design of the clay layer for a landfill liner, and the subgrade on permeable foundations.

For greater drainage, the subgrade soil's permeability needs to be increased. For that, A.K. Anupam et al. (2012) mixed fly ash (FA) and rice husk ash (RHA) and used falling head permeability method to measure the hydraulic conductivity of soil. The results of the permeability test for soil mixed with FA and RHA are shown in table 4.

Table 2-5: Permeability result of soil mixed with FA and RHA (A.K. Anupam et al. 2012)



Percentage of Soil	Percentage of Ash	Permeability (cm/sec)	
		FA	RHA
100	0	8.61×10^{-10}	8.61×10^{-10}
95	5	1.5×10^{-9}	6.41×10^{-8}
90	10	6.5×10^{-9}	2.71×10^{-8}
85	15	4.8×10^{-8}	8.4×10^{-7}
80	20	3.27×10^{-7}	6.47×10^{-6}
75	25	8.6×10^{-7}	5.8×10^{-6}
70	30	4.7×10^{-6}	6.14×10^{-5}
65	35	2.57×10^{-5}	7.48×10^{-4}
0	100	7.5×10^{-2}	1.5×10^{-2}

According to the data, the soil's permeability value is 8.61 10-10, which is extremely low in comparison to the pavement subgrade layer's capacity for drainage. Effective drainage for subgrade soil is achieved by adding 20 percent FA and 15 percent RHA to the soil, which increases the permeability to 3.27 10-7 and 8.4 10-7, respectively. The permeability of the soil continues to rise as a result of more FA and RHA additions.

2.9 Factors Affecting Strength of Subgrade

Multiple parameters regulate the elements that have an impact on the structural integrity of flexible sections. It has been discovered that the strength of subgrade soils is extremely sensitive to the type of soil, thickness of surface, base and sub-base layers, level of compaction, moisture content, density, and stress level that the soil is subjected to. According to Gautam, B. (2008), less stress will be placed on layers for a given traffic volume and applied load as layer thickness increases.

2.9.1 Compaction

The degree of compaction, degree of saturation, moisture content during compaction, and method of compaction have an impact on the strength of subgrade. Lower strengths are produced by materials with lower degree of compaction. Also, materials that are compacted on the wet side of the ideal moisture content range results in lower strength. Highest strength is obtained for soils when they are compacted to their maximum dry density for optimum saturation level (P. Tian et al. 1998).

2.9.2 Dry Density

As long as the mean normal load is modest, the subbase or subgrade course are typically stiffer as density increases. When the level of stress is modest, Barskale and Itani found that increasing density results in a rise in strength. Rada and Witczak claim that as sample density increases, the strength also does, however the increase is relatively less than the changes brought on by changes in moisture content and stress level. The impact of density at high stress levels is less striking than the impact of gradation or material type.

2.9.3 Liquidity Index

Ahmad Safuan A. Rashid et al. (2014) studied the effect of soil liquidity index on strength properties for low traffic volume subgrade roads. Based on the OMC value from the compaction test, different moisture contents (0.9, 1.0, and 1.1 from OMC) are used to evaluate the impact of the soil Liquidity Index. All soil samples were tested for strength using the Unconfined

Compressive Strength (UCS) method to establish their optimal moisture content after seven days of curing. Finally, a relationship was developed between subgrade design strength and soil liquidity index that is useful as a guideline for a road contractor or consultant to construct the subgrade at the minimum moisture content.

2.9.4 Moisture Content

It is generally accepted that the strength and stiffness of soil is greatly influenced by the moisture content or level of saturation. Unbound paving materials' strength often declines when moisture content or saturation level rises. According to study the strength of granular materials falls with approaching total saturation level from the investigation of the behavior of granular materials with high degree of saturation. Similar to this, Lekarp et al. reported that as the saturation level approached 100%, the robust modulus of the base material drastically decreased. The robust moduli of the coarse granular materials were also measured by Ekblad and Isacsson at varied moisture concentrations up to saturation. According to the authors, even when the moisture level rose to saturation, the materials with high fines contents displayed a large reduction in their resilient moduli, but the materials with low fines contents displayed a slight loss.

Refeai & Suhaibani (2002) studied the effect of moisture content and relative density on the strength of subgrade materials by testing at two different relative densities and their corresponding moisture content from the compaction curve. The study revealed that both moisture content and relative density has significant impact on the strength of subgrade.

2.10 Challenges of Using Waste Materials in Construction

Although there are numerous benefits to using waste materials to build pavement, there are also a number of challenges to use them practically (Jamshidi et al 2019), such as-

- The primary issue with plastic roads is the manufacture of the plastic required to build them. The Indian municipality of Maraimalai Nagar accepted the idea of building plastic roads out of leftover plastic, but at first had trouble finding enough labor to collect enough plastic. The community came up with a solution: in exchange for collecting 500 kilos of single-use plastics with a thickness of less than 40 microns, people would receive a four-gram gold coin. Ironically, Maraimalai Nagar had to scrap the plan after a year because they could not keep up with the demand for plastic to make the roads. The town was encouraging the citizens to continue creating the single-use plastic that they were trying to eliminate; therefore, this initiative was doomed to failure from the start. So, it should be taken into account that there is enough plastics for building plastic road and the plastics are easily available.
- Once plastic is produced, there is no safe way to handle or dispose of it. Plastics will continue to exist on the planet after we are gone. The appearance of plastic roadways can suggest that plastic usage is acceptable. Any efforts to eliminate plastic can ultimately fail due to this false belief, which may also probably lead to an increase in its manufacturing.
- A considerable initial investment is required to build infrastructure for sorting the materials based on type, source, and risk. Waste materials should also be treated so they it matches the specifications. At first appearance, using waste materials that require sophisticated equipment to handle might not seem tempting. For instance, employing waste

materials results in expenses because it requires building facilities and hiring laborers, but the long-term cost of paving and repairing it is lower.

- The utilization of various waste materials for pavement construction should be taught to pavement engineers, material technologists, and paving workers. Technical guidelines and practice codes should be made available in detail to help with this. There are no standardized practice standards for the use of waste glass, plastic, or blast furnace slag, despite the fact that such technical codes have been developed for the use of RAP.
- It is concerning how well these pavements will work overtime. The best mixes of different waste elements should be identified through laboratory experiments to solve this problem. The compatibility of various waste material kinds is a crucial element in establishing such a balance. In other words, it is preferable for the waste materials, binder, and aggregate components to have synergistic effects.
- The chemical makeup of plastic, which might contribute to environmental issues because of plastic roadways, is another difficulty. The majority of plastic debris that is dumped across the world breaks down into minute fragments through a process called photodegradation—plastic breaks down when exposed to elements like light and heat—and eventually makes its way into the ecosystem through soils and waterways. These microplastics behave very similarly to polychlorinated biphenyls (PCBs), which are magnets that draw in all nearby pollutants. Microplastics are easily carried through a variety of habitats and may eventually become more polluting. Organisms may mistake them for food and perish as a result of poisonous buildup. Therefore, it is important to look at the chemical components of plastics. Further research is necessary because there are

contradicting reports and research findings regarding the composition of leachate from pavement built from waste materials.

- How often the waste materials can be recycled and used for paving construction is another important consideration. The type of waste material, its chemical make-up, the energy source, the environmental impact, and the economic rationale all play a role in determining the right number of uses. It is impossible to provide a conclusive solution that covers all compositions. Therefore, it is essential to rank different waste products according to how likely they are to be recycled. To develop a multi-variable criterion for ranking various waste products, more research is required.

CHAPTER 4

METHODOLOGY

3.1 Introduction

The purpose of this experimental program was to determine the performance of soil when treated with recycled plastics. Moisture Density test, Unconfined Compressive Strength, permeability test and swelling test were conducted for soil mixed with different types of recycled plastic materials at different percentages. The strength, permeability and swelling of plastic mixed samples were then compared to the control soil sample (without any plastic content). The following sections include descriptions of the test procedures, requirements, and testing equipment.

3.2 Sample Collection

Three types of recycled plastics (HDPE, PET, PP) and soil have been collected for this experimental program.

3.2.1 Soil Collection

For this research, soil sample has been collected from FM-156 Haslet Site on 14th November 2021 through boring. Disturbed and undisturbed soil has been collected from different depths (5', 10', 15', 20') and then, the soil has been classified according to ASTM guidelines to check if the soils from different depths are of same category.

Figure 3-1 Collection of Soil

3.2.2 Recycled Plastic Collection

For this experimental work, recycled plastic is presented as a novel approach. The Society of the Plastics Industry (SPI) has designated seven different types of plastics, each of which is designated by an SPI code or number. Given their accessibility and affordability, the experimental work uses high density polyethylene (HDPE), polyethylene terephthalate (PET), and polypropylene (PP).

The Republic Services Material Recovery Facility (MRF), located in Fort Worth, Texas, was used to gather high density polyethylene (HDPE), polypropylene (PP), and polyethylene terephthalate (PET) plastic. The MRF typically collects waste from adjacent cities' curbside trash and thoroughly sorts the waste plastics into the seven categories described before. Three different types of plastics (HDPE, PP, and PET), each weighing between 1000 and 1500 lb, were combined into one bale and taken there for the purposes of the test.

3.3 Plastic Processing

Before mixing plastic into soil for pavement subgrade, several preparations must be undertaken. The key procedures are to select the plastic that can be utilized for this specific project based on availability, cost, as well as to sort, clean, dry, and shred the plastic. Three types of plastic— High density polyethylene (HDPE), and polypropylene (PP), Polyethylene terephthalate (PET)—are selected, gathered, and sorted in accordance with their densities among the seven plastic grades previously mentioned.

3.3.1 Sorting of Recycled Plastic

Despite being collected in three distinct bales, the three different plastic kinds included some contaminants and contamination. Each bottle and plastic container are selected by hand, then carefully sorted. Due to the contamination of other materials including paper, dirt, and various forms of plastic, sorting from a large bale is essential. HDPE was used to make colored bottles for various liquids, including detergents, shampoo, beauty items, and containers. PET type plastics are used for things like water and soda bottles, food storage, and beverages. Lunch boxes, margarine containers, yogurt pots, syrup bottles, and prescription bottles are all made of PP.

3.3.2 Cleaning and Drying of Sorted Plastic

The bale was removed once the plastics had been separated and taken for cleaning. For two hours, everything of the plastic was soaked there for extensive cleaning. Later, clean water was used to rinse the plastics. All of the plastics were put outside to dry in the sun after cleaning. They were let to dry for 24 hours in the air. In order to preserve the physical and chemical makeup of the plastics, no oven or other external heat source was utilized to dry them.

Figure 3-2 Cleaning of Plastics

Figure 3-3 Plastics Drying Under the Sun

3.3.3 Plastic Shredding

Plastics that had been cleaned and dried were delivered to a facility for first shredding. Plastics were shredded into a mesh with a size range of 1 to 3 inches by Balcones Shred in Dallas.

In the civil engineering laboratory building, a small-scale shredder was used for the second stage of shredding. To shred the plastics into smaller size for this research study, we employed an Intbuying Heavy Duty Plastic shredder. To use the plastic for other purposes, the HDPE, PP, and PET had to be shredded into tiny bits of 3 mm to 6 mm. This was accomplished using an INTBUYING 220V Heavy Duty Plastic Grinder/Granulator.

Figure 3-4 Shredding of Plastics

3.4 Development of Experimental Program

This study attempts to assess recycled plastics' potential for use in treating pavement subgrade. The entire evaluation is based on the experimental program used in this study. The physical characteristics of the soil must be ascertained before the investigation can begin. The ideal moisture level of the control soil and various ratios of soil mixed with plastic must then be established for further research. When the optimum moisture content is identified, additional testing will be conducted by using it. The control soil and plastic mixed soil with optimum moisture content will then be used for unconfined compressive strength test, permeability test and swelling test as shown in figure 3-5. The optimum plastic content can be determined after conducting the test programs.

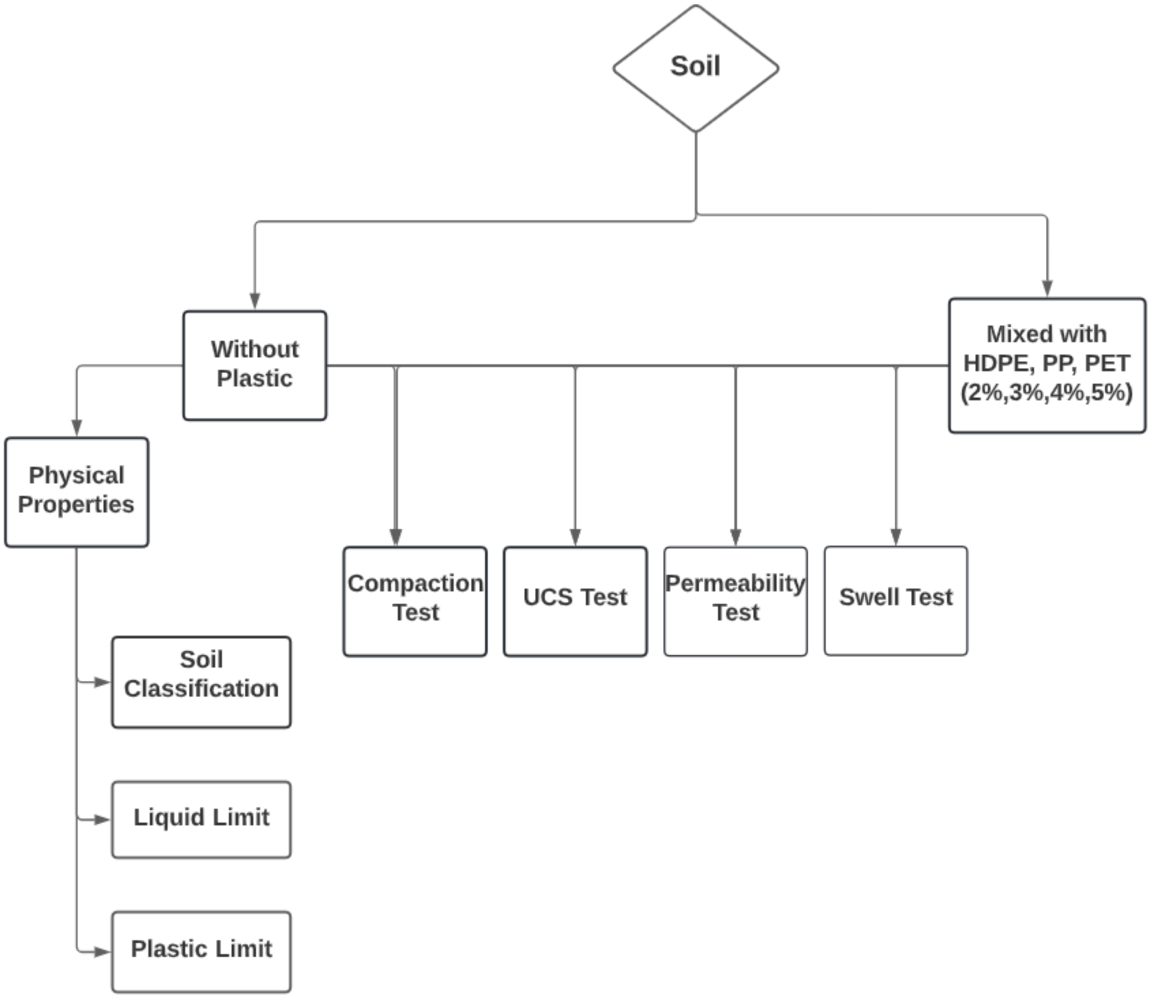


Figure 3-5 Experimental flow diagram

This study involves 104 tests in total, with many samples collected for each test to confirm the tests' repeatability. Due to this, three samples were examined for UCS and two samples for both Swelling and Permeability Test (Table 3-1).

Table 3-1 Total number of tests done in this study

Type	Plastic (%)	Strength Test		Swelling Test	Permeability Test
		Compaction Test	Unconfined Compressive Strength Test		
Control	0	1	3	2	2
HDPE	2	1	3	2	2
	3	1	3	2	2
	4	1	3	2	2
	5	1	3	2	2
PP	2	1	3	2	2
	3	1	3	2	2
	4	1	3	2	2
	5	1	3	2	2
PET	2	1	3	2	2
	3	1	3	2	2
	4	1	3	2	2
	5	1	3	2	2
Total Number of Tests					**104**

3.5 Soil Gradation

According to the standard test procedure described in TxDOT standards (Tex- 110E), sieve analysis was used to determine the particle size distribution for soil. The gradation of the subgrade materials was established in accordance with Tex-110E requirements. If the percentage of material passing through the No. 200 sieve is less than 1%, the Texas Department of Transportation's (TxDOT) specification Item 276 states that no hydrometer analysis is necessary.

For the sieve analysis, each sieve's retained material was weighed, and the percentage of material that made it through the sieve was determined. The weight of the entire sample was divided by the amount of material retained in each sieve, and the difference was deducted from the overall percentage of material. On semi-log graph paper, the percentage of material passing through each sieve was plotted against the sieve size.

After sieve analysis, the sample passed through No. 200 sieve was found much more than 1%, so hydrometer analysis was performed. According to ASTM D7928, some soil was at first mixed and thoroughly stirred with dispersing agent (sodium hexametaphosphate solution). The soil slurry was then transferred to mixer and consequently to an empty sedimentation cylinder by adding more distilled water. The open end of the cylinder was covered with a stoper and mixed properly by turning upside down and back upright and then left the mixture for 30 minutes. On the other side, control cylinder was prepared by adding dispersing agent with distilled water only and then shaken thoroughly. Hydrometer was inserted and the readings were recorder for both the control cylinder and soil mixed cylinder. Hydrometer reading was then corrected using meniscus correction and temperature correction and equivalent particle diameter was calculated. Finally, percent finer was determined and adjusted and the grain size versus adjusted percent finer graph was plotted in semilogarithmic graph paper.

3.6 Atterberg Limit Test

For all Atterberg limits tests, soil samples must pass through a No. 40 (425 mm) test sieve and must be prepared wet or dry according to the criteria for each test. Water is added to test specimens to change their moisture content. The mixture is then stirred for at least 16 hours.

- **Liquid Limit:** ASTM D4318 test procedures are employed for this test. For liquid limit test, Casagrande liquid limit device was used. Water was added to a portion of soil sample passing No. 40 sieve, the mixture was chopped, stirred, and kneaded repeatedly. Then the mixture was placed in the brass cup of the device and a groove was created in the cup's center. The cup of the device was raised to a certain height and then allowed to fall onto a hard rubber base using a manually turned cam or a small motor. The dropping was at a rate of two drops per second until the groove was closed around 13 mm. Several blows were applied, and the number of blows against moisture content was plotted. The moisture content related with 25 blows of the blower is considered as the liquid limit of the soil specimen.

- **Plastic Limit:** For the plastic limit determination, the soil was kneaded with water repeatedly. By manually rolling out a little ball of moist plastic soil into a 3mm thread and repeatedly remolding it, the Plastic Limit is determined. Once the thread was broken at 3 mm in diameter, it was placed in a moisture can. The samples were then dried in an oven between 100°C and 110°C temperature for 24 hours. The moisture content at this condition is considered as plastic limit of the soil specimen. ASTM D4318 is the standard test procedure that was followed for this test.

3.7 Moisture Density Test

The moisture content at which a particular material can be compacted to produce its maximum dry density (MDD) is known as the optimal moisture content (OMC). In order to determine the maximum dry density that can be attained at the optimum moisture content, this test was carried out in accordance with the AASHTO T 180-93 standard. The test result illustrates the change in density for various combinations of recycled materials at various moisture contents.

For the compaction test, A 5.5 lb hammer was used to compact the soil, which is dropped onto a mold with three equal layers of earth at a distance of 12 inches. The hammer is dropped 25 times on each layer. Five samples with varying moisture contents were compacted. Moisture content was determined after the samples were compacted and dry density was determined.

Following that, the moisture vs. dry-density curve was plotted in order to calculate the optimum moisture content and maximum dry density from the peak of the curve.

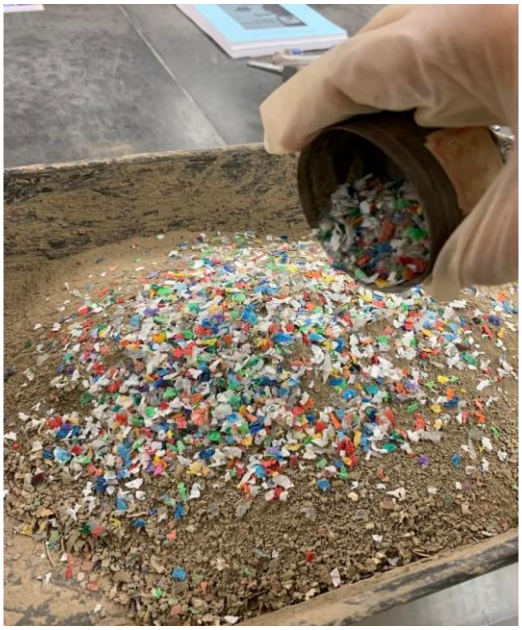
3.8 Specimen Preparation

To prepare remolded soil specimen, the following procedures were followed (Figure 3-:

- The specific amount of soil is placed in a pan and retained in an oven at 100°C temperature for at least 24 hours so that the soil becomes oven dried. Then the oven dried soil was crushed and pulverized and passed through #50 sieve.
- For making control soil sample, the soil is mixed with required amount of water so that it reaches its maximum moisture content. The water is mixed manually, and it is kept for 24 hours, so that the mixture becomes uniform.
- For plastic mixed soil samples, the required amount of shredded plastics was weighed and kept in a separate container. Then the soil is manually mixed with specific amount of plastic alongside water and kept for 24 hours.
- A mold of 2.8 inches diameter and 7 inches height is sprayed with WD-40 thoroughly in its surface, so that the soil does not stick to the mold. Then the soil is poured in the mold in three layers in such a way so that the soil sample is prepared at 95% compaction. After compacting each layer, the upper surface of the layer is scratched with a knife so that the new layer is perfectly bonded with the old one. Each layer of soil is compacted in 2 inches, so the whole specimen becomes around 6 inches.
- An extruder is then used to extrude the sample from the mold.
- To avoid any disturbance in the specimens they were wrapped with plastic and stored in the moist room having controlled humidity of about 100% and a constant temperature of

70°F for curing period of seven days. Then the specimens were tested for UCS, hydraulic conductivity and swelling tests.

(a) Mixing of soil with water



(b) Mixing of soil with shredded plastic

(c) Spraying WD-40

(d) Pouring of soil in the mold

(e) Compaction of soil

(f) Scratching soil surface

(g) Specimen extrusion

(h) Prepared control specimen kept at moisture room

(i) Prepared plastic mixed specimen kept at moisture room

Figure 3-6 Specimen preparation

3.9 Unconfined Compressive Strength

The strength of a material is measured by its unconfined compressive strength (UCS) test. The maximum axial compressive stress that a cylindrical sample of a material can withstand with no confining stress is known as the unconfined compressive strength. This test was carried out to find out how the inclusion of plastic waste pieces affected the soil's unconfined compressive strength. ASTM D2166 was followed for conducting the test. All the UCS test specimens were prepared at their respective maximum dry density and optimum moisture content.

The prepared specimen is placed in the loading device so that it is centered on the bottom platen. The loading device is adjusted carefully so that the upper platen just makes contact with the specimen. The deformation indicator is made zero. Then the load is applied so as to produce an axial strain at a rate of 1⁄2 to 2 %/min. The load, deformation, and time values are recorded at sufficient intervals to define the shape of the stress-strain curve (usually 10 to 15 points are sufficient). The rate of strain is chosen so that the time to failure does not exceed about 15 min. The loading is continued until the load values decrease with increasing strain, or until 15 % strain is reached. A graph is plotted by the computer showing the relationship between compressive stress versus axial strain. The maximum value of compressive stress, or the compressive stress at 15 % axial strain, whichever is secured first, is selected, and reported as the unconfined compressive strength.

(a) (b)

Figure 3-7 Specimens after UCS test (a) control specimen; (b) specimen of soil mixed with 5% HDPE

3.10 Swell Test

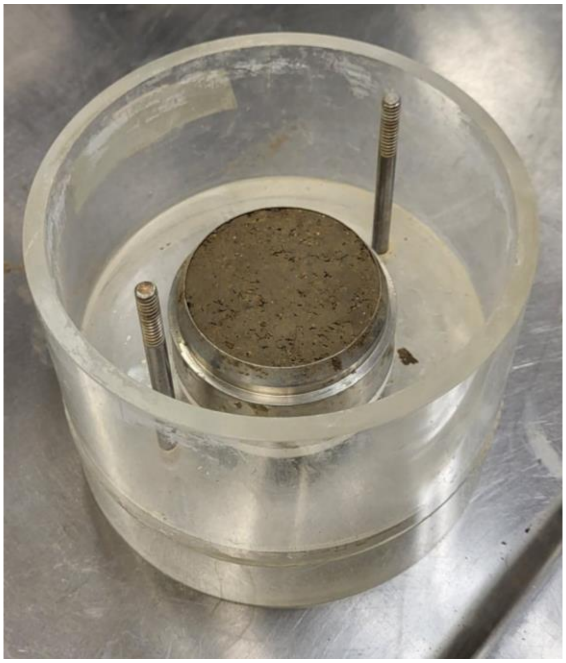
Swell test is used for measuring one-dimensional wetting-induced swell or collapse hydro-compression strains of compacted or natural soils over a range of vertical stresses. The data from these tests can be used to estimate one-dimensional ground surface heave or settlement.

Following the ASTM D4546 guidelines, the one-dimensional swell strain test was carried out in a conventional consolidometer setup. The procedure is explained below:

- The previously prepared soil specimen is cut and put inside a ring of 2.86 inches diameter and 1 inch height. Then the ring is placed inside the consolidometer and it is set up properly.
- A gauge is connected to the consolidometer.
- A seating load of 1 kPa is applied to the consolidometer.

- Once the soil specimen was properly loaded, the test setup is flooded with water from both ends, and the specimen was left to swell in a vertical direction. The soil sample is allowed to swell for 24 hours or until plateau conditions are reached in the swell deformation readings. Swell deformation measurements are collected at regular time intervals and used to determine vertical swell strains.

(a) Compacted soil sample kept in a ring



(b) Ring placed inside consolidometer

(c) Consolidometer setup

(d) Gauge connection

Figure 3-8 Swell test setup

3.11 Permeability Test

Permeability refers to how easily water can move through the soil and the extent to which it is impacted by the connecting void space. This study investigates the effect of recycled waste plastic treatment on permeability characteristics of subgrade soil. For this case, permeability test is performed through triaxial setup.

A sample size of about 2:1 in terms of height to diameter was used for the test. To make sure it had the right length and diameter, the previously created sample was trimmed. The specimens were soaked, consolidated, and sheared after sample preparation. These were all carried out in a pressure chamber. The specimen was placed vertically inside a pressure chamber and enclosed by a thin rubber membrane. Clean water was used to fill the pressure chamber. The confined water pressure was adjusted by adjusting the surrounding water pressure. The volume of the flowing water was also used to gauge the sample's volume change.

3.11.1 Specimen Preparation and Assembling the Equipment

The tested soil sample was placed in a triaxial cell and covered with an impermeable membrane. O-rings were employed to secure the impermeable membrane. To make sure the porous stones were saturated and that there was as little air trapped inside the sample membrane as possible, they were shocked. The specimen's top and bottom surfaces were placed in direct touch with the porous stones by sandwiching a pair of filter sheets between them. Water was introduced to the triaxial chamber after the sample was prepared and the triaxial cell was covered.

3.11.2 Sample Saturation

After adding water to the triaxial chamber, the sample was saturated using the back pressure saturation method. According to cell pressure, back pressure (pressure within the membrane) increased. The porous stone on the specimen's top and bottom, evenly distributes pressure and strain in addition to serving as drainage. The sample was allowed to saturate at a specific cell pressure. The difference in pore pressure brought on by the rise in cell pressure was measured the next day. The ratio of an increase in pore water pressure to an increase in cell pressure delivered to a specimen under undrained conditions during triaxial testing is known as the pore pressure coefficient B. The estimation of saturation conditions is done using the B value and it is calculated using the following equation.

$$\mathrm{B} = \frac{\Delta \mathrm{u}}{\Delta \delta_3}$$

Where $\Delta \mathrm{u}$ =Change in pore pressure, and $\Delta \delta_3$= Change in cell pressure.

According to Chaney (1978), an undrained test will be deemed acceptable, if the B-value is 0.95 or greater. As a result, it was ensured that the B value in this study would be higher than 0.95. The sample needed seven to 10 days to get saturated.

3.11.3 Hydraulic Conductivity of Triaxial Sample

The hydraulic conductivity of the specimens was measured using the falling head permeability tests. Following back pressure saturation, the effective stress was modified and the head pressure across the sample was set. The stand-tubes in FlexPanel were made of plexiglass tubes and were used for back-pressure saturation as well as for reading the input and outflow from the samples. Pore-pressure transducers were used to track all pressures (Cell pressure, Base pressure, and Top pressure). Since no sample had a B value lower than 0.95 at the conclusion of the saturation process, the samples were taken to be fully saturated throughout the tests. By raising the input stand tube pressure (base pressure) while keeping the outflow line pressure (top pressure) at the final back pressure applied during saturation, a gradient was created across the specimen. Burette initial measurements were taken and recorded. An automatic volume change apparatus measured the flow volume continuously, allowing continuous measurements of volume change.

The hydraulic gradient is computed in terms of head of water in all cases. The hydraulic conductivity of the soil sample was determined by the following falling head equation.

$$K = \frac{aL}{A(t_i - t_f)} \ln(\frac{h_i}{h_f})$$

Where, K = hydraulic conductivity, cm/s

a = cross-sectional area of standpipe, cm^2 (0.305 cm^2)

A = cross-sectional area of sample, cm^2

L = length of the sample, cm

$t_i - t_f$ = time lapse, sec

h_i = initial head difference between inflow and outflow stand-tube (base pressure tube and top pressure tube), cm of water

h_i = final head difference between inflow and outflow stand-tube (base pressure tube and top pressure tube), cm of water

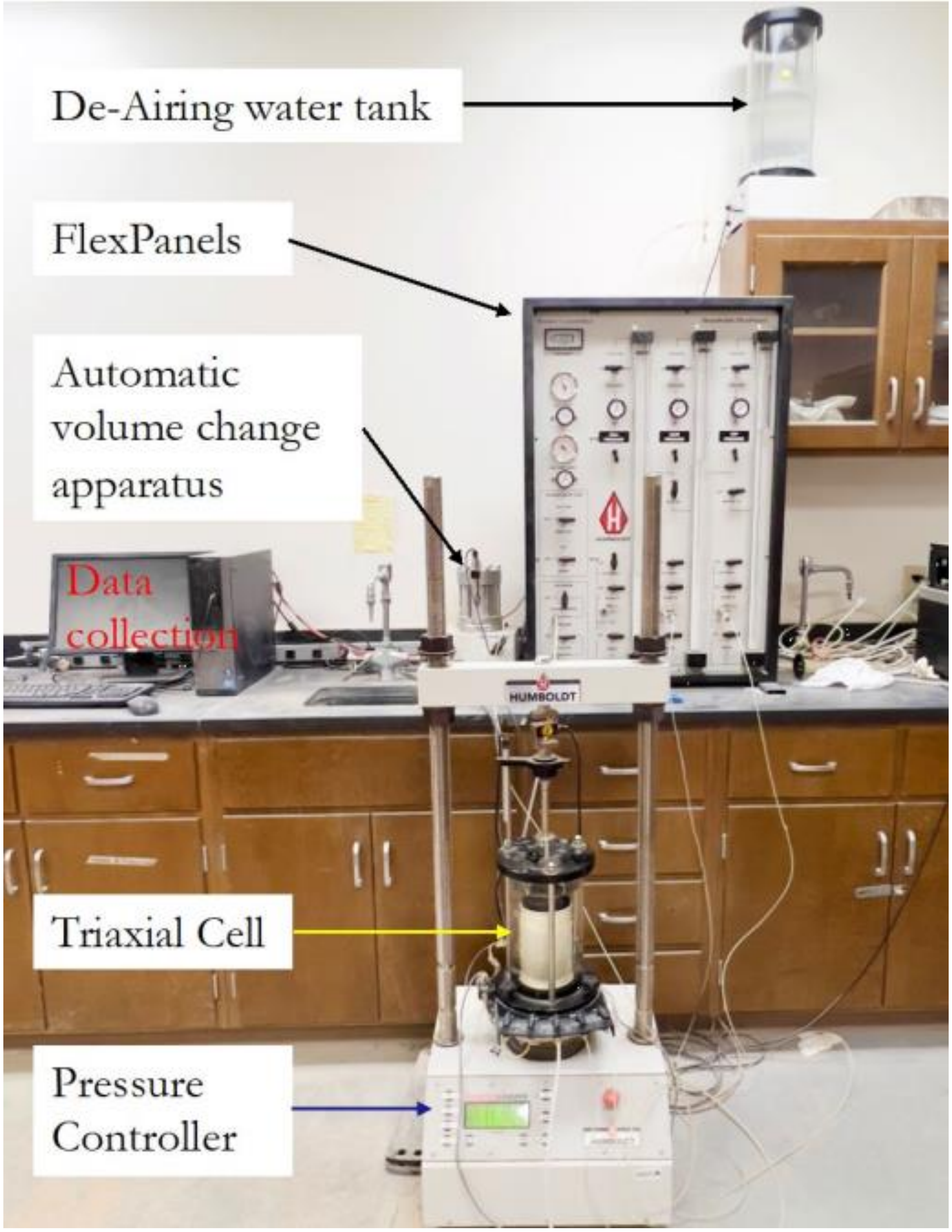


Figure 3-9 Permeability testing equipment (triaxial cell)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The results obtained from optimum moisture content and maximum dry density, unconfined compressive strength test, and free swell test and permeability test are presented and analyzed here in this chapter. Test data is analyzed in terms of changing plastic content.

4.2 Grain Size Distribution

Sieve sizes were performed in accordance with ASTM D6913 standard test methods for particle-size distribution (gradation) of soils using sieve analysis. If more than 1% of the soil passed the No. 200 sieve, then hydrometer analysis was required.

According to the sieve analysis findings, about 20% of soil sample retained on the #200 sieve, indicating fine grained soil. The retained soils were sieved using #4, #10, # 30, #40, #60, #100 and #200 US standard sieves and the amount of soil retained in each sieve was then measured before calculating the percentage of materials passing through the sieve. By dividing the weight of material retained on each sieve by the total weight of the sample, the percentage of the materials retained on each sieve was obtained. The amount of material that passed through each sieve was calculated by deducting the percentage retained on each sieve from 100%. The particle/grain size distribution curve was obtained by plotting the percent of materials that passed through each sieve against the size of sieve on a semi-log graph. The soil passed through No. 200 sieve was then tested using a hydrometer according to ASTM D422-3 as the soil passed through No. 200 sieve was much more than 1 percent. The gradation of the soil is shown in Figure 4.1.

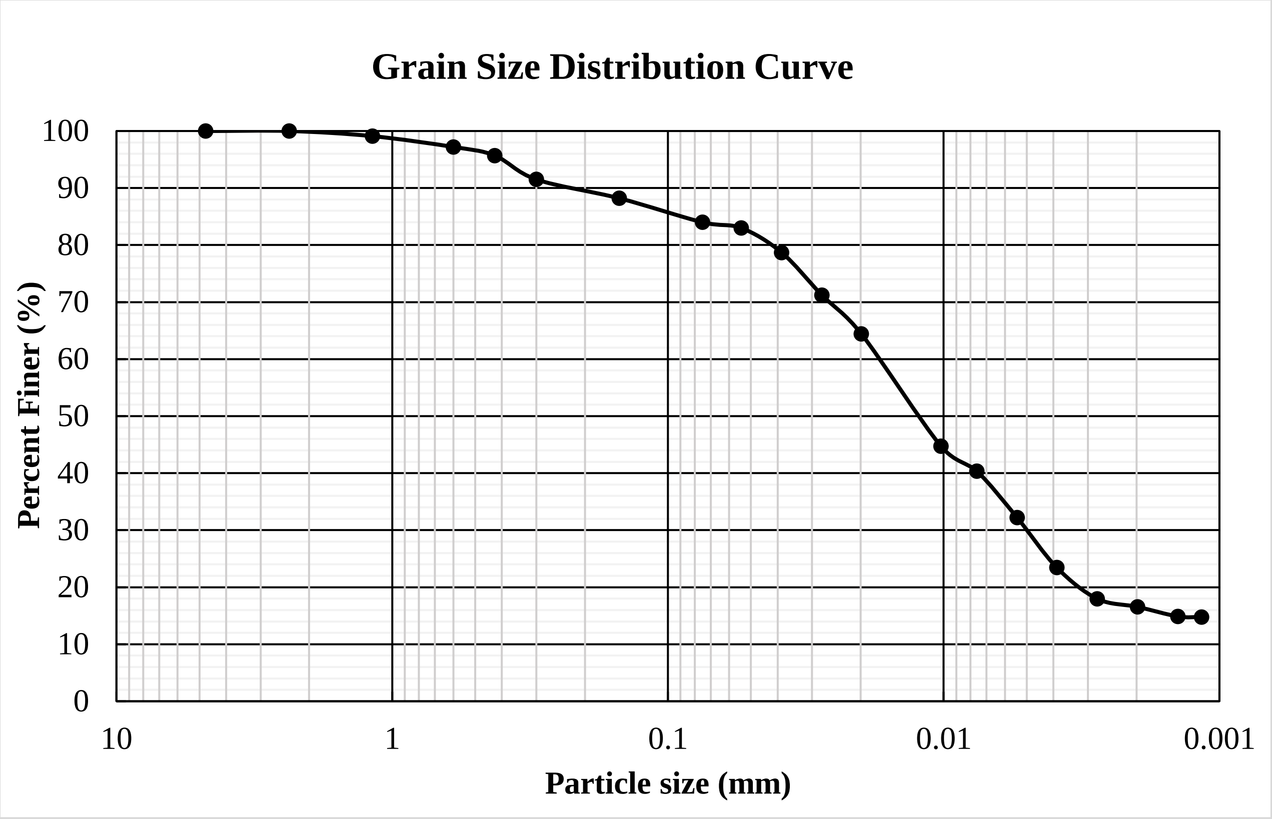


Figure 4-1 Grain size distribution curve

4.3 Atterberg Limit Test

Atterberg limit tests were performed on the soil samples according to ASTM D318 standard. Disturbed soil samples that were collected from 10’, 15’, 20’ and 25’ depths were used for Atterberg limit test to know if the soils are of same category or not. If the soils are of same group, then they will be mixed together for further tests. For Atterberg limit test, the soil from different depths passing through a sieve of No. 40 were only used in this test. Casagrande liquid limit device was used for this test. Several blows were applied following the ASTM procedure and then the number of blows against moisture content was plotted in a graph paper. The moisture content associated with 25 blows of the blower was taken as the liquid limit of the specimen.

For plastic limit determination, water mixed soil sample was rolled as thread. The moisture content at which the thread is broken at 3mm is considered as plastic limit of the soil specimen. The liquid limit values for all depths of soil were between 50 to 65 and the plastic limits were between 25 to 30.

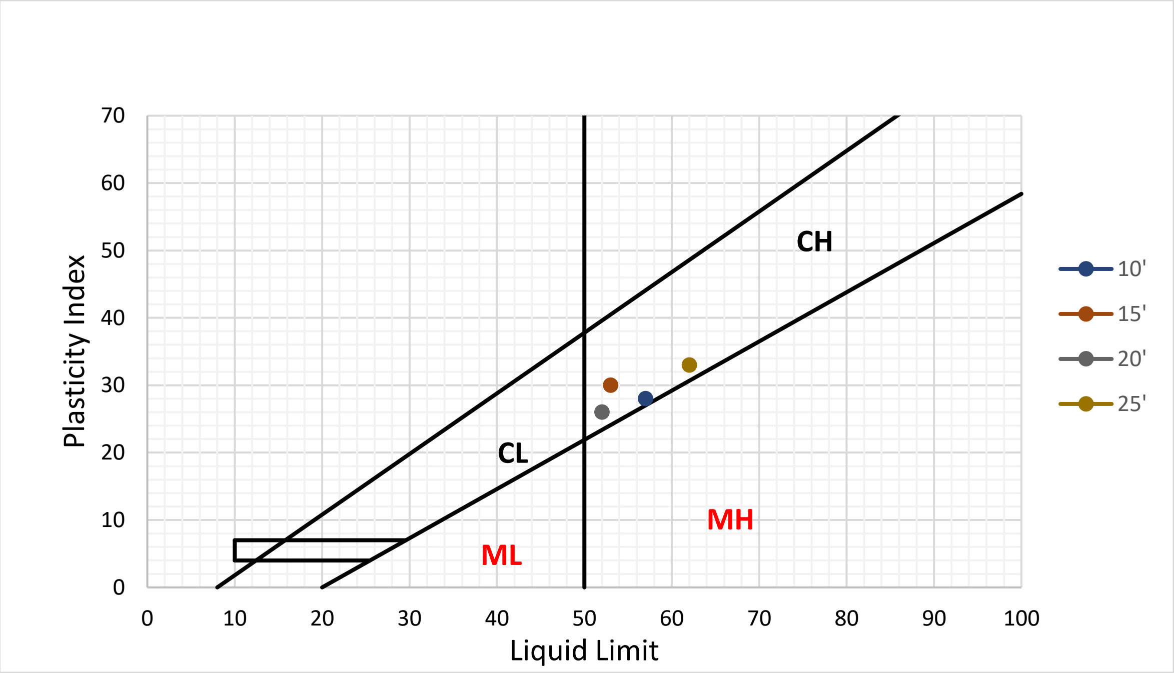


Figure 4-2 Plasticity chart

The plasticity chart for the sample collected from Haslet site is shown in figure 4-2. Based on the sieve analysis and Atterberg limits results, the soil sample was classified according to the United Soil Classification System (USCS) as high plastic clay (CH). Samples collected from all the depths showed similar results and all of them are high plastic clays (CH).

4.4 Standard Proctor Compaction Test

The Standard Proctor Compaction Test determines the maximum dry density (MDD) of soil to which a certain type of soil can be compacted with a controlled compactive force at the optimum moisture content (OMC). The test was conducted according to ASTM D698-91 to determine the maximum dry density that can be achieved at the optimum moisture content. The test result shows the variation in density for various combinations of recycled materials over a broad range of moisture contents. The moisture level at which a particular material can be compacted to produce its maximum dry density is known as the optimal moisture content (OMC) (MDD). OMC and MDD tests on each of the material combinations at various plastic contents were carried out in this study. The amount of compaction energy needed is 5.50 lbf. The molds of 4-inch diameter is used. The dry density for various moisture levels was calculated after compaction tests were conducted on specimens with five different moisture contents. The obtained dry densities were plotted against the moisture contents, and the optimum moisture contents were determined from the peak of the trend curve.

4.4.1 Compaction Test Results for Soil Mixed With HDPE:

Figure 4-1 shows the result of compaction test for control soil and soil mixed with different percentage (2%, 3%, 4%, 5%) of HDPE. From the graph, the optimum moisture content and maximum dry density are obtained for both the control soil (soil without HDPE) and stabilized soil sample (soil mixed with HDPE).

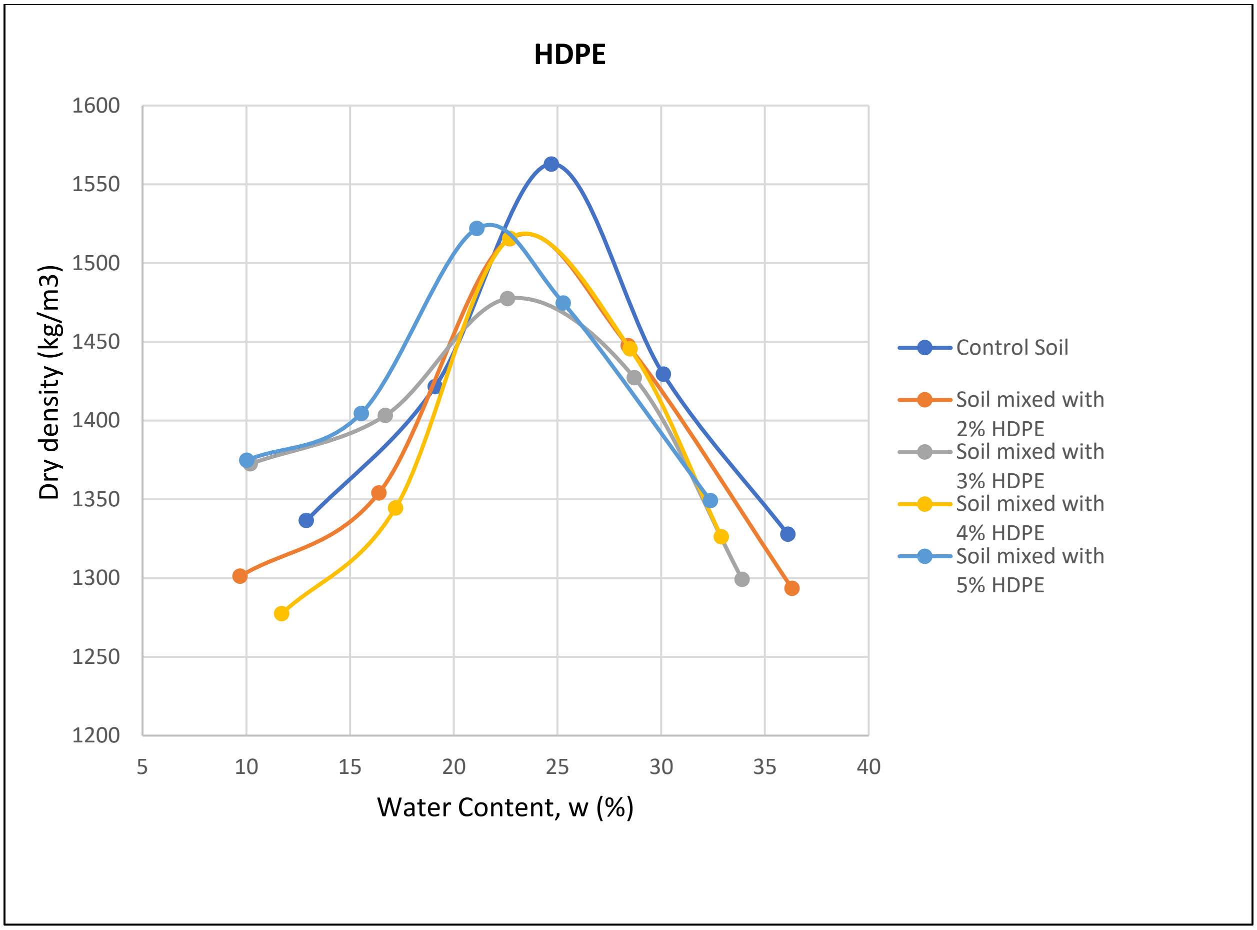


Figure 4-3 Compaction test results for soil mixed with and without HDPE content

The value of optimum moisture content varied from 21-25%, with maximum dry density values ranging from 1470-1570 kg/m^3. The maximum OMC was observed for control soil sample, which was 24.7%. When the soil was mixed with different percentages of HDPE, the OMC was gradually decreasing. Finally for 5% HDPE, the OMC was around 21%. Similar behavior was observed for MDD. The highest MDD was obtained for control soil sample. When the soil was mixed with 2% and 3% HDPE, the MDD were decreasing gradually. But after the further addition of HDPE, the MDD started to increase, though it was still lower than the maximum dry density of control soil sample.

These findings are similar to those of Kumar et al. (2018), Dhatrak and Konmare (2015a, b), Paramkusam (2013), and Nsaif (2013). At different plastic contents of 0%, 0.20%, 0.50%, 0.80%, and 1.00% of the dry weight of soil, Kumar et al. (2018) cut the PE into 1.0 cm, 2.0 cm, and 3.0 cm lengths. They discovered that the value of MDD declines with increasing plastic content and plastic length. They came to the conclusion that a plastic content of 1% of the soil's dry weight and a plastic strip inclusion length of 3.0 cm produced the greatest reduction.

Hassan et el. (2021) also observed the similar pattern for compaction test. They conducted test on natural and stabilized soils with four plastic contents (1%, 2%, 3%, 4%) of the soil weight. Their test results also revealed that the plastic pieces decrease maximum dry density (MDD) and optimum moisture content (OMC) of the stabilized soils, which are required for the construction of embankments of lightweight materials.

4.4.2 Compaction Test Results for Soil Mixed With PET:

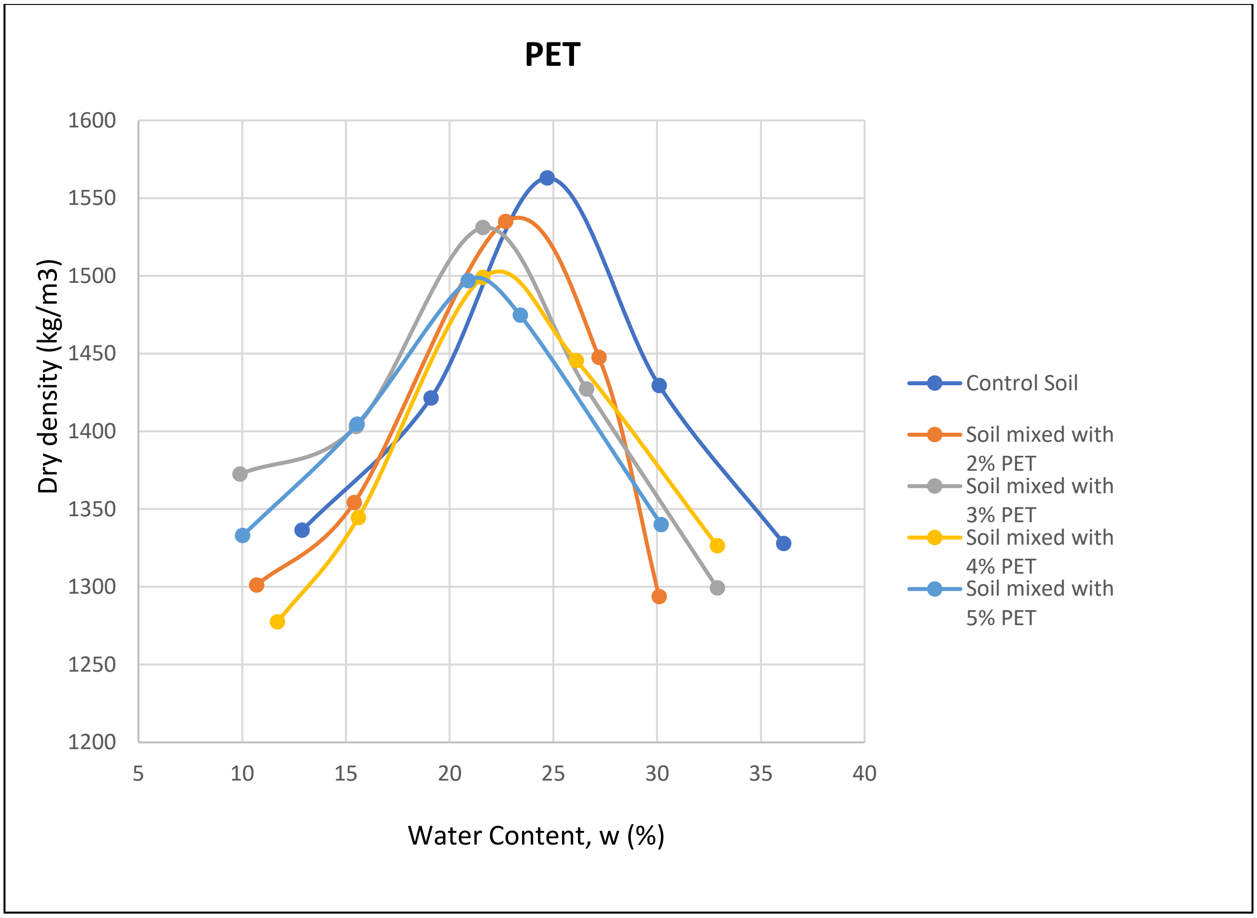


Figure 4-4 Compaction test results for soil mixed with and without PET content

As it can be seen in the compaction test results (figure 4-2), the OMCs and MDDs decrease for the stabilized soils compared to the control soils. The decrease in both of the properties can be noticed as the plastic content increases. The results revealed that by increasing the PET percent, OMC was decreased from 9% for 2% PET content to 18% for 5% PET content. Similarly, the MDD for both lengths at all plastic contents showed reduction in a value with the increase in the PET percent. The highest decrease was obtained at 5% PET content.

Nsaif (2013) looked into how plastic wastes made from plastic bottles that contained 0, 2, 4, 6, and 8% of the soil's dry weight in fibers affected the behavior of stabilized soil. According to Nsaif (2013), soils' OMC and MDD decrease when plastic concentration rises. The percentage of plastic content that decreased the most, by 8%, was observed.

4.4.3 Compaction Test Results for Soil Mixed With PP:

Soil mixed with PP at various plastic contents, shown in figure 4-3, revealed different behavior in terms of OMC and MDD. It was found that MDD decreased at 2% plastic content by 35 kg/m^3. However, after that, by increasing the PP content with 3%, 4% and 5% MDD was increased. For 3% PP content, the MDD was still less than control soil, but for 4% and 5% PP content, MDD went beyond control soil. The highest increase of MDD was observed for 5% PP content which was 30 kg/m^3 greater than control soil sample. Similar pattern was noticed for OMC.

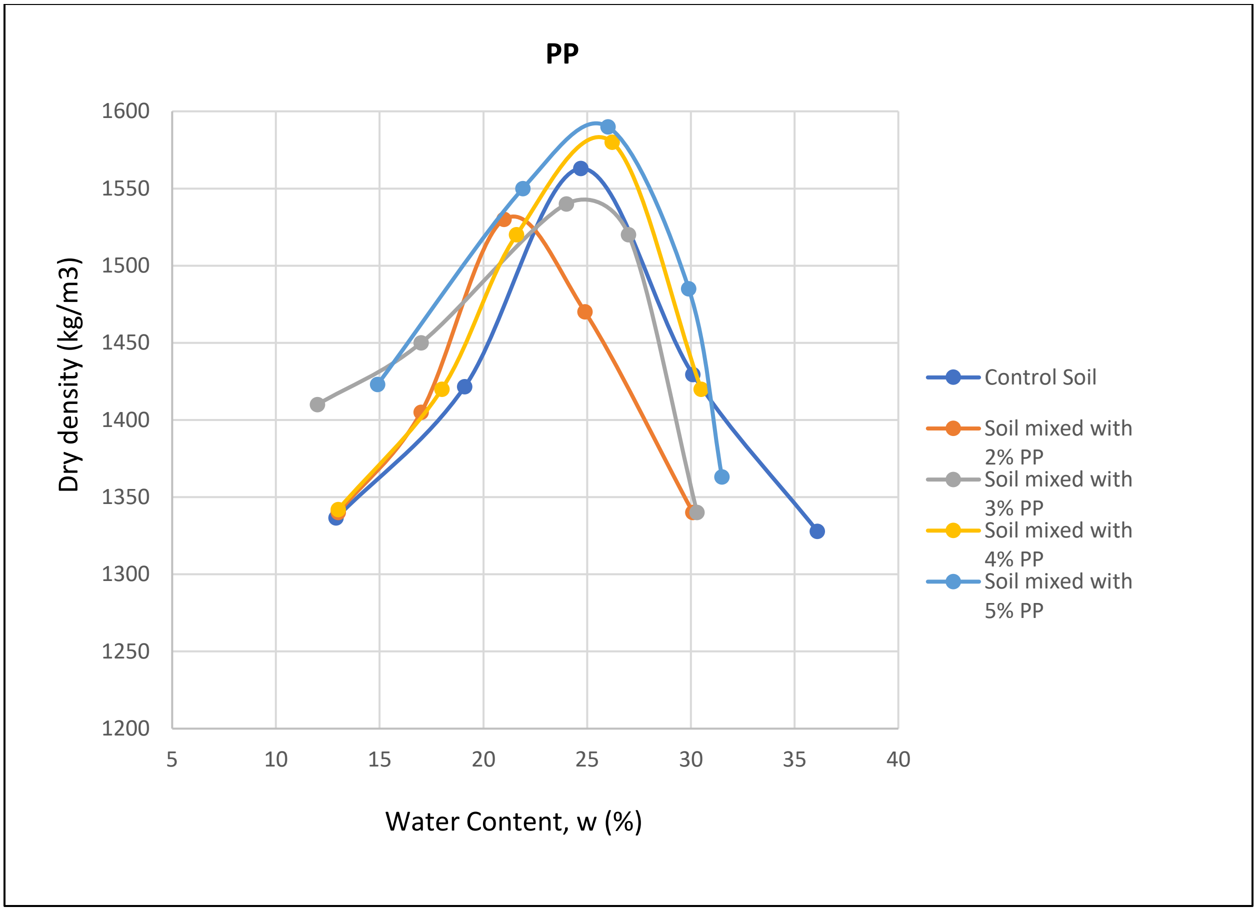
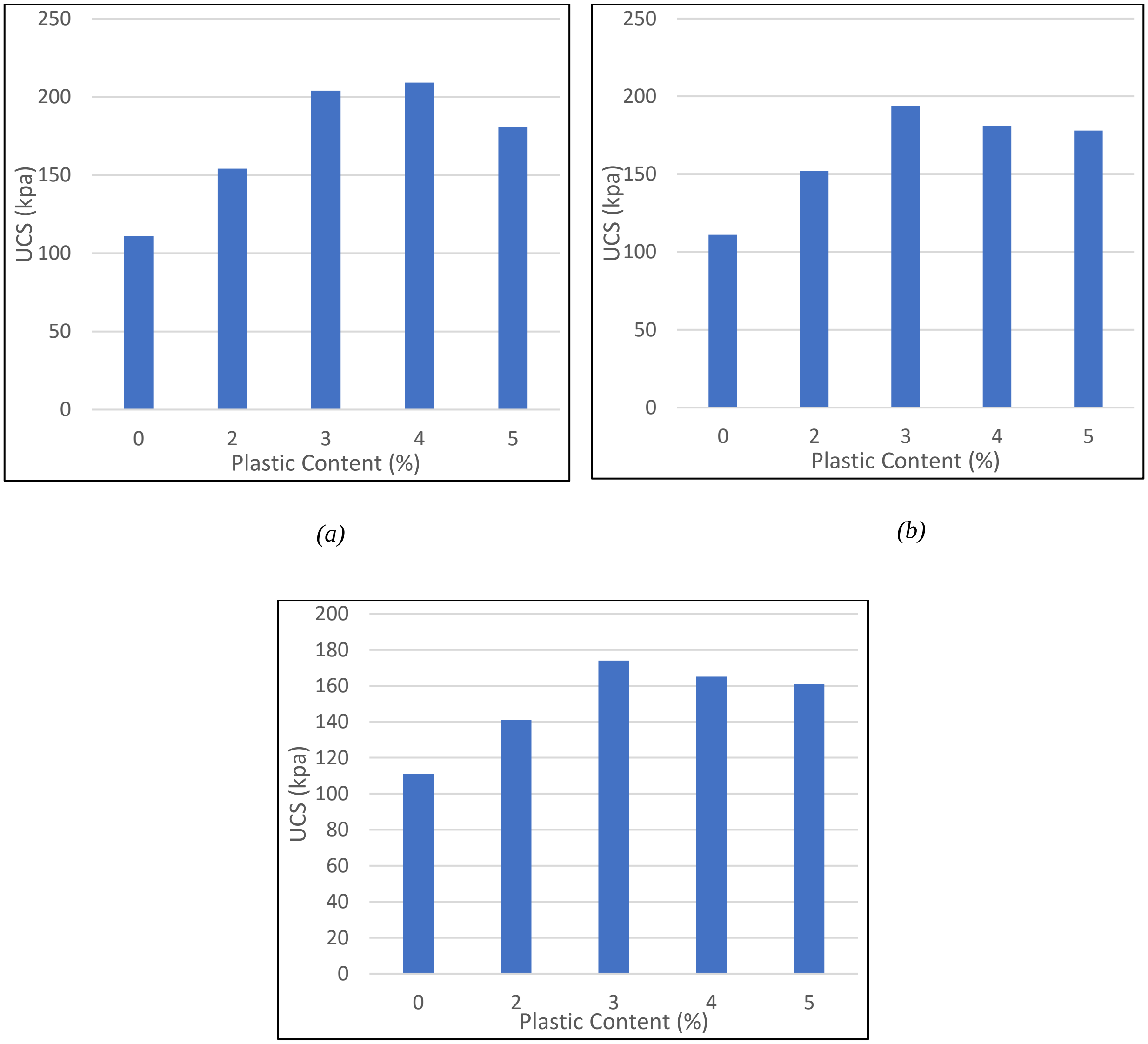


Figure 4-5 Compaction test results for soil mixed with and without PET content

Taha et al. (2020) investigated the effects of polypropylene (PP) of 12.0 mm in length on the mechanical behavior of clayey soils. They mixed the soil with 0%, 1.5%, 2.25%, and 3% of PP content by the soil weight. Their study concluded that the increase in plastic content results in an increase in MDD and a decrease in OMC with an optimum plastic content of 3%.

4.5 Unconfined Compressive Strength Test

Figure 4-6 shows the result of unconfined compressive strength test when soil is mixed with HDPE, PET and PP respectively. From the figures, it can be seen that the addition of HDPE, PET and PP plastic significantly increased the soil's strength compared to the control soil's strength which was 111kpa. However, this increase in UCS has an optimum point dependent on the ratio of plastic content; after that, the curve flattens and continues around the same strength with the increase in plastic content. For HDPE, the optimum plastic content is 4% and for PET and PP, the optimum plastic content is 3% based on the unconfined compressive strength test results.



(a)

(b)

(c)

Figure 4-6 UCS results for (a) HDPE, (b) PET, (c) PP

Table 4-1 summarizes the UCS test results for HDPE, PET and PP and reveals that comparing among these three types of plastic, HDPE has higher optimum strength than the other two, then comes PET and PP respectively. For soil stabilized with different percentages of HDPE content, the value of UCS increased from 111 kPa (control soil) to 209 kPa with an improvement of 88% strength, then the strength started to decrease. But for every percentage of HDPE content, the UCS value was much greater than the control soil. The lowest increase in UCS was at 5% HDPE content was 68%.

Similarly, for soil mixed with PET and PP, the optimum plastic content was 3%. The value of UCS increased from 111 kPa (control soil) to 194 kPa (PET) and 274 kPa (PP) with an improvement by 75% and 57% respectively. The lowest increase in UCS was at 5% plastic content for both PET and PP.

Table 4-1: UCS result for HDPE, PET, PP

Plastic Content (%)	UCS (kPa) for HDPE	UCS (kPa) for PET	UCS (kPa) for PP
0	111	111	111
2	143 (+29%)	152 (+37%)	141 (+27%)
3	204 (+84%)	194 (+75%)	174 (+57%)
4	209 (+88%)	181 (+63%)	165 (+49%)
5	181 (+68%)	178 (+61%)	161 (+45%)

Numerous studies (Puppala and Musenda 2000, Naeini and Sadjadi 2008, Oliveira et al. 2018, Sharma 2017, Sai and Srinivas 2019) have investigated the impact of different types of plastic on soil strength with similar findings. Their findings showed that the UCS of soil is greatly raised by the addition of shredded plastic.

According to Muntohar (2009), when fibers (like plastic) are used to stabilize soils, the applied load is transferred to the frictional interface between the soil particles and the fibers. The interfaces between soil and fibers grow as fiber content rises, which increases the friction between soil particles and fibers (Olgun 2013). This makes it challenging for soil particles surrounding the fibers to shift positions and thus improves the soil's cohesiveness between soil particles (Muntohar et al. 2013). The great tensile strength of fiber also contributes significantly to the formation of the soil to enhance its UCS and sustain greater load (Tang et al. 2007). Since HDPE is known to have greater tensile strength than PET and PP, soils stabilized with HDPE have a higher UCS than that of PET and PP-stabilized soils. AlAfandi (2015) combined cement and waste polyethylene (from water bottles) in the form of fibers to increase the tensile and compressive strength of clayey soils. The fiber lengths were 1.0 cm, 2.0 cm, and 3.0 cm, while the fiber concentrations were 0.4 %, 0.8 %, and 1.2 % of the soil's dry weight. He discovered that fiber-stabilized soil has a higher unconfined compressive strength (UCS) than tensile strength. The ideal fiber length and content were 2.0 cm and 1.2 %, respectively.

Table 6 shows that as the amount of plastic rises, the UCS increases up to a certain level before declining. According to Naeini and Sadjadi (2008), an increase in plastic content above a certain proportion causes soil particles to split and slip over one another, decreasing the soil's strength.

4.6 Free Swell Test

The main issue with expansive soil is that it changes in volume under various moisture conditions. The soil swells and its volume increase in a wide range from the original value as the moisture content rises. This feature occurs at the particle level when water molecules enter between layers by severing the connections that bind the chemical structure that resembles a sandwich. This issue is specifically resolved by changing the soil's chemical composition by the application of various chemicals.

As for this experiment, plastic strip was used to function as a physical agent and reduce the soil's capacity to swell. From visual inspection during experiments and the results from free-swell tests for the soil containing different percentage of plastic strips, there is no chemical bonding between the soil and the strip. Therefore, the reduction in swelling is a sole effect of the physical interaction between the soil and the plastic strip.

The free swell of control soil is observed to be 2%. To reduce swelling of the soil, 2%, 3%, 4% and 5% of three types of plastics (HDPE, PET and PP) are mixed with the soil sample and they are tested afterwards. For the swelling test, all the samples are prepared at their corresponding optimum moisture content. The one-dimensional free swell test is performed according to ASTM D4546-14 standards and is used to measure the free 1-D swell of cohesive soils. Table 4-2 gives a summarized version of the swelling test results for control soil sample and sample containing each plastic content. The values are shown in graphical form in figure 4-8.

Table 4-2 1D free swell test results for HDPE

Plastic Type	**Plastic Content (%)**	**Swelling (%)**	**Improvement**
Control	0	2	-
HDPE	2	1.10	45%
	3	0.77	62%
	4	0.60	70%
	5	0.54	73%
PET	2	1.14	43%
	3	0.91	55%
	4	0.70	65%
	5	0.59	71%
PP	2	1.24	38%
	3	0.93	54%
	4	0.83	59%
	5	0.67	67%

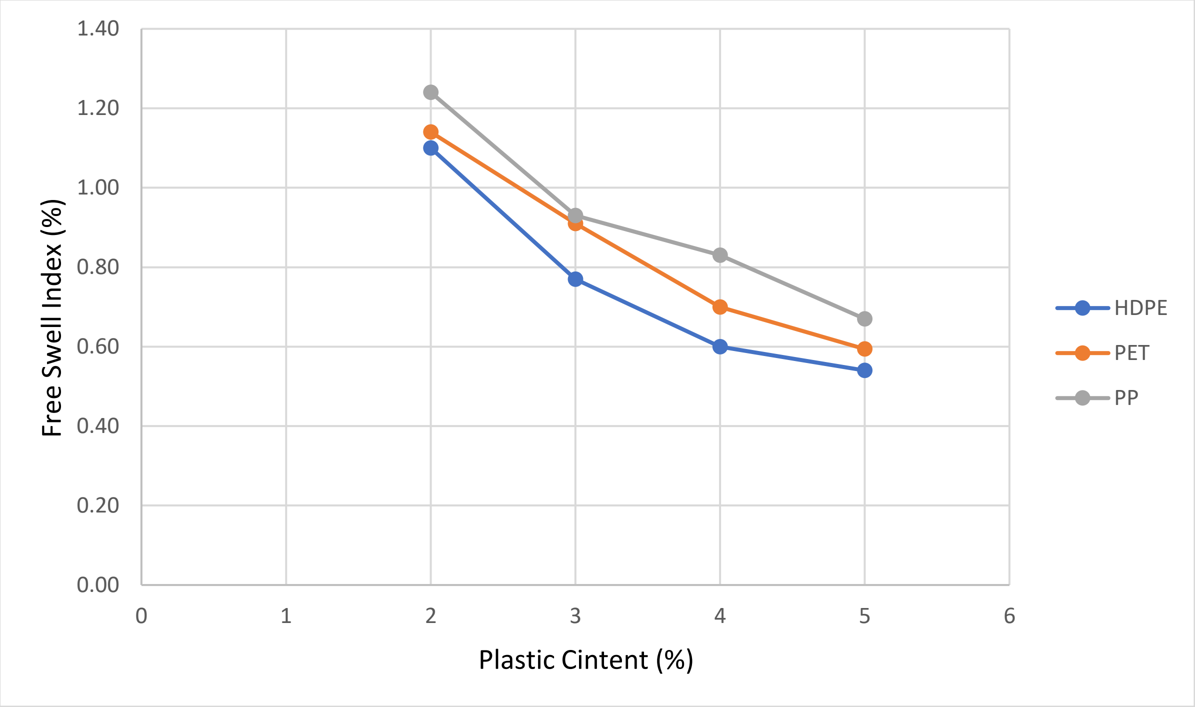


Figure 4-7 Free Swell Index versus Plastic Content

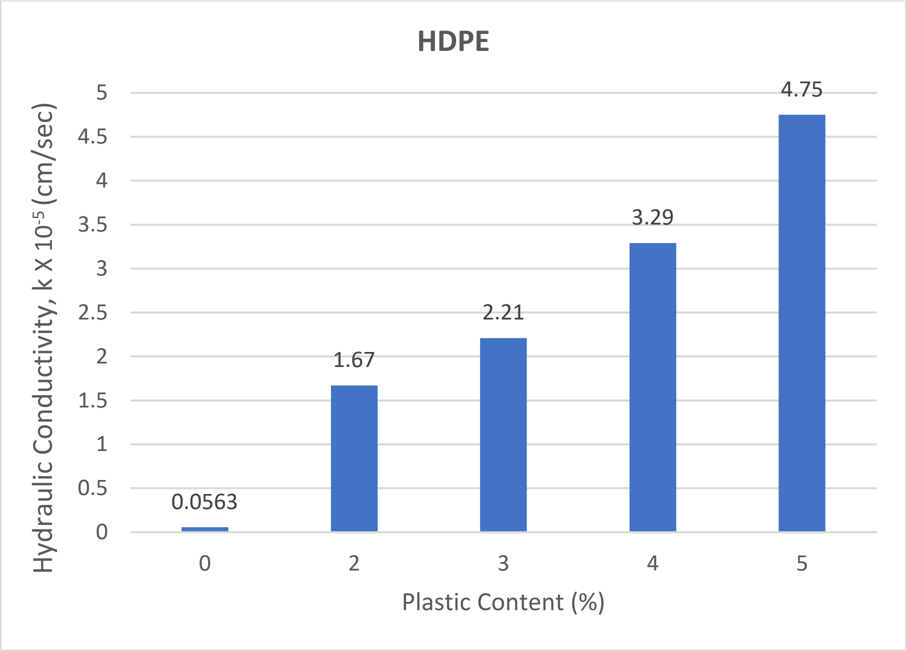
It is seen that with the increase of each plastic percentages, the free swell index is decreased, and the decrease is non-linear. By the addition of small percentage of plastic, the decrease in FSI is significant. The FSI of control soil was found 2% and it reduced to 0.54% by adding 5% of HDPE, 0.59% by adding 5% PET and 0.67% by adding 5% of PP. HDPE showed the best results among HDPE, PET and PP followed by PET and PP.

4.7 Permeability Test

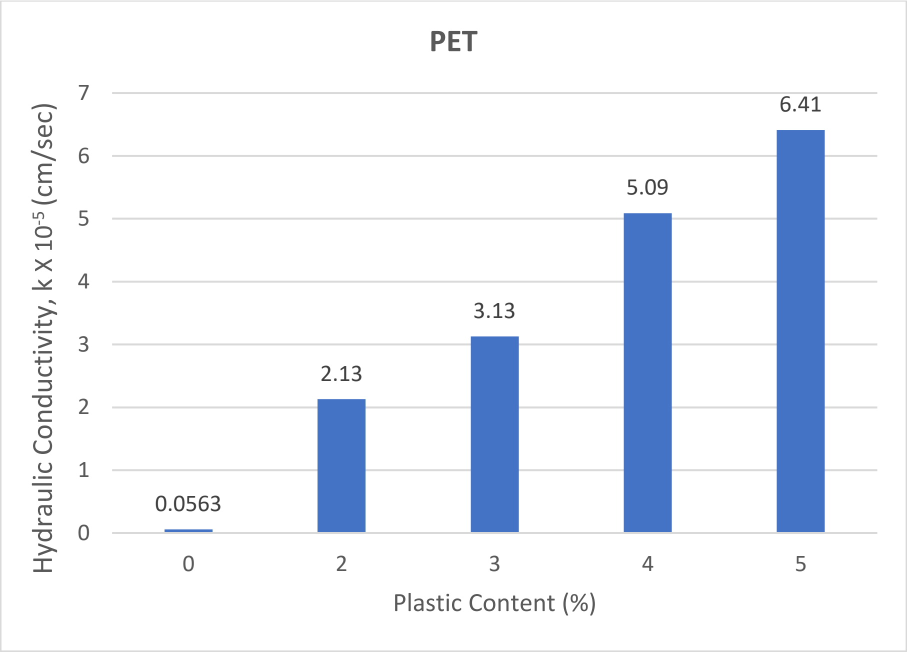
Water flow through a volume of soil is measured in terms of permeability. It is one of the most significant geotechnical characteristics. But figuring out this metric is perhaps the most challenging. It largely regulates the strength and deformation behavior of soils. It has a direct impact on the amount of water that will flow toward an excavation, the design of the subgrade on permeable foundations, and the design of the clay layer for a landfill liner. For the fine-grained soil used in this investigation, a falling head permeability test is conducted. Table 4-3 displays the results of the permeability test for soil containing HDPE, PET and PP.

Table 4-3 Permeability result

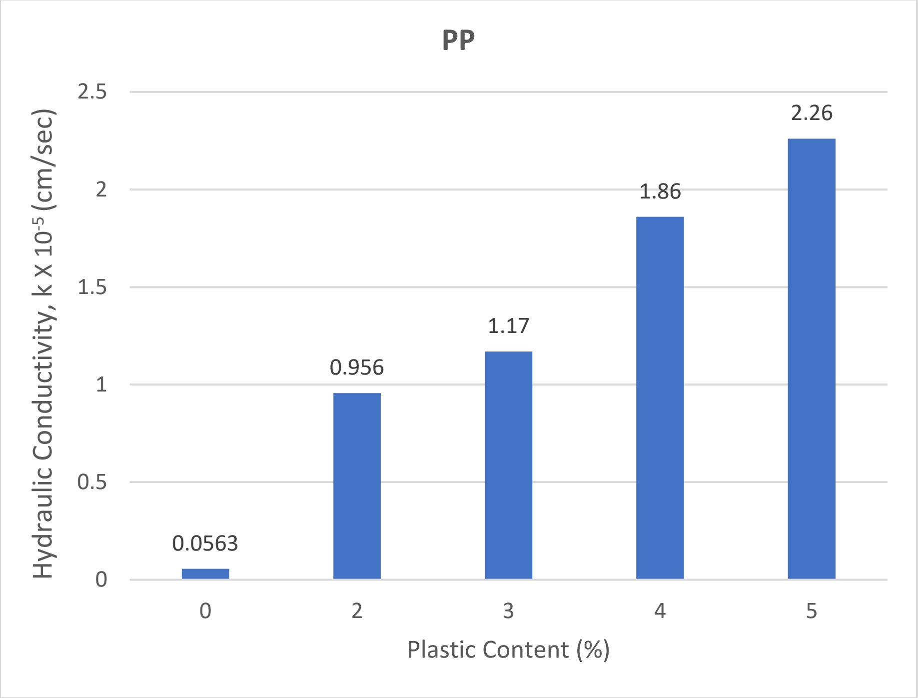
Plastic Type	**Plastic Content (%)**	**Hydraulic Conductivity, K (cm/sec)**
Control	0	$5.63 \text{ X } 10^{-7}$
HDPE	2	$1.67 \text{ X } 10^{-5}$
	3	$2.21 \text{ X } 10^{-5}$
	4	$3.29 \text{ X } 10^{-5}$
	5	$4.75 \text{ X } 10^{-5}$
PET	2	$2.13 \text{ X } 10^{-5}$
	3	$3.13 \text{ X } 10^{-5}$
	4	$5.09 \text{ X } 10^{-5}$
	5	$6.41 \text{ X } 10^{-5}$
PP	2	$9.56 \text{ X } 10^{-6}$
	3	$1.17 \text{ X } 10^{-5}$
	4	$1.86 \text{ X } 10^{-5}$
	5	$2.26 \text{ X } 10^{-5}$


HDPE
Hydraulic Conductivity, k X 10-5 (cm/sec)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0563
1.67
2.21
3.29
4.75
0
2
3
4
5
Plastic Content (%)

(a)


PET
Hydraulic Conductivity, k X 10-5 (cm/sec)
7
6
5
4
3
2
1
0
0.0563
2.13
3.13
5.09
6.41
0
2
3
4
5
Plastic Content (%)

(b)



(c)

Figure 4-8 Hydraulic Conductivity results for (a) HDPE; (b) PET and (c) PP

According to the table, the permeability value of the soil is 5.63 X 10^{-7} cm/sec which is extremely low in comparison to the subgrade layer of the pavement's capacity for drainage. Thus, for better drainage, it is necessary to increase the permeability of the subgrade soil. The soil's permeability increases to 1.67 X 10^{-5} cm/sec when only 2% HDPE was mixed with soil and when 5% HDPE are added to it, and it rises to 4.75 X 10^{-5} cm/sec. Again, by adding 2% of PET, the hydraulic conductivity of the soil was found to be 2.13 X 10^{-5} cm/sec and with 5% of PET, the hydraulic conductivity was 6.41 X 10^{-5} cm/sec. So, PET showed better result than HDPE n case of hydraulic conductivity of soil. On the other hand, when the soil was mixed with PP, the hydraulic conductivity was increased too, but not as much as HDPE or PET.

CHAPTER 5

SUMMARY AND CONCLUSION

The increase in the awareness of waste management and environment-related issues has led to substantial progress in the utilization of waste/by-products like plastics. This paper has presented various aspects on plastics and its usage in soil for improving subgrade performance, which could be summarized and concluded as:

1. Three different recycled plastics, including polyethylene terephthalate (PET), polypropylene (PP), and high density polyethylene (HDPE), were collected from the Republic Services Material Recovery Facility (MRF). In most cases, the MRF gathers waste from adjacent cities' curbside bins and thoroughly sorts the waste plastics into the seven categories.
2. Processing was done independently on the recycled plastic. Sorting, cleaning, drying, and shredding the materials for later use were all part of this process.
3. Soil was collected from FM-156 Haslet Site through boring. Different depths of soil were collected and mixed to ensure the uniformity.
4. Three types of plastics (HDPE, PET and PP) with four different percentages (2%, 3%, 4% and 5%) have been mixed with soil to understand the benefit of plastics for improving pavement subgrade.
5. The physical properties of soil such as particle size gradation, Atterberg limit test, maximum dry density and optimum moisture content, were determined and the effect of plastic on strength, permeability and hydraulic conductivity were evaluated.

6. The addition of shredded plastics to soil showed decrease in optimum moisture content and maximum dry density for HDPE and PET. But for PP, though the OMC and dry density decreased for 2% and 3% of plastic content, and for 4% and 5% of plastic content, the result showed decrease in OMC and MDD. The decrease in OMC and MDD is required for the constructions of embankment of lightweight materials.
7. The results showed that plastic played an important role in improving the strength characteristics. Soil stabilization with plastic content showed that for UCS, the increase in plastic content was resulting in the increase in UCS ascendingly, but to an optimum point. After a peak value of UCS, the increase in plastic content resulted in the decrease of UCS value. Therefore, the optimum plastic content shall be sought for stabilization with the highest value of UCS.
8. HDPE, PP and PET can be effectively used to improve the physical and strength properties of soil materials as a foundation for engineering projects.
9. Clayey soil selected for this study had poor drainage condition. In order to improve the drainage, its permeability needs to be increased. This experimental study was aimed to analyze the effect of admixing HDPE, PET, and PP type of plastics on the permeability of clayey soil for improving drainage properties.
10. Based on extensive experimental study carried out, it was noticed that the hydraulic conductivity of high plastic clay is increased on admixing plastics with soil, which improves the drainage of pavement subgrade layer. So, shredded HDPE, PET and PP can be used to improve permeability and thus improving drainage of subgrade layer.
11. Addition of shredded plastics significantly improved swelling property of expansive soil. Based on the test results, it can be stated that, as the percentages of plastic increases, the

swelling decreases but non- linearly. Soil mixed with 5% HDPE content showed the most swelling improvement of 73%.

12. Plastic stabilization is cost effective, and it can be used successfully for a sustainable road construction if compared with chemically stabilized soils. The stabilization with chemical agents is accompanied by carbon dioxide emission, while plastic stabilization is not; this is one of the advantages of plastic stabilization over chemical stabilization.

CHAPTER 6

RECOMMENDATIONS FOR FUTURE STUDIES

1. The current study was performed using only shredded plastics as the stabilizing agent. Other alternative stabilizers such as fly ash or lime mixed with plastics as alternative stabilizer, can be undertaken in the future.
2. Current study was conducted with only one specific shredding size (3mm * 1mm) of plastic. Other plastic sizes can be used in future investigations as alternatives to check if length of plastic has an effect on soil properties or not.
3. In the present study, only three types of plastics were used, which were HDPE, PET, and PP. Other plastic materials such as LDPE, PVC, PS, etc. can be used for future study.
4. HDPE, PET and PP were mixed separately for this experimental program. As sorting of different plastics were time consuming, combination of different plastics can be utilized for a future study.
5. Fat clay (CH) type of soil from the Haslet, Texas only was used in the current study. Other type of soil or soil from other parts of the state could also be used in future investigations.
6. Future studies can do a thorough life cycle study and cost analysis to determine whether using plastic in pavement is sustainable and cost-effective.
7. Other percentages of plastics rather than 2%, 3%, 4% and 5% should be used for further study to get the optimum plastic content for pavement subgrade.
8. Other test like Modulus of Resilient can be performed in future study to check if it shows the similar trend with plastic content as UCS test showed.

9. Present study was performed with the soil that is very less expansive (meaning low swelling). Further study should be performed where soil sample is very expansive so that the behavior of plastic with expansive soil can be determined.
10. Microplastic analysis should be performed to check the extent of harmfulness to the environment or living organisms by the chemical composition of plastic.

CHAPTER 7

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