SOIL IMPROVEMENT THROUGH UTILIZATION OF SHREDDED WASTE PLASTIC BOTTLES

BY

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NUST- 2018-MS-Geotech-00000275368

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geotechnical Engineering

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

H-12 Sector, Islamabad, Pakistan

2022

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Thesis titled

SOIL IMPROVEMENT THROUGH UTILIZATION OF SHREDDED WASTE PLASTIC BOTTLES

Submitted by

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has been accepted towards the partial fulfillment

of

the requirements

for

Master of Science in Geotechnical Engineering

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MY PARENTS, WITHOUT THEM NONE OF THIS WOULD'VE BEEN POSSIBLE

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ACKNOWLEDGEMENT

I would first like thank our prestigious institute National University of Science and Technology for giving us the opportunity to partake in this research which has been great source of learning. Ie would especially like to thank Dr. Badee Alshameri my supervisor and mentor, who gave me a vision and guided towards it. Without Dr. Badee Alshameri's help this research would not have been possible. I would also like to thank Dr. Zain Maqsood, Naqeeb Nawaz, Muhammad Jawad Hassan, and Geotechnical Engineering Lab staff for their cooperation, help and guidance during this research.

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LIST OF SYMBOLS / ABBREVIATIONS

MDD	Maximum dry density
OMC	Optimum moisture content
CBR	California bearing ratio.
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
G_s	Specific gravity
D_{50}	Particle size with 50% finer material.
SDG `	Sustainable Development Goal

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ABSTRACT

Management of waste plastic bottles is one of the major environmental challenges in the world. Plastic bottles are composed Polyethylene Terephthalate (PET) which is non-biodegradable and causes environment problems. Various studies have been carried out on use of waste plastic bottles in the form of custom-made strips as stabilizer however, no significant research has been carried out on use of waste plastic bottles shreds already available in the market. These shreds do not require any special technology or arrangement to produce in bulk quantity for commercial use as soil stabilizer. In this study, locally available plastic shreds prepared from waste plastic bottles were used to stabilize low plastic silty clay. Standard proctor test and direct shear tests were carried on soil stabilized with 3 different size plastic shreds (2 mm, 6 mm and 10 mm) and in four different concentrations (1%, 3%, 5% and 10%). The result showed that the maximum dry density (MDD) decreased while optimum moisture content (OMC) increased with increase in plastic content and shred size. An increase of 10.2% in angle of internal friction of soil was observed with inclusion of 2 mm shred in 1% concentration then no significant increase beyond this percentage. There was less significant increase in cohesion for 2 mm shred in 1% concentration while decrease with increase in shreds concentration and size. It was concluded that mixing waste plastic shreds with soil in 1% concentration improves the shear strength of the silty clay soil along with reduction in non-biodegradable plastic waste.

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Chapter 1

Background

1.1 Introduction

Performance of a pavement through its life depends greatly on quality of subgrade soil. If subgrade is made up of problematic soil it will reduce the stability of pavement and can cause severe damage to the pavement structure. Clayey subgrade soils are considered problematic due to their change in volume in response to moisture changes. These soils lose their strength when their moisture content increase and do not provide the required strength to support the traffic load. In order to avoid these damages and meet the strength requirements, soil treatment and stabilization is required (Ranjitha., 2020). Two kinds of soil stabilization methods are generally used: Mechanical stabilization and Chemical or additive stabilization. Mechanical stabilization is a process in which properties of soil are improved through change of gradation and application of mechanical energy (Afrin, 2017). Chemical stabilization is improvement in properties of soil by addition of an additive or chemical such as lime, cement, bitumen and fly ash etc (Kalyana Chakravarthy et al., 2020)(V. Mallikarjuna1, 2016). Chemical stabilization improves the engineering properties of soil and increases its strength, durability and stiffness (Firoozi et al., 2017; Maaitah, 2012).

Management of plastic waste bottles has become a big challenge for countries around the globe. Plastic debris accumulating in oceans, poles and landfills are creating serious environmental problems. Available research indicates that million metric ton plastic waste end up in oceans and so far about 710 million metric ton plastic waste has accumulated in aquatic and terrestrial ecosystems (Borelle et al., 2020) . Plastic bottles are major source of plastic pollution and total consumption of plastic bottles will cross half a trillion by 2021 which will outrun the recycling efforts and create environmental problems (Laville & Taylor, 2021). Plastic Shreds used in this study were prepared from waste plastic bottles. The plastic bottles are made up of Polyethylene Terephthalate (PET) which is a byproduct of petroleum and have very good wearing resistance and tensile strength which makes it good for soil stabilization (Peddaiah et al., 2018). However, PET is nonbiodegradable therefore creates environmental pollution and using PET in soil improvement will result in sustainable management of nonbiodegradable plastic waste.

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Research has established that waste plastic can be used as reinforcement for stabilization of problematic soils. It not only improves the engineering properties of soil but is also a sustainable economical solution for disposal of waste plastic bottles (Shah et al., 2022). Waste plastic is one of the cheapest and readily available waste material that can be utilized for soil stabilization (Babu & Chouksey, 2011). Most of the plastic waste is composed of Polyethylene (PE) used in non-woven plastic bags and pipes, Polypropylene (PP) used in woven plastic bags and Polyethylene terephthalate (PET) in plastic bottles. All these kinds of plastics have been found useful in soil stabilization and act as cheap and environmental friendly alternative for traditional stabilizing agents such as lime and cement (Hassan et al., 2021; Ilieş et al., 2017). Consoli et al. (2002) conducted a study on engineering behavior of sand reinforced with plastic waste and found that PE fibers improve the peak shear strength of cemented and uncemented soil. In another research, clayey soil was reinforced with waste plastic strips and results showed meaningful increase in CBR and UCS strength of the soil (Iravanian & Ahmed, 2021). Stabilization of expansive clay with waste plastic bottles strips showed reduction in free swell and increase in UCS and CBR strength of soil (Kassa et al., 2020). Results of mixing waste PE strips with clayey soil showed significant increase in CBR and Shear strength of soil (Mir, 2020). Peddaiah, Burman and Sreedeep, (2018) conducted a study to investigate the effect of plastic bottles strip on silty sand. Series of proctor, direct shear and CBR tests were conducted in this research and the results showed significant increment in CBR and shear strength of soil. Unconsolidated undrained triaxial tests were performed to study the mechanical behavior of silty soil reinforced with PET fibers. The results indicated increase in shear strength of soil with increase in the quantity of PET fibers (Botero et al., 2015). Plate load test and triaxial tests were performed on PET reinforced sand and the results showed considerable increase in bearing capacity of soil (Ferreira et al., 2021). Non-metallic waste bottles were used in experimental study of regur soil stabilization. Results of the study found significant increase in CBR and UCS strength (Bharani et al., 2022). The effect of shredded plastic on the shear strength of desert sand was studied and result showed that the internal friction angle of sand increased by 7 degrees with plastic inclusion (Kazmi, 2020).

Most of the literature is based on use of waste plastic bottles in the form of strips as stabilizer however, no significant research has been carried out for the use of waste plastic bottles in the form of shreds for soil improvement of low plastic fine soil. The shreds used

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in previous research are custom made however, in this research plastic shreds already available in market are used which do not require any special arrangement or technology to produce it in bulk quantities for commercial use in construction industry as soil stabilizer. In this research three different sizes (2 mm, 6 mm, 10 mm) of waste plastic bottles shreds available in market were mixed with silty clay soil by weight in 5 different percentages (1%, 3%, 5%, 10%). Proctor and direct shear test were conducted on the samples to find the optimum percentage and size of shreds for improvement in shear strength of low plastic silty clay.

1.2 Problem Statement

Subgrade strength is one of the most important factor that affect the performance of a road (Muhammad Hussain, Imran Hafeez, M.A.Kamal, Rana Faisal Tufail, Muhammad Zahid, 2013) In Pakistan, majority of road failures are associated to poor subgrade made up of unsuitable material such as clay. Roads constructed on clayey soils without any soil improvement/ stabilization start showing signs of distress and rutting very early in their life (I. Ahmed et al., 2013; A. H. Khan, 2016). Mardan Western By Pass road is to be constructed on clay soil subgrade with high water table due to which it was suggested to improve the soil prior construction (B. Khan et al., 2012). Low quality subgrade material is one of the causes of failure of Jamshoro Sehwan road in Sindh province (Mushtaque Ahmed Pathan, Ms. Maryam Maira, 2020). Gujranwala–Lahore section of National Highway-5 (N-5) was constructed on clayey subgrade soil without any improvement/ stabilization. Resultantly, ruts begun to form in this section of Highway due to low strength of subgrade. This section of highway requires frequent repairs which result in huge cost to the concerned department (Liaqat et al., 2019). In Potohar region of Pakistan clay is the most abundant material and there is scarcity of good quality subgrade material. Generally, soils from excavation are used without any improvement/ stabilization as subgrade due to high cost of traditional stabilization materials such as sand, lime, and cement. (Memon et al., 2019). On the other hand, plastic bottles are a cheap waste material which is readily available in abundance and can be used as reinforcement in soil for improving its engineering properties. Use of plastic bottles as reinforcement is a cheap sustainable alternative to the traditional methods of soil improvement such as lime and cement treatment.

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1.3 Aim / Objectives

Aim of this study is to find a sustainable solution for disposal of waste plastic bottles by using plastic bottle shreds as a reinforcement in low plastic silty clay soil to improve its engineering properties with the following objectives:

- To study the effect of different shred sizes and content on MDD and OMC of the soil
- To study the effect of different shred sizes and content on shear strength of soil
- Determination of optimum size and content of plastic shred to be mix with clayey soil for maximum increase in shear strength of soil

1.4 Sustainable Development Goals

In 2015, 17 goals for sustainable development were set for 2030 by the all the members of united nations. These goals are called SDGs (Sustainable Development Goals) and the aim of these goals was to reduce poverty, improve health and education, economic growth, peace, and preservation of life on earth. Following are the 17 SDGs defined by the United Nations: No Poverty, Zero Hunger, Good Health, Quality Education, Gender Equality, Clean Water and Sanitation, Affordable and Clean Energy, Decent Work and Economic Growth, Industry, Innovation, and Infrastructure, Required Inequalities, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life Below water

This study will help in achieving SDG 14 and 15 as plastic is major source of pollutant for oceans and land. According to United Nation's 75% of the plastic waste end up floating in oceans or clogging the landfills. Pakistan alone produces 3.9 million Tons of plastic waste and most of it end up in oceans or water bodies and endanger the aquatic life in oceans. Sustainable use of plastic is essential for preservation of life on land and below the water.

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1.5 Scope of research

- Collection of disturbed samples from Naval Anchorage ib Islamabad.
- USCS classification of soil samples
- Index Properties Test of Soil
- Collection of waste Plastic bottles shreds
- Preparing samples for testing by mixing different size and content of plastic bottle shred with soil
- Perform Standard Proctor Test to find MDD and OMC
- Perform Direct Shear test on samples prepared at OMC and MDD.

1.6 Expected Outcomes:

Following are the expected outcomes of this research:

- Determination of effect of plastic shreds reinforcement on MDD and OMC
- Determination of optimum content of plastic shred to be mix with low plastic silty clay for maximum Shear Strength.
- Determination of optimum size of plastic shred to be mix with clayey soil for maximum shear strength.

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Chapter 2

Literature Review

2.1 Introduction

Subgrade is the bottom most layer of pavement structure that acts as foundation of road and distributes the stresses produced by traffic loads into the surrounding soil. Most of the failures in flexible pavements are attributed to weak subgrade material.(Adlinge & Gupta, 2009). Clay is considered problematic soil in civil engineering due to large volumetric changes with increase in moisture content. (Firoozi et al., 2017; Khalid et al., 2014; Paige-Green, 2008) When roads are constructed on such weak subgrade soils stability and settlement considerations are essential.(Edinçliler & Cagatay, 2013). Such problematic soils are treated with suitable material to improve their engineering properties and make them suitable for pavement and other structures (Andavan & Maneesh Kumar, 2020). The process for improvement of engineering properties of soils through chemical or mechanical alteration is called soil stabilization (Aggarwal & Sharma, 2011; ASTM, 1992; Prof et al., 2013). The concept of soil stabilization is approximately 5000 years old. Roads in ancient Egypt were stabilized earth roads. Greeks and Romans used lime as stabilizer in construction of their roads (McDowell C 1959 Quart. Color. Sch. Mines, 1959).

2.2 Soil Stabilization Techniques

Soil stabilization techniques can be broadly classified into two groups Mechanical Stabilization and Chemical Admixture Stabilization (Andavan & Maneesh Kumar, 2020; Mishra et al., 2019).

Mechanical stabilization is one of the oldest methods for soil stabilization, which is achieved by compaction and interlinking of soil particles. The gradation of soil is altered by mixing it with a soil of different gradation to achieve a well graded soil mixture which can be compacted into a dense mass.(Afrin, 2017). The three essentials for obtaining a properly stabilized soil mixture are: proper gradation, satisfactory binding soil, and proper control on mixing of soil. Mechanical stabilization increases the strength and decreases

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the voids rate by adjustment of composition of soil (Onyelowe & Okafor, 2012). Mechanical stabilization include soil replacement surcharge loading, geotextiles, fibers, polymers, glass and plastic waste products etc. (Arrieta Baldovino et al., 2020; Mishra et al., 2019).

Chemical stabilization is modification of soil properties by addition of chemical additives such as lime, cement, bitumen, and fly ash etc. It is most common method for stabilization of soils and is considered more effective and economical than mechanical methods (Mosa et al., 2017; Olaniyan et al., 2011). Lime has proved one of the most effective methods for stabilization of clays. Lime not only reduces the plasticity and volumetric changes in clays but also increases its strength and stiffness by cementation (Consoli et al., 2011; Dash & Hussain, 2012). Another common soil stabilization method is mixing soil with cement and mixture is called soil-cement. This method has been in practice for almost 100 years (McDowell C 1959 Quart. Color. Sch. Mines, 1959). Mixing cement with soil improves the engineering properties of soil such as strength, volumetric stability, durability, and stiffness (Estabragh et al., 2013; Madhu et al., 2018). Fly ash is a byproduct obtained from burning of coal which has been used in stabilization of soils research has shown that fly ash improves the properties of soils by reducing liquid limit, plastic limit and increasing the CBR and UCS (Firoozi et al., 2017).

2.3 Use of Waste Plastic for Soil Stabilization

Use of waste materials are one of the most economical and effective method for improvement in engineering properties of soil (Vijayakumar et al., 2019). Waste plastic is one of the cheapest and readily available waste material that can be utilized for subgrade improvement and soil stabilization (Fauzi et al., 2016). Most of the plastic waste is composed of Polyethylene (PE) used in non-woven plastic bags and pipes, Polypropylene (PP) is used in woven plastic bags and Polyethylene terephthalate (PET) in plastic bottles. All these kinds of plastics have been found useful in soil stabilization and act as cheap and environmental alternative of traditional stabilizing agents such as lime and cement (Hassan et al., 2021; Riaz et al., 2014; Zukri et al., 2017). (Kalyana Chakravarthy et al., 2020)z mixed clayey soil with different percentages of raw plastic bottle strips and conducted Standard Proctor and Unconfined Compression tests. The results obtained showed significant increase in maximum dry density and shear strength of soil. (Iravanian

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& Ahmed, 2021) studied the effect of reinforcing clayey soil with waste plastic strips. Their results showed meaningful increase in CBR and UCS strength. (Kazmi, 2020a) used shredded plastic waste as an additive to improve the shear strength of desert sand, results showed 7 degree increase in internal angle of friction with addition of 0.4% plastic shreds. (Necmi.Yarbaşı & Ekrem, 2020) performed UCS on clayey soil reinforced with waste plastic bottle fibers. The samples were exposed to freeze and thaw cycles. It was observed that strength and resistance to freeze thaw of soil had increased with addition of plastic bottle fibers. (Dinis Gardete & Luzia, 2020) studied the effect of mixing two types of plastic waster shredded packaged labels and grounded bottles on CBR strength of clayey and silty sand. (Mir, 2020) studied the effect of mixing waste PE strips with clayey soil and found significant increase in CBR and Shear strength of soil. (Meenakshi & Mohini, 2019) studied the effect of reinforcing sand with PET shreds of different aspect ratio and found that addition of PET Shreds increase the CBR and shear strength of soil while it decreased the optimum moisture content and maximum dry density.(D Gardete et al., 2019) stabilized clayey sand with waste plastic label shreds and tyre shreds. CBR test result showed 20% increase with addition of 1% plastic shreds whereas decrease in CBR value was observed with inclusion of waste tyre shreds.(Farah & Nalbantoglu, 2019) (Peddaiah et al., 2018) investigated the effect of plastic bottles strip on silty sand. Series of proctor, direct shear and CBR test were conducted in this research and the results showed significant increment in dry unit weight, CBR and shear strength. (Zukri et al., 2017) investigated the utilization of PET and PP waste fibers for stabilization of pekan clay. The investigation concluded that PET and PP fibers act as reinforcement and stabilize the clayey soil.(Fauzi et al., 2016) evaluated the improvement in engineering properties of clay soil by using high density polyethylene (HDPE) waste cuttings and crushed waste glass. Results showed that engineering properties and CBR strength improved with increase in HDPE and glass content. (Botero et al., 2015) studied the mechanical behavior by conducting unconsolidated undrained triaxial test on silty soil reinforced with PET fibers. The results indicated increase in shear strength of soil with increase in the quantity of PET fibers. Table 1 & 2 show that with addition of plastic waste UCS and CBR values are improved significantly.

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Table 1: Improvement in CBR by addition of Plastic Waste

Natural Soil type	**Type of Waste**	**Shape & Size for maximum value**	**Plastic Content % for maximum value**	**CBR % Value of Natural Soil**	**Maximum CBR % Value after stabilization**	**Increment %**	**Reference**
Clay	Plastic Bags	Strips 15x40 mm	0.4%	7.05%	9%	28%	(Iravanian & Ahmed, 2021)
Clay	PE Water Bottles and PP Woven Bags	Strips of PE Bottles 2cm x 2.5-3mm	4%	4%	7.2%	80%	(Hassan et al., 2021)
Clay	LDPE Waste Plastic	Strips of Aspect Ratio 3	1%	4.87%	10.71%	120%	(Mir, 2020)
Silty Sand	PET Waste Plastic Bottles	Strips of 15x25mm	0.4%	3.3%	16.5%	400%	(Peddaiah et al., 2018)
Sand	Waste Plastic Bottles	Chips of 12x4mm	0.75%	9%	10%	11%	(Farah & Nalbantoglu, 2019)

Table 2 Improvement in UCS by addition of Plastic waste

Natural Soil type	**Type of Waste**	**Shape & Size for maximum value**	**Plastic Content % for maximum value**	**UCS Value of Natural Soil**	**Maximum UCS Value after stabilization**	**Increment %**	**Reference**
Clay	Plastic Bags	Strips 15x40mm	0.4%	44 kPa	108 kPa	145%	(Iravanian & Ahmed, 2021)
Clay	PE Water Bottles and PP Woven Bags	Strips of PE Bottles 2cm x 2.5-3mm	4%	148 kPa	276 kPa	86 %	(Hassan et al., 2021)
Clay	LDPE Waste Plastic	Strips of Aspect Ratio 3	1%	60 kPa	88 kPa	47 %	(Mir, 2020)
Silty Sand	PET Waste Plastic Bottles	Strips of 5mm x 3mm	1%	12.52 kg/cm^2	14.15 kg/cm^2	13 %	(Singh & Mittal, 2019)
Red soil and sand	PET Waste Plastic Bottles	Strips of 12mm x 4mm	1%	110 kPa	160 kPa	45 %	(Babu & Chouksey, 2011)

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2.4 Use of Plastic for Soil Stabilization in Pakistan:

Very little research has been conducted in Pakistan on the use of plastic for soil stabilization, (S. A. Khan, 2005) used plastic cuttings obtained from shopping bags for soil stabilization in his study. Results showed significant improvement in unsoaked CBR values however, improvement in soaked CBR values was very less compared to unsoaked CBR.(A. H. Khan, 2016) conducted a research to evaluate suitable technique for stabilization of commonly available subgrade soils of Pakistan based on cost effectiveness and ease in construction. This study showed polythene and polyester wastes have the potential to economize the stabilization cost with cement and bitumen.(Ali et al., 2019) carried out research to find the effect of silty sand with woven waste bag layers. In this research modified proctor and CBR test were carried out on sand reinforced with woven bags layers. Results showed that plastic bags layers can improve the strength of soil.(Memon et al., 2019) conducted a research study to assess the potential use of PET strips obtained from waste plastic bottles as reinforcement in clay soils. Results showed that with addition of 1.5% PET strips CBR value of soil was doubled.

2.5 Problem in Potohar region

Disposal of plastic waste is one of the major environmental problems of world. With the increase in population use of plastic is also increasing. One of the major parts of the plastic waste is PET bottle used for storing of beverages and water. These bottles are normally thrown in garbage cans and bins after use and unfortunately very low amount of these bottles get recycled and it is estimated that 1.6 million ton of plastic bottles per year are not recycled. These bottles end up in oceans and land fill causing environmental problems, so far about 710 million metric ton plastic waste has accumulated in aquatic and terrestrial ecosystems (Borelle et al., 2020). These plastic bottles are nonbiodegradable and last for centuries before decomposing. Properties such as durability and resistance to water make plastic environmental hazard however, these properties of plastic make it good reinforcement material in geotechnical engineering. Research has established that wasted plastic bottles can be used as reinforcement for stabilization of problematic soils. It not only improves the engineering properties of soil but is also a sustainable economical solution for disposal of waste plastic bottles (Sagar Mali, Sachin Kadam, Sagar Mane, Krushna Panchal, Swati Kale, 2019).

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Subgrade is one the most important structure of road. Roads constructed on weak subgrade soil start detoriating very early in their life as a result potholes and rutting began to develop which result in very high maintenance cost. Figure 1 & 2 show deterioration of newly built road in Islamabad due to poor subgrade soil.

Figure 1 Settlement of road due to poor subgrade

Figure 2 Rutting of road due to poor subgrade

In developing countries such as Pakistan subgrade improvement / stabilization is generally ignored in projects due to large cost associated with traditional stabilization methods such as lime and cement. On the other hand, very little amount of plastic waste

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is recycled in developing and due to no waste management system, this plastic waste ends up in rivers and oceans causing serious environmental problems. On average a person in Pakistan's Urban areas generate 0.1021 kg of plastic waste per day (S. Ahmed & Mahmood, 2020). Pakistan's population is 224.77 million and generates 22.94 million Kg of waste plastic waste every day. Research has proven that plastic waste is economical solution for improvement and stabilization of weak subgrade soils. Use of plastic as reinforcement not only improves the subgrade but also reduces the plastic waste by reusing it. The cost of plastic being waste material is very less compared to other stabilization material which in turn reduces the cost of subgrade stabilization. Use of plastic in stabilization of subgrade solves two problems with one solution. It reduces the plastic waste by reusing plastic and reduces the cost of stabilization by low cost readily available waste material.

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Chapter 3

Methodology

3.1 Introduction

In this Chapter the methodology of experimental laboratory work carried out in this research is explained. Figure 3 shows the flow chart of activities in this research. Furthermore, this chapter will give a comprehensive detail of material used, testing procedure & standards, sample preparation, apparatus used, and data processing of each test carried out to achieve the aims of this research.

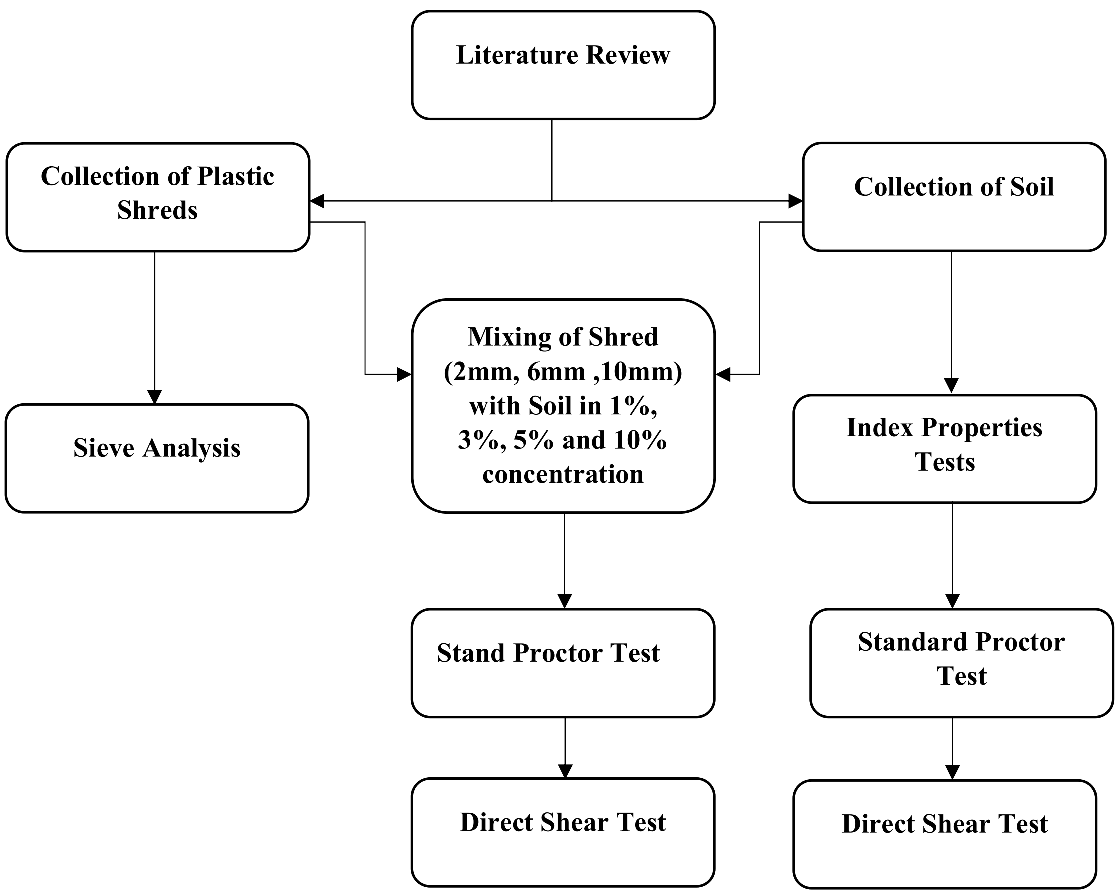

Figure 3: Methodology Flow Chart

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3.2 Soil

Natural soil (Silty Clay) used in this study was collected from Ghagri Area Naval Anchorage Islamabad at the depth of 1 m. Following test were carried out find the engineering properties of natural subgrade soil; gradation & particle size distribution, Atterberg limits, specific gravity test, proctor test, direct shear test.

3.3. Plastic Bottles Shreds

In this research waste Polyethylene Terephthalate (PET) bottles were collected different junkyards in Islamabad and were transported to a recycling factory that converts PET Plastic bottles in to shreds to be used in manufacturing of polyester fiber. In this factory these waste bottles were shredded in three different of 2 mm, 6 mm, and 10 mm to be utilized as reinforcement to improve the properties of weak clayey subgrade soil. Sieve analysis was conducted on plastic shreds.

3.4 Sample Preparation

Natural soil samples and PET shreds were collected and transported in plastic bags to the Nust Institute of Civil Engineering Laboratory and where air dried in accordance with AASHTO T87- 86. Different laboratory tests were conducted on natural soil samples and PET Shreds. Thereafter, natural soil and PET shreds were mixed manually to prepare the samples with 1%, 3%, 5% and 10% PET content for each of three plastic shreds sizes. Following tests were performed on 13 samples prepared with different shred and PET content; proctor test and direct shear test

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3.4 Laboratory Experiments

In this research eight different laboratory experiments were conducted in accordance with ASTM standards. Table 3 Shows the Laboratory tests and standards performed in this research:

Table 3 Laboratory Experiments

Research Material	Tests	Standards
PET Shreds	Particle Size Distribution (Gradation)	ASTM D6913
Natural Soil (Clay)	Specific Gravity	ASTM D854
	Atterberg Limits	ASTM D4318
	Soil Classification	ASTM D2487
	Standard Proctor Test	ASTM D698
	Direct Shear Test	ASTM D3080
Natural Soil mixed with PET Shreds	Standard Proctor Test	ASTM D698
	Direct Shear Test	ASTM D3080

3.4.1 Specific Gravity

Specific gravity is defined as ratio of weight of soil of a certain volume to weight of water of same volume. Specific gravity is used in calculation of phase relationships. Figure 4 shows general ranges of specific gravity or different soils. The test was performed in accordance with the ASTM D854-98 Standard Test Method for Specific Gravity of Soil.

Table 4 General Ranges of Specific Gravity

Soil Type	Range of G_s
Sand	2.63 to 2.67
Silts	2.65 to 2.7
Clay and Silty Clay	2.67 to 2.9
Organic Soil	Less Than 2

Procedure

- Weight the volumetric flask (W1).
- Put about 100 g of oven dried soil sample in the volumetric flask and measure weight (W_2).

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- Fill water about two third of volumetric flask and heat the flask for 2 hrs. to remove entrapped air.
- Allow the mixture to cool and add water up to calibration mark and weight the volumetric flask (W_3).
- Record the temperature of soil mixture and find the value of temperature correction factor $\boldsymbol{\alpha}$.
- Empty the flask and clean it. Fill the flask completely with water and weight it (W_4).
- Calculate Specific Gravity by formula

$$G_s = \frac{(w_2 - w_1)\alpha}{(w_4 - w_1) - (w_3 - w_2)} \qquad (1)$$

- Repeat the experiment three times and take average of three values.

3.4.2 Particle Size Distribution (Gradation)

Particle size distribution (Gradation) is one of the most basic and important tests in soil mechanics. In this test percentage of different size of grains present in soil is determined. The gradation of soil gives us idea about engineering properties of soil such as permeability, compressibility, and shear strength etc. Moreover, selection of fill material is also based on gradation in construction of roads and embankments. The test was conducted in accordance with ASTM D6913 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. Sieves set, Sieve shaker, Soil pulverizer, Weight balance were used in this test

Procedure

- Take about 500g of oven dried soil sample.
- Pulverize the soil by mortar and pestle.
- Measure the weight of soil.
- Assemble the sieves with larger opening at the top and others in descending order. Place the pan at the bottom.
- Pour soil sample into sieves and place top cover on sieve set.
- Place the sieve set in sieve shake and shake for 10-15 mins.
- Weight the amount of soil retained on each sieve.

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- Calculate and plot the percent finer against grain size on logarithmic scale as shown in Figure 5.

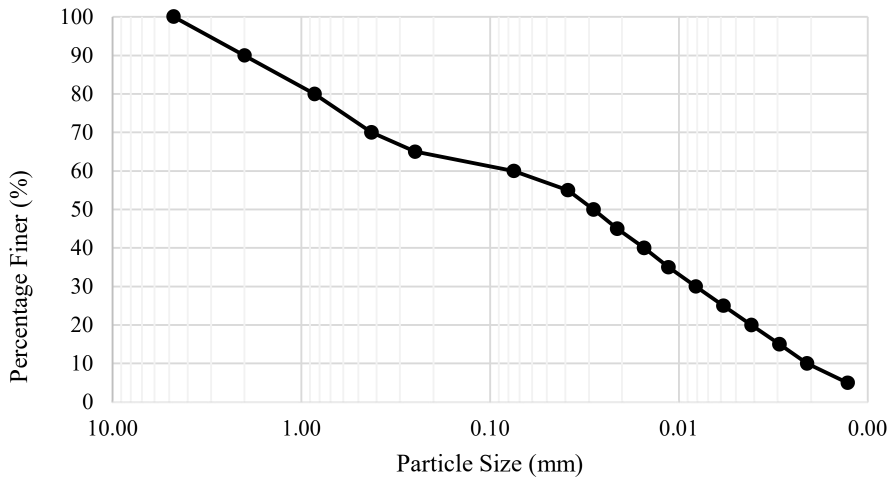

Figure 4 Typical Soil Gradation Graph

3.4.3 Atterberg Limit

Swedish scientist Albert Atterberg defined 7 limits to define soil known as Atterberg Limits however, in current engineering only two of them are used liquid and plastic limit. Liquid limit is defined as moisture/ water content at which soil changes from plastic state to liquid state. Plastic limit is defined as moisture/ water content at which soil changes from semi liquid to plastic state. Atterberg limits are used in classification of soils and correlations for variety of engineering properties have been developed with Atterberg limits. Apparatus used in this test are Liquid limit device, evaporating dish, Grooving tool, Glass plate, Weight Balance, Oven, Moisture cans

Procedure

Liquid Limit

- Record the mass of three moisture cans.
- Take about 250g of air-dried soil sample passing through sieve no 40 in evaporating dish and mix with water until uniform paste is achieved.

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- Place the paste inside the cup of liquid limit device and smoothen the surface with spatula.
- Using grooving tool cut a groove along the center of brass cup.
- Turn the crank of apparatus at the rate of 2 drops per second and record the no of drops for two halves of the grove in soil come in contact.
- Take a sample using spatula and put it in moisture can and measure the weight of can and place it in oven for 16 hours.
- Repeat the process for three different trials to get three readings between 25 to 35, 20 to 30 and 15 to 25.
- Find the moisture content for each trial.
- Plot semi log graph between moisture content and number of drops.
- Moisture content corresponding to log of 25 on the graph is liquid limit of soil as shown in Figure 6.

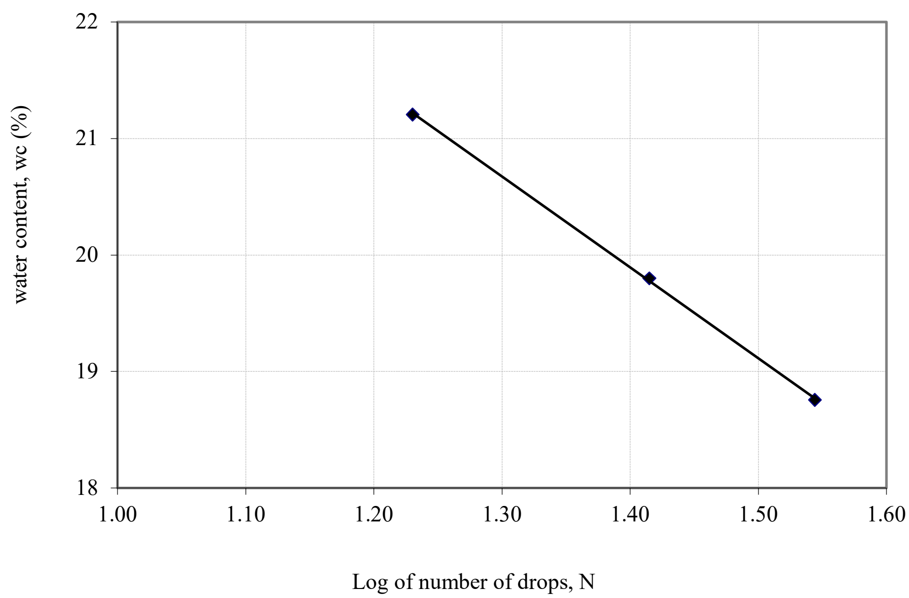

Figure 5 Graph Between Water Content and Log of Number of Drops

Plastic Limit

- Record the mass of three moisture cans.
- Take about 20g of air-dried soil sample passing through sieve no 40 in evaporating dish.
- Add water from Plastic bottle and mix it with soil.

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- Prepare soil into ellipsoidal mass and roll the mass between palm and fingers on glass plate to form thread of diameter of 1/8 inch.
- Break the thread into various pieces and roll the mass again until 1/8-inch thread crumbles.
- Take the sample in moisture can and place it in oven for 24 hours and find its moisture content.

3.4.4 Soil Classification:

In this test soil is classified and group name is given to natural soil based on particle size distribution and Atterberg limits of soil. Correlation have been developed with group classification of soil to provide insight of engineering behavior of soil. This classification divides soils into three major groups coarse grain soils, fine grained soils, and highly organic soils. These groups are further divided 15 soil groups as shown in table 3. Classification of soil was conducted in accordance with ASTM D 2487 – 06 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

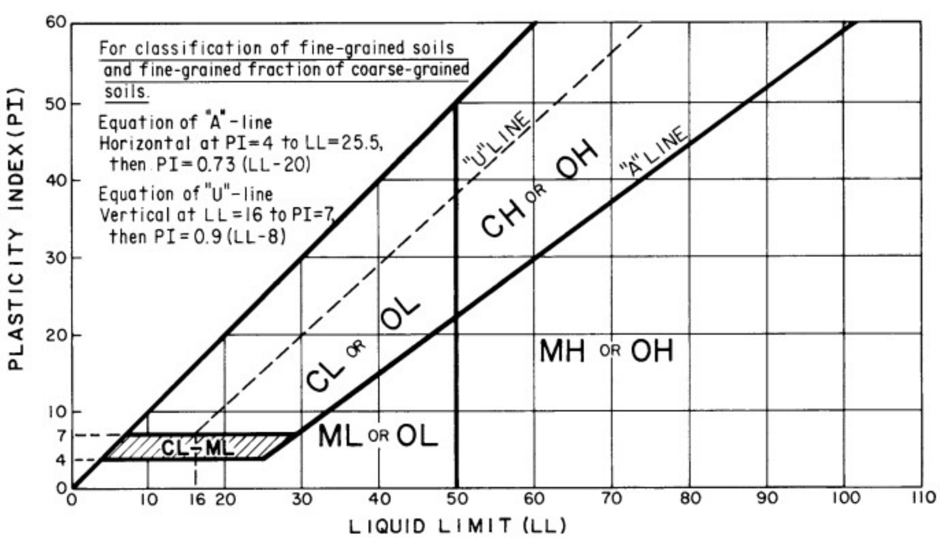

Figure 6 Plasticity Chart (ASTM D2487, 2017)

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3.4.5 Standard Proctor Test

Soils in fills and embankment are compacted to increase shear strength and reduce the compressibility and permeability. In this test maximum dry density and optimum moisture content of soil is determined which provides the basis for compaction achieved and water required to achieve the compaction on site. The test was performed in accordance with ASTM D698 -07 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3)). Appratus used in test were Proctor mold, 2.5 Kg Rammer, mixing pan, #4 Sieve, Drying Oven, Moisture can, Graduated cylinder, Straight edge, Weight balance

Procedure

- Take about 5 Kg of air-dried soil in mixing pan, break all lumps, and pass it through sieve # 4
- Find the weight of soil and mold without base plate and collar.
- Add approximate 5 % moisture to the soil and mix it.
- Place the first layer of soil in proctor mold and compact it with 25 blows of rammer.
- Place the 2nd layer of soil in proctor mold and compact it with 25 blows of rammer.
- Place the 3rd layer of soil in proctor mold and compact it with 25 blows of rammer.
- Remove the mold by detaching collar and base plate.
- Determine the weight of soil with mold
- Take sample of soil in moisture can and measure its weight.
- Place the moisture can in oven for 24 hrs. and find its moisture content.
- Increase the moisture by 2% and repeat the experiment.
- Take 4 readings and two readings after the weight starts decreasing.
- Plot the graph between moisture content and corresponding maximum dry density.
- Find the optimum moisture content and corresponding maximum dry density from graph as shown in figure 8.

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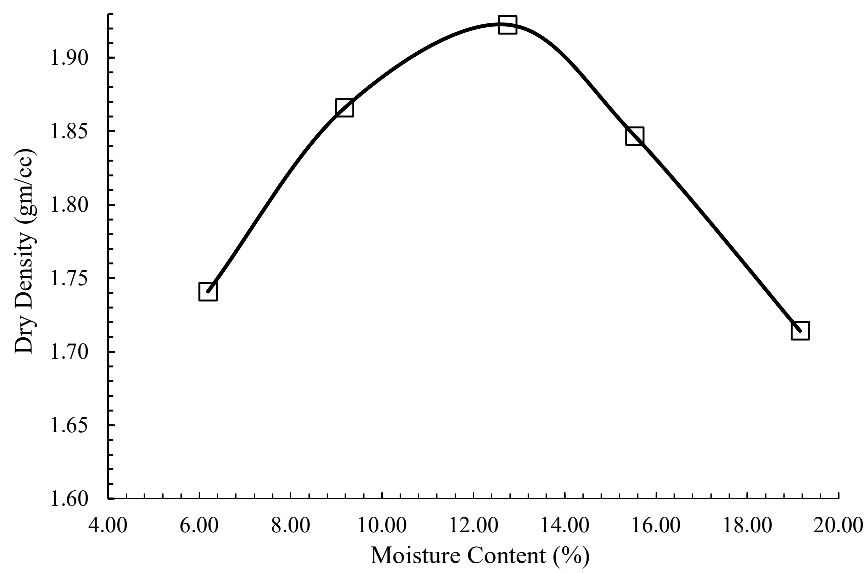

Figure 7 Typical Compaction Curve

Limitations

- This test cannot be used for soils containing more than 30 % over size fraction (material retained on 3/4-inch sieve).
- Soil that degrades during compaction create problem as degradation increase the MDD.
- Gap graded soils are problematic due to large voids.

3.4.7 Direct Shear Test

This test is performed to find the consolidated drained shear strength and angle of friction of soil. The test was performed in accordance with ASTM D 3080 - Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. The apparatus used in test were Direct shear device, Shear box, porous inserts, Load and deformation gauges, Filter paper, Balance, Porcelain dish, Tamper

Procedure

- Take some soil sample in porcelain dish and weight it W_1. Fill the shear box in layers and compact it with tamper.
- Measure the dimensions of sample (Length, Breadth and Height).

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- Place porous inserts and filter paper on top and bottom of specimen and load the shear box inside the direct shear device.
- Apply the desired Normal Load N on the specimen
- Free the two halves of shear box by removing two pins.
- Fix vertical and horizontal dial gauges to the shear box.
- Apply horizontal load S at the rate of 0.0001 to 0.04 in/min (0.0025 to 1.0 mm/min) to the shear box.
- Note the readings of vertical dial gauge and proving ring and continue until failure.
- Repeat the same process for different normal stresses.
- Now plot normal stress and shear stress and find the cohesion intercept C and angle of friction Φ as shown in figure

Limitations

- Failure plane is predetermined.
- Pore pressure cannot be determined.
- Can only be performed with drained conditions

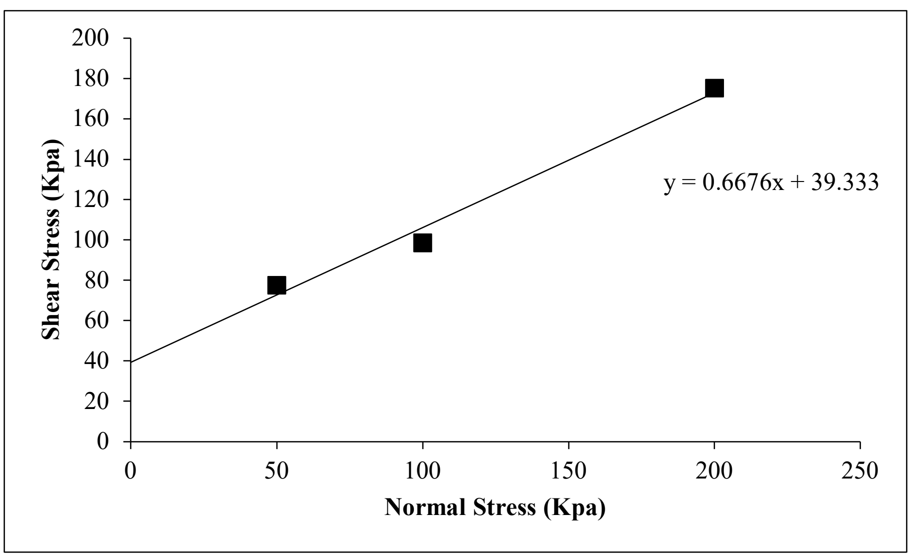

Figure 8 Shear Stress vs Normal Stress Graph

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Chapter 4

Results and Discussions

4.1 Index Properties of Soil

The soil under study is silty clay which was collected from Ghagri Area Naval Anchorage in Islamabad from depth of 1 m. The natural soil is composed of 8.5% sand 60% Silt and 31.6% Clay. The USCS classification of soil is CL-ML with Liquid Limit and Plastic limit of 20% and 15% approximately. Table 5 Shows the engineering properties of natural soil and Figure 9 shows the grainsize distribution of the soil. Pumping action occur in soil with high silt content and these soils are difficult to compact and cause performance problems. Pumping is basically migration of fines from subgrade to overlaying layers and it occurs in soils with PI less than 10. When cyclic loading is applied wet soils with high silt content pore water pressure is developed which is unable to dissipate due to low hydraulic conductivity of soil which results in pumping and loss of strength. Soils with PI less than 10 have very low cohesion and hydrostatic forces break the bond between soil particles due to which fine particles in soil start moving upward causing pumping. Due to problematic nature of soil the engineering department of the Naval Anchorage used soil replacement technique and mixed soil with sand 50% by weight for soil improvement prior construction of infrastructure

Table 5: Engineering Properties of Soil

Soil Properties	**Result**	**Standard**
Specific Gravity (G_s)	2.75	ASTM D854
Liquid Limit %	20	ASTM D4318
Plastic Limit %	15	ASTM D4318
Plasticity Index	5	ASTM D4318
Maximum Dry Density MDD	1.92	ASTM D698
Optimum Moisture Content OMC	12.75	ASTM D698
Sand %	8.5	ASTM D6913
Silt %	60	ASTM D7928
Clay %	31.6	ASTM D7928
Soil Classification USCS	CL+ML	ASTM D2487

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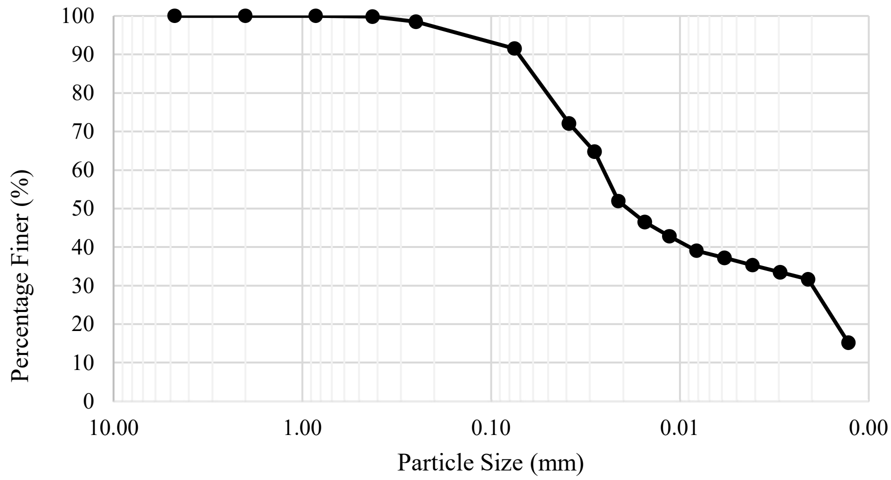

Figure 9 Particle Size Distribution of Soil

4.2 Plastic Shred

Plastic Shreds were obtained from waste plastic bottles. The plastic bottles used are made up of Polyethylene Terephthalate (PET). PET is byproduct of petroleum and have very good wearing resistance and tensile strength which makes it good for soil stabilization (Peddaiah et al., 2018). However, PET is nonbiodegradable and therefore causes environmental pollution. In this research plastic bottle shreds were obtained by a factory in Lahore that collected plastic bottles from whole city through scavengers and shredded them into three different sizes with large shredders. These three different sizes of shreds were purchased from the factory and sieve analysis was performed to find the average size of shred particles result is shown in Table 6. Figure 10 shows the visual representation of different shred sizes.

Table 6 Plastic Shred Size

Name of Plastic Shreds	Passing	Retained	Average Size D_{50}
P1	3/4" (19 mm)	#10 (2 mm)	10 mm
P2	3/8" (9.50 mm)	#10 (2 mm)	6 mm
P3	#8 (2.36 mm)	#30 (0.6mm)	2 mm

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4.3 Compaction Results

Figure 10 Plastic Shred Sizes

Standard proctor test was conducted on samples prepared by mixing plastic shreds of 2 mm, 6 mm, and 10 mm in 1%, 3%, 5% and 10% concentration. Compaction curves for different plastic concentration are shown in Figures 11, 12, 13 and 14.

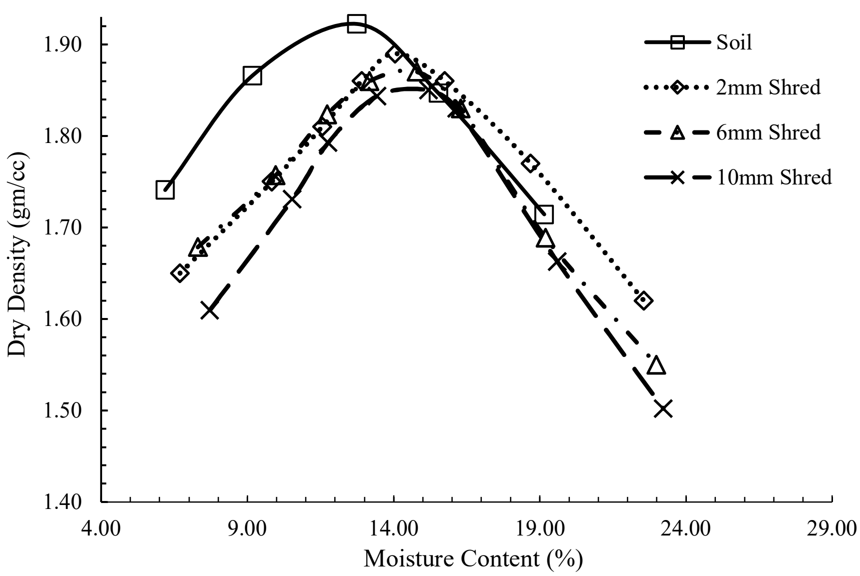

Figure 11 Compaction Curve for 1% Plastic Shred Concentration

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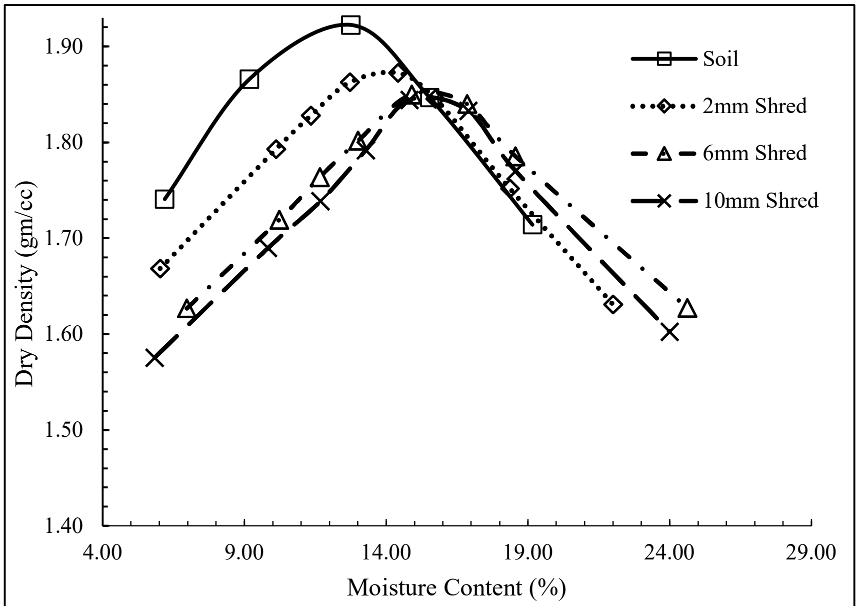

Figure 12 Compaction Curve for 3% Plastic Shred Concentration

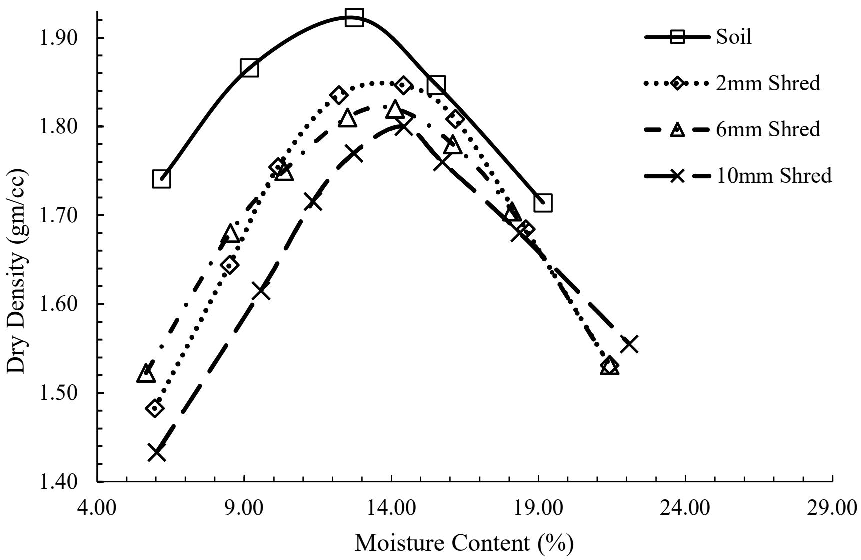

Figure 13 Compaction Curve for 5% Plastic Shred Concentration

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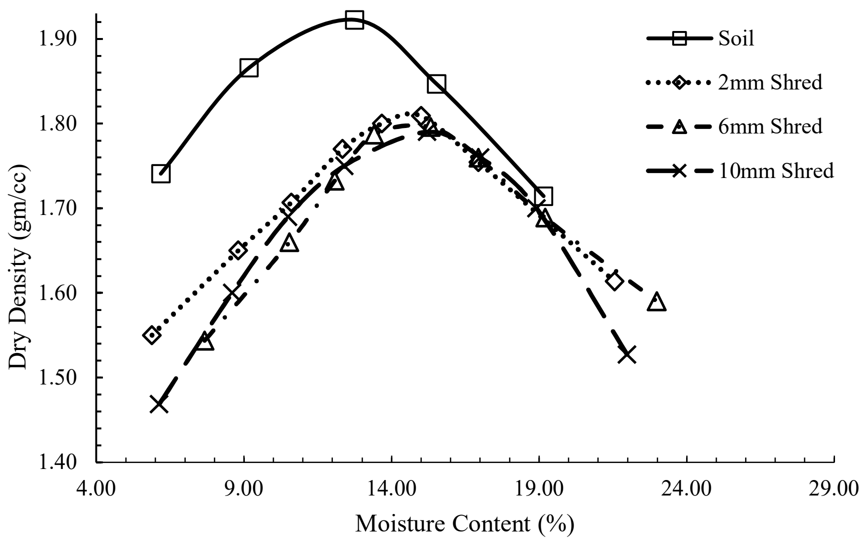

Figure 14 Compaction Curve for 10% Plastic Shred Concentration

4.3.1 Effect of Plastic Concentration and Shred Size on MDD:

Results showed that with the inclusion of plastic shreds, the Maximum Dry Density (MDD) decreased. It can be inferred from Figures 11, 12, 13 and 14 that the MDD of the soil decreases as the shred size and plastic concentration is increased. The maximum value of MDD is observed at 1% plastic content and decreases as the plastic content and shred size is increased. The MDD decreases with increase in plastic content because plastic is much lighter material than the soil particles under study, and therefore it decreases the MDD of the soil (Ojuri & Ozegbe, 2016). Furthermore, the possible reason for decrease in MDD with increase in shred size could be that the presence of larger plastic shred particles creates a barrier like effect and prevents rearrangement of the soil particles which in turn decreases the density of the soil (Iravanian & Ahmed, 2021).

4.3.2 Effect of Plastic Concentration and Shred Size on OMC:

It can be observed from Figures 11, 12, 13 and 14 that the OMC increases and moves to the right with the increase in percentage of plastic content and shred size. The possible reason for it could be that plastic is inert material however bipolar molecules of water adhere to plastic shreds and form a film around it and causes increase in moisture content (Iravanian & Ahmed, 2021). Furthermore, as the plastic concentration and shred size is

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increased the cumulative surface area and size of film will also be increased thus resulting in increase of OMC.

4.4 Direct Shear Results

Direct shear tests (ASTM D3080/D3080M-11, 2011) were performed on samples with MDD and OMC determined by the proctor test by mixing plastic shreds of 2 mm , 6mm and 10mm in 1% , 3%, 5% and 10 % concentrations. Shear stress vs Normal stress graph for different plastic contents is shown in Figures 15, 16, 17 and 18. Table 7 shows the effect of different plastic concentration on friction angle and cohesion.

Table 7 Direct Shear Results

Description	**Size of Shred (mm)**	**Cohesion C (kPa)**	**Friction Angle ø Degrees**	**Change in Friction angle %**	**Change in Cohesion %**
Natural Soil	0	39.2	31.3	-	-
Phase-I 1% Plastic Concentration	2	40.2	34.5	10.2%	2.6%
	6	39.5	34	8.6%	0.9%
	10	38.5	32.5	3.8%	-1.7%
Phase-II 3% Plastic Concentration	2	35	31	-1.0%	-10.6%
	6	33.3	29.7	-5.1%	-14.9%
	10	31	28.5	-9.0%	-20. 9%
Phase-III 5% Plastic Concentration	2	31.8	29.2	-6.7%	-18.7%
	6	30	27.6	-11.8%	-23.4%
	10	26.2	25.1	-19.8%	-33.2%
Phase-IV 10% Plastic Concentration	2	23.8	26.7	-14.7%	-39.2%
	6	21.5	23.9	-23.6%	-45.1%
	10	17.7	22.1	-29.4%	-54.9%

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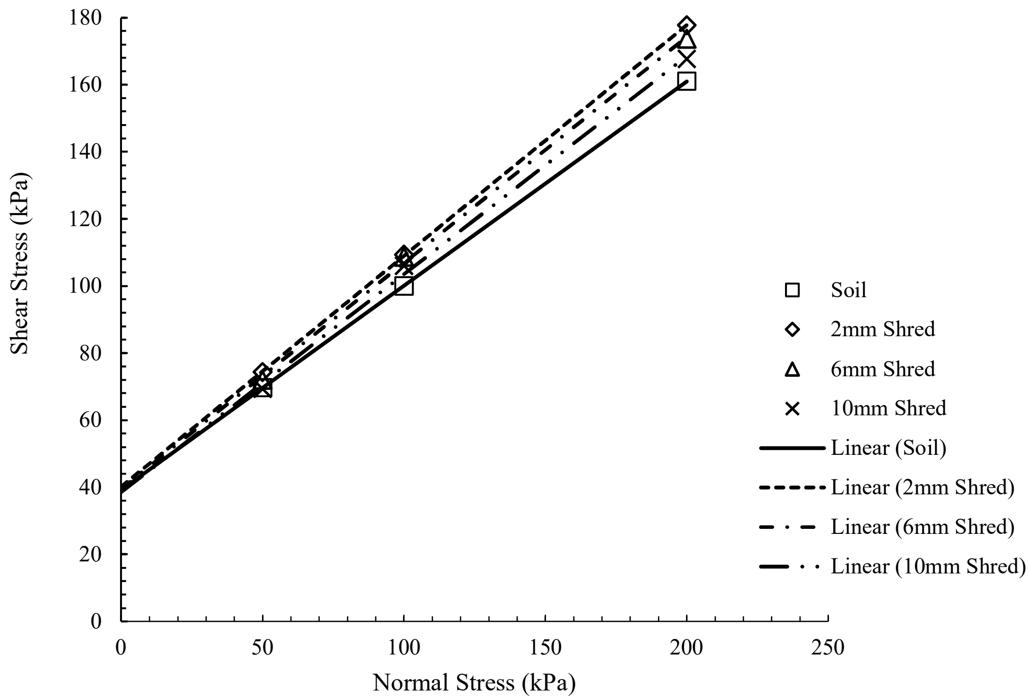

Figure 15 Shear Stress vs Normal Stress for 10% Plastic Concentration

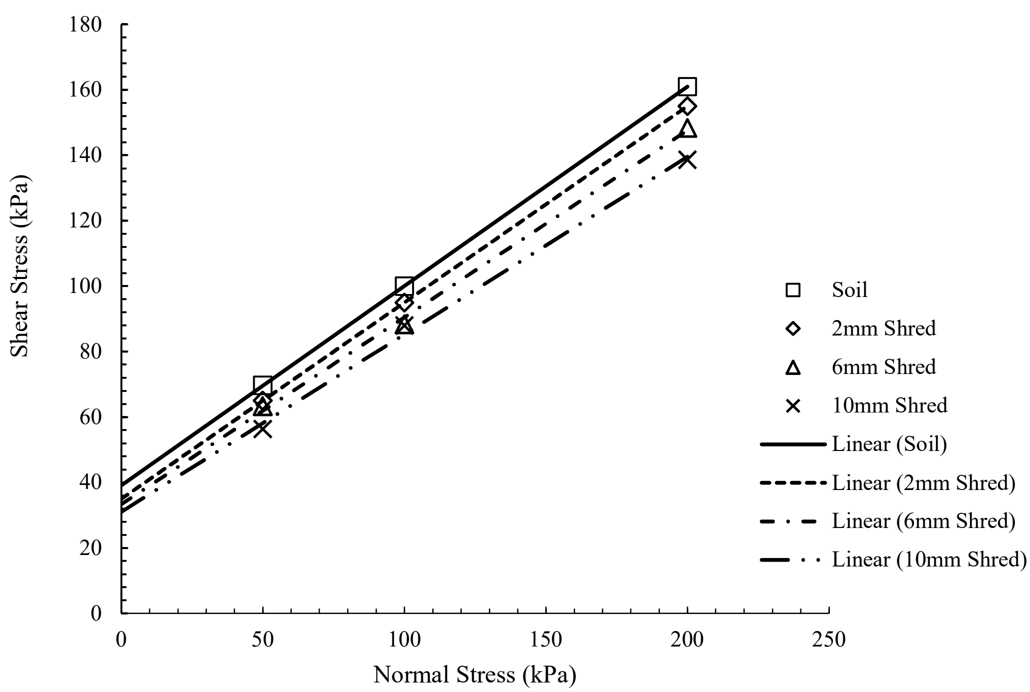

Figure 16 Shear Stress vs Normal Stress for 3% Plastic Concentration

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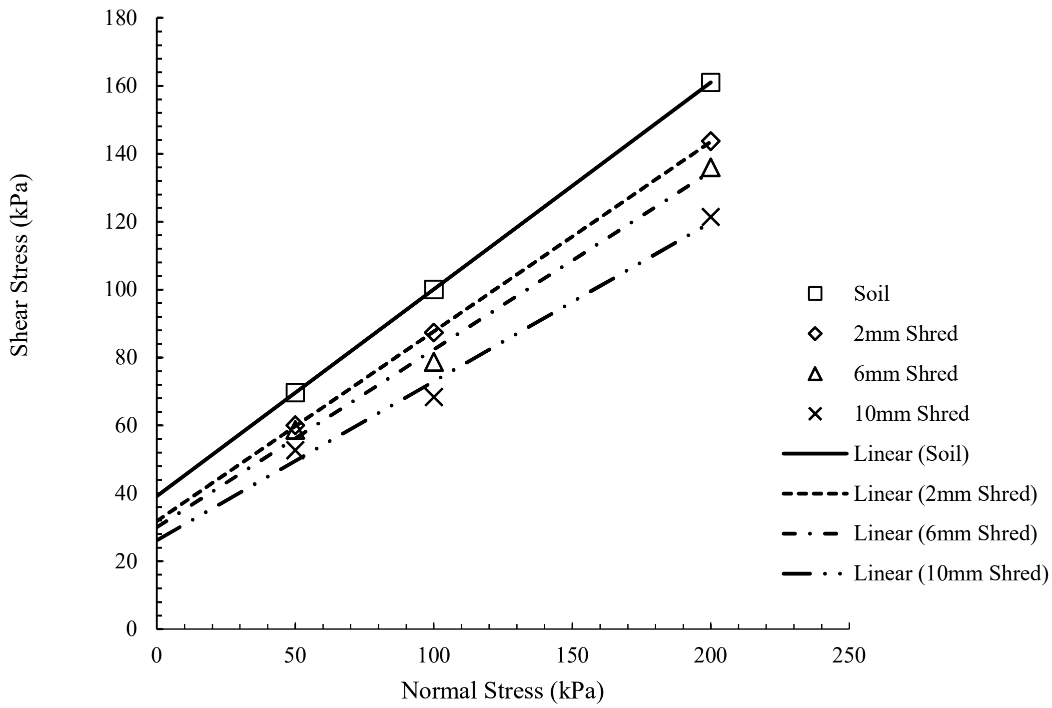

Figure 17 Shear Stress vs Normal Stress for 5% Plastic Concentration

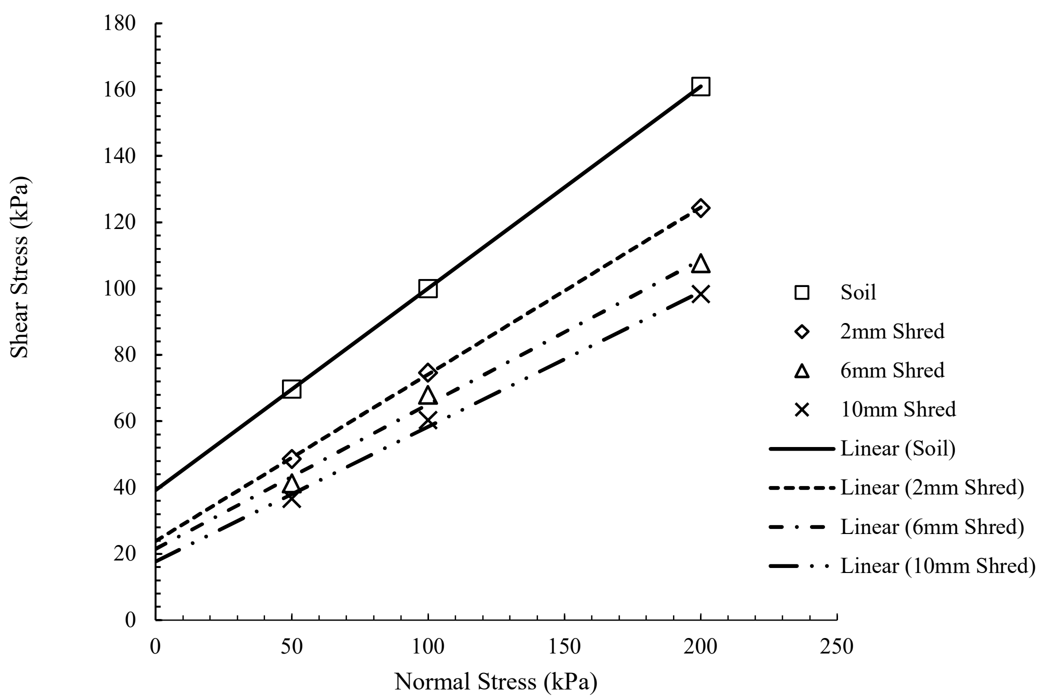

Figure 18 Shear Stress vs Normal Stress for 10% Plastic Concentration

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4.4.1 Effect of Plastic Concentration and Shred Size on Angle of Internal Friction ø

Direct shear test results showed that the shear strength parameters increase up to 1% plastic concentration by mass however, for higher percentages 3%, 5%, 10% the shear strength parameters decrease as shown in Table 7. Untreaded soil had 31.3 degrees angle of internal friction, maximum friction angle of 34.5 degrees was observed with inclusion of 2mm shreds in 1% and minimum friction angle of 22.1 was observed by addition of 10mm shreds in 10 % concentration. Shear stress vs normal stress for 1%, 3%, 5% and 10% plastic shred concentration are shown in Figures 15, 16, 17 and 18 respectively. It can be concluded from figure 19 that angle of internal friction decrease with increase in shred size and the maximum increase in angle of internal friction was observed in soil mixed with 2 mm shred. With inclusion of 2 mm shreds in 1 % concentration the frictional angle of soil increased by 10% however, for concentrations above 1% the friction angle decreased which can be attributed to reduction in particle to particle contact of soil which results in reduction of shear strength and friction angle (Kazmi, 2020b). Another reason could be that creating smaller shred size involves more shredding and cutting compared to larger sizes which results in more undulation and corrugation in smaller particles due to which friction angle decreases in larger shred particles (Peddaiah et al., 2018).

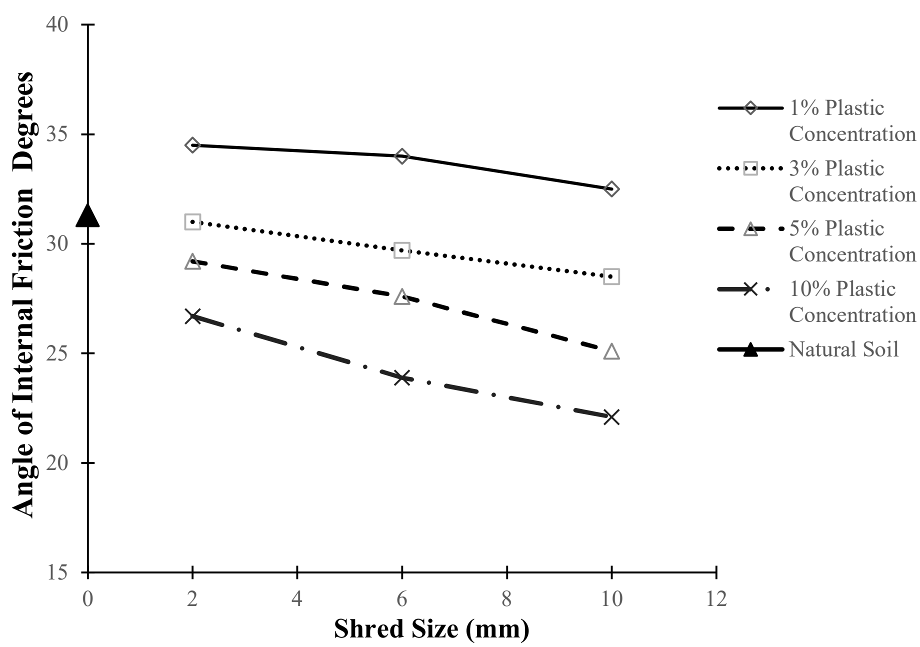

Figure 19 Variation of angle of internal friction with Plastic Concentration

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4.4.2 Effect of plastic concentration and shred size on cohesion C

Table 7 and Figures 15, 16, 17 and 18 shows that there was insignificant increase in cohesion at 1% plastic concentration however, cohesion decreased with increase in both plastic concentration and size of shred. The untreated soil had cohesion of 39.2 kPa which increased to 40.2 kPa however with further increase in plastic concentration the cohesion decreased and minimum cohesion of 17.7 kPa was observed with inclusion of 10mm shreds in 10% concentration. Figure 20 shows the trend of decrease in cohesion with increase of plastic content, plastic shred size and content in soil. It can be attributed to the fact that Plastic stabilizes the soil mechanically however, with inclusion of plastic soil particle to particle interaction decreases and larger particles of plastic break the bonding between soil particles that result in reduction of cohesion

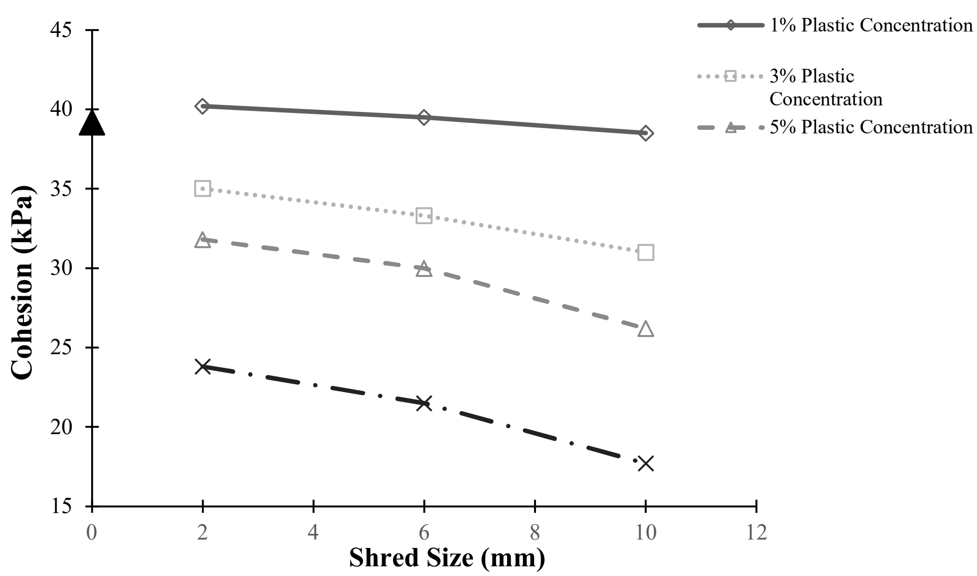

Figure 20 Variation of Cohesion with Plastic Concentration

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Chapter 5

Conclusions and Recommendations

5.1 Conclusions

In this study the effect of locally available waste plastic shreds of different sizes (2mm, 6mm and 10mm) and plastic shred concentration (1%, 3%, 5% and 10%) on engineering properties of soil and a sustainable solution for disposal of waste plastic was explored. Standard Proctor test and Direct shear test were conducted on 13 samples of soil and plastic mixture were conducted. Results showed increase in strength of soil and following was concluded:

- MDD decreases while OMC increases with increase in plastic concentration and shred size.
- Angle of internal friction increase up to 10.2% corresponding to 1% plastic concentration by mass however, for higher percentages of 3%, 5% and 10%, it decreased.
- On the other hand, cohesion decreased with an increase of shred size and concentration
- Lower shred size i.e.,2 mm exhibited the highest increase in shear strength
- 2 mm shred size at 1% concentration is optimum for maximum increase in shear strength

5.2 Recommendations

Following topics of research are recommended related to this study

- Study the effect on engineering properties of mixing plastic shreds with soil in concentrations below 1%
- Study the effect on engineering properties of mixing plastic shreds with high plastic clays

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