Research proposal on Stabilizing Clayey Soil using plastic waste materials: FINAL VERSION




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DELTA ACADEMY

Acknowledgement

A bachelor's degree is earned over the course of four years, with the last semester requiring a significant amount of effort and time. Now is the time to express gratitude to everyone who assisted me in completing my thesis. I'd like to thank Leads for construction and Christophe Egyed in particular for their assistance with this project. Mr. Christophe significantly assisted me in enhancing my research whenever I thought it was complete and I have covered all the subjects and presented me with intriguing topics. In addition, he spent considerable time answering many of my queries despite the fact that he had other tasks that required his attention. I have liked my experience at Leads for construction and working with Mr. Essam Hedia and my co-workers. All of the excursions I've taken around Egypt to observe the implementation of one of the major projects there were quite enjoyable. I would also want to thank the HZ University of Applied Sciences and all the lecturers for the four years of excellent education. During the first two years of this four-year programme, the foundation was established, which aided me immensely during the third-year internship, minor abroad, and graduation internship. During my internship for graduation, I received personal supervision from Mr. Essam Hedia and Mr.Christope, who assisted me by asking the right questions, helping me to organise the layout of my thesis, and narrowing my research, thereby ensuring that I have a completed thesis by the deadline and that I am an expert on the subject for future research, in case anyone asked me or I assisted in the extension of such research.

Hazem Hedia

August 2022, Alexandria Egypt

Summary:

Most world governments are concerned with waste disposal. The large accumulation of these waste items is causing environmental and monetary issues. According to (Awuchi, 2019), the predicted average daily production of plastic waste is 15.4 billion pieces. Plastic waste is the most prevalent form of waste. These are the most often used material types in our daily lives. Massive amounts of plastic garbage are produced, including plastic bottles made of polyethylene terephthalate (PET), as well as plastic bags and carpets made of polypropylene (PP). Polyethylene products are widely regarded as the primary constituents of waste materials. Plastic has a negative impact on the environment and human health, despite its numerous benefits in daily life.

Due to the impossibility of eradicating plastics from the world, researchers have begun focusing on the plastic's potential uses to combat the issue. Utilizing the plastic by recycling it, using it to improve the soil's engineering capabilities, or creating goods that are entirely recyclable.

If construction has existed, the requirement of increasing the engineering properties of soil has been recognized.

The modern era of soil stabilization began during the 1960's and 70's when general shortages of aggregates and fuel resources forced engineers to consider alternatives to the conventional techniques of replacing poor soils at building sites with shipped-in aggregates that possessed more favorable engineering characteristics. Consequently, now is the optimal time for such techniques, as there are numerous projects around the world utilizing soil stabilization techniques, such as cement soil stabilization, to improve the soil's properties. One of these projects is the construction of a 185-kilometer highway connecting Cairo to Alexandria. This project employed cement soil stabilization, and it is now one of the top highways/ roads in Egypt.

This research will discuss the impact of plastic garbage, namely polyethylene terephthalate (PE) and polypropylene (PP), on clay soil.

Egypt has one of the warmest climates in the world, therefore lower temperatures might result in a slower growth of tensile strength, leading to an increase in cracks because the tensile stresses will more frequently surpass the tensile strength, whilst higher temperatures may have the reverse effect.

This study investigates the effect of using plastic waste as fibre-shaped waste materials on geotechnical properties of soils. Several standard geotechnical laboratory tests were performed in order to identify the effect of length and contents of fibres that are randomly distributed throughout

the soil and its effect on pavement thickness, cost effectiveness of such technique compared to native soil and cement stabilized soil.

The soil used in this study was collected near lake Marriot in Alexandria, Egypt the sample is divided into four equal parts by removing two diagonally opposite parts and then mixing two remaining parts properly. The physical properties of the soil are shown in Table below; this soil is classified as clay soil according to the American Society for Testing and Materials (ASTM) with about 93% silt and clay.

The mixing of the soil:

For all tests, the adopted content of fibers was first manually mixed into the air-dried soil in small increments. Considerable care was taken to achieve homogeneous mixture during the mixing process. Then, the required water was added

Considered aspects during the study:

- Temperature of pavement and its effect of plastic being melted
- Mechanisms and applicability of various stabilizing agents
- Ecological impact of using plastic waste materials in the soil and cement particles (its effect on the micro-organisms)
- Advantages of such technique/method
- What happens to the plastic after the life cycle of the road (how to get rid of it)
- Different plastic sizes need more investigation
- Relationship of CBR and E-dynamics
- prevention of expansion and contraction of plastic

Laboratory tests:

- standard compaction test (proctor test)
- unconfined compressive strength test
- California Bearing Ratio test
- and resilient modulus tests

Kenpave calculations:

- Asphalt thickness estimation on different traffic loads
- Cost estimation
- Base layer thickness estimation (Using odemark method)
- Stabilized vs unstabilized soil (in terms of thickness, reliability compared to traffic load)

- Asphalt thickness clayey stabilized vs cement stabilized
- Cost estimation for clayey stabilized soil vs cement stabilized

Conclusion

Stabilization significantly enhances the engineering qualities of soils, including their physical, mechanical, and strength properties. This research examined these qualities using an experimental laboratory test program on two distinct waste polymers often found in disposal bins, namely polyethylene and polypropylene. The following are the major findings drawn from this research described here:

1. Soil stabilization using fiber has a distinct tendency for UCS and Mr., as increasing the fiber content does not result in an ascending trend in UCS, however increasing the fiber content resulted in an ascending trend in Mr. values. As a result, the optimal fiber content should be found for stabilization with fibers at the maximum UCS and Mr. values.
2. PE and PP could be utilized to improve the physical and mechanical qualities of soil materials used in engineering projects.
3. The length of the fiber had an influence on the strength attributes of the stabilized soil, as increased length resulted in increased strength. This may require more research to determine the optimal fiber length which results in the optimum strength qualities.
4. For road pavement design codes of practice that use the CBR and Mr. as design parameters, the fiber 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 fiber stabilization is not; this is one of the advantages of fiber stabilization over chemical stabilization.
5. While increasing the fiber content increased the value of CBR and Mr, the optimal fiber content for UCS was between 1% and 2% for both PE and PP.
6. The Microplastics has a bad side effects on the micro-organisms in the soil but while has to do with if the land will be used for agriculture purposes where most of the impacts occur.
7. Clayey soil stabilized using plastic is very effective in terms of strength and cost however the long-term side effects of such method is still unknown so further research on how you can get rid of the plastic in the soil after the lifetime of the road needs further investigation

8. Cement soil stabilization is effective in terms of cost compared to unstabilized soil and effective is the ESALS 10^6 but not as effective as the soil stabilized with plastic fibers in the use of highways with high loads i.e., heavy trucks (ESALS 10^7)
9. Plastic fiber content (PE 1cm length) reduces the thickness by 0.75cm, and 0.50 for the 2cm length of PE, while PP didn’t have a noticeable effect compared to the PE plastic.

Preface:

I was eager to study civil engineering since I am 16 years old, since my father is a successful civil engineer and contractor in Egypt, I have applied to Hz university of applied sciences not a typical research university because I am more of a practical person than a researcher, I would prefer to know how things are being made/executed and then improve them.

During my 4-year program at Hz university of applied sciences the first 2 years lays the foundation for any person to become a civil engineer by covering all the basic for being a civil engineer.

The main 2 topics that took my attention and I became really interested in is soil mechanics and transport and infrastructure, Thanks to Mr. Repko and Mr. Christophe for teaching me and really putting the effort to make me understand the subjects well since they always have taken the time to talk about their real-life experience and explaining the theory behind each formula and pointing out examples from real life that the books got wrong.

On the 4th year we are asked to find a graduation internship and that we research a topic of our choice, since my family business is in construction, I have decided to do my graduation project here since I will have the opportunity to choose whatever topic I want and make sure I will get the best supervision and support to help me finish my research.

My motivation for such topic as I said came from my passion of soil mechanics but also to help make a better sustainable projects in the future since the whole world is moving towards less co2 emissions and reduce the use of plastic in day to day life, and the way I saw it since you can’t entirely get rid of plastic you have to get the best out of it and utilize it, so I researched for soil stabilization topic till I found some studies addressing a matter of soil stabilization using plastic waste materials and that caught my attention. I read it and saw that there might be some potential with such subject in the future. And since soil stabilization is very common nowadays especially in plastic with weak soil, and that I saw several projects use cement as stabilizing agent in the soil to enhance its mechanical properties, I saw it’s a good idea to choose and pursue such topic and bring value to the geotechnical engineer’s community. Thanks especially to Mr. Christophe for opening my eyes and guiding me through the thesis by coming up with eye opening questions, Mr. Essam Hedia my in company supervisor by providing me with all the resources and connecting me with people who might help me in such topic, Mr. Seif Adel for answering my questions and helping me to understand kenpave program and providing with book of pavement designing which helped me a lot carrying out my calculations to help me finish my research and knowing if it’s worth it trying in real life or not.

Writing this thesis wasn't easy since there wasn't enough information on the internet for the topic. And there are some stuff needs to be investigated even after I finished with writing my thesis.

August 2022 Alexandria, Egypt

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1. Introduction

1.1 Background information

As long as construction has existed, the requirement of increasing the engineering properties of soil has been recognized.

Numerous ancient cultures, including the Chinese, Romans, and Incas, improvised soil suitability using a variety of techniques, some of which were successful that the buildings and streets they created still stand today. Several remain in operation.

The modern era of soil stabilization began during the 1960's and 70's when general shortages of aggregates and fuel resources forced engineers to consider alternatives to the conventional techniques of replacing poor soils at building sites with shipped-in aggregates that possessed more favorable engineering characteristics.

Waste disposal is a concern for most of the world's governments. The massive collection of these waste products is producing environmental and financial difficulties. According to (Awuchi, 2019)the average daily creation of plastic garbage is projected to be 15.4 billion pieces. Plastic garbage is the most widespread type of waste. These are the most often used material types in our daily lives. Massive amounts of plastic garbage are produced, including plastic bottles made of polyethylene terephthalate (PET), as well as plastic bags and carpets made of polypropylene (PP). Polyethylene products are widely regarded as the primary constituents of waste materials. Despite its numerous benefits in daily life, plastic has a detrimental effect on the environment and human health.

1.2 Problem statement

Most plastics are not biodegradable, and it can take from 20 to 500 years to decompose, depending on the material and structure (Armentrout, 2021). Also, it has a lot of harmful effects on the environment such:

- Kills Animals
- Litters the landscape
- Plastic bags block drains
- Plastic releases toxic when burned
- Plastic pollutes soil
- Plastic pollutes ocean
- Petroleum is required to produce plastic bags.
- Littering the Environment

➢ Hazard to Children.

As seen in figure 1 Microplastics in the surface ocean, 1950 to 2050

Microplastics are buoyant plastic materials smaller than 0.5 centimetres in diameter. Future global

accumulation in the surface ocean is shown under three plastic emissions scenarios: (1) emissions to the oceans stop in 2020; (2) they stagnate at 2020 emission rates; or (3) continue to grow until 2050 in line with historical plastic production rates.

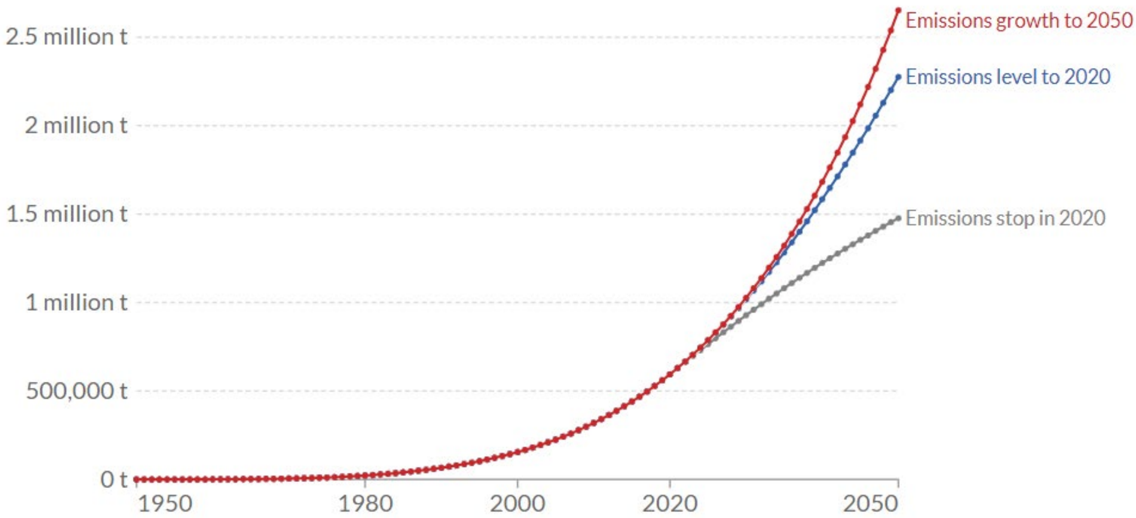

Figure 1 Microplastics in the surface of the ocean, since 1950 till 2050 (expected growth).
Source: Lebreton et al. (2019). A global mass budget for positively buoyant macroplastic debris in the ocean.

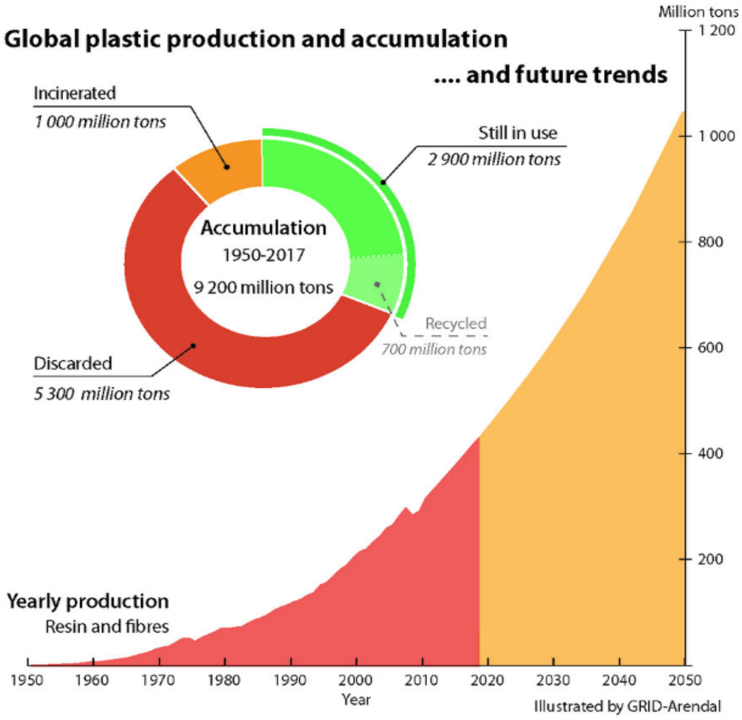

Figure 2 Global plastic production and accumulation over the years
source: UNEP-2021.

Global cumulative production of plastics since 1950 is forecast to grow from 9.2 billion tons in 2017 to 34 billion tons by 2050 (Geyer 2020).

Many countries are planning to decrease or prevent the effect of plastic materials through efficient recycling and reusing these materials in a wide range of fields.

Numerous researchers have conducted studies to determine efficient techniques for reducing the pollution caused by these materials, including recycling, and reusing them in civil engineering applications as a way to protect the environment from plastic waste material pollution. A practical application of these materials is to be used as stabilizing agent in road construction. Traditional soil stabilizers such as cement and lime are commonly employed to strengthen weak soils' geotechnical qualities; (Yadav et al, 2018) and (Yadav and Tiwari , 2016). Numerous investigations have confirmed the efficiency of these materials in improving the characteristics of soils (Bell, 1996); (Yadav and Tiwari , 2017); (Rasul et al, 2018). However, due to their widespread use, these materials are not cost-effective (Obo and Ytom, 2014). As a result, numerous researchers look for more cost-effective soil stabilizers, such as plastic, tire chips, and rice husk.

Plastic wastes can be used to stabilize soil, which benefits the pavement's foundation layers (Khattab et al., 2011) Thus, this can help solve the waste problem by reducing the quantity of garbage and recycling it for the purpose of strengthening the qualities of soils. One way to utilize plastic to stabilize soil is to use discrete fibers of plastic (Yetimoglu and Salbas, 2003) since when plastic materials are integrated into soils, they behave similarly to fiber-reinforced soil. Numerous studies have been undertaken to determine the efficacy of plastic waste products in the form of discrete fibers on soil characteristics (Babu and Chouksey, 2011); (Ahmadinia et al., 2012); (Modarres and Hamedi, 2014) (Peddaiah et al., 2018); (Kwestan Salimi & Mahmoud Ghazavi , 2019). These researchers discovered that stabilizing soils with plastic waste materials improves the attributes of weak soils by increasing unconfined compressive strength test (UCS), California bearing ratio (CBR), and Resilient modulus (Mr) and decreasing soil fluidity.

The purpose of this research is to determine the effect of utilizing plastic trash as fiber-shaped waste on the geotechnical parameters of soils. Numerous typical geotechnical laboratory tests were conducted to determine the effect of the length and content of randomly distributed fibers in the soil. These tests consisted of soil index properties, standard compaction test (proctor test), unconfined compressive strength test, California Bearing Ratio test, and resilient modulus tests.

1.3 Research questions

Main research questions:

- What is the optimal mixture and friendly approach to stabilize clayey soil with plastic waste materials?

Sub questions:

- Is it cost effective?
- How efficient is it compared to other soil stabilization methods (in terms of soil properties)?
- What is the environmental impact of this method?
- Is this method applicable in all the countries?
- What is the method effect on optimum moisture content and maximum dry density of the soil?
- Will the plastic melt under high temperatures?
- Does it increase the maximum axial compressive stress of the soil?
- Is it more effective than cement stabilized soil?

1.4 Goals and objectives

- ✓ The goal for this research is to investigate if mixing clayey soil with plastic increase its strength and cost effective of the pavement.
- ✓ To plastic strips with clayey soil in various percentages and determine the CBR values.

2. Theoretical framework

The properties of clayey soil in its natural existence appear to pose numerous challenges in civil engineering construction, which gives rise to new interventions of stabilization using plastic waste. The principal properties of expansion and contraction are the major basis of the theoretical presuppositions of clayey soil stabilization with plastic materials regarded as waste. In this regard, civil engineer experts have come to show interest in reinforcing clayey soil with polypropylene and sisal fibers to increase its shear strength through academic researches (Kassa et al, 2020) From a theoretical and practical context, stabilization alters the plasticity index of clayey soil, as changes in its volume and compressibility occur significantly. Stabilization of clayey soil with plastic matter involves the reduction on liquid limit of the soil and increase in its plastic limit, thus, enhancing the workability on its surface.

2.1 Clay soil:

The clay soil was collected from a lake near King Mariout in Alexandria city, as see in the figure below.

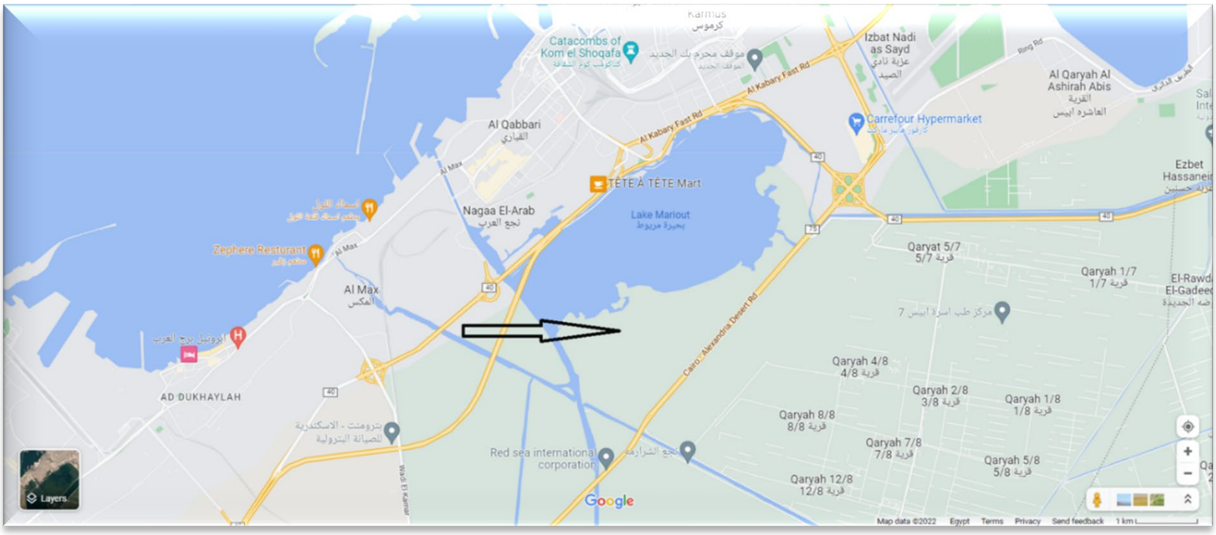

Figure 3 approximate location of soil sample

The sample is divided into four equal parts by removing two diagonally opposite parts and then mixing two remaining parts properly. The physical properties of the soil are shown in Table below; this soil is classified as clay soil according to the American Society for Testing and Materials (ASTM) with about 93% silt and clay.

Soil properties	Results	Standards
Specific gravity (Gs)	2.7	ASTM D854-02
Liquid limit (%)	48.2	ASTM D4318-00
Plastic limit (%)	29.1	ASTM D4318-00
Plasticity index (%)	19.1	ASTM D4318-00
Maximum dry density (kg/m3)	1645	ASTM D698
Optimum moisture content (%)	21	ASTM D698
Sand (%)	7	
Silt (%)	42	
Clay (%)	51	
Soil classification (USCS)	CL	ASTM D2487-00

Table 1 soil properties

Clay is a very important material in geotechnical engineering because it is often observed in geotechnical engineering practice. Generally, this soil type has numerous problems due to its low strength, high compressibility, and high level of volumetric changes. Clay needs to be improved before it can be used in road construction, dams, slurry walls, airports, and waste landfills. Improved gradation, a reduction in plasticity and swelling potential, as well as an increase in strength and workability, generally improve the stability of clay. Clay is a fine-grained soil, but not all fine-grained soils are clay. Clay minerals are very electrochemically active; thus, they affect soil microstructures. Due to these characteristics, many important soil problems related to clay have been observed in the past, the importance of which is understood.

The main concepts in clayey soil stabilization include the compaction characteristics, unconfined compressive strength test (UCST), and free swell test. The compaction characteristics concept involves the addition of lime and plastic shreds that have varying water content, then compacting the resulting mixture in molds standardized into different layers (Chakeri, 2022).However, the UCST concept involves stabilization trials using different plastic shreds but constant level of lime in compressing the mixture (Peddaiah et al, 2018). All these methods show improvement in the clayey soil's properties, which increases its suitability for civil engineering activities. Furthermore, coir fibers are helpful in stabilizing clayey soils, as they have high water retention capabilities, are non-toxic, abundant, and have low density, which are perfect properties for construction foundation. Therefore, it is important for a civil engineer researcher to consider the various concepts that exist for stabilization of clayey soil, as this will help reduce wastage of time and financial resources, as they are most important factors in the construction industry.

2.2 Plastic waste materials:

In this research, polyethylene terephthalate (PE) (water bottles) and polypropylene (PP) (woven polypropylene bags) wastes are used as fiber stabilizers as shown in Fig. 1. Plastic fibers were prepared by cutting waste bottles and bags into two sizes in lengths of 1.0 and 2.0 cm and in widths of 2.5 to 3.0 mm each as shown in Fig. 2. The fiber contents were applied at 1%, 2%, 3%, and 4% of dry weight of the clayey soil. The reason we didn't choose larger is because we wanted to limit the use and see what is the minimum quantity of plastic that could have a good side effect on the soil stabilization.

2.2.1 Plastic Waste Material

In this research, polyethylene terephthalate (PE) (water bottles) and polypropylene (PP) (woven polypropylene bags) wastes are used as fiber stabilizers as shown in Fig. 1. Plastic fibers were prepared by cutting waste bottles and bags into two sizes in lengths of 1.0 and 2.0 cm and in widths of 2.5 to 3.0 mm each as shown in Fig. 2. The fiber contents were applied at 1%, 2%, 3%, and 4% of dry weight of the clayey soil. The reason we didn't choose larger is because we wanted to limit the use and see what is the minimum quantity of plastic that could have a good side effect on the soil stabilization.

Figure 4 plastic waste materials

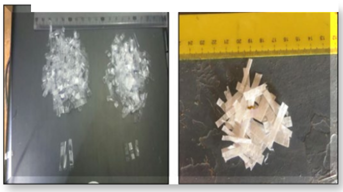

Figure 5 Sample of the fibers used

2.3 Climate in Egypt

Egypt's climate is dry, hot, and dominated by desert. It has a mild winter season with rain falling along coastal areas, and a hot and dry summer season (May to September). Daytime temperatures vary by season and change with the prevailing winds.

As the figure 6 below, that the average temperature all over Egypt is 30°c.

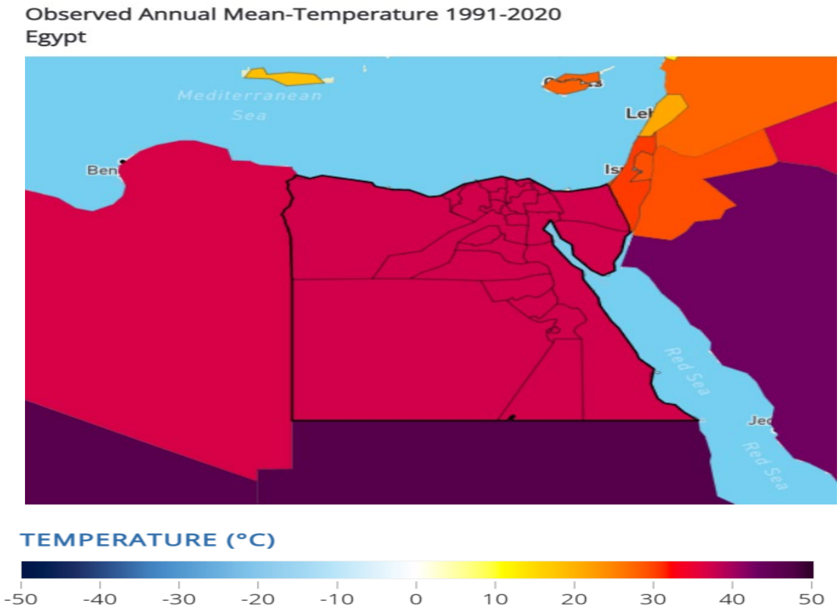

Figure 6 Climate in Egypt

2.4 Pavement and temperature

The elasticity modulus values of a flexible pavement layer decrease with increasing temperature. In contrast, the elastic modulus values increase when the temperature of the flexible pavement layer is decreased.

Low temperature cracking is the most prevalent distress found in asphalt pavements built in cold weather climates. As the temperature drops the restrained pavement tries to shrink. The tensile stresses build up to a critical point at which a crack is formed, which means in low temperature environment, since in Egypt is high temperature environment.

The high temperature of pavement makes the asphalt softer, thus the risk is high that heavy vehicles cause rutting due to the plastic deformation, which will decrease the pavement evenness and consequently affect the traffic safety.

2.4 Steps to be taken throughout the research

To evaluate that mixing clayey soil with plastic materials is efficient, the following steps needs to be taken:

Mixing the clayey soil with plastic fibers for all the laboratory tests, the adopted content of fibers will be manually mixed into the air-dried soil in small increments. Considerable care was taken to achieve homogeneous mixture during the mixing process. Then, the required water will be added

2.5 Laboratory tests:

Compaction test: the purpose behind the test aims to establish the maximum dry density that may be attained for the soil sample with a standard amount of compaction effort. When a series of soil samples are compacted at different water content, the plot usually shows a peak (the main purpose is to yield the maximum density) (dry unit weight).

Unconfined compressive strength test: The primary purpose of the Unconfined Compression Test is to determine a measure of the unconfined compressive strength of rocks or fine-grained soils in this case will be the soil that possess sufficient cohesion to permit testing in the unconfined state (measuring the maximum amount of compressive load a material can bear before fracturing).

California bearing ratio test: the primary purpose of the California bearing ratio test for the evaluation of subgrade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers in other terms to evaluate the strength of soil subgrades and base course materials and from that determine the thickness).

Resilient modulus (triaxial test): enables parameters such as cohesion (c'), internal angle of friction (ϕ') and shear strength to be determined. The triaxial test can also be used to determine other variables such as stiffness and permeability with the correct equipment. (It helps measure of fundamental material property, dynamic load testing similar to traffic loading and essential input in mechanistic-empirical pavement design.

2.6 Preform calculations to determine the subbase thickness using Odemark formula:

1) Odemark formula Odemark's (J) equivalent-layer-thickness (ELT) concept is often used as a simple method of approximation in pavement structural analysis since it permits the conversion of a multi-layered system into a single layer with equivalent thickness.
2) Perform several calculations to determine the thickness of asphalt when the sub-base is mixed with plastic and compare it to the native soil.
3) Compare this soil stabilization technique with cement stabilization technique.
4) Determine the thickness of the asphalt thickness for both situations and compare them to check which one is more effective.
5) Preform cost estimation for both techniques.
6) All the calculations will be done using Kenpave program and MS excel based on the formula and results from the program and plot a graph to be easier for understanding.
7) Research the ecological impacts of microplastics in the soil and cement.

2.7 Kenpave

Calculate stresses, strains, and deformations in flexible and rigid pavements using KENPAVE, a computer program for pavement analysis and design. The software KENPAVE was developed by YANG H. HUANG in 1993. professor emeritus of civil engineering in the University of Kentucky, is used to simulate typical flexible and rigid pavement designs. The packages that form KENPAVE software consists of LAYERINP, KENLAYER, SLABSINP and KENLAYER. KENSLABS. KENPAVE supports both English and SI units. The KENLAYER computer program applies only to flexible pavements with no joints or rigid layers. For pavements with rigid layers, such as PCC and composite pavements, the KENSLABS program should be used. The backbone of KENLAYER is the solution for an elastic multilayer system under a circular loaded area. The solutions are superimposed for multiple wheels, applied iteratively for non - linear layers, and collocated at various times for viscoelastic layers.

As a result, KENLAYER can be applied to layered systems under single, dual, dual-tandem, or dual-tridem wheels with each layer behaving differently, either linear elastic, nonlinear elastic, or viscoelastic. Damage analysis can be made by dividing each year into a maximum of 12 periods, each with a different set of material properties. Each period can have a maximum of 12 load groups, either single or multiple. The damage caused by fatigue cracking and permanent deformation in each period over all load groups is summed up to evaluate the design life

2.8 Cement stabilized soil

By combining subgrade soil with cement and water, soil cement stabilization is a construction technique used to strengthen the soil's strength. The water hydrates the cement, causing chemical processes that form a matrix between the soil particles and improve soil strength to the soil.

3. Methodology

3.1 Answering the sub questions

In the following section, the answering of all sub questions will be briefly discussed. First of all, the activities will be described that have or will be done to answer these questions.

Secondly, the final product, that will answer the sub question, will be specified. Finally, the types of sources used to answer the sub question will be listed.

“Is it cost effective?”

This question will be answered in the section of results when the estimation of the asphalt thickness is done based on when the is subbase mixed with plastic fibers and compared to cement stabilized technique.

“How efficient is it compared to other soil stabilization methods (in terms of soil properties)?”

This question will be answered in the results chapter when the calculations for clayey stabilized soil with plastic fibers and cement are done and being compared.

“What is the environmental impact of this method?”

The environmental impact of this method will be covered in the discussion part under the title ecological impact, the task isn’t yet completed but as far as the research goes there are bad side effects of the micro plastics being in the soil because it effects the plant growth and the micro-organisms.

“What is the method effect on optimum moisture content and maximum dry density of the soil?”

Based on the results drawn from the compaction test, the optimum moisture content and maximum dry density of stabilized soils are lower than those of native soils, as the fiber content increases.

“Will the plastic melt under high temperatures?”

Generally speaking, the plastic will melt under high temperatures, but to avoid such situation, a layer of sand separating the pavement and the stabilized soil will prevent such situation from happening. (This question will be discussed in the results and discussion section)

“Does it increase the maximum axial compressive stress of the soil?”

Yes, it does increase the maximum axial compressive stress of the soil. Based on the unconfined compressive strength test, the soil stabilized with 1.0-cm and 2.0-cm-length PE fiber, the optimum fiber content was 1%. UCS improved from 148 kPa (native soil) to 261 kPa (1.0-cm fiber length) and 291 kPa (2.0-cm fiber length), a 76.4 and 96.6 percent improvement, respectively. The lowest increase in UCS occurred at a fiber content of 4% for 1.0-cm fiber length and 2% for 2.0-cm fiber length.

Similarly, the optimal fiber percentage for soil stabilization with 1.0-cm and 2.0-cm lengths of PP fiber was 1%. UCS increased from 148 kPa (native soil) to 233 kPa (1-cm fiber length) and 256 kPa (2-cm fiber length), representing a 57.4 and 73% improvement, respectively. The lowest increase in UCS occurred at a fiber content of 4% for 1.0-cm fiber length and 2% for 2.0-cm fiber length

“Is it more effective than cement stabilized soil?”

The answer for this question will be discussed in the results chapter specifically the comparison part between plastic stabilized fiber soil and the cement stabilized fiber content

3.2 Standards being followed throughout the research

TEST	STANDARD
COMPACTION TEST	ASTM D698
UNCONFINED COMPRESSIVE STRENGTH TEST	ASTM D2166
CALIFORNIA BEARING RATIO	ASTM D1883
RESILIENT MODULUS (TRIXIAL TEST)	AASHTO T307

Table 2 Test standards

3.2.1 What is the ASTM standard?

ASTM International, formerly known as American Society for Testing and Materials, is a global leader in developing voluntary consensus standards used by individuals, companies, and other institutions around the world. ASTM is made up of over 30,000 volunteer members from more than 140 countries.

The organization meets the criteria for international standards developing organizations as set forth by the World Trade Organization. The entire membership of the ASTM elects a board of directors to govern and make decisions.

Scientists, engineers, architects, and government agencies rely on ASTM safety standards to ensure the quality and consistency of materials. While these standards are voluntary, they are mandatory when authorities need to cite them in contracts, government codes, regulations, or laws.

ASTM standards are crucial in evaluating the material, chemical, mechanical, and metallurgical properties of metals. This information helps guide product manufacturers toward proper processing and application procedures.

3.2.2 What is the AASHTO standard?

The American Association of State Highway and Transportation Officials (AASHTO) is a standard setting body which publishes specifications, test protocols, and guidelines that are used in highway design and construction throughout the United States. The reason this standard is being followed in this study is because there are a lot of values, procedures, and common standard (although not many) being used in Egypt that has been derived from the American standards with some differences for example in the safety factors, but procedures of testing or anything similar is the same between both countries.

3.2.3 Difference between ASTM and AASHTO?

AASHTO focuses on writing standards that meet the needs of the domestic transportation industry, ASTM International focuses on writing standards that meet the needs of all the world's industries. They maintain standards covering crayons to field goal posts and everything in between.

3.4 Multi criteria analysis

For a clear and easier to understand comparison between clayey stabilized soil using plastic fibers and cement stabilized soil, a multi-criteria analysis (MCA) will be done. The goal of this MCA is to determine which one is better overall.

Asphalt thickness

The asphalt thickness is a defining factor in this regard since it will play a big role in how much would it cost to use such method and how reliable could it be to withstand high traffic load

Ecological impact

The ecological impact of mixing the soil with plastic fibers or cement on the long-term and how would it effect the micro-organisms of the soil and the plant growth.

Cost effectiveness

Which one is more cost effective when it’s compared under different traffic loads?

3.5 Grading of multi criteria analysis

Criteria

Asphalt thickness, Ecological impact, and cos effectiveness.

The grading will be varying from -2 to be very unfavorable, -1 unfavorable, 0 neutral, +1 to be favorable and +2 very favorable.

3.6 Laboratory Tests

Numerous laboratory tests are conducted to determine the strength and mechanical properties of both native and stabilized soils, including the determination of unstabilized soil index properties and standard proctor compaction, the unconfined bearing ratio test, the California bearing capacity (soaked), and the resilient modulus for stabilized and unstabilized soils.

All tests are performed in line with ASTM standards, except for the resilient modulus, which are performed in accordance with AASHTO T307. For all tests, the adopted content of fibers is first manually mixed into the air-dried soil in small increments. During the mixing process, great care is taken to ensure a homogeneous mixture. Then, the required water was added as shown in Fig. 3.

Figure 7 Mixing of fibers with clayey soil

3.6.1 Compaction Test

The laboratory compaction tests are performed in accordance with the ASTM D698 procedure. The purpose of this test is to determine the effect of plastic fiber on optimum moisture content (OMC) and maximum dry density (MDD) of stabilized soils and to use the optimum moisture content that is obtained in this test for preparing samples for unconfined bearing ratio, California bearing ratio, and resilient modulus tests, dry density, and optimum moisture content.

3.6.2 Unconfined Compressive Strength Test

The purpose of this test is to determine the effect of incorporating plastic waste pieces on the unconfined compressive strength of soils. The test is conducted according to ASTM D2166. All the unconfined compressive test specimens are prepared at their respective maximum dry density and optimum moisture content. All prepared specimens were air-dried in the open laboratory environment and were cured for 7 days.

3.6.3 California Bearing Ratio Test

For the California bearing ratio test, cylindrical specimens are formed in a rigid metallic cylinder mold with an internal diameter of 150 mm and a height of 175 mm, utilizing their maximum dry density at optimal moisture content. A mechanical loading machine equipped with a movable base that moves at a uniform rate of 1 mm/min and the calibrated proving ring is used to record the load. For this, static compaction is carried out through keeping the mold assembly in the compression machine and compacting the soil by pressing the displacer disc till the level of the disc reaches the top of the mold. This examination is conducted in compliance with ASTM D1883. The soaked specimens in this research are prepared at the optimal moisture content as determined previously by the standard compaction test. (This test helps in knowing the thickness of the pavement)

3.6.4 Resilient Modulus

The repeated load from a triaxial test has also been conducted in this research to investigate the effect of plastic material stabilizers on resilient modulus values that represent the mechanical property of the soils. This parameter is significantly important to assess the performance of material under the repeated load of moving vehicles. In this test, a series of repeated loads are applied to the soil samples including the rest period. This test is conducted by using an ELE triaxial device (ELE is an International company that specialises in the design, manufacture and supply of high-quality construction materials testing equipment and environmental instrumentation.) and in accordance with the AASHTO T307 testing protocol as this standard is mostly used for determining resilient modulus in the laboratory. The haversine type of load is used with duration of a 0.1-s and 0.9-s recovery period. The sample dimensions are 100 mm in diameter and 200 mm in height. The curing period for all samples were 7 days. AASHTO T307 standards recommend three confining stresses in three cycles (41.36, 27.57, and 13.78 kPa) and five deviatoric stresses (13.79, 27.58, 41.39, 55.161, and 68.95 kPa).

Sequence number	Confining pressure (kPa)	Cyclic stress (kPa)	Constant stress (kPa)	Load cycle no.
0	41.37	24.82	2.76	1000
1	41.37	12.41	1.38	100
2	41.37	24.82	2.76	100
3	41.37	37.23	4.14	100
4	41.37	49.64	5.52	100
5	41.37	62.05	6.89	100
6	27.58	12.41	1.38	100
7	27.58	24.82	2.76	100
8	27.58	37.23	4.14	100
9	27.58	49.64	5.52	100
10	27.58	62.05	6.89	100
11	13.79	12.41	1.38	100
12	13.79	24.82	2.76	100
13	13.79	37.23	4.14	100
14	13.79	49.64	5.52	100
15	13.79	62.05	6.89	100

Table 3 Resilient modulus loading sequence

3.7 Results

3.7.1 Assumptions

Traffic load

To determine asphalt thickness, you must consider the traffic load according to the fatigue formula as you can see in the formulas below, however you need to consider the E value which it should be constant along with the vertical displacement as you can also see below in the table 4 which is considered according to the traffic load. As stated from the book pavement analysis and design by Yang H. Huang.

Traffic classification		
Type of street or highway	**Range of heavy trucks expected in design period**	**ESAL**
Residential streets. **Rural farm and residential roads**	**7000 to** **15,000**	**10^4**
Urban minor collector streets **Rural minor collector roads**	**70,000 to** **150,000**	**10^5**
Urban minor arterial and light industrial streets. **Rural major collector and minor arterial highways**	**700,000 to** **1,500,000**	**10^6**
Urban interstate highways and **Some industrial roads**	**7,000,000 to** **15,000,000**	**10^7**

Table 4 Traffic load classification
Source: pavement design and analysis

Fatigue crack model

Miner's (1945) cumulative damage concept has been widely used to predict fatigue cracking. It is generally agreed that the allowable number o f load repetition is related to the tensile strain at the bottom of the asphalt layer. The amount of damage is expressed as a damage ratio between the predicted and the allowable number of load repetitions. Damage occurs when the sum of damage ratios reaches the value 1. Because of variabilities, damage will not occur all at once when the ratio reaches exactly 1. If mean parameter values are used for design, a damage ratio o f 1 indicates that the probability of failure is 50%—that is, that 50% of the area will experience fatigue cracking.

By assuming the damage ratio to have a log normal distribution, the probability of failure, or the percentage of area cracked, can be computed, and checked against field performance. The major difference in the various design methods is the transfer functions that relate the HMA tensile strains to the allowable number of load repetitions. In the Asphalt Institute and Shell design methods, the allowable number of load repetitions Ni to cause fatigue cracking is related to the tensile strain e t at the bottom of the HMA and to the HMA modulus E2 by

$$N_f = ff(\varepsilon t)^{-f2} (E1)^{-f3}$$

For the standard mix used in design, the Asphalt Institute equation for 20% of are a cracked is

$$N_f = 0.0796\,(\varepsilon t)^{-3.291} (E1)^{-854}$$

and the Shell equation is

$$Nf = 0.0685(\varepsilon t)^{-5.671} (E1)^{-2.363}$$

Subsoil

The subsoil is formed of clayey soil mixed with plastic waste materials with a 1590 kg/m^3 and 17%, and increase of its compressive strength by 96.6%, with CBR value increased by of 80%, and 22% increase of Mr. values.

Temperature:

The Temperature is assumed to not have any effect on the plastic mixed with the soil since there will be a layer of sand around 20cm separating the stabilized soil from the asphalt layer.

3.8 Test results

3.8.1 Compaction Test

Compaction tests on native soils and soils stabilized with PE and PP stabilizers of 1.0 cm and 2.0 cm in length at various stabilizer content ratios are shown in Figures 4-11. The OMC was 21% and the MDD was 1645 kg/m3 for native soil.

Figure 8 proctor test/ compaction test

Figure 9 Removal of the compacted sample with an extruder

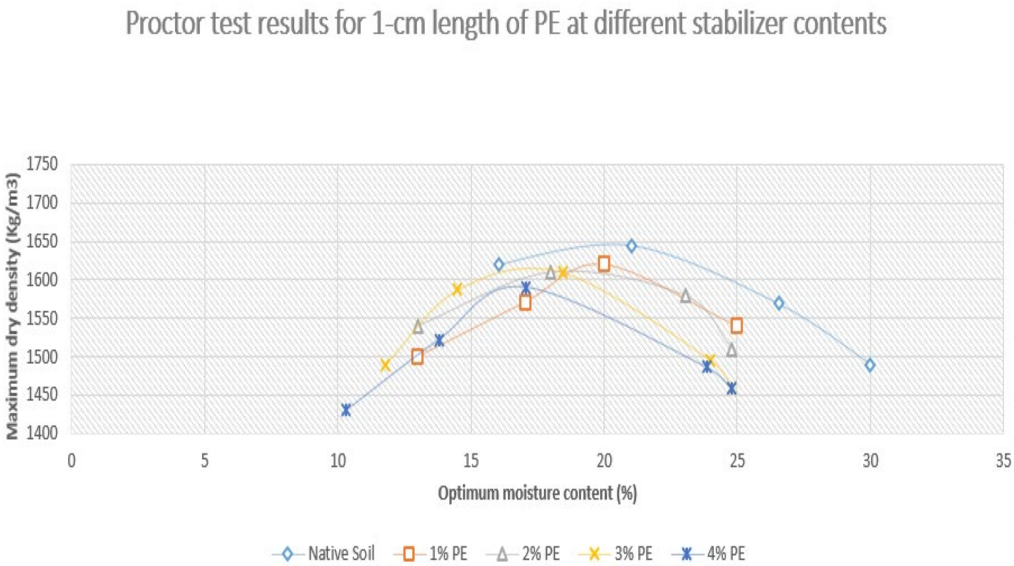

Figure 10 Proctor test results for 1cm of PE

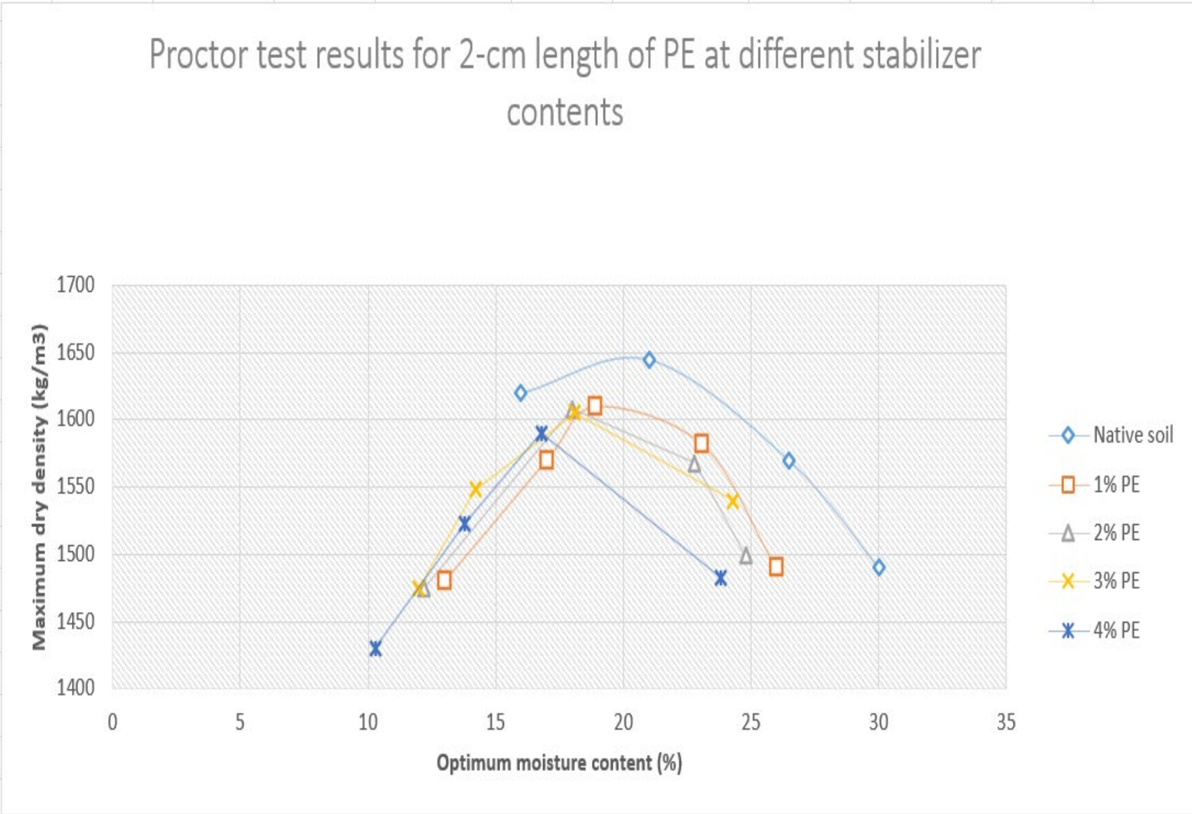

Figure 11 Proctor test results for 2 cm length of PE at different stabilizer contents

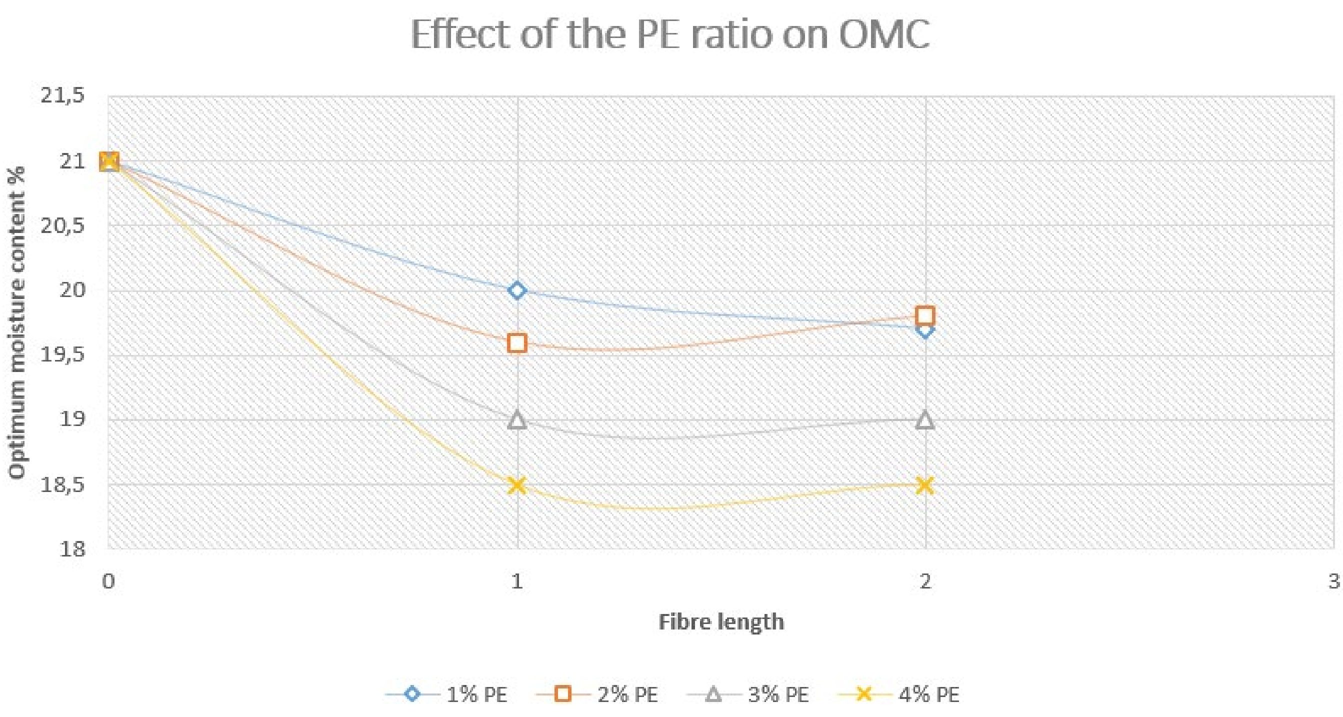

Figure 12 Effect of PE ratio on OMC

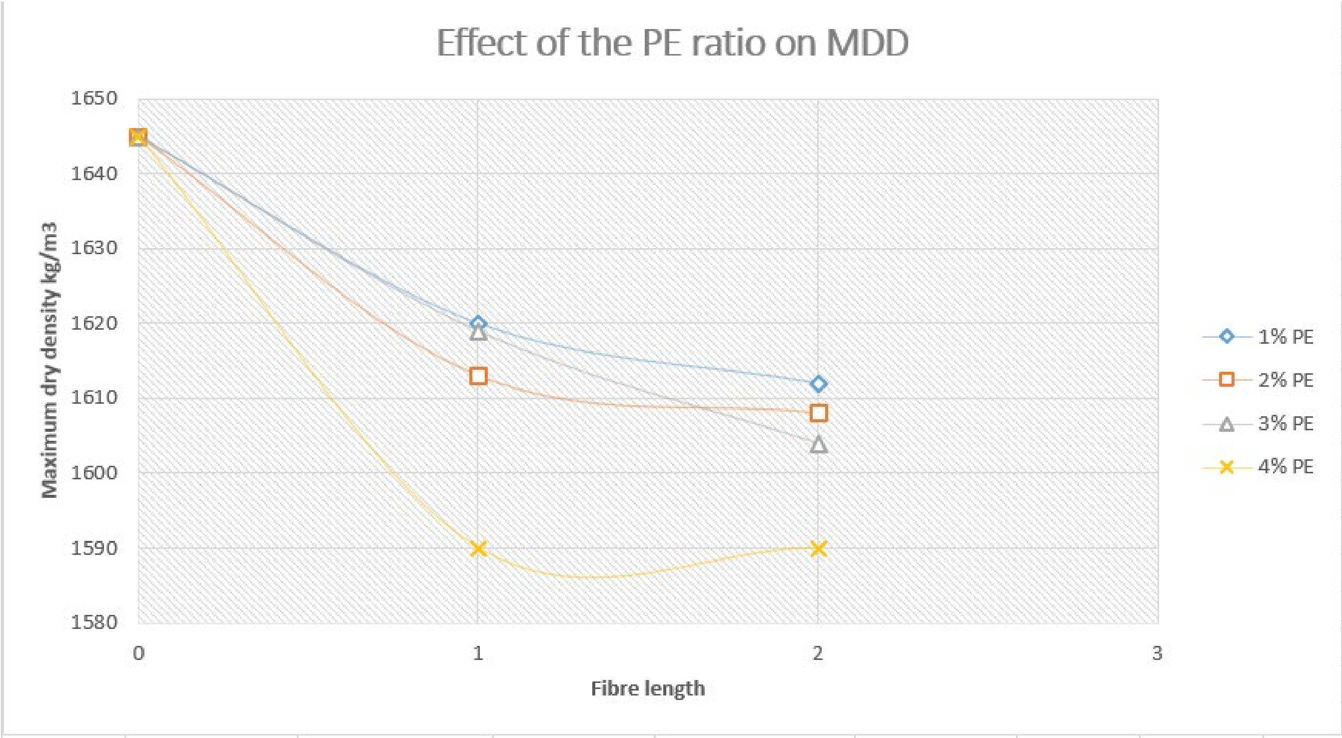

Figure 13 Effect of the PE ratio on maximum dry density

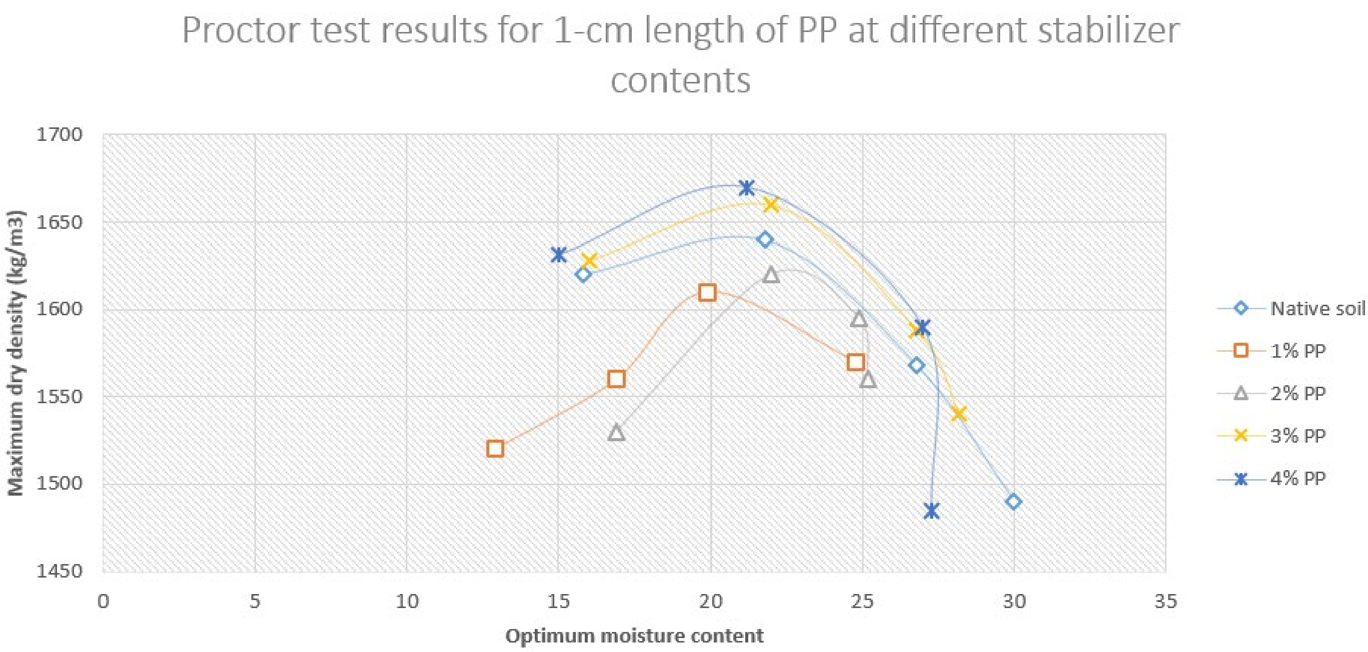

Figure 14 Proctor test results for 1-cm of PP at different stabilizer contents

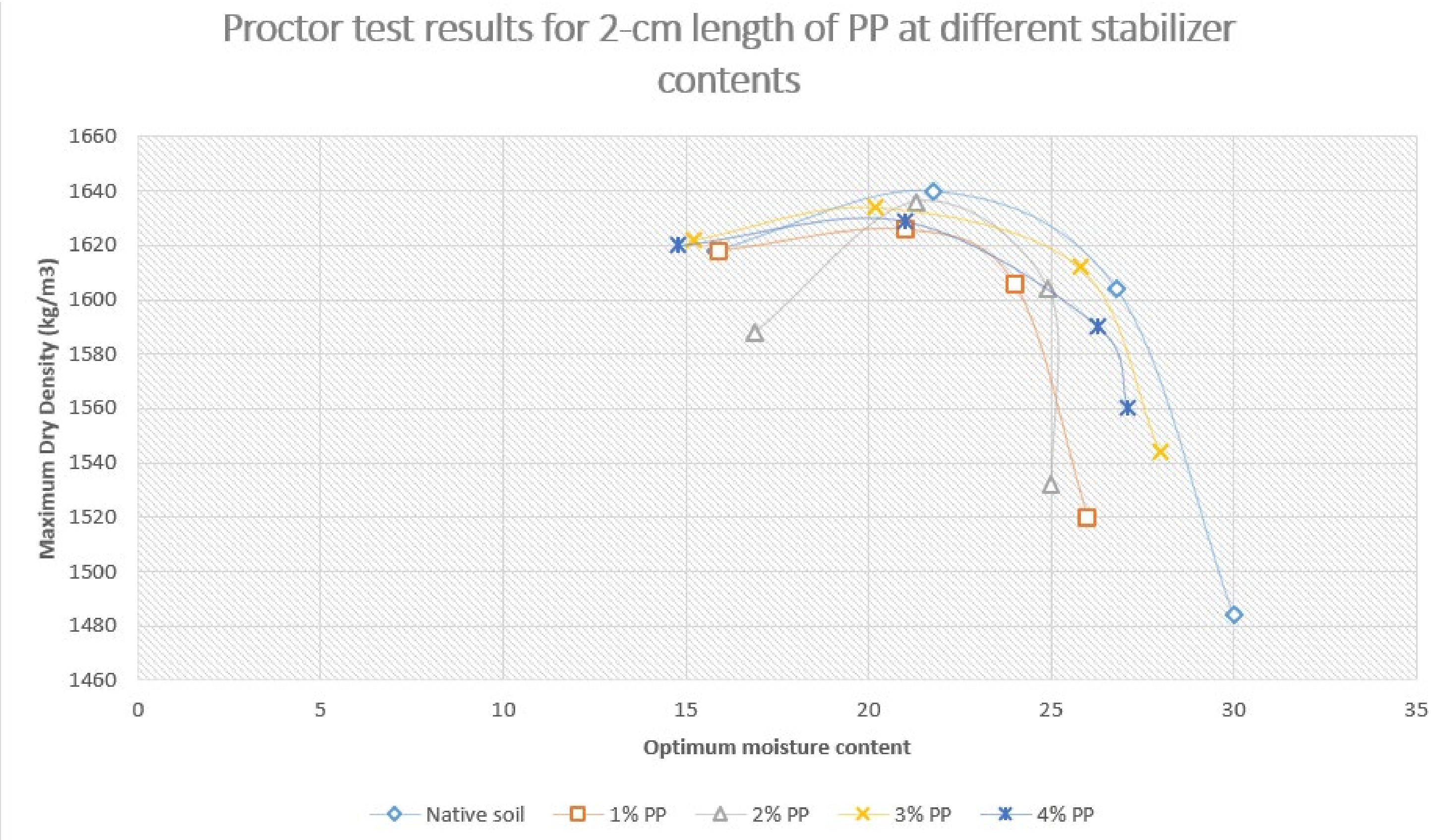

Figure 15 Proctor test results for 2-cm of PP at different stabilizer contents

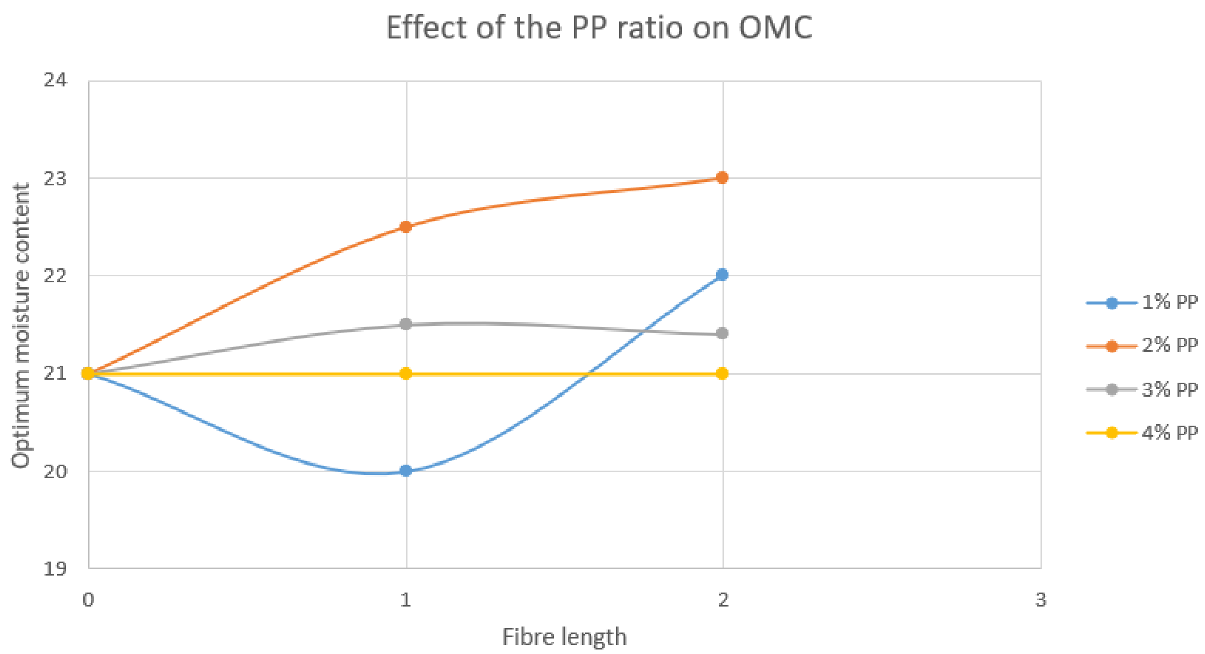

Figure 16 Effect of PP ratio on optimum moisture content

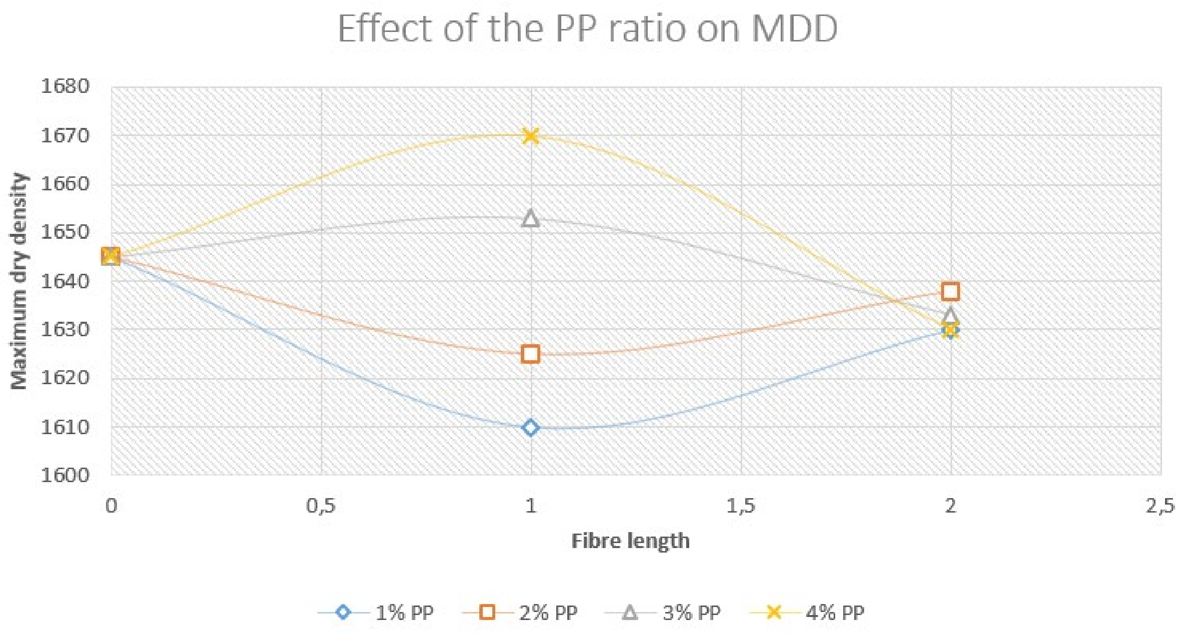

Figure 17 Effect of the PP ratio on MDD

As demonstrated by the compaction test findings, the optimum moisture content and maximum dry density of stabilized soils are lower than those of native soils (unstabilized soil). Both qualities degrade as the fibre content increases. These are noticeable in Figures. 10 and 11. This consistent impact of increasing the fibre content is not noticeable in the stabilisation using PP fibres (see Figures. 10- 17).

The results indicated a similar trend in terms of the optimum moisture content decrease for soils stabilised with PE at various fibre contents of 1.0 cm and 2.0 cm in length. The results indicated that raising the PE % resulted in a drop in the optimum moisture content. The decrease value for PE with a length of 1.0 cm or 2.0 cm ranges from 20% for a 1% PE content to 17% for a 4% PE content.

Similarly, the maximum dry density for both lengths at all fibre contents decrease in value as the PE percent increases. The greatest reduction of 55 kg/m3 is observed at 4% fibre content for both lengths. These data demonstrate unequivocally that the increase in the percentage of PE results in a decrease in both the optimum moisture content and maximum dry density values; additionally, increasing the length of PE from 1.0 to 2.0 cm results in a greater decrease in the optimum moisture content, as shown in Figures 15 and 16, with the exception of maximum dry density at 3%, which exhibits an odd trend. These findings were consistent with those of (Bala, 2013), (Hussain, 2018), splits the PE into 1.0 cm, 2.0 cm, and 3.0 cm lengths at various fibre contents of 0%, 0.20%, 0.50%, 0.80%, and 1.00% of the dry weight of soil. Scientists find that when the plastic's length and content rise, the value of maximum dry density decreases. They find that the greatest decrease occurred at a plastic content of 1% of the dry weight of the soil and a plastic strip inclusion length of 3.0 cm. This research has demonstrated that increasing the plastic content of soils reduces both the optimum moisture content and maximum dry density. The greatest reduction was observed at an 8% plastic level.

Soil stabilized with PP at various fibre contents of 1.0 cm and 2.0 cm exhibited varied the optimum moisture content and maximum dry density behaviour. maximum dry density was found to be reduced by 35 and 20 kg/m3 for 1.0-cm lengths with a 1% and 2% fibre content, respectively. However, that, by increasing the fibre content by 3% and 4%, maximum dry density increases by 20 and 30%, respectively. maximum dry density decreases with increasing PP content in fibres with a 2.0-cm length. This is due to the fact that plastics are not absorbent materials compared to clay soils, which have high affinity to water due to its surface tension. The greatest drop occurs at a 4% fibre content of 25 kg/m3. (Feng, 2020) study the mechanical properties of clayey soils using polypropylene fibre (PF) with a length of 12.0 mm. Scientists did find that the soil with PF contents of 0%, 1.50%, 2.250%, and 3% by weight. Their study reveals that the increase in the fibre content results in an increase in maximum dry density and a decrease in the optimum moisture content when the fibre content increases to a maximum of 3%.

3.8.2 Unconfined Compressive Strength (UCS) Test

As shown in table 5 below, the addition of PE and PP fibre significantly increased the stabilized soil strength in comparison to the native soil strength of 148 kPa. However, this increase in UCS has a limit dependent on the fibre content ratio, as seen in Figure. 20, where the increase in fibre content is

Figure 18 UCS test device in the laboratory

limited to 1%; afterwards, the curve flattens and maintains the same strength despite the increase in fibre content. When PE and PP are compared, the former exhibits greater UCS values than the latter for 1.0-cm and 2.0-cm fibre lengths. In all situations, the findings for fibres with a 2.0-cm length are greater than those for fibres with a 1.0-cm length.

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%)

Table 5 UCS test results

For soil stabilized with 1.0-cm and 2.0-cm-length PE fiber, the optimum fiber content was 1%. UCS improved from 148 kPa (native soil) to 261 kPa (1.0-cm fiber length) and 291 kPa (2.0-cm fiber length), a 76.4 and 96.6 percent improvement, respectively. The lowest increase in UCS occurred at a fiber content of 4% for 1.0-cm fiber length and 2% for 2.0-cm fiber length.

Similarly, the optimal fiber percentage for soil stabilization with 1.0-cm and 2.0-cm lengths of PP fiber was 1%. UCS increased from 148 kPa (native soil) to 233 kPa (1-cm fiber length) and 256 kPa (2-cm fiber length), representing a 57.4 and 73% improvement, respectively. The lowest increase in UCS occurred at a fiber content of 4% for 1.0-cm fiber length and 2% for 2.0-cm fiber length (Muntohar, 2009) stated that when fibers are used to stabilize soils, the applied load is transmitted to the frictional interface between the soil particles and the fibers. Increased fiber content results in increased interfaces between soil and fibers, which results in increased friction between soil particles and fibers (Olgun, 2013). This makes it more difficult for soil particles around the fibers to shift their position, hence increasing soil cohesiveness (Muntohar et al, 2013). Additionally, the high tensile strength of fiber contributes significantly to the soil's ability to bear additional loads and improve its UCS (Tang et al, 2007)). Given that PE has a higher tensile strength than PP, soils stabilized with PE have a higher UCS than soils stabilized with PP.

As seen in table 5, increasing the fiber content increases the UCS up to a certain point and subsequently declines. According to (Naeini and Sadjadi, 2008), increasing the fiber content over a certain percentage result in the sliding of fiber panels over one another and the separation of soil particles, hence decreasing the soil's strength (The increase in cohesion of soil-fibre matrix may be due to the increase in the confining pressure because of the development of tension in the fibre, and the moisture in the fibre helps to form absorbed water layer to the clay particles, which enables the reinforced soil to act as single coherent matrix of soil fibre mass. The decrease in cohesion of soil-fibre matrix with addition number of fibres (more than 2% fibre content) may be due to separation of clay particles due to the addition of fibres) of the soil is with increase of physical stress since it will end. The UCS results shown unequivocally that longer fiber lengths (2.0 cm) increase in strength more than shorter fiber lengths (1.0 cm). Soils were stabilised with fibres; the fibre transferred the applied load to the frictional interface between soil particles and fibres. As fibre contents increase, the interfaces between soil and fibres increase, and this leads to increasing the friction between soil particles and fibres (Olgun 2013). This makes it difficult for soil particles that are surrounding the fibres to change their position and thus enhance the soil cohesion between soil particles. Numerous researchers have examined the influence of PE on soil UCS, with similar (Puppala and Musenda, 2007) (Ghorbani et al., 2018); (Oliveira et al., 2018); (Sharma, 2017); (Louzada et al., 2019) Their findings indicate that the addition of PE and PP to soil considerably increases its UCS. However, a further research and investigation should be carried to determine the optimum fiber content that produces the highest UCS value as show in figure 19. for example, a small fraction can be tried such as 0.5% increments.

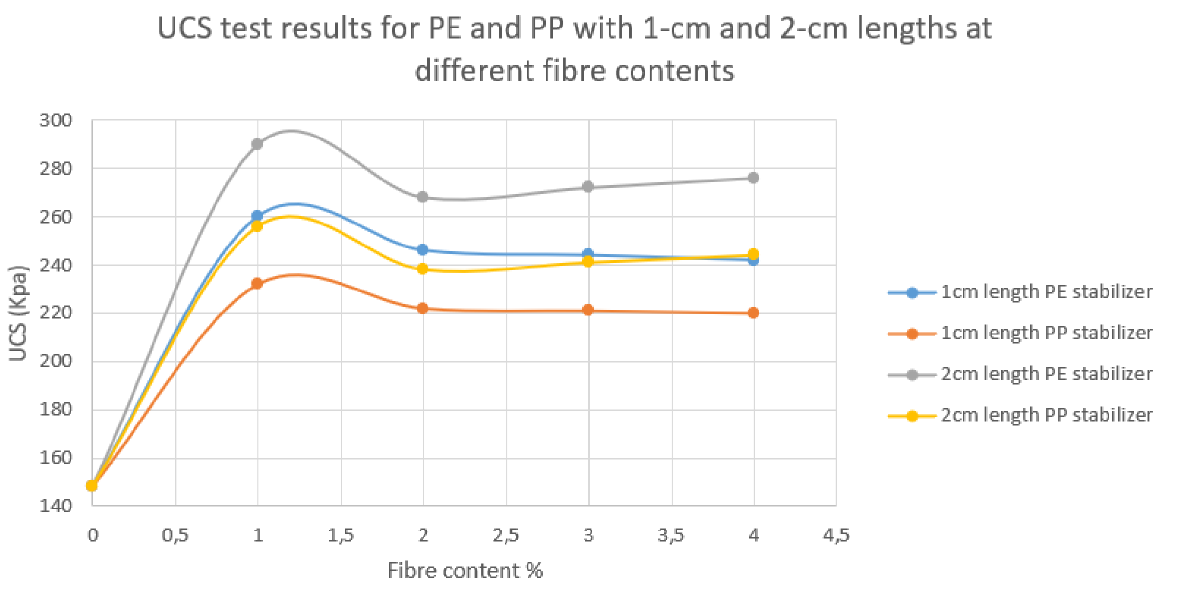

Figure 19 unconfined test results of PE and PP with 1-cm and 2-cm lengths at different fiber contents

The decrease at 2% fiber content is due to moisture content as shown in previous graphs the optimum moisture content increased at 2%, thus clay particles shrink and pull more tightly to each other causing cracks in the ground

3.8.3 California Bearing Ratio (CBR) Test

The table below presents the data of the CBR test. The CBR value for the native soil was 4 %. As it can be observed, the addition of PE and PP fiber to the clayey soil improved the strength greatly compared to the native soil strength. In addition, this increase in CBR may be observed with an increase in the fiber content ratio for both types of stabilizers and fiber lengths. The comparison between PE and PP demonstrates that the first one has higher CBR values than the second one for 1.0-cm and 2.0-cm lengths of the fiber. Figures 20-23 demonstrate the profile of penetration versus the load in the CBR test increasing CBR by 55% (from 4.0 to 6.2) and 80% (from 4.0 to 7.2), respectively.

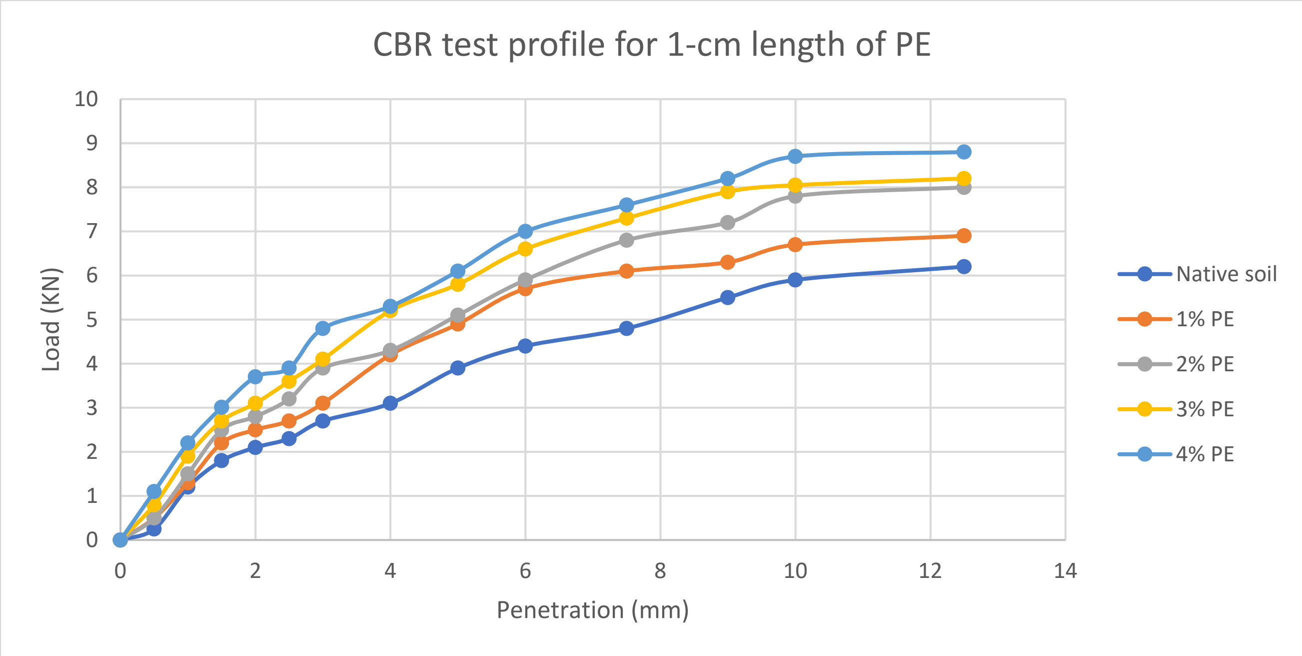

Figure 20 California bearing ratio for 1-cm length of PE

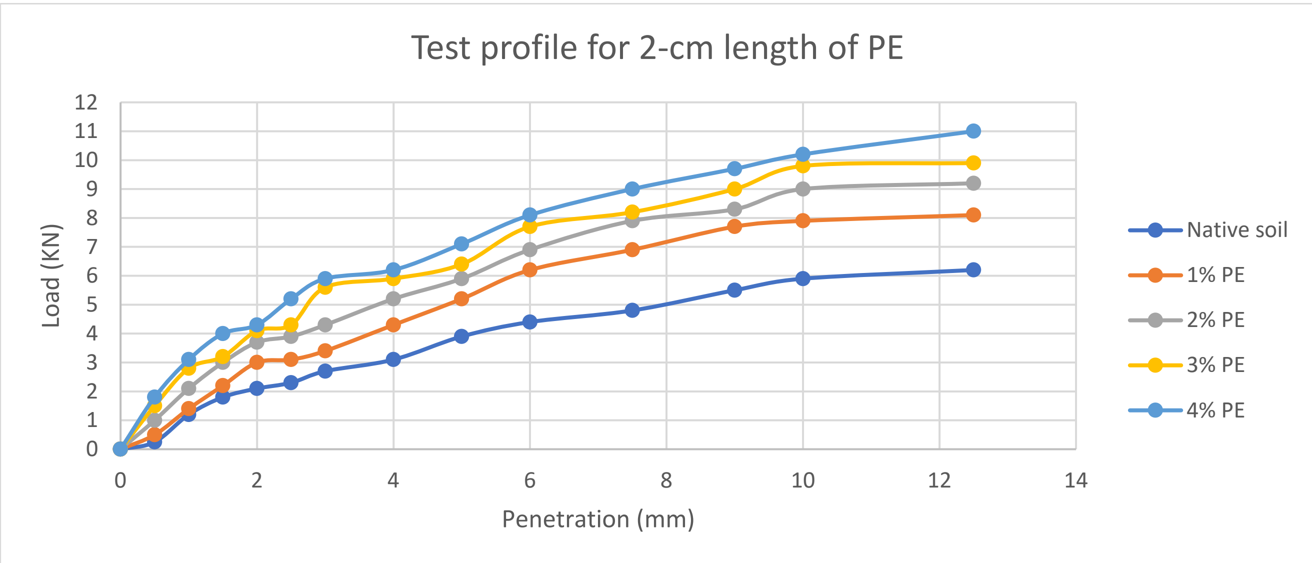

Figure 21 Test profile for 2-cm length of PE

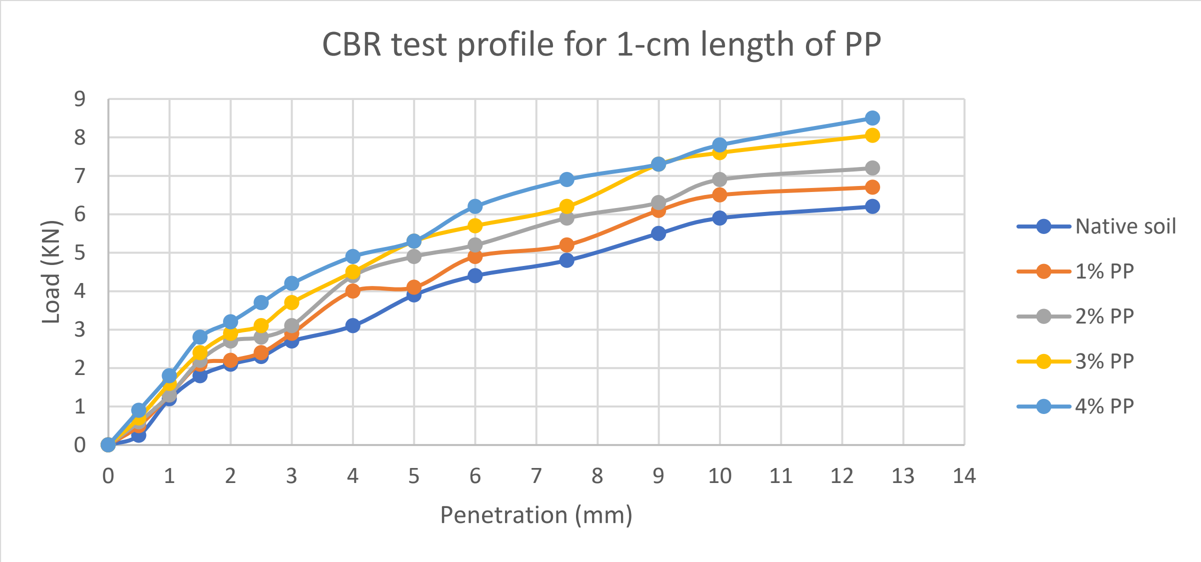

Figure 22 California test profile for 1-cm length of PP

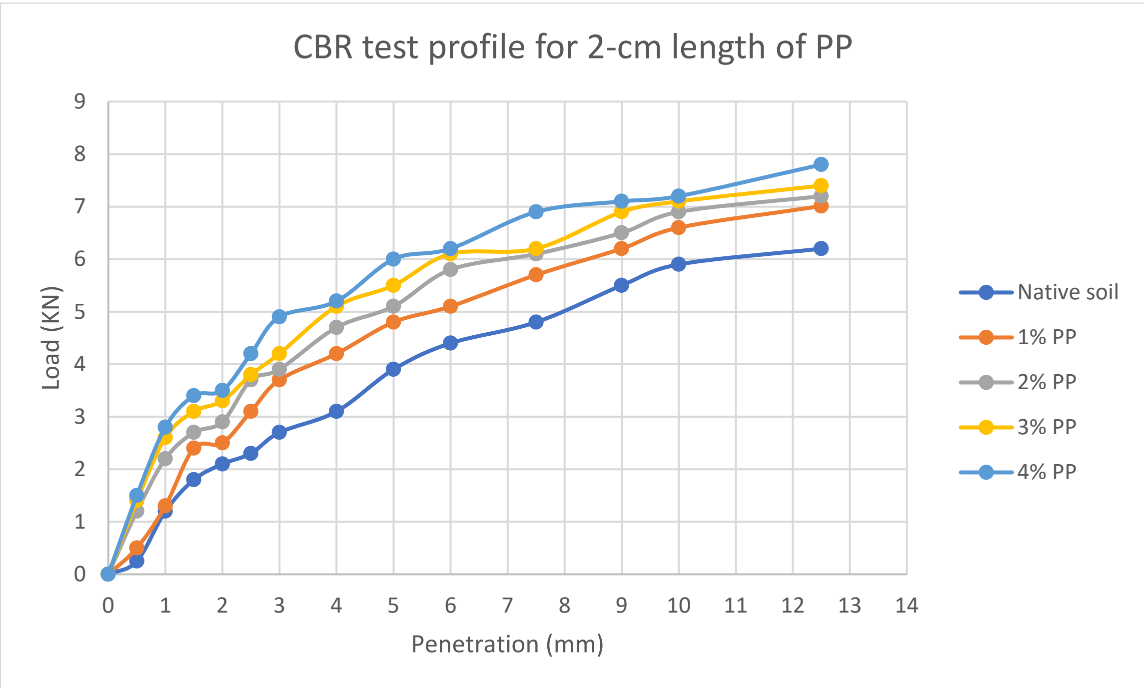

Figure 23 California bearing ratio test profile for 2-cm length of PP

The addition of 1.0-cm and 2.0-cm lengths of PE fiber improved the CBR values of the soil stabilized with PE by 55% (from 4.0 to 6.2) and 80% (from 4.0 to 7.2), respectively. Additionally, adding 1.0-cm and 2.0-cm lengths of PP fiber improved CBR by 42.5 percent (from 4.0 to 5.7) and 50% (from 4.0 to 6.0), respectively, for the soil stabilized with PP. These findings clearly demonstrated that fiber content and fiber length had a considerable influence on CBR values, which (corroborated, 2011). Increases in the CBR value with the addition of plastic fiber are mainly attributable to soil and fiber interactions, as the fiber offers resistance to the penetration plunger; hence, increases in the CBR value are also corroborated by this behavior ((Neopaney et al., 2012); showed that stabilizing soils with polyethylene fibers increased the CBR values by approximately 30% when compared to unstabilized soils, since the average CBR value of unstabilized clayey soil is 6.29, liquid limitation (LL) value of 47.33%, plasticity index of 29.88%. Additionally, (Madavi and Patel, 2017) determined that a plastics content of 4% is optimal for achieving the greatest CBR value. (Kumar et al., 2018) determined that a 2.0-cm fiber plastic length is the optimal length for obtaining the greatest CBR value. This increase in the CBR values of subgrade soils can have a significant effect on the required foundation thicknesses, particularly for pavement design methods such as Highway England's Design Manual for Roads and Bridges (DMRB), which base the pavement foundation thickness on the CBR and modulus of elasticity of subgrades. The increased CBR and modulus of elasticity of the subgrade result in a significant decrease in the needed sub-base thickness, which leads in a reduction in road pavement construction costs.

3.8.4 Resilient Modulus (Mr) Test

The resilient modulus test shown that for native soil and stabilized soils with two different types of fibers at four different fiber content ratios are shown in Tables below. In general, increasing deviatoric stress results in an improvement in resilient modulus for coarse-grained soils, but fine-grained soils exhibit the reverse behavior. As can be observed from the data, an increase in deviatoric stress leads in a drop in resilient modulus in the majority of situations, whereas a decrease in confining stress results in a decrease in resilient modulus. In all cases, increasing the fiber content resulted in an increase in resilient modulus, indicating an improvement in the behavior of stabilized soils. This can also be explained by increasing the interconnection between soil particles, resulting in a decrease in strains in response to applied stresses (Yaghoubi et al., 2016). The tables 6-9 and figures 24-27, illustrate the effect of confining and deviatoric stress on the change in resilient modulus under various stress settings. Several other studies, including those by (Perera et al., 2019) (Arulrajah et al., 2017), and (Yaghoubi et al, 2016), observed similar results. (Kaushik and Sharma, 2019) investigated the effect of waste polypropylene fibers on the moisture retention capacity of clay soil. Polypropylene fibers were introduced at concentrations of 0.3 percent, 0.4 percent, 0.5 percent, and 0.6 percent by weight of the soil. According to their research, a fiber content of 0.4 percent was judged optimal for obtaining the greatest Mr value.

Confining pressure (kPa)	Cyclic stress (kPa)	Fibre content (%)				
		0	1	2	3	4
41.37	24.82	140	145.2	147.9	148	171
41.37	12.41	142	144.6	155.0	168	188
41.37	24.82	141	147	153	150.4	169
41.37	37.23	136	138.4	143.8	144	158
41.37	49.64	134	136.6	141.8	141	150
41.37	62.05	134.8	137.0	137.7	140.3	147
27.58	12.41	133.77	136.0	136.7	159	172
27.58	24.82	133.1	135.3	141.8	151	162
27.58	37.23	133.4	136.1	137.7	146	157
27.58	49.64	132.7	136.6	138.7	141	147
27.58	62.05	133.6	137	137.7	136	143
13.79	12.41	130	137.2	138.7	148	167
13.79	24.82	132	136.1	135.7	145	149
13.79	37.23	132.1	135.6	136.7	144	147
13.79	49.64	132.3	134.3	136.5	140	146.3
13.79	62.05	132.5	134.2	135.7	139	144

Table 6 Resilient modulus values of PE at different ratios for 1-cm length

Confining pressure (kPa)	Cyclic stress (kPa)	Fibre content (%)				
		0	1	2	3	4
41.37	24.82	140	144	147.9	152	158
41.37	12.41	142	158	162	168	170
41.37	24.82	141	151.3	153	166	163
41.37	37.23	136	143.2	145	148	154
41.37	49.64	134	146.9	151.2	149	159
41.37	62.05	134.8	143.9	142	146	148
27.58	12.41	133.77	153.7	159	163.3	167
27.58	24.82	133.1	154.3	153	154.9	163
27.58	37.23	133.4	140.9	142	149.9	155
27.58	49.64	132.7	136.6	144	141	143
27.58	62.05	133.6	140	138.2	140	141
13.79	12.41	128	145.3	148.3	153	158
13.79	24.82	130	138.2	148	147	152
13.79	37.23	132.1	138.7	142.11	149	152
13.79	49.64	132.3	140	137.7	142	149
13.79	62.05	132.5	137	139	143	142

Table 7 Resilient modulus values of PE at different ratios for 2-cm length

Confining pressure (kPa)	Cyclic stress (kPa)	Fibre content (%)				
		0	1	2	3	4
41.37	24.82	140	142.1	144.2	143.2	142.8
41.37	12.41	142	144.3	146.6	145.3	144.6
41.37	24.82	141	143.56	145.2	145.1	144.8
41.37	37.23	136	138.97	139.7	139.1	139.1
41.37	49.64	134	136.6	140	138.8	138.7
41.37	62.05	134.8	135.8	138	137.3	136.7
27.58	12.41	133.77	135.7	137.5	137.1	136.9
27.58	24.82	133.1	135.32	138.2	137.5	136.4
27.58	37.23	133.4	134.88	136.7	135.6	135
27.58	49.64	132.7	134.55	135.4	134.8	134.2
27.58	62.05	133.6	135.2	137.4	136.9	135.5
13.79	12.41	130	134.22	137.9	136.8	135.9
13.79	24.82	132	133.8	134.8	134.3	134
13.79	37.23	132.1	134.1	136.8	134.9	134.3
13.79	49.64	132.3	133.3	134.5	134.1	133.9
13.79	62.05	132.5	133.9	134.2	134.1	134

Table 8 Resilient modulus values of PP at different ratios for 1-cm length

Confining pressure (kPa)	Cyclic stress (kPa)	Fibre content (%)				
		0	1	2	3	4
41.37	24.82	140	147.2	145.3	143	140
41.37	12.41	142	150.1	146.8	144.9	142
41.37	24.82	141	148.6	145.2	145	141
41.37	37.23	136	142	139.7	139.4	136
41.37	49.64	134	141.9	139.1	139	134
41.37	62.05	134.8	140.9	137.8	137.2	134.8
27.58	12.41	133.8	138.2	137.6	137	133.77
27.58	24.82	133.1	139.9	138.2	137.4	133.1
27.58	37.23	133.4	138.2	136.4	135.8	133.4
27.58	49.64	132.7	138.7	135.8	135.1	132.7
27.58	62.05	133.6	137.6	138.2	136.2	133.6
13.79	12.41	130	138.3	136.8	136.3	130
13.79	24.82	132	135	134.8	134.2	132
13.79	37.23	132.1	137.2	135.6	135	132.1
13.79	49.64	132.3	135.3	135.3	134.9	132.3
13.79	62.05	132.5	134.9	135.1	134.7	132.5

Table 9 Resilient modulus values of PP at different ratios for 2-cm length

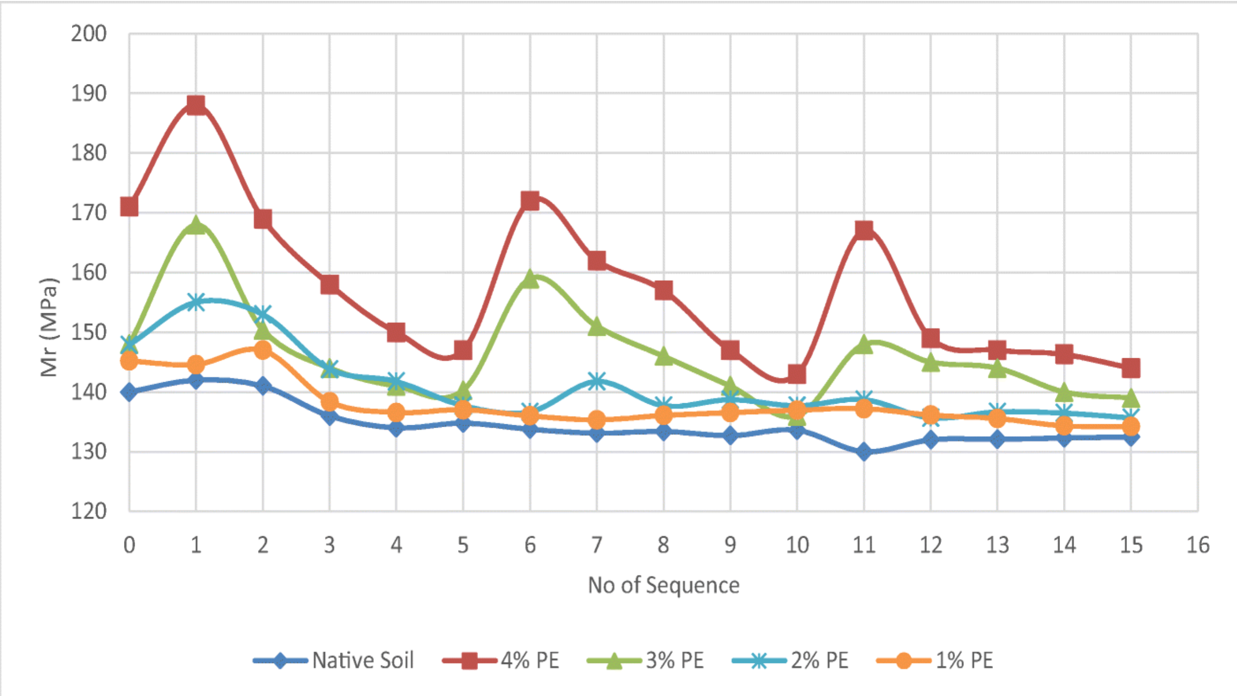

Figure 24 Resilient modulus of PE at different ratios for 1-cm

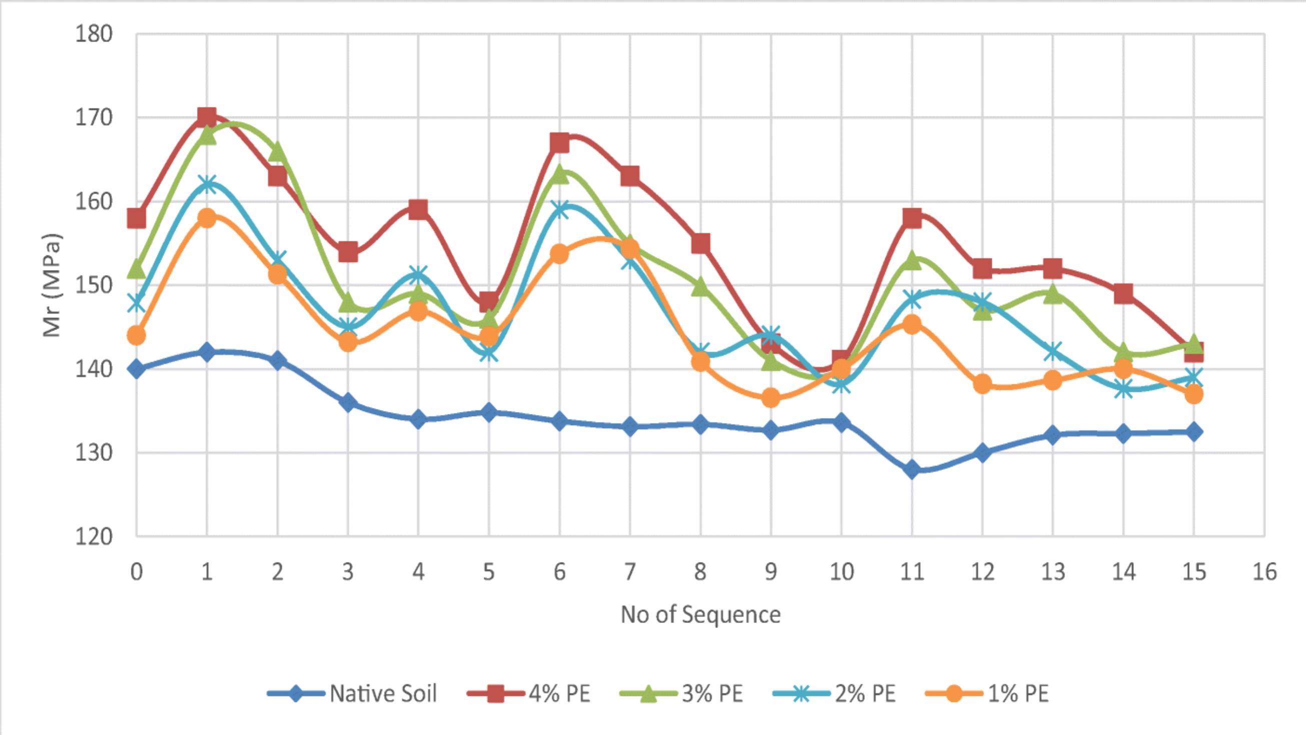

Figure 25 Resilient modulus of PE at different ratios for 2-cm length

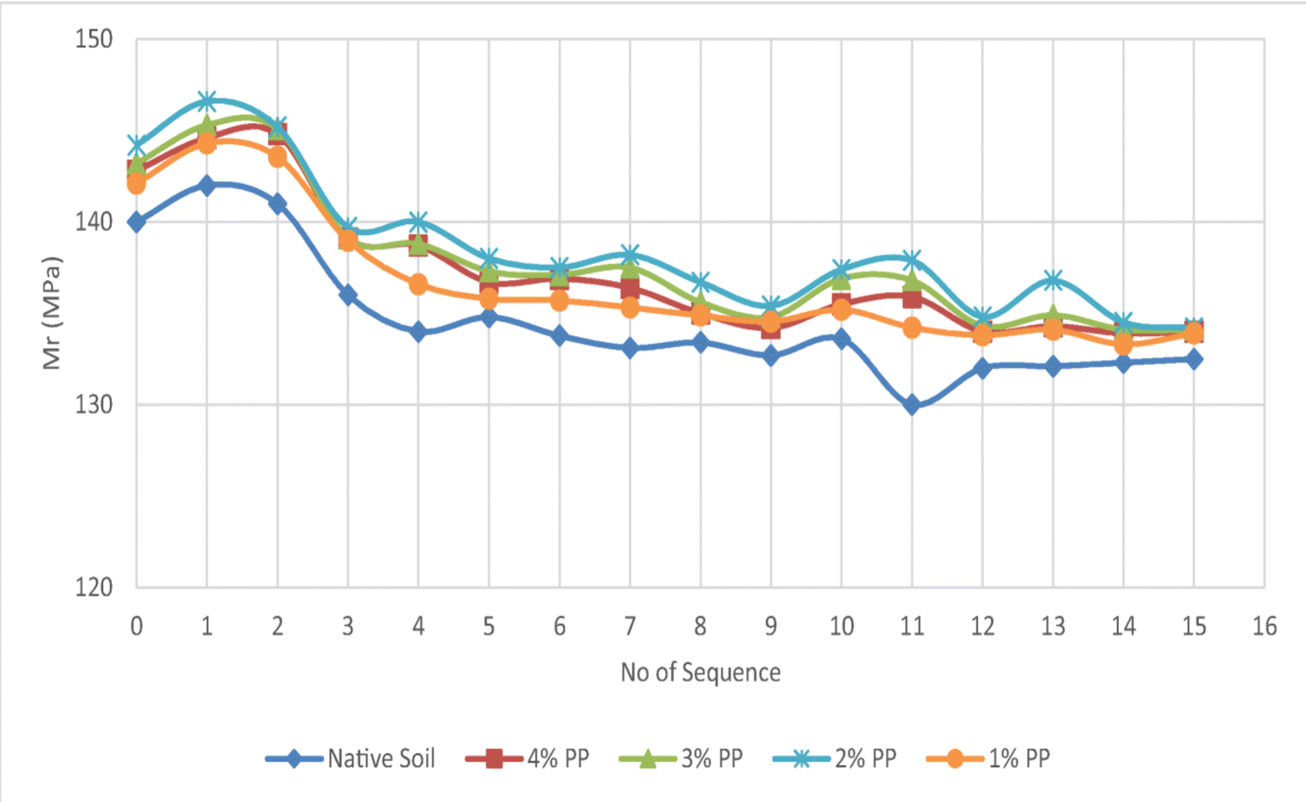

Figure 26 Resilient modulus of PP at different ratios for 1-cm length

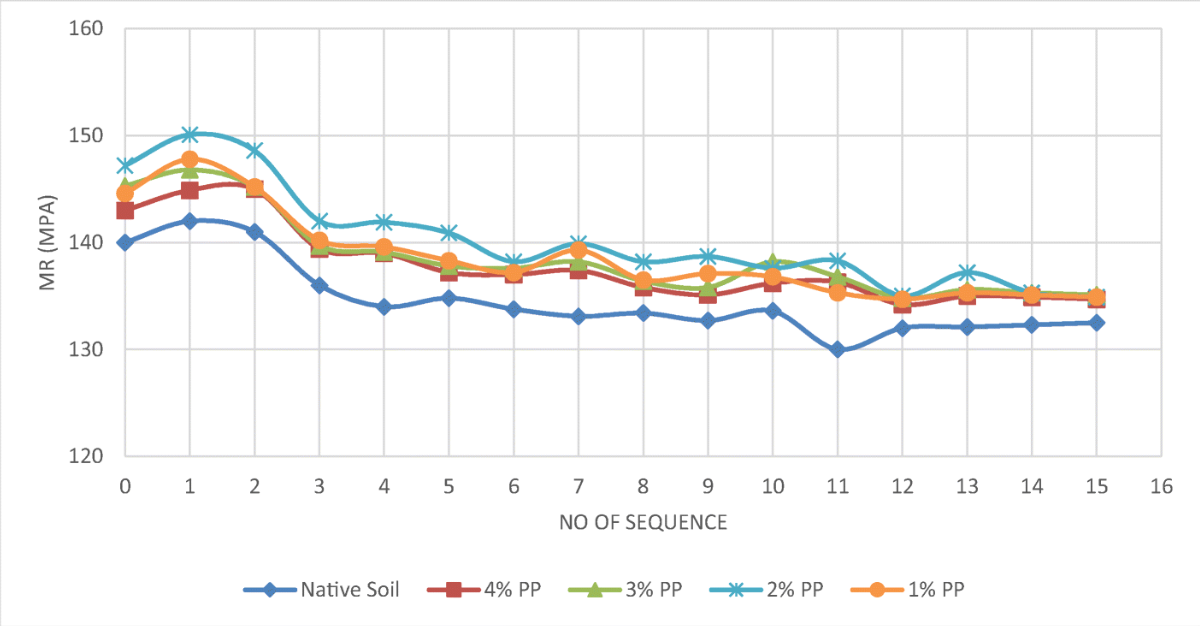

Figure 27 Resilient modulus of PP at different ratios for 2-cm length

The results generally indicates that soils stabilized with PE have higher Mr. values than soils stabilized with PP. Additionally, by increasing the fiber content in both PE fiber lengths, Mr. values increases. The results indicates that 2.0-cm PE fibers has a greater Mr. than 1.0-cm PE fibers. Mr. values are first elevated to a certain level for the purpose of stabilizing soils with PP; afterwards, these values decrease. For both PP fiber lengths, the optimal fiber content was 2%. (Ahmadinia et al. , 2012) and (Perera et al. , 2019) shown that adding PE materials increased Mr. values. (Perera et al., 2019) discovered that adding PE and increasing deviatoric stress while maintaining the confining pressure results in increased Mr. values.

“Why the UCS values is dropping but not the CBR values?”

One of the reasons there is the UCS values are dropping while the CBR values aren’t because the UCS test enables parameters such as cohesion (c'), internal angle of friction (ϕ') and shear strength to be determined, while the CBR values depend not only on soil type but also on density, moisture content and method of preparation. And from the CBR values Mr. values can be calculated using odemark’s method which makes the test more reliable and important than UCS. And because as stated earlier the CBR test depends on several factors.

3.8.5 KENPAVE calculations

To calculate the improvement in the mechanical behaviour of the soils stabilised with fibres, a pavement section was analysed using the KENLAYER programme; for simplicity, the linear elastic method was followed. The load of the tyre was simulated to have a circular shape with a diameter of 152 mm and a pressure of 860 kPa. The proposed pavement section has dimensions and properties as presented in table 5.

Layer	Thickness (mm)	Resilient Modulus (Mpa)	Poisson's ratio
Asphalt concrete	0.10	4000	0.4
Unbound granular	0.20	200	0.3
Subgrade	-	200	0.45

Table 10 Kenpave calculations assumptions

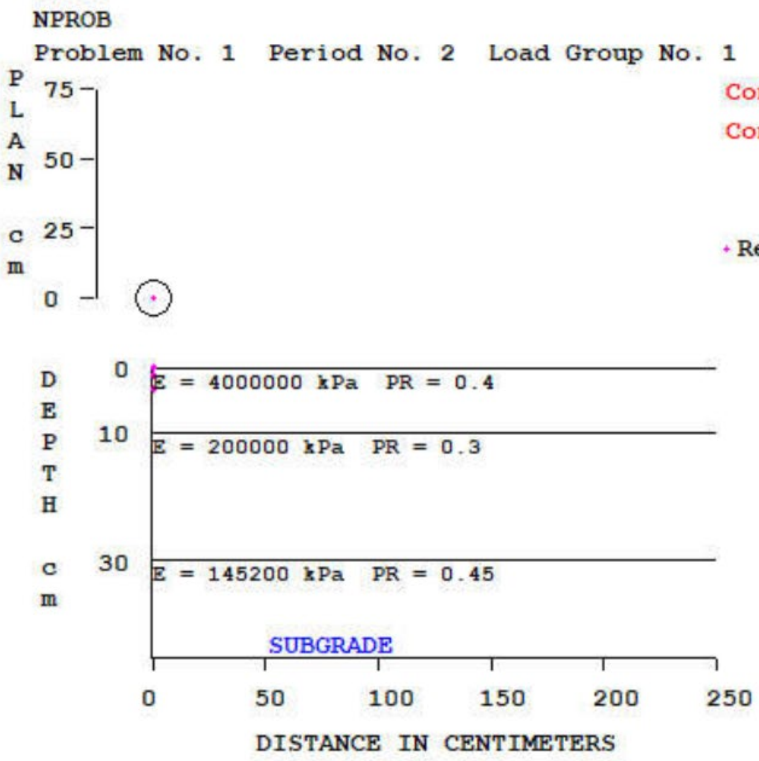

Figure 28 load diagram from Kenpave program

The values of the modulus of elasticity of the asphalt and granular layers were 4000 MPa and 200 MPa, respectively, and the stabilized subgrade layer's modulus was taken to be variable according to the different scenarios of the soil stabilization.

The findings of the analyses are shown in the following table. When can be observed, the compressive strain at the top of the subgrade soil improves as the fiber content increases from 0 to

4 percent and the fiber length increases from 1 to 2 centimeters. Although surface deflection is not a design requirement for road pavements, a similar pattern can be seen. Assuming that the asphalt concrete layer is constant throughout all situations, the tensile strain at the base of the layer remains same. Rasul et al. (2016) and Rasul et al. (2018) found that stabilization with cement, lime, and mixtures of both led to a considerable rise in UCS and Mr values with the addition of stabilizer. In this study, stabilization with fiber resulted in an increase in UCS up to a certain ratio of fiber content, beyond which UCS decreased, although Mr values increased. This can be a significant difference between employing chemical agents and fibers for stabilization, in which case the best suited stabilizer for the needed qualities can be selected. For subgrade soils in which resilient modulus is an essential feature to enhance, for instance, fiber can be employed, however for other applications where UCS is a crucial property, a chemical agent would be preferable.

Results of the analysis of the pavement section

Fibre type	Fibre length (mm)	Fibre content (%)	Vertical coordinate (z) (mm)	Deflection (mm)	Vertical strain (μstrain)	Radial strain (μstrain)
PE	10	0	0.000	**0.678**	– 387	366
			10.000	0.678	570	**– 401**
			30.001	0.472	**811**	– 350
		1	0.000	**0.674**	– 386	365
			10.000	0.674	569	**– 400**
			30.001	0.468	**804**	– 347
		2	0.000	**0.670**	– 385	364
			10.000	0.670	569	**– 400**
			30.001	0.464	**798**	– 344
		3	0.000	**0.661**	– 383	363
			10.000	0.661	567	**– 399**
			30.001	0.455	**785**	– 339
		4	0.000	**0.650**	– 380	361
			10.000	0.650	566	**– 397**
			30.001	0.443	**766**	– 330
	20	0	0.000	**0.678**	– 387	366
			10.000	0.678	570	**– 401**
			30.001	0.472	**811**	– 350
		1	0.000	**0.666**	– 385	364
			10.000	0.666	568	**– 399**
			30.001	0.460	**793**	– 342
		2	0.000	**0.661**	– 383	363
			10.000	0.661	567	**– 399**
			30.001	0.455	**785**	– 339
		3	0.000	**0.652**	– 381	361
			10.000	0.652	566	**– 397**
			30.001	0.445	**770**	– 332
		4	0.000	**0.654**	– 381	361
			10.000	0.654	566	**– 398**
			30.001	0.447	**773**	– 333

Table 11 Results of analysis of the pavement section

3.8.6 Asphalt thickness calculations

To determine asphalt thickness, you must consider the traffic load according to the fatigue formula, however you need to consider the E value which it should be constant along with the vertical displacement as you can also see below in the figure which is considered according to the traffic load. As stated from the book pavement analysis and design by Yang H. Huang.

Traffic classification		
Type of street or highway	**Range of heavy trucks expected in design period**	**ESAL**
Residential streets. **Rural farm and residential roads**	**7000 to** **15,000**	**10^4**
Urban minor collector streets **Rural minor collector roads**	**70,000 to** **150,000**	**10^5**
Urban minor arterial and light industrial streets. **Rural major collector and minor arterial highways**	**700,000 to** **1,500,000**	**10^6**
Urban interstate highways and **Some industrial roads**	**7,000,000 to** **15,000,000**	**10^7**

Table 12 traffic classification for pavement design
Source: pavement design and analysis

Fatigue crack model

Miner's (1945) cumulative damage concept has been widely used to predict fatigue cracking. It is generally agreed that the allowable number of load repetition is related to the tensile strain at the bottom of the asphalt layer. The amount of damage is expressed as a damage ratio between the predicted and the allowable number of load repetitions. Damage occurs when the sum of damage ratios reaches the value 1. Because of variabilities, damage will not occur all at once when the ratio reaches exactly 1. If mean parameter values are used for design, a damage ratio o f 1 indicates that the probability of failure is 50%—that is, that 50% of the area will experience fatigue cracking.

By assuming the damage ratio to have a log normal distribution, the probability of failure, or the percentage of area cracked, can be computed, and checked against field performance. The major difference in the various design methods is the transfer functions that relate the HMA tensile strains to the allowable number of load repetitions. In the Asphalt Institute and Shell design methods, the allowable number of load repetitions Ni to cause fatigue cracking is related to the tensile strain et at the bottom of the HMA and to the HMA modulus E2 by

$$N_f = ff(\varepsilon t)^{-f2} (E1)^{-f3}$$

For the standard mix used in design, the Asphalt Institute equation for 20% of are a cracked is

$$N_f = 0.0796 (\varepsilon t)^{-3.291} (E1)^{-854}$$

and the Shell equation is $$Nf = 0.0685(\varepsilon t)^{-5.671} (E1)^{-2.363}$$

for PE having fibre length = 1cm					
	Fibre content = 0%	Fibre content = 1%	Fibre content = 2%	Fibre content = 3%	Fibre content = 4%
	Mr =140kPa	**Mr=145.2kPa**	**Mr =147.9kPa**	**Mr =148kPa**	**Mr =171kPa**
Asphalt layer thickness (cm)	Vertical Displacement (mm)	Vertical Displacement (mm)	Vertical Displacement (mm)	Vertical Displacement (mm)	Vertical Displacement (mm)
10	1,55514	1,51833	1,50121	1,4994	1,36307
10,2	1,5401	1,50577	1,48706	1,48632	1,35148
10,4	1,5266	1,4905	1,47405	1,4726	1,33996
10,6	1,51211	1,47739	1,45984	1,4589	1,3282
10,8	1,49698	1,46202	1,44623	1,44483	1,31633
11	1,48178	1,44827	1,43164	1,4308	1,30396

Table 13 Asphalt thickness calculations for 1cm of PE fiber

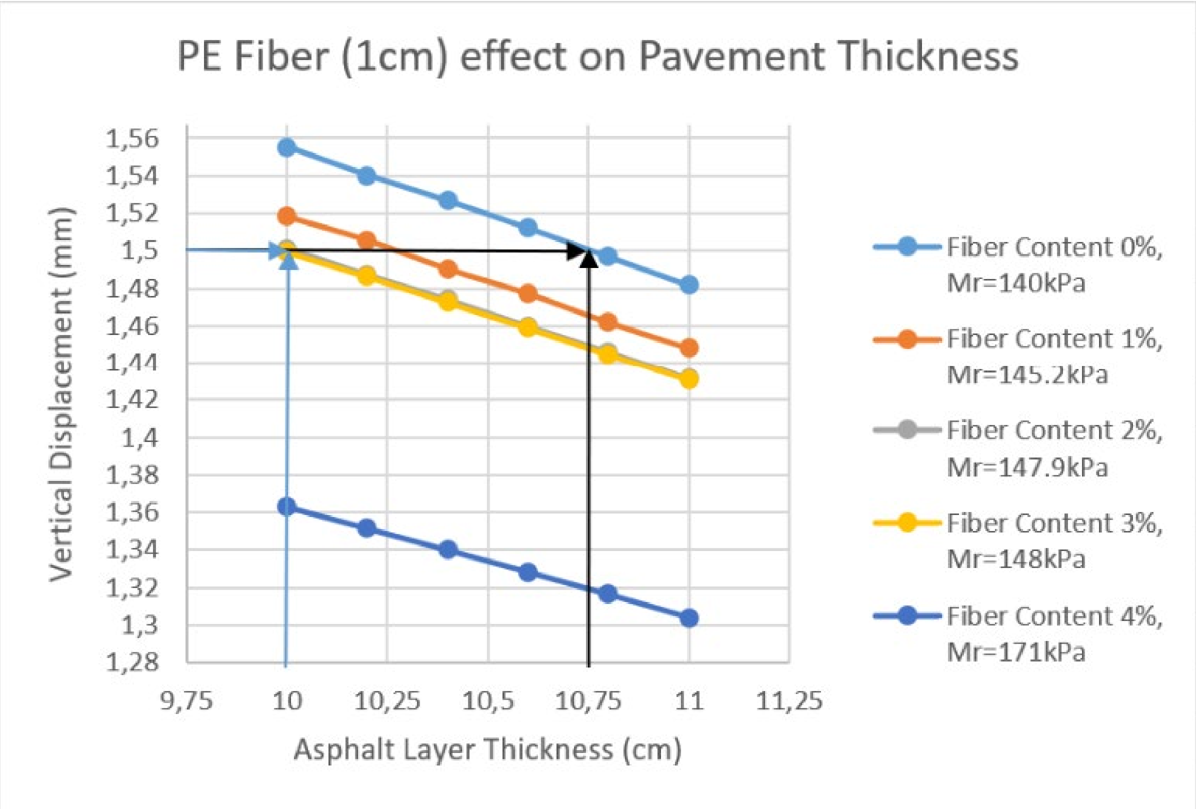

Figure 29 PE fiber with 1cm and its effect on pavement thickness

for PE having fiber length = 2cm					
	Fiber content = 0%	Fiber content = 1%	Fiber content = 2%	Fiber content = 3%	Fiber content = 4%
	Mr =140kPa	**Mr =144kPa**	**Mr =147.9kPa**	**Mr =152kPa**	**Mr =158kPa**
Asphalt layer thickness (cm)	Vertical Displacement (mm)	Vertical Displacement (mm)	Vertical Displacement (mm)	Vertical Displacement (mm)	Vertical Displacement (mm)
10	1,55514	1,52755	1,50121	1,4742	1,43774
10,2	1,5401	1,51313	1,48706	1,46093	1,42472
10,4	1,5266	1,49927	1,47405	1,44794	1,41148
10,6	1,51211	1,48488	1,45984	1,43435	1,3282
10,8	1,49698	1,46999	1,44623	1,42105	1,38613
11	1,48178	1,45596	1,43164	1,40772	1,37261

Table 14 PE fiber 2cm asphalt calculations thickness

As seen in the figure 29 above the results from kenpave program with a constant value for vertical displacement 1.5mm and the resilient modulus values that has been concluded from the previous test that has been done on the soil, if you look on the first graph at 0% fiber content (140kpa) and at 3%

fiber content (148kpa) and follow the line you fill find that for the 0% the asphalt thickness is 10.75cm while at 3% the asphalt thickness dropped by 0.75 to be 10cm which shows that adding fiber content with a length of 1cm reduces the asphalt thickness by 0.75cm.

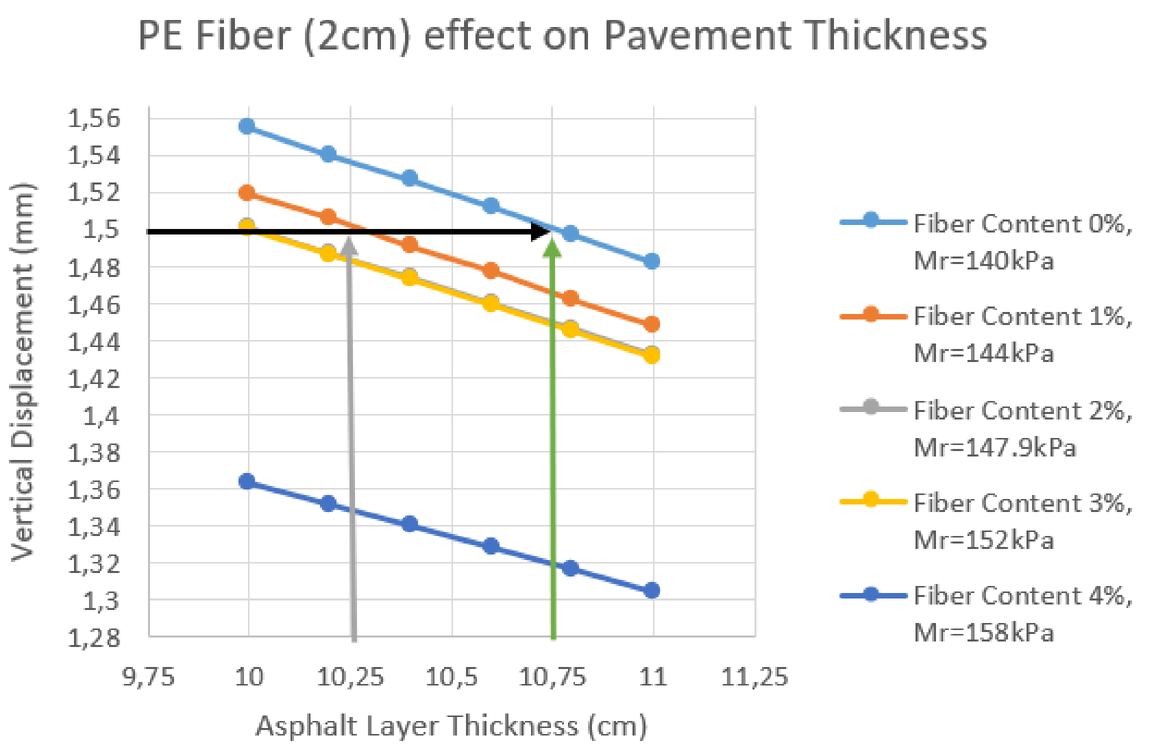

Figure 30 PE 2cm effect on pavement thickness

As seen in figure 30 above for the 2cm it didn't have positive effect as compared to the 1cm, so that concludes that 1cm is optimum fiber content as seen at 1.5mm vertical displacement the native soil asphalt thickness is 1.75cm while for 1% the thickness is 10.25 which is 0.5 reduction, but further research on larger lengths should carried out to be more certain.

Note: These calculations are based on the Mr results from the test that's made in the laboratory other calculations carried out based on higher Mr results calculated from the CBR test using Odemark formula, which can be found in the next chapter cost analysis and asphalt thickness estimation.

3.8.7 Base layer calculations

According to odemark method the base layer along with the E-modulus of the soil has been calculated according to Mr. modulus. And seen in the table 15 below that at 4% PE 2cm had the best effect on the base layer in terms of reduction because as you can see the native soil had an equivalent thickness of 47.8 cm while the 4% plastic content is 45.9 which is a reduction in thickness with approximately 2cm which at the end that will influence the cost of any project.

Native soil CBR	Mr Value (MPa)	Equivalent Thickness (cm)	1% PE CBR	Mr Value (MPa)	Equivalent Thickness (cm)	2% PE CBR	Mr Value (MPa)	Equivalent Thickness (cm)
17,22652885	140,0	47,8	20,2224	145,2	47,2	23,9673	147,9	46,9

3% PE CBR	Mr Value (MPa)	Equivalent Thickness (cm)	4% PE CBR	Mr Value (MPa)	Equivalent Thickness (cm)
26,9633	148	46,9	29,2102	171,0	44,7

Table 15 Base layer thickness calculations

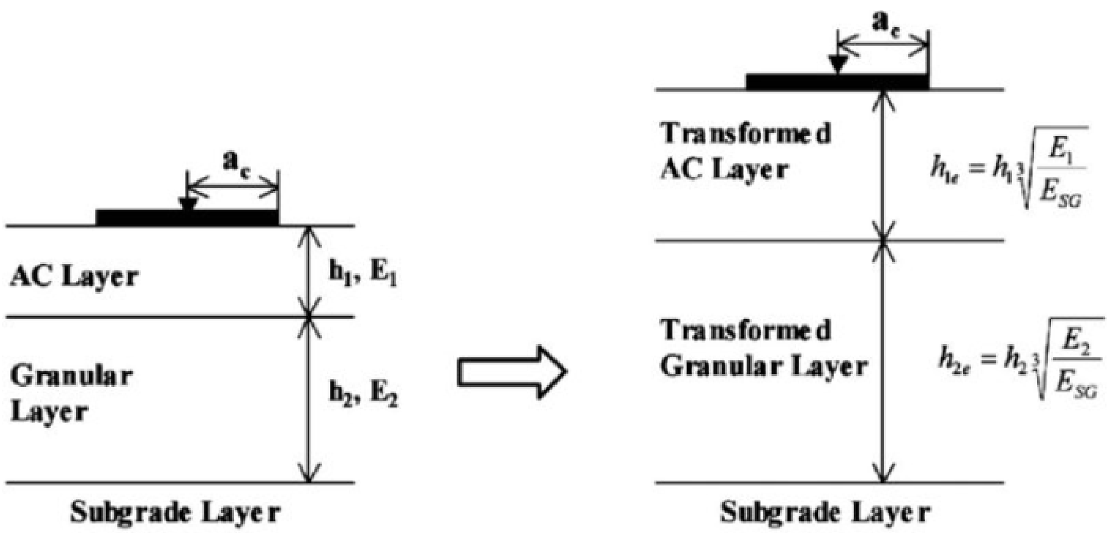

Figure 31 odemark method

$$h_e = h_{1e} + h_{2e} = h_1 \sqrt[3]{\frac{E_1}{E_{SG}}} + h_2 \sqrt[3]{\frac{E_2}{E_{SG}}} = \sum_{i=1}^{i=n-1} h_i \sqrt[3]{\frac{E_i}{E_{SG}}}$$

3.8.8 Cost analysis and asphalt thickness

The calculations are executed is by making a constant granular layer running the program with taking in consideration different traffic loads which is ESALS (the calculations are based on the fatigue formula) as seen in the previous calculations when demonstrating if stabilizing the soil with plastic does help or not. (The Mr Modulus has been recalculated using odemark formula since it provided higher Mr Modulus and has been considered to optimize and figure out what how thick the asphalt could be under severe conditions along with the highest traffic load that has been considered

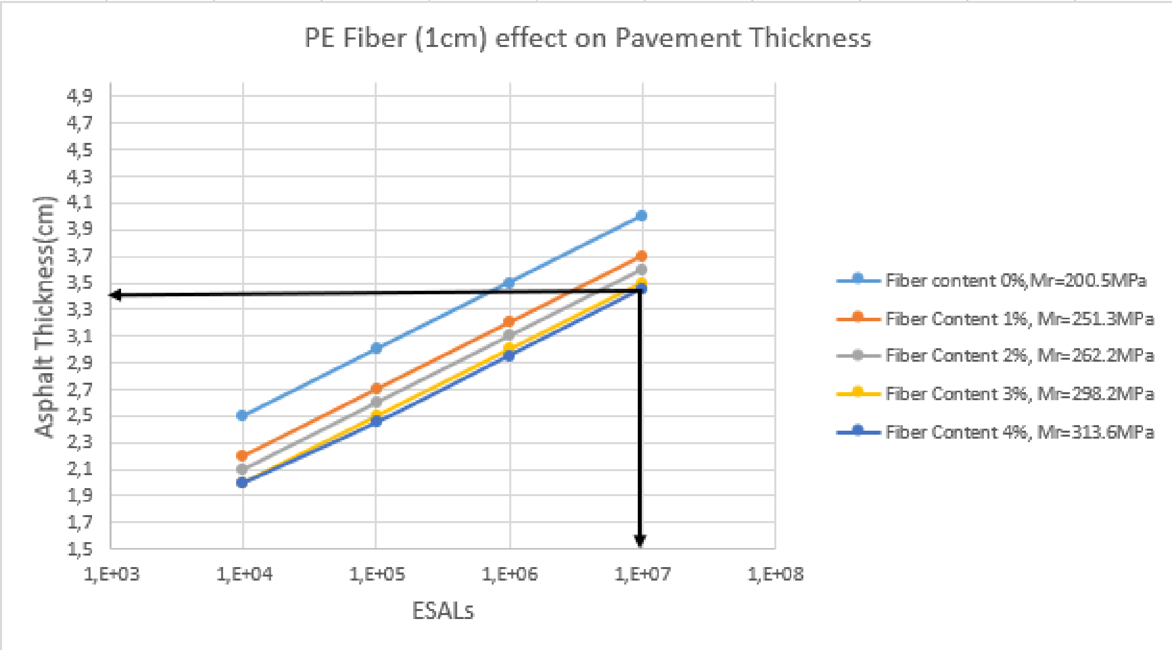

Figure 32 PE fiber 1cm effect on pavement thickness

As seen in the figure 32 above the asphalt thickness with 0% of plastic content was around 3.95 with the highest traffic load 10^7 while the asphalt that has been stabilized with plastic was 3.4 which is a reduction of about 0.55cm. for the 2cm PE had the same results as seen the graph below

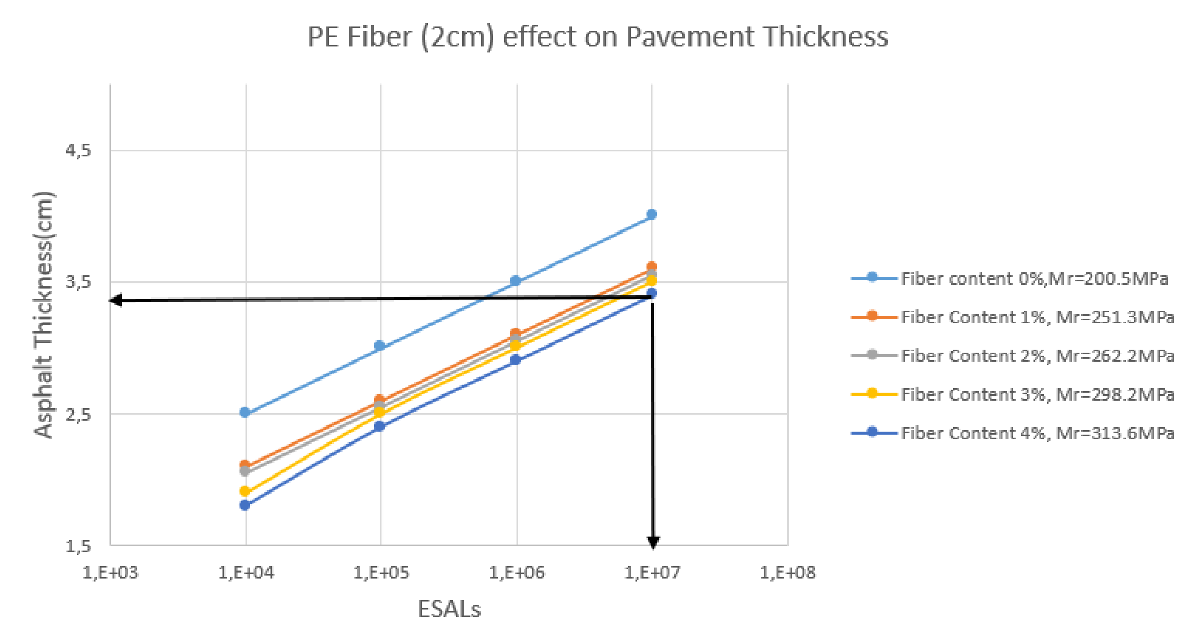

Figure 33 PE 2cm fiber and its effect on pavement thickness

3.8.9 Cost analysis

The cost has been calculated based on per km length of road, as seen in the graph below the native soil with 0% plastic content it costs 13,724.00$, while the 3% and 4% plastic content 13,240.38$ and 13,192.01 respectively, that concludes that the soil stabilized with 4% plastic is cost effective than the soil that has not been stabilized at all. (That's 53200$ cheaper on a large scales project that will add up even more) that's for the 1cm length of PE plastic.)

Cost analysis for PE having fibre length = 1cm

Cost			**Native Soil**			**Fiber content = 1%**		
			Mr =200.5kPa			**Mr =251.3MPa**		
Asphalt Price per m^2	Gravel per m^2	Sand per m^2	Asphalt layer thickness (cm)	ESALs	Cost	Asphalt layer thickness (cm)	ESALs	Cost
26,5	13,5	8	2,5	1,00E+04	$12.273,13	2,2	1,00E+04	$11.982,95
26,5	13,5	8	3	1,00E+05	$12.756,75	2,7	1,00E+05	$12.466,58
26,5	13,5	8	3,5	1,00E+06	$13.240,38	3,2	1,00E+06	$12.950,20
26,5	13,5	8	4	1,00E+07	$13.724,00	3,7	1,00E+07	$13.433,83

Table 16 Cost analysis for Pe fiber with 1cm length

Fiber content = 2%			**Fiber content = 3%**			**Fiber content = 4%**		
Mr =262.2MPa			**Mr =298.2MPa**			**Mr =313.6MPa**		
Asphalt layer thickness (cm)	ESALs	Cost	Asphalt layer thickness (cm)	ESALs	Cost	Asphalt layer thickness (cm)	ESALs	Cost
2,1	1,00E+04	$11.886,23	2	1,00E+04	$11.789,50	2	1,00E+04	$11.789,50
2,6	1,00E+05	$12.369,85	2,5	1,00E+05	$12.273,13	2,45	1,00E+05	$12.224,76
3,1	1,00E+06	$12.853,48	3	1,00E+06	$12.756,75	2,95	1,00E+06	$12.708,39
3,6	1,00E+07	$13.337,10	3,5	1,00E+07	$13.240,38	3,45	1,00E+07	$13.192,01

Table 17 Cost analysis for asphalt thickness (PE 1cm)

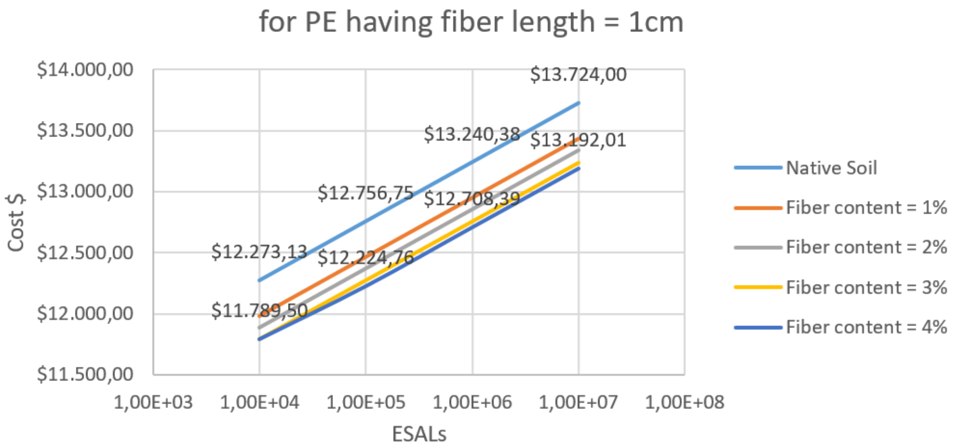

Figure 34 Cost estimation for asphalt thickness for 1cm of PE plastic

As seen in figure 34 above for the 2cm length of PE plastic the native soil costs 13,724.00, and the 3% and 4% plastic content costs 13,240.00 and 13,143.65 respectively, as seen in the figure below. That's translates to that 4% plastic content for 2cm length of PE would cost 58000 less.

cost analysis for PE fibre with length of 2cm								
Cost			**Fiber content = 0%**			**Fiber content = 1%**		
			Mr =200.5MPa			**Mr =267.3MPa**		
Asphalt Price per m^2	Gravel per m^2	Sand per m^2	Asphalt layer thickness (cm)	ESALs	Cost	Asphalt layer thickness (cm)	ESALs	Cost
26,5	13,5	8	2,5	1,00E+04	$12.273,13	2,1	1,00E+04	$11.886,23
26,5	13,5	8	3	1,00E+05	$12.756,75	2,6	1,00E+05	$12.369,85
26,5	13,5	8	3,5	1,00E+06	$13.240,38	3,1	1,00E+06	$12.853,48
26,5	13,5	8	4	1,00E+07	$13.724,00	3,6	1,00E+07	$13.337,10

Fiber content = 2%			Fiber content = 3%			Fiber content = 4%		
Mr =303.3MPa			Mr =333.2MPa			Mr =402.9MPa		
Asphalt layer thickness (cm)	ESALs	Cost	Asphalt layer thickness (cm)	ESALs	Cost	Asphalt layer thickness (cm)	ESALs	Cost
2,05	1,00E+04	$11.837,86	1,9	1,00E+04	$11.692,78	1,8	1,00E+04	$11.596,05
2,55	1,00E+05	$12.321,49	2,5	1,00E+05	$12.273,13	2,4	1,00E+05	$12.176,40
3,05	1,00E+06	$12.805,11	3	1,00E+06	$12.756,75	2,9	1,00E+06	$12.660,03
3,55	1,00E+07	$13.288,74	3,5	1,00E+07	$13.240,38	3,4	1,00E+07	$13.143,65

Table 18 cost analysis for PE having fiber length = 2cm

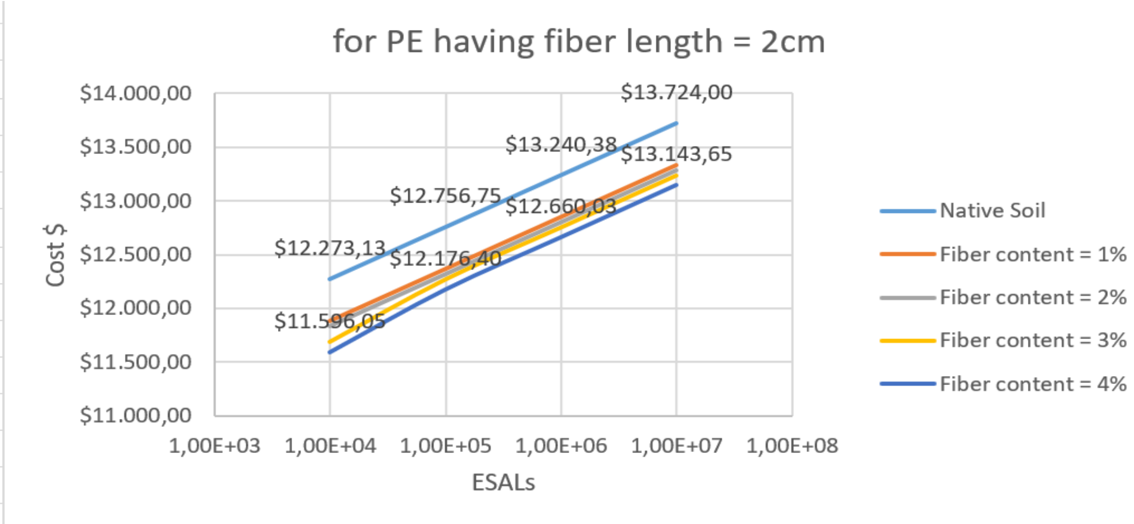

Figure 35 Cost estimation for 2cm length of PE plastic content

3.9 Comparison between Soil stabilized using plastic fiber and cement stabilized soil

In this chapter the comparison highlights mainly the cost, with addition to the ecological impact. As seen in the figure 36 below 10^7 the cost is 17921$ while clayey stabilized soil at 10^7 is 13,143.65$

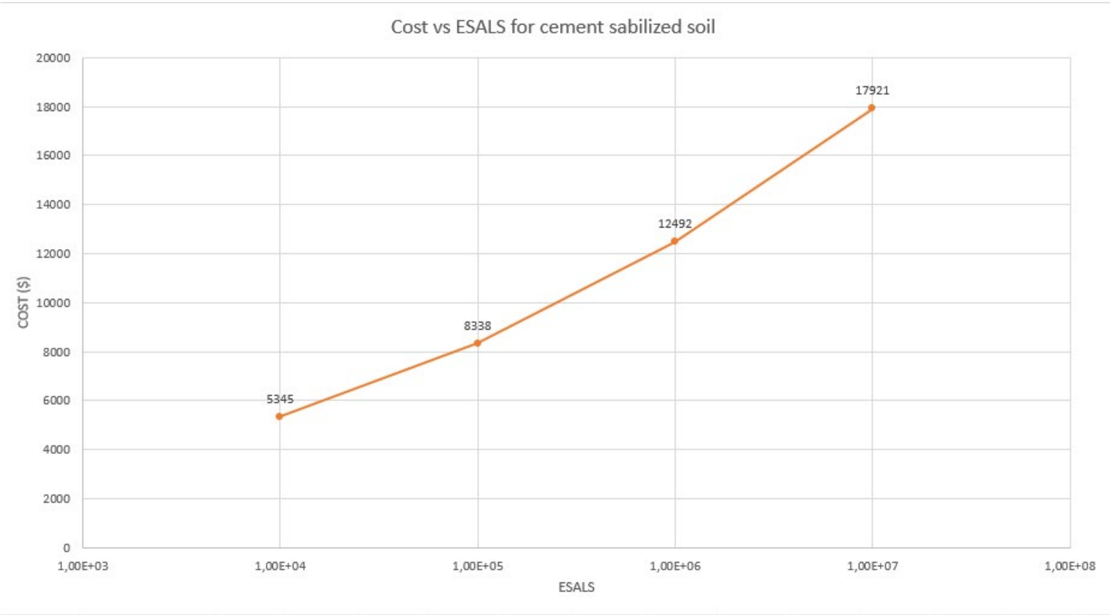

Figure 36 Cost vs ESALS for cement stabilized soil

Asphalt thickness at different ESALS	
Clayey stabilized soil using plastic	Clayey stabilized soil using cement
10^4 the cost is 11.596$	10^4 the cost is 5,345$
10^5 the cost is 12,176.40$	10^5 the cost is 8,338$
10^6 the cost is 12,660.03$	10^6 the cost is 12,492$
10^7 the cost is 13,143.65$	10^7 the cost is 17,921$

Table 19 Asphalt thickness at different ESALS

As seen in the table 19 above for the most common ESALS which is 10^6 (used for urban minor arterial and light industrial streets, rural major collector, and minor arterial highways) Cement stabilized soil is more cost effective, whereas for the 10^7 ESALS (used for Urban interstate highways some industrials roads and for heavy trucks highways) the clayey stabilized soil using plastic is more cost effective, furthermore a combination of both is recommended.

Criterion:	Plastic fiber stabilized soil	Cement stabilized soil
Ecological impact	-2	-1
Cost effectiveness	+2	+2
Asphalt thickness	+2	+1

Table 20 Multi criteria analysis table

3.9.1 Ecological impact of Cement stabilization

There aren't enough studies addressing the ecological impact of the micro-cement particles found in the soil, therefore the ecological impact of the cement industry of the environment is considered, to be able to compare both methods together.

The environmental impact the cement industry is responsible for 10% of the co2 emissions and accounts for 12–15% of the total energy consumed in the global industrial sector, further investigation on the micro cement particles left in the soil and its effect needs to be done. However theoretically speaking also after a long time the cement can be taken out easier from the soil compared to the plastics/micro plastics and has less effect on the living organisms compared to the microplastics.

3.9.2 impacts of microplastics in soil

Several organisms inhabit the soil; big ones, such as gophers and turtles, tend to prey on smaller organisms and plant material. The soil is also home to several tiny organisms, such as insects, worms, and germs. They constitute a web of life with their own food chain. To understand more about what occurs when microplastics enter the ecosystem, the researchers collected samples of microplastics and combined them with fresh, pristine soil containing a variety of indigenous creatures.

Researchers discovered that after the introduction of microplastics, populations of worms and microarthropods (invertebrates with exoskeletons visible to the human eye, such as springtails and mites) decreased. Further research revealed that when more microplastics are injected, the numbers of such organisms continued to decline. In addition, they observed that the introduction of microplastics into soil samples did not result in a decrease in soil microbes. They propose that microplastics cascade through the soil and food webs, creating alterations that may impair the carbon and nitrogen cycle of the soil.

The ecological impacts of exposure to microplastics on soil ecosystem compositions and functions are complicated and cause for serious concern (Guo et al., 2020; Wang et al., 2022; Xiao et al., 2022). Microplastics can impact soil nitrogen cycle and soil structure. Existence of microplastics poses a hazard to the survival, growth, and development of soil animals and plants. Furthermore, microplastics can impact microbial populations and alter the activity of soil enzymes. Based on existing studies, you may find a summarized outline for the six elements in the following figure 37, as follows:

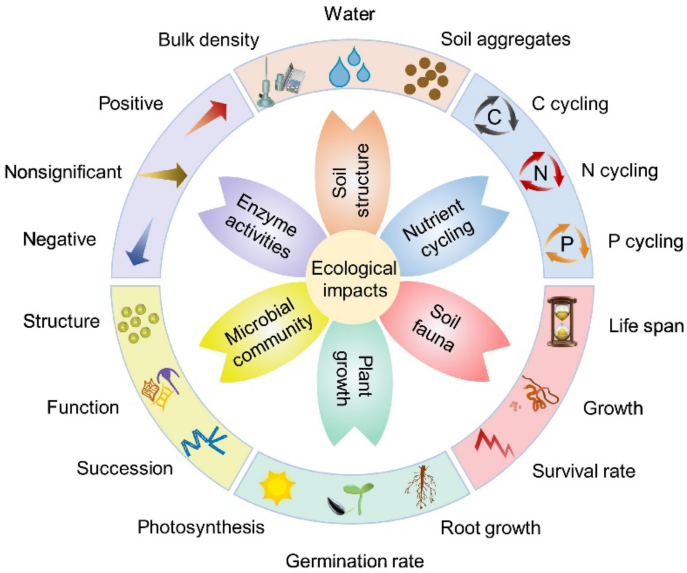

Figure 37 6 aspects of the ecological impact of microplastics on the soil

3.9.3 Impacts on soil structure

The presence of microplastics will alter soil structure and have an influence on soil bulk density, water evaporation, and water availability, with the consequences varying depending on the kind of microplastics present (de Souza Machado et al., 2019). Polyester fibre microplastics can alter the distribution and aggregation of soil pores but have no significant effect on soil bulk density and saturated water conductivity (Zhang et al., 2019a). Polyethylene microplastics (which is one of the types of the plastics that is used in the study) with tiny particle size and high concentration (2 mm, 1 percent) had a stronger effect on soil water evaporation rate (increased by 25.90% –30.20%), indicating that microplastic contamination was one of the reasons of soil water deficit (Wan et al., 2019). In addition, according to Zhang and Liu (2018), 72% of microplastics in soil are attached to soil aggregates, while the remaining 28% are distributed throughout the soil. Compared to big and small aggregates, microplastics prefer to aggregate in micro-aggregates, which prevents micro-aggregates from combining effectively with macro-aggregates (> 0.25 mm) and lowers the soil structure's stability to some degree. According to recent research, practically all kinds of microplastic (fibre, film, foam, and debris) diminish soil aggregates by about a quarter because they inject breaking points into the aggregates (Lozano et al., 2021). Notably, microplastic pollution will also damage the aeration, water permeability, and porosity of soil because of their low air permeability and water permeability, and they may even induce hypoxia in the soil (Keller et al., 2020). Diverse study findings have elucidated the complexities of soil contamination by various microplastics and cautioned that the impact of microplastics on soil water transport and retention need more investigation.

3.9.4 Impacts on soil nutrient cycling

Microplastics have several effects on the soil carbon (C) cycle (Rillig, 2018). In addition to their carbon content, microplastics can impact plant development, soil microbial activities, and the breakdown of soil organic matter (Rillig et al., 2021). Microplastics added to soil may greatly alter soil carbon emission (Gao et al., 2021a). The content of DOC tended to rise as the concentration of microplastics in soil rose (Liu et al., 2017). A study indicated that a concentration of 5% (w/w) microplastics had no discernible influence on soil DOC, but a concentration of 28 percent PP microplastics can raise soil DOC by 35%. This may be because the high degree of microplastic addition stimulates humus formation in the soil (Ren et al., 2020).

Nitrogen (N) cycling, a crucial biogeochemical process in soil ecosystems, is impacted by microplastics (Seeley et al., 2020; Tong et al., 2022). Rong et al. (2021) conducted indoor microscopic tests to determine the impacts of LDPE microplastics on soil N cycling. The results demonstrated that microplastics influenced soil N cycling by altering the functional genes of soil bacteria engaged in N cycling. The influence of microplastics on N cycling is mostly represented in two processes, nitrification, and denitrification (Barnard et al., 2005), which can enhance N2O emission during nitrification and hinder N2O emission during denitrification. Due to the reciprocal cancellation of promoting and inhibitory effects, microplastics have little impact on soil N emission (Gao et al., 2021a).

3.9.5 Impacts on plant growth

Plants are ecosystem producers, and their development is significantly impacted by soil microplastics (Zhang et al., 2021b). The impacts of microplastics on plants span the whole plant growth cycle, from seed germination to grain production (Bosker et al., 2019; Qi et al., 2018; Wu et al., 2022). Seed (Lepidium sativum) germination is hindered by microplastics with varying concentrations (10^3, 10^4, 10^5, 10^6, and 10^7 particles mL^{-1}) and particle sizes (50 nm, 500 nm, and 4800 nm), and the germination rate decreased with increasing microplastics particle size. It is possible that physical obstruction of the stomata by microplastics impairs water absorption (Bosker et al., 2019). Residual PE microplastics in mulching film inhibited the growth of wheat roots and stems and slowed the plant's development, resulting in a decreased yield (Qi et al., 2018). Microplastics and nano plastics can be absorbed by plant roots and accumulated in plants, producing cell membrane alterations and oxidative stress while travelling from roots to edible aboveground sections, posing a threat to the food chain (Su et al., 2019; Luo et al., 2022).

4. Discussion

The values of shear strength (τ) cohesion (c) and internal friction angle (ϕ) for both unreinforced and reinforced soils obtained from tests showed that the addition amounts of fiber have the significant influence on the development of cohesion and internal friction angle.

4.2 Climate effect on plastic fibers in the soil.

One of the sub-questions that's should be answered is does the hot climate will affect the plastic fibers in the soil when the pavement gets hot, theoretically speaking of course but in order to tackle such problem a layer of around 20cm of sand separates the pavements and the clayey stabilized soil using plastic fiber from each other to avoid such problem from happening.

Thermal Degradation – Plastic materials subjected to prolonged exposure to high temperatures will lose strength and toughness, becoming more prone to cracking, chipping, and breaking, at a rate in proportion to the temperature and time of exposure. Materials exposed to higher heat for longer duration will wear substantially faster than those exposed to more moderate temperatures and exposure times.

The Continuous Use Temperature Rating is based on a thermal aging test that predicts the temperature at which a 50% loss of the original mechanical properties will occur after 100,000 hours of continuous exposure at that temperature. (See table 21 below)

Plastic material	**Representative continuous use temperature ratings °C "F)**
Polyethylene (PE)	50 (122)
Polypropylene (PP)	65- 125 (149-257)
Polvvinvichioride (PVC)	65 - 110 (149-230)
Acrylonitrile butadiene styrene (ABS)	75 - 90 (167-194)
Acetal (POM)	85 - 110 (185-230)
Liquid crystalline polymer (LCP)	180 -240 (356-464)
Polybutylene terephthalate (PBT)	120 -140 (248-284)
Polyethylene terephthalate (PET)	140 - 155 (284-311)
Nylon 6,6 (PA)	110 - 140 (230-284)
Epoxy	90-160 (194-320)

Phenolic	150 - 180 (302-356)
Polycarbonate (PC)	110 - 130 (230-266)
Polyester, unsaturated	130 - 180 (266-356)
Polyether ether ketone (PEEK)	180 - 260 (356 - 500)
Polyetherimide (PED)	160 - 180 (320-356
Polyimide (PI)	220 - 240 (428 - 464)
Polyphenylene oxide (PPO)	85 - 110 (185 - 230)
Polyphenylene sulfide (PPS)	200 - 220 (392 - 428)
Polystyrene (PS)	50 (122)
Polytetrafluoroethylene (PTFE)	180 (356)
Polysulfide (PSO	140 - 160 (284 - 320)

Table 21 plastic material its melting point

As for contraction or being melted plastic will already begin melting at 105°C.

Hypothetically if the stabilized soil is at 2-3 meters deep or more the temperature will not get that high or low for the plastic to expand or contract even if it happened the plastic will only be 1-4% of the soil, therefore it will not have too much of an effect (effect could be neglected)

4.3 Advantages of Soil Stabilization

By stabilizing the soil on-site, projects save the expenditures associated with removing existing soil and transferring new materials to the site. In locations where harsh weather conditions cause construction to halt or slow down during periods of the year, soil stabilisation can allow work to continue by stabilising the original soil and allowing work to continue according to Britpave Trade Association"" in United Kingdom. Therefore, stabilization techniques are a means of cost savings because work can continue through more weather conditions (Patel and Patel , 2012)

The specific advantages of treated soils are that they accelerate the construction process since the needed is often significantly less, requiring less material and manpower. Significantly increases strength and durability, particularly in areas where the available soil materials are poor. May minimize or completely remove the need for costly surface treatment or rendering (Halland et al., 2012)

4.3.1 Disadvantages of Soil Stabilization

Previous research has demonstrated the benefits of soil mixtures. However, several disadvantages that are inherent in the treated soil, which can be identified as necessary stabilizing materials, may not be available in some developing countries or may be expensive for transportation. The mixing and construction operations might be difficult depending on the stabilizer type selected. This can raise the probability of complications, which can have a negative impact on the budget and timeline (Jawad et al. 2014). Chemical reactions that are detrimental Two unwanted (destructive) chemical reactions are likely to occur in the treated soil. The first is carbonation, and the second is a reaction with the soil's sulphate salt. Carbonation is the chemical interaction between the additives and the atmospheric carbon dioxide (Umesha et al., 2009).

4.4 End of life cycle of the road

One of the sub questions in this research is what happens to the plastic after the road reaches the end of its life cycle? How to get rid of the plastic in the soil?

Theoretically speaking, getting rid of the plastic by heating up the soil is a solution, but this topic needs further investigation/research.

4.5 Facts for clayey stabilized soil using plastic waste materials and cement stabilized

- ✓ The increase of plastic content in the clayey soil reduces the optimum moisture content in the soil (based on the compaction test/proctor)
- ✓ The increase of plastic content especially Pe at 2cm length in the soil increases the axial compressive stress by 96.6%
- ✓ Plastic content PE especially increase the CBR values (strength of the soil in terms of vertical load/penetration) increase by 55% (from 4.0 to 6.2) and 80% (from 4.0 to 7.2), respectively, based on 1cm and 2cm length, while 2cm had the largest effect.
- ✓ Plastic content PE 1cm especially increased the MR values by 22%
- ✓ The increase in fibre content is not resulting in the increase in UCS ascendingly, while for Mr, the increase in fibre content resulted in the increase in Mr values.
- ✓ PE and PP fiber can efficiently be used to improve the physical and strength properties of soil materials as a foundation for engineering projects.
- ✓ Plastic fibers (micro plastics) has harmful side effects on the soil and the living organisms in it and affects the plant growth, and the soil nutrient cycle.

- ✓ Cement stabilization method is very effective especially in urban minor arterial and light industrial streets, rural major collector, and minor arterial highways. (ESALS 10^6).
- ✓ Plastic stabilized soil is very effective in Urban interstate highways some industrials roads and for heavy trucks highways. (ESALS 10^7).
- ✓ Cement soil stabilization and plastic soil stabilization, both methods are very effective in reducing the asphalt thickness, and cost too.
- ✓ MR test results showed an odd result on graph where there was a sudden drop in between that till this point isn't explainable since the graph went up again. (Such result needs further investigations).

5. Conclusion

Stabilization significantly enhances the mechanical properties of clayey soil, including their physical, mechanical, and strength properties. This research examined these qualities using an experimental laboratory test programme on two distinct waste polymers often found in disposal bins, namely polyethylene and polypropylene. The following are the major findings drawn from this research described here:

1. Soil stabilization using fiber have a distinct tendency for UCS and Mr., as increasing the fiber content does not result in an ascending trend in UCS. However, increasing the fiber content resulted in an ascending trend in Mr. values. As a result, the optimal fiber content should be found for stabilization with fibers at the maximum UCS and Mr. values.
2. PE and PP could be utilized to improve the physical and mechanical qualities of soil materials used in engineering projects.
3. The length of the fiber had an influence on the strength percentages of the stabilized soil, as increased length resulted in increased strength. This may require more research to determine the optimal fiber length which results in the optimum strength qualities.
4. For road pavement design codes of practice that use the CBR and Mr. as design parameters, the fiber 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 fiber stabilization is not; this is one of the advantages of fiber stabilization over chemical stabilization.
5. While increasing the fiber content increased the value of CBR and Mr., the optimal fiber content for UCS was between 1% and 2% for both PE and PP.
6. The Microplastics has a bad side effects on the micro-organisms in the soil but while has to do with if the land will be used for agriculture purposes where most of the impacts occur.
7. Clayey soil stabilized using plastic is very effective in terms of strength and cost however the long-term side effects of such method is still unknown so further research on how you can get rid of the plastic in the soil after the lifetime of the road needs further investigation
8. Cement soil stabilization is effective in terms of cost compared to unstabilized soil and effective is the ESALS 10^6 but not as effective as the soil stabilized with plastic fibers in the use of highways with high loads i.e., heavy trucks (ESALS 10^7)
9. Plastic fiber content (PE 1cm length) reduces the thickness by 0.75cm, and 0.50 for the 2cm length of PE, while PP didn’t have a noticeable effect compared to the PE plastic.

6.Recommendations

Further investigation on the long-term effect of having plastic in the soil and how can you get it out after the life cycle of the road since this is the one of the most crucial points that needs to be covered after the cost analysis which is covered in this paper, However theoretically speaking if we heated up the soil, that's one way to extract the plastic, but further investigation needs to be done on this matter. Use plastic waste materials for heavy load highways (ESALS 10^7) and cement stabilized soil for more moderate load highways and urban areas (ESALS 10^6)

Further investigation for different plastic thickness and length should be made to identify the optimal fiber length and thickness especially for PE plastic fiber since it's more effective than PP plastic fiber

Soil stabilization should be well promoted among the professionals in road construction industry as a solution for the problem of scarcity of soil with good quality. The promotion should be done through improving their knowledge and loyalty on stabilization technology.

For higher UCS values, compaction should be done as soon as mixing completed. Therefore, site mixing is appropriate rather than central plant mixing in the future.

The moisture content of the soil should be maintained lower at the mixing time and when compacting, it should be relevant to optimum moisture content

7.APPENDIX

Mechanisms and applicability of various stabilizing agents (Firoozi et al., 2017) and (Grogan et al. , 1999)

Mechanism	Effects	Suitable soils
Granular Blending to poorly graded soils, usually coarse into fine (not clayey) soils	Higher compacted density, more uniform mixing, increased shear strength	Gap-graded or gravel deficient (gravel, sand addition), or harsh [a]FCR (loam addition)
Cement Mixing small amounts (cement modification) or larger proportions (cement binding) into soil or [a]FCR	Improve shear strength, reduces moisture sensitivity (modification), greatly increases tensile strength and stiffness (binding)	Most soils, especially granular ones, large amounts of cement needed in clay-rich and poorly graded sands, hence expensive
Lime Mixing hydrated lime or quick lime in small to moderate amounts into soils	Increases bearing capacity, dries wet soil, improves friability, reduces shrinkage	Cohesive soils, especially wet, high – PI clays
Lime Pozzolan Mixing lime plus fly ash or granulated slay into soil or [a]FCR	Similar to cement but slower acting and less ultimate strength	As for cement, plus clayey soils that do not react with lime
Bitumen Agglomeration, coating and binding of granular particles	Water proofs, imparts cohesion and stiffness	Granular, non-cohesive soils in hot climates
Fly ash Mixing with an activator to form cementitious compounds	Waterproof concrete	Some materials will activate the fly ash; lime or cement may be used to act as an activator by providing the required calcium hydroxide
Fiber The use of hair-sized polypropylene fibers in soil stabilization	Increases the stiffness of soil and also the immediate settlement of soil reduced considerably, the strength and angle of internal friction increase	Tropical soil, clay soil

Tropical soils are **found under very hot conditions, and high yearly rainfall**. They are the worlds oldest soils. They are so old, that they are RUSTY! These soils have little ORGANIC MATTER, and very little NUTRIENTS! OXISOL. Examples of tropical soils **Oxisols, Ultisols, Alfisols, Aridisol, Inceptisols, and Entisols**. These soils occur in most tropical areas of Africa, Asia, and North and South America.

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