Using PET plastic to modify and improve asphaltic pavement's resistance to moisture susceptibility and to cut down environmental impact of PET Plastic Waste

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Final Year Project Titled

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DEDICATION

This thesis is dedicated to our parents and our teachers, who taught us to be brave, resilient, and irrepressible. Their guidance and encouragement, motivation, and mentorship is the reason why we are able to complete this final year project and our degree successfully.

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In the name of God (Allah), the most gracious, the most merciful and compassionate,

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LIST OF ACRONYMS

AASHTO – American Association for State Highway Transportation Officials

AC – Asphalt Course

ARL – Attock Refinery Limited

ASTM – American Society of Testing and Materials

BS – British Standards

HMA – Hot Mix Asphalt

ITFT – Indirect Tensile Fatigue Test

ITS – Indirect Tensile Strength

LDPE – Low Density Polyethylene

NHA – National Highway Authority

OBC – Optimum Bitumen Content

PARCO – Pak Arab Oil Refinery

PET – Polyethylene Terephthalate

UTM – Universal Testing Machine

VA – Voids Filled with Air

VMA – Voids Filled with Mineral Aggregates

VFB – Voids Filled with Effective Bitumen

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Abstract

With an ever-increasing population of Islamic republic of Pakistan, and exponential consumption of PET plastic materials filling our landfill sites and blocking canals, waterways, and drainages, a viable and a reliable solution for reuse or recycling of PET must be proposed. Burning and disposing in traditional ways produces harmful quantities of not only CO2 but other by-product such as benzo pyrene and polyaromatic hydrocarbons PAHs which are both carcinogens. Thus, our project consists of analyzing and testing the addition of PET waste in Hot mix asphalt (HMA), to enhance the properties of asphaltic pavements while utilizing the recycled PET and replacing a percentage of bitumen, saving costs, logistics and the environment from further pollution and production of greenhouse gases while reducing waste at landfill sites.

Asphaltic pavement in Pakistan suffers from failures and damage throughout the country, some are less damaged while others can be a cause of serious injury or even death, resulting in unsafe and inconvenient travel ways for the people. During Monsoons season, rain further induces damage and causes potholes and cracks to widen in the roads, making them undriveable and inflicts damage to vehicles and obstruction for the pedestrians, infusing frustration among people.

As a result of our study, we determined that the addition of Polyethylene Terephthalate (PET) into asphalt concrete has increased the TSR – Tensile Strength Ratio . The TSR value increases from 0.674 in virgin asphalt cake to 0.758 in 8% PET based modified asphalt cake which indicates an increase in the resistance to moisture susceptibility hence an improved service life and pavement performance. Also, assuming a 10KM long flexible pavement, we will be utilizing an approximately 85000kg weight of PET and this can significantly tackle the issue of plastic pollution in terms of plastic bottles and PET based packaging material.

CHAPTER 1

INTRODUCTION

1.1 Background

Polyethylene terephthalate is a thermoplastic polymer which is part of the polyester family. PET is the most recycled material in the world and all its products have 100% percent recyclable tags. Recycled PET can be made into fabric, fibers and sheets for packaging and manufacturing automotive products. Naturally, PET is a flexible and colorless and semi-crystalline resin. Some of its properties include stability, alcohols and solvents, moisture, and resistance to impact. Due to the water resistance, high mechanical strength, and chemical inertness it is widely used in manufacturing of water bottles, tapes, packaging trays, blisters, cosmetic jars, microwavable containers, transparent films etc.

Asphaltic pavement in Pakistan suffers from failures and damage throughout the country, some are less damaged while others can be a cause of serious injury or even death, resulting in unsafe and inconvenient travel ways for the people. During Monsoons season, rain further induces damage and causes potholes and cracks to widen in the roads, making them undriveable and inflicts damage to vehicles and obstruction for the pedestrians, infusing frustration among people.

1.2 Problem Statement

Meanwhile in Pakistan, PET water bottles, cups and food packaging materials are a common sight at any landfill yard. Over 250 million tons annually of plastic bottles are disposed of by Pakistani citizens, which end up filling landfills and waterways and becoming a source of pollution and blockage of our drainage systems. Until this day, no proper solution of reusing

PET plastic has been proposed either by the government or responsible organizations, which could hypothetically solve half of our littering and solid waste management issues.

Given the dangers of greenhouse gases and melting poles of our dear planet, the problems associated with pollution and production of CO2 should be averted as soon as possible. One of the first tasks on this mission is tackling the waste plastic disposal. Reusing or recycling of PET could be a significant step in the right direction and help make the quality of air we breathe safer, cleaner, and healthier for ourselves and our future generations to come.

1.3 Purpose of Research

With an ever-increasing population of Islamic republic of Pakistan, and exponential consumption of PET plastic materials filling our landfill sites and blocking canals, waterways, and drainages, a viable and a reliable solution for reuse or recycling of PET must be proposed. Burning and disposing in traditional ways produces harmful quantities of not only CO2 but other byproducts such as benzo pyrene and polyaromatic hydrocarbons PAHs which are both carcinogens.

Meanwhile, in the past 5 years Pakistan and its citizen has seen accelerated development in the transportation industry which includes Metro Bus projects of Islamabad-Rawalpindi, Lahore and Multan, Construction of motorways such as M1, M4 and M9 as well as rehabilitation and reconstruction of Karakoram highway, Hazara motorway and swat expressway. With projects moving at a brisk pace on China-Pakistan Economic Corridor (CPEC), it is safe to assume that this development will continue just like this.

Thus, our project consists of analyzing and testing the addition of PET waste in Hot mix asphalt (HMA), to enhance the properties of asphaltic pavements while utilizing the recycled PET and replacing a percentage of bitumen, saving costs, logistics and the environment from further pollution and production of greenhouse gases while reducing waste at landfill sites.

1.4 Research Objective

The research objectives include the following

- To use PET plastic to improve the performance and design life of pavement
- To improve the useful service level
- To improved resistance to moisture susceptibility
- To improve Aggregate-Asphalt pavement bond which will contribute positively to the structural strength of pavement
- To improvement overall strength and abrasion resistance
- To work on environmental sustainability

1.5 Organization of Report

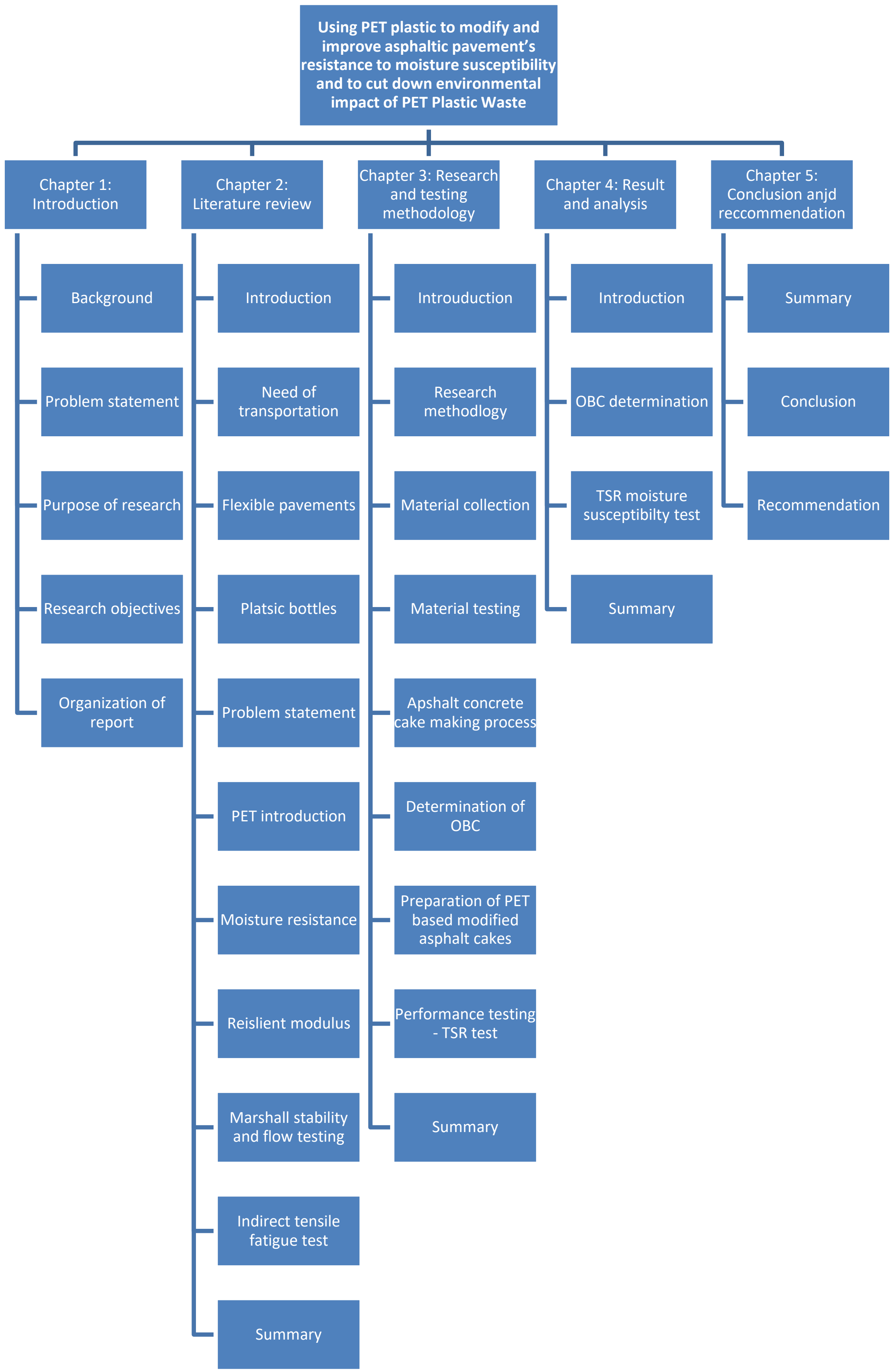
Chapter 1 It gives a brief overview of problems associated with generation of PET plastic waste, their possible use in HMA pavement, problem statement, research objectives.

Chapter 2 Includes literature review on needs of transportation, design methods of flexible pavements, previous research related to incorporation of polyethylene terephthalate plastic in pavement and problems associated with it. Finally, it includes research of different methods used for moisture susceptibility and other performance tests.

Chapter 3 explains the methodology adopted in this research which includes the collection and laboratory characterization of materials, the Marshall mix design and performance testing.

Chapter 4 presents the performance test results and their analysis.

Chapter 5 Summarizes the conclusions of laboratory testing, future recommendations are also discussed.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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter contains a brief review of the literature and theory related to the necessity of transportation, different methods to design flexible pavement. Some overview of plastic related garbage including plastic bottles (PET), plastic bags, high density plastic and PVC pipes etc. Therefore, we will utilize one of its forms, that is plastic bottles which are made of Polyethylene terephthalate (PET).We will incorporate this PET in flexible pavement and see its impact on pavement performance and how it can positively contribute to the environment. This chapter will also give details of the various tests performed such as Tensile strength ratio (TSR) on asphalt mixes.

2.2 Need of Transportation

A proficient transportation framework is the base of any nation's economy. A huge number of individuals travel by means of roads in our nation. The disintegration in the measures of Pakistan Railway and the absence of an inconceivable and satisfactory open transportation framework like the London Underground. Moscow Metro. Shanghai Metro, Indian Metro has led to poor transport facilities. It connects the countries' parts by creating efficient transport communications between different locations. Better transportations lead not only to the advancement of a country but also helps in boosting the country's economy. In short, the efficient the transportation system, the more successful is the country.

Pakistan was under the worst transportation system but now it has developed a lot. Motorway is being constructed and still its expansion is in progress. The aggregate length of Pakistan's motorways is 1010 km as of 4 Feb 2017. Around 3690 km of motorways are now under development in various parts of the nation. A large portion of these motorway ventures will be finished by 2019. The metro service at three different cities i.e., Islamabad, Lahore and Multan are being constructed and are under process in other cities of Pakistan. The Orange line train services in Lahore are some of the best examples of the transportation revolution in Pakistan.

Currently, Pakistan in collaboration with China is constructing a trade route that is known as "China Pakistan Economic Corridor" (CPEC). It is a cluster of different infrastructure projects worth 54 billion dollars. Karachi and Lahore will be connected by a 1100 km long. Furthermore, the Karakoram highway that connects Khunjerab, China border with Rawalpindi is being completed and is soon to be functional. The main railway line between Peshawar and Karachi will also be modernized to allow for train travel at up to 160 km/hr by December 2019.

2.3 Flexible Pavements

Flexible pavements are usually constructed using asphaltic surface course, also called bituminous wearing course with two to three layers underneath that includes the base course, subbase course followed by the subgrade. The basic purpose of having a multilayer structure of the asphaltic pavement is to distribute the load uniformly and on a wider area to reduce the amount of stress and the resulting deformations.

The overall design of the flexible pavement is focused on the concept of having a multi-layer structure to ensure that each proceeding layer is protected from the load transferred through the previous layer to the maximum possible extent. Another key benefit of having a multi-layer flexible pavement structure is that it is highly weather resistant, and the arrangement of layers is such that the most weather resistant and structurally strong material with the highest elastic modulus is on the top acting as surface course. This ensures better performance to failures such as fatigue and rutting.

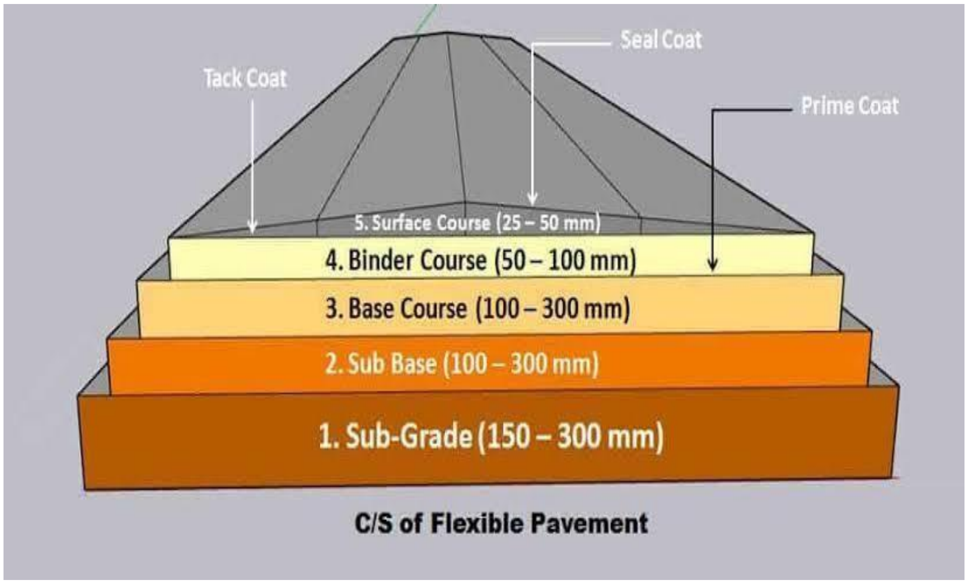

Figure 2.1 Flexible Pavement Cross Section

2.3.1 Design Methods

Two methods are used for the design of Flexible pavements which include

- Marshall Mix Design
- Super pave Mix Design

We used the Marshall mix design method to determine our OBC.

2.3.2 Marshall Mix Design

One of the most popular method of asphaltic pavement design was first developed by Bruce Marshal in 1939 and then modified by the US Army. This technique focuses on the determination of optimum bitumen content (OBC) for different blends of aggregate used. It also encounters traffic level in the design of pavement.

For the determination of OBC samples are prepared for different asphalt content generally in the range of 3.5 % to 6% of total sample weight. 3 samples are prepared for each asphalt content. After that, the following tests are performed on these samples.

1. Bulk Density Test

2. Flow and Stability Test
3. Density and void analysis

Five different curves are plotted versus asphalt content at x-axis.

The optimum bitumen content for the mixture is determined by finding the arithmetic mean of the following 3 bitumen contents: corresponding to.

1. Maximum stability
2. Maximum bulk specific gravity (Gmb)
3. Median of designed limits of percent air voids (VA) in the total mix (i.e., 4%)

The bitumen contents are found from the graphs obtained in previous step

2.4 Plastic Bottles

Plastic bottles are made of Polyethylene terephthalate(PET), it is a major source of pollution and most of the plastic waste bottles, and other plastic wastes are dumped in landfills that not only degrade the environment but also consume the costly land. With passage of time, we see more and more areas of land converted into landfills since these plastic wastes are Non- biodegradable.

We will be utilizing this waste to modify asphaltic pavements to improve service life and resistance to moisture susceptibility while at the same time reducing pollution.

Figure 2.2 PET Plastic bottles

2.4.1 Impact of plastic on Environment

Due to the rapid increase in the population, there is also an increase in industry in various fields and obvious generation of waste production of many types is observed. Some of the waste products are non-biodegradable such as slag, scrape tires, plastic etc. that persist in the environment for thousands of years leading to the waste disposal crisis and environmental problems. Today, as we look around, many things are made up of plastics or contain plastic content. We can find plastics in many useful materials we use. But as its disadvantages begin to roll out its use has been restricted by the government agencies, now the influence is on its recycling.

Some estimates relating to plastic waste in Pakistan is mentioned below:

- Plastic waste in Pakistan is more than 3.3million Tons/annum
- 65% of the total waste in Pakistan.
- Expected annual increase of 15% usage.
- 250 million tons of garbage in Pakistan are plastic bottles containing PET mainly.
- 55 billion plastic bags are being used in the country.

Apart from having impacts on human health, these plastic products have caused serious impacts on the health of animals, especially aquatic life. These polythene bags and bottles also have serious impacts on nature as usual practice to dispose of is to bum it which releases carbon dioxide contributing to global warming. These plastic products also cause blockage of drainage pipes ultimately leading to urban flooding and causing pavements to be more prone to water, therefore decreasing the pavements' service life.

2.4.2 Previous Work

Hot mix asphalt (HMA) is generally used in most of construction projects in Pakistan like road surfacing, airports, parking lots etc. The bituminous concrete is a blend of asphalt and aggregate mixed to achieve proper performance criteria. The reason for deterioration of roads of Pakistan is continuous increase of traffic and insufficient degree of maintenance due to lack of funds. To secure the roads several types of measures are found effective, secure the funds for the maintenance, use material of better quality, improve the roadway design, and use of better construction methods. Around the globe, polythene bags are causing much pollution to the surrounding environment. Globally, the interest is inclined towards re- using polythene bags for valuable motives. This project is focused on replacing some percentage of bitumen with **PET** to make some beneficial use of plastics.

2.5 Problem Statement

Some of the key failures of Hot Mix Asphalt (HMA) include overloading, temperature related deflections and performant deformations like fatigue cracking etc. To overcome this issue, modified asphaltic pavement using different polymers have been developed while taking into consideration the actual traffic load and scenarios. These polymers are derived from different manufacturing processes as well as through the waste that is dumped on landfills. The rise in the population has considerably boosted the industry's production of different types of waste materials. Such challenges are being confronted more by developing countries including Pakistan and India. One of the easiest solutions to this problem is recycling waste into useful products. In addition, the use of plastic as drinking bottles to contain various liquid products has become a common practice all over the country. The following research focuses on finding optimum PET % that can substitute bitumen in HMA, affecting the performance of pavement by increasing its resistance to moisture susceptibility and also contribute towards reuse of waste bottles.

2.6 PET Introduction

Polyethylene terephthalate (PET) was discovered in 1957 in North America by DuPont chemists looking to make new synthetic fibers, the same place where Nylon was discovered in 1935.

As PET has wide range of application from packaging, sheets, automotive parts to consumer plastic water bottles and soda bottles, the quantity of the plastic polymer is quite high in our environment, but fortunately, the PET is 100% recyclable so it can be recycled to make further new things once it is produced and using it to modify and improve our roads through addition into bitumen has been studied on for more than a decade or two with promising results.

2.6.1 PET Chemical Composition

PET stands for Polyethylene terephthalate that is a condensation polymer manufactured by the ethylene glycol esterification with either terephthalic acid or rather dimethyl terephthalate (G.L. Robertson, 2014). This resin is then extruded and cut into small pallets, which are then melted and formed into different shapes and products

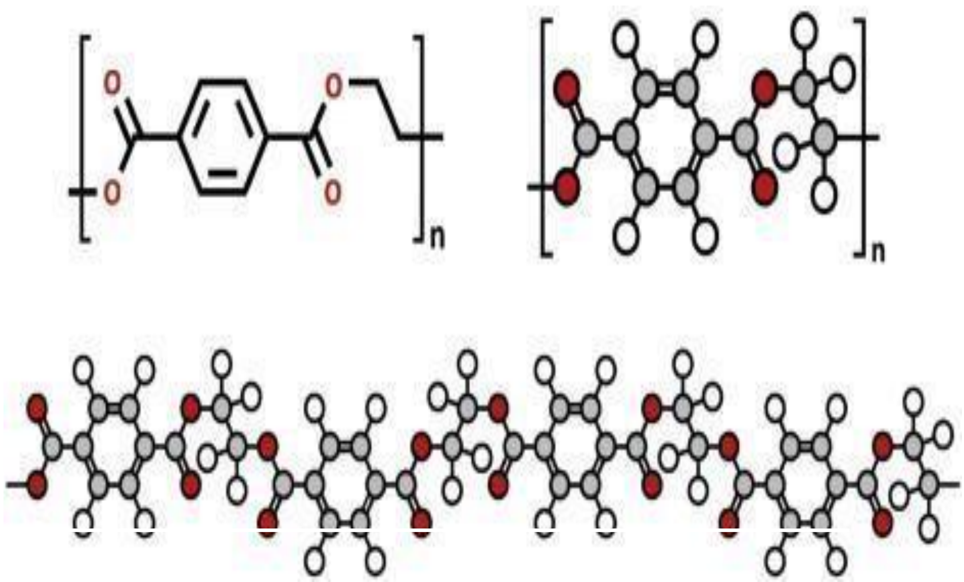

Figure 2.3 PET Molecular Structure

PET can be completely recycled, and in fact it is the most recycled plastic polymer worldwide. Around 1.5 billion pounds of used PET products are found in the United States annually (petresin.org). PET is identifiable by the number 1 among the recycling logo found at the bottom or side of the containers, as no other plastic product carries this sign.

Figure 2.4 Recycle 1 sign

PET is a thermoplastic material ($(C_{10}H_8O_4)_n$) with great mechanical strength and is also used as an alternative synthetic fiber. PET has numerous applications in consumer and industrial products; thus, it is a common waste at landfills.

Recycling PET solves numerous environmental problems and utilizing it to improve the service life and maintenance of the asphalt pavement is even better as it saves time and cost by reducing moisture susceptibility and increasing service life of the pavement.

Akinleye Monsuru Tunde (2020) researched the performance characteristic model of dissolved plastic bottle modified bitumen for hot mix asphalt production. High density polyethylene bottles were cut into 15-25mm pallets and added to 60/70 grade bitumen after pyrolysis and mixed into hot mix asphalt (HMA). The PET was added by weight from 1% through to 17%, and each addition was tested for strength. The results concluded that addition increases softening, viscosity, flash, and fire point of bitumen but decreases the penetration and ductility of bitumen.

One of research by Adebayo Olatunbosun sojobi (2016) showcased an environmentally-friendly way of utilizing wastes for road construction in two different ways. In the first method, utilized molten plastic bottle wastes to coat the aggregates used in asphaltic road construction and in the second method, he utilized molten plastic wastes to replace the asphalt cement. The results highlighted that the bituminous asphaltic concrete produced using the plastic-coated aggregates was able to utilize more plastic wastes compared to the plastic modified bitumen. However, the plastic-modified bitumen experienced more stability, although they were close. Dry process was preferred and utilized in the mixing process for BAC preparation because it allowed for utilization of more plastic wastes in BAC,16.7% by weight of total aggregates. While in the wet process only 9% by weight of OBC. A portable gas cooker was used to melt the plastic wastes, heat the aggregates, and prepare the BAC at appropriate test/mixing temperatures. The plastic wastes were first shredded and heated in the oven to 170°C for a duration of 60 minutes.

2.7 Moisture Resistance

Splitting, rutting and crack developments in the asphalt roads in Pakistan is common throughout the country. Moisture finds its way inside the asphalt concrete and causes damage. To solve these issues, strict bitumen placement standards must be enforced, and laying temperature maintained by the paver machine and checked frequently by the quality control engineer, but it is impossible to maintain these solutions on such a large scale. Addition of PET promises better moisture and rutting resistance, without having to change conventional practices in our construction industry. Since PET has high mechanical strength as well, it can improve more than just the moisture resistance of the asphalt concrete.

Ahmed Mancy Mosa (2017) carried out the research on modification of HMA using plastic waste bottles and was able to prove through Rutting Susceptibility Test (AASHTO T324) and Indirect Tensile Strength Test (T283) that rutting, and moisture susceptibility decreases with the addition of 0.5% PET With respect to aggregate. In this test, plastic bottles were used with a maximum size of 2.36mm.

Figure 2.5 Rutting failure

Aghayan, R. Khafajeh (2019) performed indirect tensile strength test to calculate the tensile strength ratio (TSR) of conditioned and unconditioned samples. The TSR was higher for mixes containing PET, and the TSR increased with increased percentage from 2% to 4% addition of PET into HMA. On the other hand, increasing the percentage addition further decreases the moisture resistance, thus optimum percentage addition of PET must be found for improved asphalt concrete.

2.7.1 Procedures for Evaluating Moisture Susceptibility

Moisture induced stress test (MIST) simulates the field conditions. It exposes the HMA specimen to repeated pore pressures as experienced by the pavement on the field due to repeated tire load. It is basically an assembly consisting of a compressor to load air and a vacuum to load air in and out of the HMA specimen.

Determining the dynamic modulus can aid in evaluating the moisture susceptibility of HMA mix as dynamic modulus is the indicator of viscosity of the mix. Determining dynamic modulus before and after condition of mix can be handy to check tensile strength ratio of HMA sample

Moisture damage can also be evaluated from Hamburg wheel tracking devices. Several different factors influenced the results from this device. Several studies were done to list down the factors affecting the results from Hamburg devices. These were identified as quality of aggregate, asphalt cement stiffness, long and short-term aging of asphalt cement, the properties of crude oil from which asphalt was extracted, compaction temperature etc.

Indirect tensile strength test (ITS) can be useful for performance testing of pavement. By determining the tensile strength of pavement in conditioned and unconditioned state, we can evaluate moisture damage and resistance to moisture susceptibility. The test involves loading the specimen in diametric orientation and measure the maximum value of load until the specimen breaks or cracks as a measure of strength of pavement

In 1998, Maine Dot recommended and concluded that the determination of the tensile strength ratio (TSR) of conditioned sample to an unconditioned sample is the most appropriate measure of moisture damage to pavement (Washington state department of transportation, 2009). This method can be more acceptable by consideration of contact angle measurement and dynamic modulus results (TAO & MALLICK, 2008).

The procedure used in this research is based on AASHTO T283 which determines the tensile strength ratio of conditioned sample to unconditioned sample. The conditioning of the sample is done in a water bath at 60C for 24 hours after which it is placed for another 1 hour at 25C. The unconditioned sample is placed for 25C in a temperature-controlled sample for 1 hour. The TSR ratio should be minimum 70% for satisfactory functioning of the road.

2.8 Resilient Modulus (M_R)

The resilient modulus allows us to compare samples under various conditions like stress, level, density, and moisture. M_R could be determined by the application of cyclic axle load on the cylindrical samples.

Figure 2.5 Triaxial Testing of Asphalt Cake

The difference between modulus of elasticity and resilient modulus is that in elasticity modulus is determined by dividing stress by strain of slowly applied loading whereas Resilient modulus consists of dividing stress by strain of lowly applied loading, and triaxial test is carried out for Resilient modulus.

D.Movilla Quesada (2019) carried out his research with goals of increased stiffness and stability by addition of PET. PET was added using the dry process and 6 different percentages were used and compared with the virgin sample, totaling 24 samples. As PET increases from 0 to 14%, stability increases and is maximum at 14% with a value of 20KN. As PET increases, flow increases, and optimum flow is between 10% to 14% of PET. Marshall stiffness is maximum at 14%. VA and VMA also increase with increase in PET (suitable around 14%). As PET increases up till 14%, the Mr (Modulus of Rigidity) also rises.

Wan Mohd Nazmi, Fauzi Abdul Wahab (2013) set out to Determine the effect of adding PET as a partial fine aggregate in asphalt mix and its deformation behavior. The maximum size of PET that was added did not exceed 3mm. 20% content of PET in Marshal Cake was mixed, with 50 blows on each side while testing, assuming medium traffic flow conditions.
However, in their research The Resilient modulus (Mr) value of unmodified asphalt is greater than recycled PET modified asphalt, stating that addition of recycled PET does not enhance stiffness of asphalt properties. Therefore, they recommend that instead of addition in bitumen, aggregate could be coated with PET, which may result in a positive outcome.

2.9 Marshall Stability and Flow Testing:

Marshall stability is one of the most common tests performed on asphalt concrete specimens to find out their resistance to various failures such as displacement, rutting, distortion, and shearing stresses. Furthermore, their loading and flow rate can also be determined from this test.

Figure 2.6 Marshall Stability Test

Rean Maharaj (2018) performed Marshall stability and flow testing on the modified and unmodified samples, to compare their performance and find out the optimum PET addition content. The waste polymeric PET and CR were added to the mixture from 0% to 5% with increments of 0.5%. The optimum dosage found was 1.0% PET and 5.0% Crumb rubber polymers in HMA. Marshall stability of modified samples were greater than unmodified samples while flow values varied. Moreover, QUV Accelerated weather tester and compressive strength testing showed higher weather resistance with 1% PET and 5% CR showing highest resistance. Therefore, this modification provides an environmentally sound and sustainable method for the reuse of these polymers.

The waste PET was added as a partial fine aggregate with the bituminous mixture which used 60/70 bitumen grade and 12.5 mm aggregate grading by Amanina Farhana Ahmad (2017). It was blended at 140˚C-180˚C and then compacted with 50 blows each side by using a Marshall hammer. The percentage of PET ranged from 0 to 10% which was blended into the mixture. Marshall stability Test was carried, and the best proportion of PET was 6% by weight of asphalt.

The results of the study have showed better resistance against permanent deformations and rutting after comparing it with the conventional binder. The results also showed that the increasing the amount of PET would increase the softening point of the mixture, thus it can be concluded that the tendency of binder to soften in hot weather would reduce if the resistance of the binder to the effect of heat increased.

2.10 Indirect Tensile Fatigue Test

The procedure to produce specimen for this test is relatively simple and straightforward. According to the research, it has been determined that the fatigue life that is determined using this ITFT test is usually less than the one determined by other methods to determine fatigue life (Kennedy et al., 1975)

The loading applied produces vertical compressive stress and horizontal tensile stress along the diameter of the specimen; the stress is maximum at the center, the strain can be calculated by assuming that material is homogenous, force is in line with loading and there are plane stress conditions.

Major advantages of ITFT are its simplicity, field cored specimens can also be tested, the equipment can be used for other tests also and there is less variability for the same type of mix. The disadvantage is that fatigue life is underestimated as it is determined by tensile stresses. It leads to permanent deformation. Stiffness is not reliably measured as that from trapezoid or beam test. ITFT load can be varied while it can be performed across various temperatures as well. The maximum number of cycles to failure is the fatigue life of pavement.

The stress at the center of pavement can be calculated by the formula:

$$\sigma = 2000P/\pi t D$$

Whereas strain by

$$\varepsilon = [(2\Delta H/D) \times (\{1+3v\}/\{4+\pi * v-\pi\})]$$

σ= Tensile stress at the center of specimen

ε= Tensile strain at the center of specimen

P= Maximum load (Newton)

t= Specimen height (mm)

D= Specimen diameter (mm)

ΔH= Horizontal deformation

2.11 Summary

In this chapter, the benefits of transportation were discussed on how it contributes to the development of the country's economy by quoting examples from developed countries like the UK and Russia.

Then an overview was given about the design of flexible pavement, Marshall and super pave methods were discussed in this regard. Plastics and its impact on the environment were discussed on how it causes pollution to the surrounding.

Much research has used plastic bottles, more precisely PET and HDPE in pavement and have found satisfactory performance results. Then incorporation and techniques used such as crushing PET by machine or cutting by hands were also mentioned in some of the literature reviews.

Furthermore, a review was given on different test methods used for determining moisture susceptibility and fatigue life of pavement. The most common test mentioned in the literature reviewed includes Marshall stability and flow test, followed by finding Resilient modulus (Mr). The indirect fatigue test was discussed as well in detail and highlighted its advantages and disadvantages over other test methods.

CHAPTER 3

RESEARCH AND TESTING METHODOLOGY

3.1 Introduction

This chapter discusses the methodology adopted in order to achieve the objectives of the study which includes acquisition of material, testing of material, specimen preparation and various tests on specimens. The study was carried out on a control sample as well as a sample containing the PET. In this chapter, determination of OBC at various percentages of PET, using Marshall Mix Design is discussed. Based on the OBC samples for the performance testing will be prepared with and without addition of PET. The percentage of PET being used is 5-8%.

Performance testing includes moisture susceptibility testing and fatigue testing along with TSR (tensile strength ratio) test. The equipment used; procedure followed along with the input parameters used during testing on the specimen prepared will be discussed in this chapter.

3.2 Research Methodology

Virgin aggregate was acquired from the Margalla plant sites as well as through local sources. PET was also acquired from Islamabad Landfill. These materials were brought to the laboratory of NUST INSTITUTE OF TRANSPORTATION (NIT) and several tests were conducted on aggregate and PET. After that the Marshall specimen was prepared for finding OBC of samples containing PET and samples containing no PET.

3.3 Material Collection

3.3.1 Aggregate

Aggregate was collected from Margalla Crush plants and some was acquired locally. Aggregate plays a vital role in defining the strength and durability of HMA pavements as it takes the maximum load of the pavements. These strength related properties of aggregate are greatly influenced by the texture and shape. Generally angular and textured aggregate is more resistant to stresses due to application of repeated loads.

Figure 3.1 : Margalla Crush Plant

3.3.2 Bitumen

In Pakistan, mostly bitumen of grade 60/70 is used as per weather conditions. So, bitumen of grade 60/70 was acquired locally.

3.3.3 PET

Polyethylene Terephthalate being a common modifier, was also acquired locally. Most of the PET is generally present in the plastic bottles.

3.4 Material Testing

3.4.1 Aggregate

Several tests were performed according to ASTM specification to check the properties of aggregate that includes

- Flakiness test
- Specific Gravity and Water Absorption test

- LOS Angeles abrasion test
- Impact Test

3.4.1.1 Shape test of Aggregate (ASTM D 4791-99)

This test determines the percentage of flaky and elongated particles in the aggregate. Flaky particles are defined to be those having their least dimension lesser than 0.6 times their mean dimension. While elongated particles are defined to be those having their greatest dimension greater than 1.8 times their mean dimension. For better interlocking of aggregate particles angular shape is preferred. The flakiness index should be less than 15% while elongation index less than 15%.

3.4.1.2 Specific Gravity Test (ASTM C 127 & ASTM C 128)

Specific gravity is the ratio of weight of the given volume of aggregate to weight of equal volume of water at 23 degrees Celsius. This test was only performed on coarse aggregate as per C 127-88. Three weights were determined for calculating specific gravity i.e., weight of oven dried aggregate, weight of aggregate completely submerged in water and saturated surface dry weight of aggregate. Specific gravity of fine aggregate and water absorption was determined using ASTM C 128.

Figure 3.2 Sieved Aggregate

3.4.1.3 Impact Value of Aggregate (BS 812)

The impact value of aggregate gives its relative strength against the impact loading. The equipment utilized was impact testing machine, tamping rod, sieves of sizes ½", 3/8", and #8. About 350 grams of sample passing sieve ½" and retained on 3/8" was transferred in the impact testing machine cup in three layers, each layer was tamped 25 times with the help of a tamping rod. After that it was subjected to 25 blows from a rammer of 14 kg and a freefall of 38 cm. after that material was taken out from the cup and passed through sieve #8. The percent passing through sieve #8 gives an impact value of aggregate. The results are then summarized.

3.4.1.4 Los Angeles Abrasion Test (ASTM C 535)

This test is used to check the resistance of aggregate to wear and tear due to heavy traffic. Higher is the abrasion value of aggregate, the more aggregate will be adversely affected. Equipment used in this test was a Los Angeles abrasion machine, steel balls, sieve set and weighing balance. NHA Grade B was selected for this test. About 5000 grams of sample, containing 2500 grams retained of sieve ½" and 2500 grams retained of 3/8" was placed in the machine with the steel balls and drum was rotated at speed of 30-33 rpm for 500 revolutions.

After that, material from the machine was passed through a 1.7mm sieve and the weight of the sample was noted (W2). The abrasion value is defined to be = (W2/W1)*100

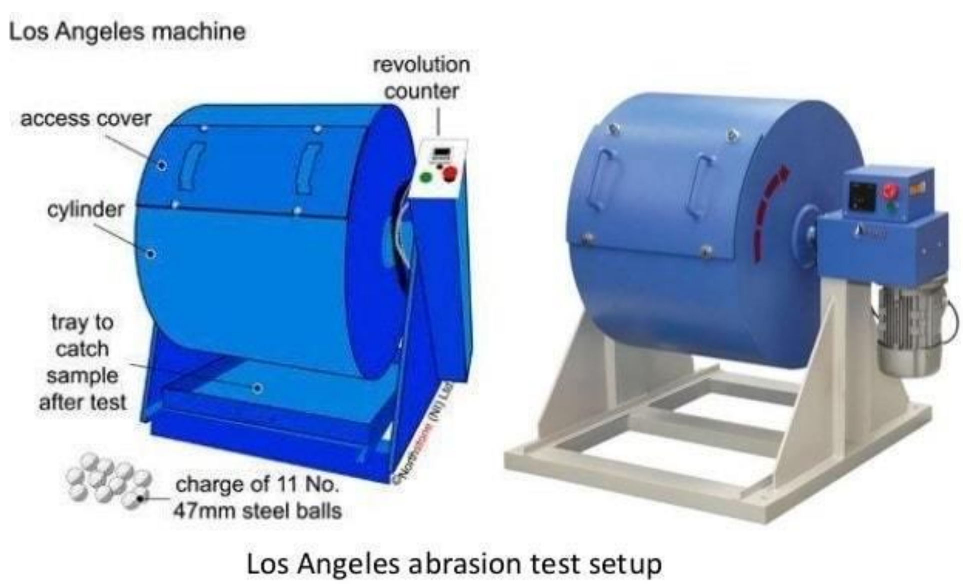

Figure 3.3 Los Angeles Abrasion Test Setup

Test	Specification	Result	Limits
Flakiness Index	ASTM D4791	12.5%	**<15%**
Elongation Index	ASTM D4791	3.26%	**<15%**
Impact Value	BS 812	18.5%	**<30%**
Specific Gravity	ASTM C127/ C128	2.549	
Los Angeles Abrasion Value	**ASTM C131**	**34%**	**<45%**

Table 3.1 : Test Results of Aggregate

3.4.2 Test on Bitumen

The experimental phase of this research started with the preparation of control samples, which basically represent unmodified, conventional HMA and modified samples in which PET was added. Having found the OBC, optimum PET content was determined following the present study methodology. Lastly a comparative analysis, based on performance evaluation of both the mixes was carried out and conclusions were noted.

The tests on the binder are as follows:

- Penetration Test
    - Softening Point
    - Ductility Test
    - Flash and Fire Point

3.4.2.1 Penetration Test (ASTM D5)

The penetration test is used to determine the penetration grade of bitumen by measuring the depth in tenths of mm up to which a standard loaded needle will vertically penetrate the bitumen specimen under given conditions of loading, time, and temperature. Softer binder gives greater values of penetration. According to ASTM D5, temperature used was 25 degree Celsius, load of 100 grams, while time for the test equals 5 seconds until and unless the situations are not explicitly stated. Using two PARCO 60/70 specimens, five values from each specimen were taken after performing penetration tests. All values obtained fulfilled the criteria of the penetration test as per specifications.

3.4.2.2 Softening Point (AASHTO T-53)

The softening point is the temperature at which the substance attains a degree of softening under specified conditions. The softening point of bitumen is usually determined by a ring and ball test. Softening point of bitumen is the average temperature at which the two disks of bitumen soften adequately to allow the steel balls of 3.5 grams to fall 25 mm. for softening point determination of asphalt as per AASHTO T-53 specifications ring and ball apparatus was used.

3.4.2.3 Ductility (ASTM D113)

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample of the material will be elongated without breaking with a specific speed i.e., 5 cm/min and at a specific temperature of 25 +- 0.5 degree Celsius. Different samples of bitumen were tested, and all gave ductility value greater than the least limit of 100 cm.

3.4.2.4 Flash and Fire Point (ASTM D3143)

Flash point is that least temperature at which the bitumen momentarily flashes at specified conditions.

Fire point is the temperature at which the material gets fired and burns under the specified conditions. Flash and Fire point tests were conducted as per D3143/D3143M-13 standards.

3.4.2.5 Viscosity Test (ASTM D4402)

Viscosity is the ratio between the applied shear stress and rate of shear called the coefficient of viscosity. This coefficient is a measure of resistance to flow. This test method outlines the procedure for measuring viscosity at elevated temperatures from 60 to over 2000 degree Celsius. A rotational viscometer uses the concept of torque. It measures the torque required to rotate an object submerged in fluid (asphalt in this case) and relates it to the viscosity of the fluid. This test is performed per the standard ASTM D4402-06.

The results obtained from testing of bituminous mixture are illustrated in following table

Serial Number	**Test Type**	**Specifications**	**Result**
1	Penetration Test at 25C	ASTM D: 5-06	69 (60-70)
2	Flash Point in C	ASTM D-92	269
3	Fire Point in	ASTM D-92	297
4	Softening Point in C	ASTM D 36 - 95	46
5	Ductility Test (cm)	ASTM 113 - 99	118
6	Viscosity Test (Pa.sec)	ASTM D 88 - 94	0.2541
7	Specific Gravity	ASTM D 70	1.02

Table 3.2 : Test Results of Bitumen

3.5 Asphalt Concrete Cake Making Process

To determine the optimum binder content (OBC), 10 asphalt concrete samples were made i.e., 2 samples were made on each percentage of asphalt that includes 3.5%, 4%, 4.5%, 5%, 5.5% wrt to the concrete mix as a whole.

3.5.1 Gradation Selection

The gradation selection was NHA Gradation B for surface course mix according to NHA 1998 Specifications. The nominal maximum size for this gradation is 19 mm (3/4") according to MS2. The gradation selected is shown in table 3.3. per percent passing against each sieve and corresponding gradation curve is plotted in Figure 3.4

Serial Number	Sieve Size (mm)	NHA Specification (% passing)	Mid gradation selected(% Passing)	% Retained
1	19	100	100	**0**
2	12.5	75-90	82.5	**17.5**
3	9.5	60-80	70	**12.5**
4	4.75	40-60	50	**20**
5	2.38	20-40	30	**20**
6	1.18	5-15	10	**20**
7	0.075	3-8	5.5	**4.5**
8	**Pan**	**-**	**-**	**5.5**

Table 3.3 NHA Grade B

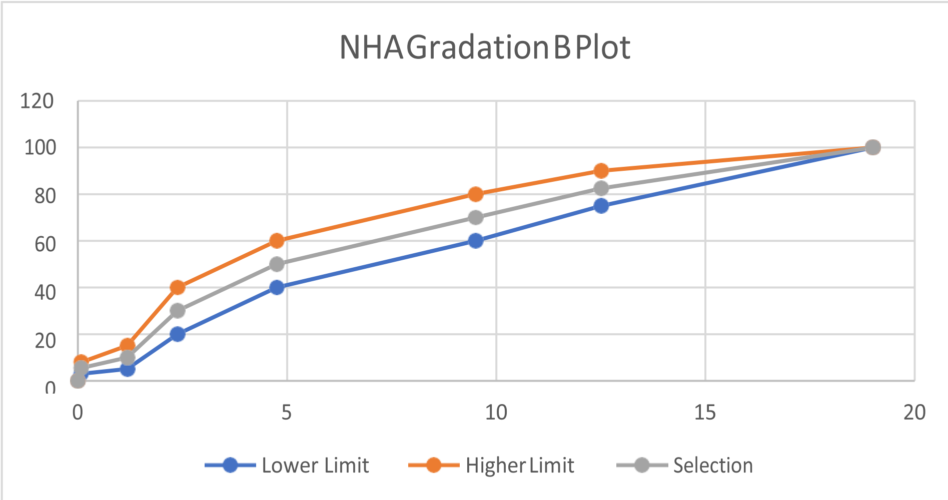

Figure 3.4 NHA Gradation (Class B) Plot

3.5.2 Sieving Process

A thorough sieving process was carried out according to NHA Gradation B and the total weight of asphalt concrete cake was set as 1200 grams. This total weight contained a portion of the sieved aggregate and bitumen in different percentages as shown in following tables. As discussed earlier, a total of 10 asphalt concrete samples were made i.e., 2 samples were made on each percentage of asphalt that includes 3.5%, 4%, 4.5%, 5%, 5.5% wrt to the concrete mix as a whole.

The following tables show asphalt concrete composition with varying percentages of binder content with respect to mass of mix.

Percentage Bitumen	3.5		
Weight of Sample	1200		
Mass of Bitumen	42		
Mass of Sample	1158		
Sieve	**Cumulative Passing**	**Percent Retain**	**Weight (g)**
A 3/4	100	0	**0**
A 1/2	82.5	17.5	**202.65**
A 3/8	70	12.5	**144.75**
A #4	50	20	**231.6**
A #8	30	20	**231.6**
A #50	10	20	**231.6**
A #200	5.5	4.5	**52.1**
PAN		**5.5**	**63.7**

Percentage Bitumen	4		
Weight of Sample	1200		
Mass of Bitumen	48		
Mass of Sample	1152		
Sieve	**Cumulative Passing**	**Percent Retain**	**Weight (g)**
A 3/4	100	0	**0**
A 1/2	82.5	17.5	**201.6**
A 3/8	70	12.5	**144**
A #4	50	20	**230.4**
A #8	30	20	**230.4**
A #50	10	20	**230.4**
A #200	5.5	4.5	**51.84**
PAN		5.5	**63.4**

Percentage Bitumen	4.5		
Weight of Sample	1200		
Mass of Bitumen	54		
Mass of Sample	1146		
Sieve	**Cumulative Passing**	**Percent Retain**	**Weight (g)**
A 3/4	100	0	**0**
A 1/2	82.5	17.5	**200.55**
A 3/8	70	12.5	**143.25**
A #4	50	20	**229.2**
A #8	30	20	**229.2**
A #50	10	20	**229.2**
A #200	5.5	4.5	**51.57**
PAN		**5.5**	**63.04**

Percentage Bitumen	5.0		
Weight of Sample	1200		
Mass of Bitumen	60		
Mass of Sample	1140		
Sieve	**Cumulative Passing**	**Percent Retain**	**Weight (g)**
A 3/4	100	0	**0**
A 1/2	82.5	17.5	**199.5**
A 3/8	70	12.5	**142.5**
A #4	50	20	**228**
A #8	30	20	**228**
A #50	10	20	**228**
A #200	5.5	4.5	**51.3**
PAN		**5.5**	**62.7**

Percentage Bitumen	5.5		
Weight of Sample	1200		
Mass of Bitumen	66		
Mass of Sample	1134		
Sieve	**Cumulative Passing**	**Percent Retain**	**Weight (g)**
A 3/4	100	0	**0**
A 1/2	82.5	17.5	**198.45**
A 3/8	70	12.5	**141.75**
A #4	50	20	**226.8**
A #8	30	20	**226.8**
A #50	10	20	**226.8**
A #200	5.5	4.5	**51.03**
PAN		**5.5**	**62.37**

Table 3.4 Asphalt Concrete Cake Composition

3.5.3 Preparation of Aggregate and Bitumen

After sieving the aggregate into different sizes required for the project as shown in previous tables, these aggregates were then oven dried at a temperature of 110 C. The total sample weight of Marshall mix is 1200 grams. The weight of Asphalt cement varied according to its percentage which is from 3.5 to 5.5% of mix. The weight of aggregate and asphalt can be obtained from following formulae

Wt = Mass of Total Mix = 1200 g

Wt = Wb + Wa

*Wb = Mass of Asphalt = X/100 * Wt* *X= Percentage of Asphalt*

Wa = Mass of Aggregate

3.5.4 Mixing of Aggregate and Asphalt

The asphalt cement is first heated until it gets in liquid form by using an electric oven at a temperature of around 110 C and is then thoroughly mixed with aggregate at a temperature of 150-160C as specified by AASHTO. The mixing process must be carried out until the point where asphalt is completely mixed with aggregate and there is visibly no particle left without asphalt cement covered. Care should be taken while carrying out the mixing process by wearing fabric-based gloves, safety goggles and safety apron.

3.5.5 Compaction of Specimen

According to Marshall Mix Design, there are three criteria for compaction depending on whether the surface is prepared for light, medium or heavy traffic. In this project, we have designed our pavement for heavy traffic so 75 blows are given on either side of asphalt concrete cake specimen to achieve adequate compaction. The loose mix obtained from heating aggregate with asphalt cement is transferred into a mould having a base plate. After achieving 75 blows on one side of the specimen, the specimen was inverted, and 75 blows were given on the other side of the specimen. To carry out this compaction, Mechanical Marshall Compactor was utilized which has a free fall drop distance of 18 inches and has a sliding mass of 10 lb.

Figure 3.5 Marshall compactor

Figure 3.6 Prepared Asphalt Concrete Cakes

3.6 Determination of OBC

To determine the optimum binder content, we need to determine the stability and flow values along with VA (Air Void Percentage), VMA (Voids filled with Mineral Aggregates) and VFB (Voids Filled with effective Bitumen). After cooling the specimen to room temperature, the volumetric of the specimen is calculated by determining Gmm (Theoretical Specific Gravity) and Gmb (Bulk Specific Gravity) values.

3.6.1 Gmb determination

The tests for Gmb and Gmm are performed in accordance with ASTM D2726 and ASTM D2041, respectively. For determination of Gmb, firstly weight in air of specimen is determined that is represented by 'Ma'. After this, the specimen's weight is measured in water using buoyancy balance and this is represented by 'Mc'. Finally, weight of specimens is measured in saturated surface dry state (SSD) and this is represented by 'Mb'.

Figure 3.7 Electronic Balance

Using the Gmb formulae (***Gmb = Ma/Mb-Mc***), following results are obtained.

						Bulk Specific Gravity (Gmb)				
% of Asphalt	**3.500**		**4.00**		**4.50**		**5.00**		**5.50**	
Ma (Dry Weight)	1140	1118	1190	1193.5	1160	1198.5	1124	1151.5	1141.5	**1176.5**
Mb (SSD)	1149.5	1135.5	1200.5	1204.9	1163.5	1203	1125.5	1154.0	1142.5	**1179.5**
Mc (In water)	647.5	648.2	683.1	686.5	664.1	687.1	660.4	666.90	688.7	**682.1**
Gmb	2.270	2.294	2.299	2.302	2.322	2.323	2.416	2.363	2.515	**2.3653**
Final Gmb	**2.2825**		**2.3011**		**2.3229**		**2.3903**		**2.440**	

Table 3.5 Gmb Bulk Specific Gravity

3.6.2 Gmm Determination

For Gmm calculation, weigh the loose mix which is represented by 'A' and then find the calibration weight of the apparatus which is represented by 'B'. After this, we transfer the mix to the apparatus and apply vacuum. After the removal of entrapped air in the mix, weigh again the apparatus containing the mix as well.

Using the Gmm formulae, **(*Gmm = A/ B-(C-A)*),** following results are obtained.

Percentage	3.5	4	4.5	5	5.5
Calibration Weight (B)	6783	6783	6783	6783	**6783**
Dry weight (A)	1118.5	1189.5	1149.5	1100.5	**1147.5**
Sample + water (C)	7471	7498	7468	7439.5	**7472.1**
Gmm (A/B-(C-A))	**2.598142**	**2.506849**	**2.474703983**	**2.4786036**	**2.503272**

Table 3.6 Gmm Theoretical Maximum Specific Gravity

3.6.3 Stability and Flow Test

After the determination of Gmb and Gmm, stability and flow tests are carried out. The specimen is transferred to a water bath at 60 C for 30 minutes after which it is tested for Marshall stability and flow using Marshall Equipment. After placing the sample in the Marshall apparatus, it is loaded at a constant deformation rate of 2inches/ minute until the specimen fails. The maximum load that specimen takes is its stability value and the strain that occurs corresponding to maximum load is its flow value measured in mm. According to Marshall Mix Design in AASHTO Table L-12-2 and L-12-4, the stability value must be more than 8000 N whereas the flow value must be within the range of 8-14mm.

The results of stability and flow tests are elaborated in following table

Percentages (%)	Gmb	Gmm	Stability (Kn)	Flow (mm)
3.5	2.283	2.598	9.22	**4.91**
4	2.301	2.507	11.03	**3.20**
4.5	2.320	2.475	10.48	**7.12**
5	2.390	2.479	7.98	**9.01**
5.5	**2.440**	**2.503**	**7.60**	**5.60**

Table 3.7 Stability and Flow Test

Figure 3.8 Stability and Flow Test

3.6.4 VA, VMA, VFB Determination

The next step in the OBC determination process is the determination of VA (Air Void percentage), VMA (Void filled with Mineral Aggregates), and VFB (Voids filled with Bitumen). For this, we used the following formulae obtained from the US Department of Transportation, Federal Highway Authority (FHWA) Article HF-1033.

VA = [(Gmm - Gmb) / Gmm] x 100

VMA = 100 - [(% of Aggregate x Gmm)/ Gsb]

VFB = [(VMA - VA)/ VMA] X 100

Percentage	Gmb	Gmm	VA (%)	VMA (%)	VFB (%)
3.5	2.283	2.598	12.149	14.03838	10.60960461
4.0	2.301	2.507	8.211475	13.34165	38.45232098
4.5	2.320	2.475	6.251414	13.08116	52.21055369
5.0	2.390	2.479	3.574739	12.80262	68.63222618
5.5	2.440	2.503	2.527582	9.542579	73.5125926

Table 3.8 VA VFB VMA

After the determination of VA, VMA, VFB, OBC (Optimum Binder Content) was determined by plotting graphs between binder percentages on horizontal axis and different properties on vertical axis that includes stability (KN), flow(mm), VA, VMA and VFB percentages. The asphalt content at 4% air voids corresponds to OBC. The graphs in reference to determination of OBC are drawn in chapter 4.

An OBC of 4.9% was determined corresponding to 4% air voids. If all properties are within the limits specified in Table L-12-2 and L-12-4 AASHTO, then well and good otherwise we have to adjust our OBC. In our case, the VMA value came out to be 13.1% i.e., within the range specified by AASHTO, VFB value came out to be 68% which is within the range of 65-75%, the flow value came out to be 9mm which was within the specified range of 8-14mm, and the stability value came out to be 8.2KN which is within the range specified by AASHTO.

3.7 Preparation of PET Based Modified Asphalt Cakes

After the determination of OBC i.e., 4.9%, the next step of our project was to prepare modified asphalt concrete cakes using polyethylene terephthalate (PET) that is obtained from crushed plastic bottles. A total of 6 asphalt concrete samples were made, 2 samples were made on OBC of 4.9%, 2 samples were made at OBC with a PET level of 5% wrt binder content and 2 samples were made at OBC with a PET level of 8% wrt binder content.

3.7.1 Sieving Process

A thorough sieving process was carried out according to NHA Gradation B and the total weight of asphalt concrete cake was set as 1200 grams. This total weight contained a portion of the sieved aggregate and bitumen in different percentages as shown in the following table. As discussed earlier, a total of 6 asphalt concrete samples were made i.e., 2 samples were made on OBC of 4.9%, 2 samples were made at OBC with a PET level of 5% wrt binder content and 2 samples were made at OBC with a PET level of 8% wrt binder content.

Percentage Bitumen (OBC)	4.9	Weight (PET=5%)	2.94
Weight of Sample	1200	**Weight (PET=8%)**	**4.704**
Mass of Bitumen	58.8		
Mass of Sample	1141.2		
Sieve	**Cumulative Passing**	**Percent Retain**	**Weight (g)**
A 3/4	100	0	**0**
A 1/2	82.5	17.5	**199.71**
A 3/8	70	12.5	**142.65**
A #4	50	20	**228.24**
A #8	30	20	**228.24**
A #50	10	20	**228.24**
A #200	5.5	4.5	**51.35**
PAN		**5.5**	**62.76**

Table 3.9 Modified Asphalt concrete cake composition

3.7.2 Preparation of Aggregate, Bitumen and PET

After sieving the aggregate into different sizes required for the project as shown in the previous table, the aggregate was then oven dried at a temperature of 110 C. The total sample weight of Marshall mix is 1200 grams. In the preparation of virgin asphalt cake samples, only OBC was considered. However, in the preparation of modified asphalt cake, PET was added in two different percentages i.e., 5% and 8% with respect to OBC level of 4.9% through wet process as shown in previous table

The weight of aggregate and asphalt can be obtained from following formulae level

Wt = Mass of Total Mix = 1200 (Virgin Cake Sample) = Wb + Wa Wb

= Mass of Asphalt = 4.9/100 * Wt   Wa = Mass of Aggregate

Wt = Mass of Total Mix = 1200 + PET (Modified cake Sample) = Wb + Wa + Wp

Wp = Mass of PET = X/100 * Wb   X= Percentage of PET

Figure 3.9 PET (Crushed plastic bottles)

Figure 3.10 Mixing Bitumen with crushed PET bottles

3.7.3 Mixing of Aggregate, Asphalt and PET

The asphalt cement is first heated until it gets in liquid form by using an electric oven at a temperature of around 110 C and is then thoroughly mixed with aggregate at a temperature of 150-160C as specified by AASHTO in the preparation of virgin samples.

In the preparation of modified asphalt cakes, asphalt cement is first heated until it gets in liquid form and then PET in the form of crushed plastic bottles, is added into asphalt cement by wet process. This mixture is then added to the aggregate and is then thoroughly mixed with aggregate at a temperature of 150-160C as specified by AASHTO.

The mixing process must be carried out until the point where asphalt pet mixture is completely mixed with aggregate and there is visibly no particle left without asphalt cement covered. Care should be taken while carrying out the mixing process by wearing fabric-based gloves, safety goggles and safety aprons.

PET Percentage Samples	Number of
OBC =4.9% (Virgin)	**2**
PET = 5%	**2**
PET=8%	**2**

Table 3.10 Test Matrix for TSR test

3.7.4 Compaction of Specimens

According to Marshall Mix Design, there are three criteria for compaction depending on whether the surface is prepared for light, medium or heavy traffic. In this project, we have designed our pavement for heavy traffic so 75 blows are given on either side of asphalt concrete cake specimen to achieve adequate compaction. The loose mix obtained from heating aggregate with asphalt cement is transferred into a mould having a base plate. After achieving 75 blows on one

side of the specimen, the specimen was inverted, and 75 blows were given on the other side of the specimen. To carry out this compaction, Mechanical Marshall Compactor was utilized which has a free fall drop distance of 18 inches and has a sliding mass of 10 lb.

Figure 3.11 Modified Asphalt cakes

3.8 Performance Testing – TSR Test

After the preparation of virgin and modified asphalt cakes, the next step was to carry out TSR test (Tensile Strength Ratio) Test to determine effect of PET addition in resistance to moisture susceptibility. For this purpose, AASHTO T-283 Procedure was followed,

3.8.1 Conditioned and Unconditioned Samples

For each percentage of PET i.e., 5% and 8% and the virgin cake, there were 2 samples. One of these samples is kept as 'unconditioned'. These samples are placed in a water bath at 25 C for 1 hour after which they are loaded into Marshall stability equipment in the configuration shown in the following picture. The other set of samples are termed as 'conditioned'. These samples are kept in a water bath at a temperature of 60 C for 24 hours after which they are loaded into Marshall stability equipment.

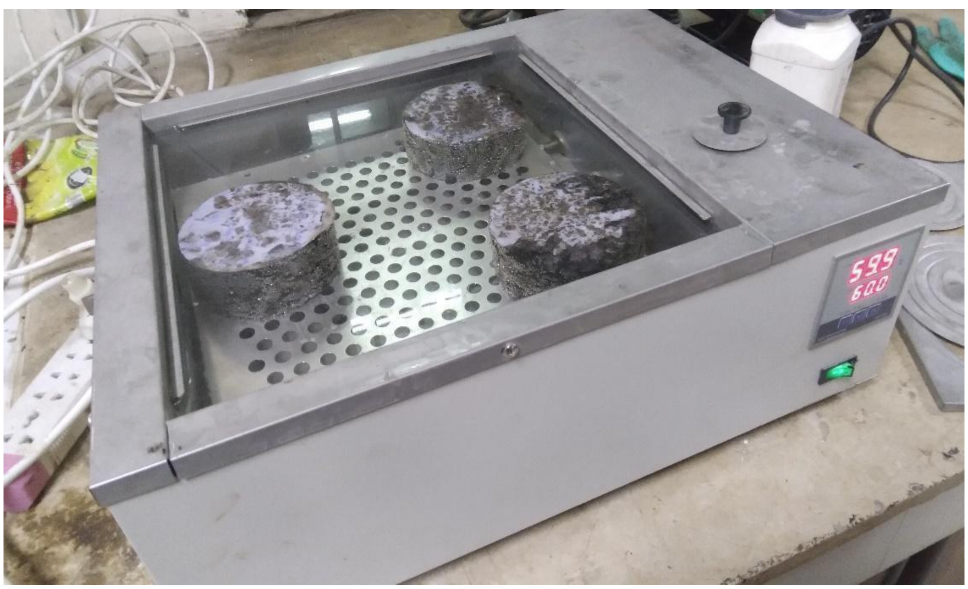

Figure 3.12 Water Bath

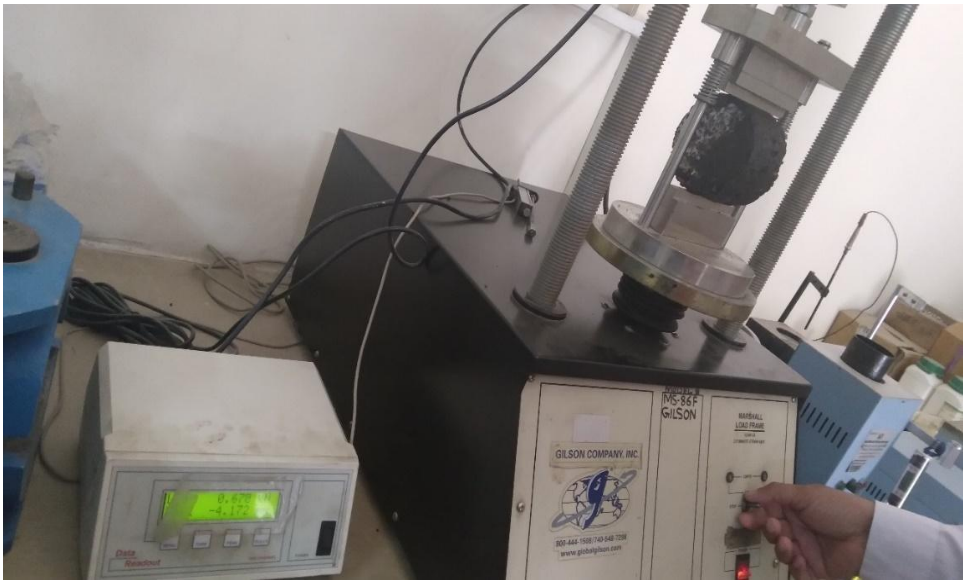

Figure 3.13 TSR Test

3.8.2 TSR Testing

Both sets of conditioned and unconditioned samples are loaded into Marshall Stability Equipment, also called UTM machine and load is applied at a loading rate of 2 inches/ minute. The maximum load at failure is determined and noted and tensile strength is determined using the given formulae. The TSR Value i.e the tensile strength ratio value is defined as the ratio of the average tensile strength of conditioned samples to the average tensile strength of unconditioned samples and should ideally be more than 70%.

To determine the tensile strength of sample from maximum load, following formulae is utilized

$$S_t = (2000 \times P) / (\pi \times t \times d)$$

St = Tensile strength (kPa)

P = Maximum Load (N)

t = thickness of specimen i.e., 64 mm d

= diameter of specimen i.e., 102 mm

Higher is the TSR value, higher is the resistance to moisture susceptibility thus increasing the service life. More importantly, the TSR value indicates potential of damage caused by water/

moisture to pavement and is defined as the ratio of the average tensile strength of conditioned samples to the average tensile strength of unconditioned samples

TSR value is determined using the following formulae

TSR = S2/ S1

S1 = Average Tensile Strength of Unconditioned sample

S2 = Average Tensile Strength of Conditioned sample

3.9 Summary

This chapter discusses in detail the methodology used to carry out our project. Firstly, the test was carried out on aggregate and bitumen. The materials that satisfied the given criteria set by ASTM were used for preparation of samples to determine the OBC. Once optimum binder content was determined, the next step was the preparation of modified asphalt cake specimens using PET (Polyethylene Terephthalate) obtained from crushed plastic bottles. In the end we carried out a TSR test as part of performance testing to determine the impact of PET addition in resistance to moisture susceptibility. Detailed graphs and results in reference to above testing will be elaborated in chapter 4.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

The study is based upon adding different percentages of PET (Polyethylene Terephthalate) with respect to binder content in asphalt concrete cake to determine the effect of it on resistance to moisture susceptibility and to deal with plastic pollution. The major source of PET in our project are plastic bottles and packaging material from landfill of Islamabad. PET based modified samples are made after determining OBC (Optimum Binder Content) using Marshall Mix Design.

In this chapter, results and graphs pertaining to OBC determination as well as the results of TSR test will be elaborated. As a matter of fact, after the determination of OBC, PET was added in three different percentages with respect to Bitumen content i.e., 0%, 5% and 8%. TSR test was than carried out according to AASHTO T283-07 procedure, the results of which are discussed in this chapter.

4.2 OBC Determination

To determine the optimum binder content, we need to determine the stability and flow values along with VA (Air Void Percentage), VMA (Voids filled with Mineral Aggregates) and VFB (Voids Filled with effective Bitumen). After cooling of specimen to room temperature, the volumetric of specimen is calculated by determining Gmm (Theoretical Specific Gravity) and Gmb (Bulk Specific Gravity) values. For the determination of stability and flow, we followed ASTM D6927 Procedure and for determining Gmm, we followed ASTM D2041 Procedure. VA, VMA and VFB were determined using the formulae’s given by Federal Highway Authority USA in their article HF1033 published in 2010.

4.2.1 Results of Stability and Flow Test & Calculation of VA VMA VFB

Properties	Range	Result	Remarks
VA	3-5%	4%	ok
VMA	Min 13%	13%	ok
VFB	65-75%	68%	ok
Stability	>8000N	8200N	ok
Flow	8-14mm	9mm	ok

Table 4.1 OBC Results

The process for the determination of these values was elaborated in chapter 3 and results are shown in following table.

4.2.2 Graphs for OBC determination

After the determination of the values given in Table 4.1, OBC (Optimum Binder Content) was determined by plotting graphs between binder percentages on horizontal axis and different properties on vertical axis that includes stability (KN), flow(mm), VA, VMA and VFB percentages. The asphalt content at 4% air voids corresponds to OBC which came out to be 4.9% as shown in following graphs:

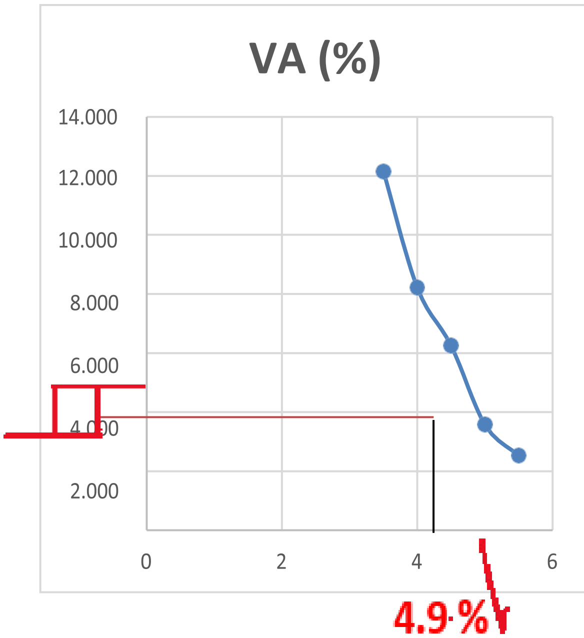

Figure 4.1

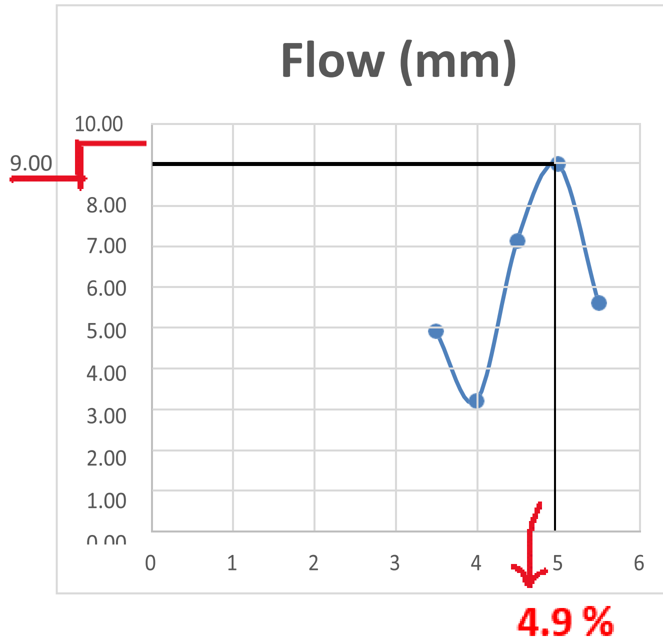

Figure 4.2

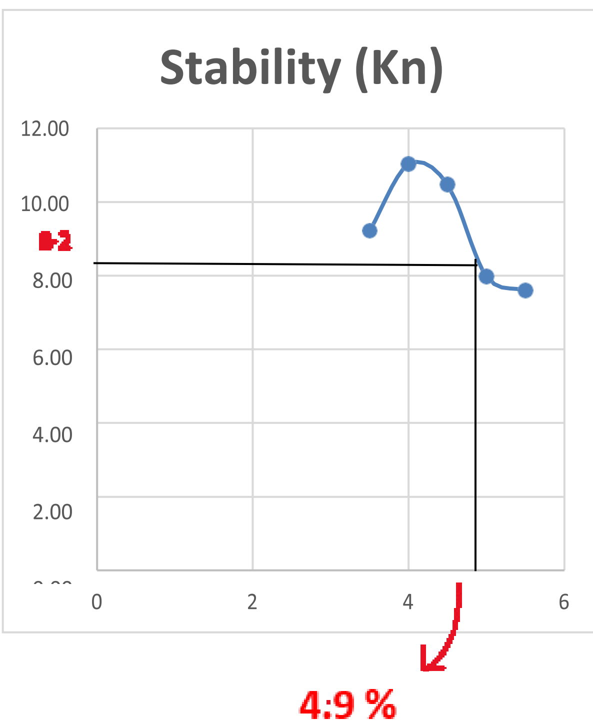

Figure 4.3

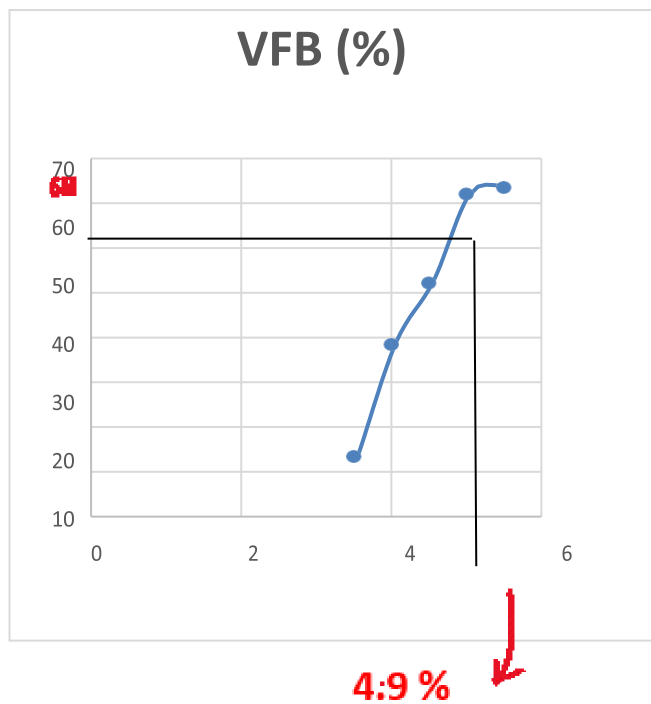

Figure 4.4

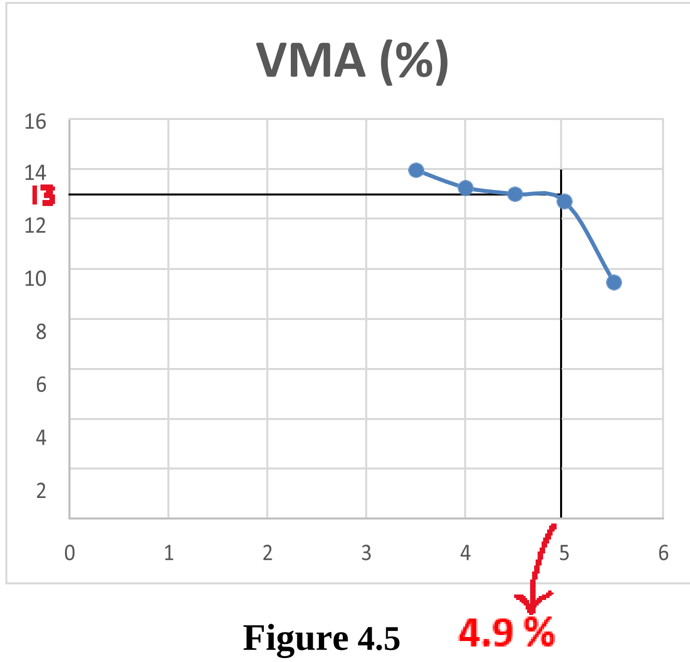

Figure 4.5

4.1.1 AASHTO Standards

Once the values for Stability, Flow, VA, VMA and VFB were determined from the graphs, they were matched against the given ranges in Table L-12/2 and Table L-12/ 4 AASHTO. All of the values came to be within ranges, so the OBC was finalized as 4.9% at an Air Void Percentage of 4%. The results are shown in following table 4.2

Properties	Results	Range	Remarks
VA	4%	3-5%	**ok**
VMA	13%	Min 13%	**ok**
VFB	68%	65-75%	**ok**
Stability	8200 N	Min 8000 N	**ok**
Flow	**9 mm**	**8-14mm**	**ok**

TABLE 4.2 L-12/2 AASHTO

4.2 TSR – Moisture Susceptibility Test

After the preparation of virgin and modified asphalt cakes as discussed in chapter 3, the next step was to carry out TSR test (Tensile Strength Ratio) Test to determine effect of PET addition in resistance to moisture susceptibility. For this purpose, AASHTO T-283 Procedure was followed.

4.2.1 TSR Testing Procedure

For each percentage of PET i.e.,0%, 5% and 8% and the virgin cake, there were 2 samples. One of these samples is kept as ‘unconditioned’. These samples are placed in a water bath at 25 C for 1 hour after which they are loaded into Marshall stability. The other set of samples are termed as ‘conditioned’. These samples are kept in a water bath at a temperature of 60 C for 24 hours after which they are loaded into Marshall stability equipment.

Both sets of conditioned and unconditioned samples are loaded into Marshall Stability Equipment, also called UTM machine and load is applied at a loading rate of 2 inches/ minute. The maximum load at failure is determined and noted and tensile strength is determined using the given formulae. The TSR Value i.e., the tensile strength ratio value is defined as the ratio of the average tensile strength of conditioned sample to the average tensile strength of unconditioned samples and should be ideally more than 70%. The results of TSR test are shown in following Table 4.3

Table 4.3

TSR Test – Moisture Susceptibility Test							
Specimen Type	**Thickness (mm)**	**Diameter (mm)**	**Conditioned Sample Load (N)**	**Tensile Strength Conditioned Sample (KPa)**	**Unconditioned Sample Load (N)**	**Tensile Strength Unconditioned Sample (KPa)**	**TSR**
Virgin 0% PET	64	102	4818	0.469669118	7186	0.700506907	**0.67470**
5% PET	64	102	4699	0.469669118	6577	0.700506907	**0.71445**
8% PET	**64**	**102**	**4810**	**0.469669118**	**6340**	**0.700506907**	**0.75867**

4.3 Summary

In this chapter, results related to OBC determination were shown in the form of graph according to Marshall Mix Design Process. OBC was determined to be 4.9% corresponding to an air void percentage of 4%. Also, results and procedure of TSR Moisture Susceptibility have also been showed in this chapter. It can be clearly seen from the results that as the PET percentage increased with respect to binder content in asphalt concrete cake, the TSR value increase showing increased resistance to moisture susceptibility. Detailed conclusion and recommendation related to our project will be discussed in chapter 5.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The aim of the project was to utilize PET (Polyethylene Terephthalate) plastic waste to modify asphaltic pavements to improve service life and resistance to moisture susceptibility while at the same reducing pollution in line with the SDG 11 (Sustainable Development Goal) which aims to make cities safe, resilient, and sustainable. Plastic Bottles containing PET polymer (Polyethylene terephthalate) is a major source of pollution and most of this plastic waste (PET Bottles and other products) is dumped directly into the landfills that degrade the environment and consume costly land. The first phase of the project included material acquisition and material testing in accordance with ASTM standards. NHA Grade B aggregate and PARCO Bitumen Grade 60/70 was utilized for the project while PET plastic waste was acquired from landfill of Islamabad. Once material testing was completed according to ASTM standards, the next step was to determine the optimum binder content for asphalt concrete according to Marshall Mix Design. Once the OBC was determined, the next step was the preparation of PET based modified asphalt concrete cakes using a wet process elaborated in chapter 3. This was followed by TSR Moisture Susceptibility testing according to AASHTO T283-07 procedure. The key findings of performance testing, their results, conclusions, and recommendations are elaborated in succeeding paragraphs.

5.2 Conclusions

The conclusions drawn from the analysis of tests conducted and elaborated in previous chapters include following

- Addition of Polyethylene Terephthalate (PET) into asphalt concrete has increased the TSR – Tensile Strength Ratio value as indicated in the results mentioned in chapter. The TSR value increases from 0.674 in virgin asphalt cake to 0.758 in 8% PET based modified asphalt cake

- An increase in TSR value indicates an increase in the resistance to moisture susceptibility hence an improved service life and pavement performance
- Assuming a 4 in thick, 2 lanes wide and 10 Km long asphalt concrete flexible pavement, 85000 kg of PET plastic waste can be utilized
- In a wide scale implementation, this can significantly tackle the issue of plastic pollution in terms of plastic bottles and PET based packaging material
- This can also play a key role in reducing the number of landfills which consume considerable amount of costly land in the adjacent areas of city like Islamabad

5.3 Recommendations

The four basic recommendations from our side include

- Addition of other plastic based polymers in asphaltic pavements must also be tested, researched, and analyzed. Some of the key plastic polymers that must be tested included LDPE (Low Density Polyethylene), HDPE (High Density Polyethylene) and PVC (Poly Vinyl Chloride)
- Other performance test such as Fatigue Test, Rutting Test, DCT (Disk Shaped Compact Tension Test) must also be carried out to determine effectiveness of plastic polymer addition in asphaltic pavements
- It is suggested that chemical properties of plastic polymers such as PET and LDPE must also be determined and their relationship with asphaltic pavement to determine the right content and amount of plastic waste addition
- Efforts must also be directed in the research and development of completely recycled plastic pavement which is made primarily of recycled and compacted plastic waste with no asphalt content

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Appendices

APPENDIX 1: MARSHAL MIX DESIGN REPORTS

Marshall Test Report

Project: FYP UG 2k13   Trial Mix   0% RAP   (1) Grade AC   ARL 60/70

		Mass, grams of compacted Specimen					Mass, grams of loose Mix							Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	In Air (A)	In Water (C)	Sat. Surface Dry in Air (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt. of Pycnometer + Glass Lid + Water (b)	wt. of Sample + Water + Pycnometer and Lid (c)	Max S.G. (loose Mix) (Gmm) =a/b-(c-a)	% Air Voids	% VMA	% VFA	Measured	Adjusted	Flow mm
3.5-A	70.485	1182	706.1	1208	501.9	2.355	1174	6774	7479.5	2.506	6.0186	13.421	55.165	12.443	10.328	2.355
3.5-B	66.675	1176	695.4	1193	497.6	2.363	1180	6774	7484.5	2.513	5.9669	13.118971	54.517	14.335	13.332	2.291
3.5-C	68.58	1169.1	692.5	1190.6	498.1	2.347	1162	6774	7472.1	2.505	6.297	13.715433	54.088	13.775	12.25975	2.1
Average	68.58	1175.7	698	1197.2	499.2	2.355	1172	6774	7478.700	2.508	6.0947	13.419	54.583	13.517667	11.972997	2.248666667
4.0-A	66.04	1158	683	1172	489	2.368	1158	6774	7465.5	2.482	4.6012	13.395267	65.65	13.886	12.91398	2.452
4.0-B	69.85	1172.5	695.6	1192	496.4	2.362	1172	6774	7475	2.488	5.0764	13.61805	62.723	15.887	13.19621	2.542
4.0-C	65	1178.1	698.4	1194.7	496.3	2.374	1178	6774	7480	2.496	4.8882	13.187991	62.935	14.3	13.728	2.655
Average	66.96333	1169.533333	692.333333	1186.23333	493.9	2.368	1169.333333	6774	7473.500	2.489	4.8555	13.400436	63.769	14.691	13.276063	2.549666667
4.5-A	66.99	1178	696.5	1190.2	493.7	2.386	1183	6774	7479.5	2.477	3.6901	13.192704	72.029	12.443	11.07427	2.766
4.5-B	66.04	1184	699.8	1196	496.2	2.386	1186	6774	7483	2.486	4.0315	13.19015	69.435	13.885	12.91305	2.699
4.5-C	64.5	1189.6	702.7	1199.6	496.9	2.394	1189	6774	7484	2.482	3.5537	12.902433	72.457	12.113	11.62848	2.763
Average	65.84333	1183.867	699.667	1195.267	495.600	2.389	1186.000	6774	7482.167	2.482	3.7586	13.095096	71.307	12.813667	11.871933	2.742666667
5.0-A	70.167	1186	714.5	1210	495.5	2.394	1187	6774	7481	2.473	3.2098	13.37658	76.005	11.497	9.54251	3.3445
5.0-B	64.8	1185	703.1	1199	495.9	2.390	1180	6774	7475	2.463	2.9987	13.519431	77.82	9.124	8.75904	3.654
5.0-C	64	1181.1	696.5	1188.7	492.2	2.400	1180	6774	7475.5	2.466	2.6928	13.156092	79.532	8.9	8.544	3.755
Average	66.32233	1184.033	704.700	1199.233	494.533	2.394	1182.333	6774	7477.167	2.467	2.9671	13.350701	77.774	9.8403333	8.9485167	3.5845
5.5-A	66.36	1178	696.4	1187	490.6	2.401	1178	6774	7471	2.449	1.9568	13.558907	85.568	9.45	8.7885	4.24
5.5-B	63.5	1180	703.5	1193	489.5	2.411	1178	6774	7472	2.454	1.7743	13.217569	86.576	8.98	8.98	4.133
5.5-C	62.75	1149.8	677	1157.8	480.8	2.391	1140	6774	7447	2.441	2.0352	13.908486	85.367	7.163	7.163	3.866
Average	64.203	1169.267	692.300	1179.267	486.967	2.401	1165.333	6774.000	7463.333	2.448	1.9219	13.561654	85.829	8.531	8.3105	4.079666667

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Sample: Controlled sample (0% RAP)

Identification: Margalla

Composition of Paving Mixture

	Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
			Bulk		Mix or Trial Number				
					1	2	3	4	5
1. Coarse Aggregate	G1		2.632	P1	48.250	48.000	47.750	47.500	47.250
2. Fine Aggregate	G2		2.618	P2	48.250	48.000	47.750	47.500	47.250
4. Total Aggregate	G4	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement	G5	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate					2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix					2.508	2.489	2.482	2.467	2.448
8. Bulk Sp. Gr. (Gmb), compacted mix					2.355	2.369	2.389	2.395	2.401
9. Effective Sp. Gr. (Gse), total aggregate					2.646	2.645	2.659	2.663	2.661
10. Absorbed Asphalt (Pba), % by wt. total agg.					0.307	0.299	0.496	0.553	0.534
CALCULATIONS									
11. Effective Asphalt content (Pbe)					3.204	3.713	4.026	4.475	4.995
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.					13.425	13.362	13.085	13.323	13.563
13. Air Voids (Va)					6.100	4.821	3.747	2.919	1.920
14. Voids Filled with Aggregate, VFA					54.559	63.918	71.365	78.094	85.845

The End