Sustainable Solutions for Structural Stability and Waste Management in Pavements

FINAL YEAR PROJECT UG 2019

BY

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This is to certify that

The Final Year Project Titled

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DEDICATION

CREDIT GOES TO OUR FAMILY MEMBERS AND TEACHERS, WHO HELPED AND INSPIRED US THROUGHOUT OUR LIFE.

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Abstract

The research focus has shifted towards sustainable and eco-friendly pavements due to the rising costs of new materials, dwindling resources, and the increasing problem of plastic waste. Developing countries like Pakistan face challenges in funding the construction, repair, and maintenance of their extensive road networks, mainly due to the disposal of Reclaimed Asphalt Pavement (RAP) from the construction industry and plastic waste. This study aims to address these issues by investigating the utilization of RAP and plastic waste in asphalt pavements. The virgin binder was modified by adding 10% Polyethylene Terephthalate (PET) and two different amounts of RAP (20% and 40%). The modified binder's conventional properties were evaluated through penetration and softening point tests. Moisture susceptibility was assessed using the Indirect Tensile Strength (ITS) test, while resistance against rutting was evaluated using the Hamburg Wheel Tracker Test. The modified binder demonstrated stability up to a temperature of 470°C and improved resistance against rutting. Marshall mix properties were determined and compared to the specifications of the National Highway Authority of Pakistan. Optimum Marshall stability was achieved with 10% Polyethylene Terephthalate (PET) and 40% Reclaimed Asphalt Pavement (RAP), while flow and air voids remained within acceptable limits. The results indicate that incorporating plastic waste in asphalt pavements enhances performance, reduces environmental pollution, and mitigates landfill problems associated with RAP and plastic waste. An Environmental Impact Assessment was conducted, revealing that RAP has a lesser adverse impact compared to virgin asphalt. A cost-benefit analysis was performed, showing that using RAP in pavements can reduce costs by up to 30% for a hauling distance of 5 km.

Keywords: Reclaimed Asphalt Pavement (RAP), Polyethylene Terephthalate (PET), sustainability, Marshall Stability and flow

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Chapter 1: Introduction

1.1 Background:

For the past two decades, Pakistan's construction industry has struggled with ongoing economic crises and uncertainty, which has had negative effects like decreased government financing and impaired construction techniques.As a result, the industry demands the investigation of alternative strategies that are no t only economical but also give priority to efficiency and safety.A significant development in Hot Mix Asphalt (HMA) technologies has offered a viable remedy in this area.Through the efficient reduction of asphalt binder viscosity, these technologies provide a number of benefits, such as lo wer mixing and compacting temperatures, decreased energy usage, and reduced environmental ri sks. One of the available technologies in the market, PET, an organic addition, has demonstrated potential in reducing temperatures during the production of asphalt concrete. Additionally, the increasing concerns regarding plastic waste, specifically polyethylene terephthalate (PET) materials, have emphasized the immediate requirement for effective waste management strategies. The fact that plastic materials, including PET, do not biodegrade and have insufficient recycling rates poses significant environmental risks. Hence, it is crucial to incorporate reclaimed materials like Reclaimed Asphalt Pavement (RAP) and PET plastic into pavement construction. This approach presents a unique opportunity to address waste management challenges and enhance the structural stability of pavements at the same time. By integrating RAP and PET plastic into pavement construction, the construction industry can contribute to sustainable practices while mitigating the negative environmental effects of plastic waste. The utilization of these reclaimed materials not only reduces reliance on new resources but also promotes efficient waste management strategies. This effort holds considerable potential for reducing the strain on landfills and minimizing the overall environmental impact. Therefore, it is essential to explore the feasibility and effectiveness of integrating RAP and PET plastic in pavement construction to address concerns related to structural stability and the urgent need for sustainable waste management practices.

1.2 Problem Statement:

Due to limited finances and the increasing volume of traffic, there is a growing demand for an alternative approach to producing Asphalt Concrete in Pakistan. This alternative should offer improved pavement performance, workability, compaction properties, and cost-effectiveness compared to traditional asphalt concrete. Moreover, the harmful effects of plastic and glass waste are well-known. While many countries have already started developing environmentally friendly pavements that incorporate waste materials, Pakistan is lagging in this aspect. Although two plastic roads have been constructed, the government is gradually recognizing the importance of utilizing waste materials in pavement construction as a viable recycling solution. Plastic, being non-biodegradable, poses a significant threat to the environment when disposed of in landfills or burned. It releases toxic chemicals such as dioxin, which are highly carcinogenic and can disrupt the endocrine system, leading to various health complications. Burning plastic also generates harmful substances like benzo(a)pyrene (BAP) and other polyaromatic hydrocarbons (PAHs), known carcinogens. Furthermore, unburnt plastic accumulates as garbage on land and in water streams, negatively impacting marine life and causing drainage system failures in Pakistan. This research study focuses on investigating Reclaimed Asphalt Pavement (RAP) and PET plastic, two waste materials with significant environmental impacts. RAP, a byproduct of road resurfacing or reconstruction, presents a considerable waste management challenge. On the other hand, PET plastic, known for its non-biodegradability and prolonged decay period of over a million years, contaminates surrounding areas and soil when dumped in landfills. However, integrating RAP and PET plastic into pavement construction holds potential for effectively addressing waste issues and conserving resources. Thus, this study aims to explore the use of RAP and PET plastic as sustainable alternatives in pavement construction. The mentioned challenges emphasize the need for a comprehensive investigation to promote the utilization of waste materials, specifically RAP and PET, in pavement construction in Pakistan. By employing this technology, the study aims to improve pavement performance, focusing on two crucial parameters: resistance against rutting and moisture susceptibility. By addressing these issues, the research aims to contribute to sustainable waste management practices and facilitate the development of high-performing pavements in Pakistan.

1.3 Purpose of Research:

The escalating demand for RAP and PET materials in Pakistan has become a critical issue as their production and consumption increase. However, attempts to meet consumer demands without regulating production have led to significant environmental hazards associated with these waste materials. In contrast, neighboring country India has already taken steps to incorporate waste materials into road construction projects. Unfortunately, Pakistan's attention and focus on exploring alternative materials remains limited. As a developing country with numerous construction projects underway and substantial potential in the construction industry, Pakistan must take proactive measures to address the environmental damage caused by the excessive dumping or burning of waste materials. It is imperative to take immediate action to prevent the situation from worsening. This situation presents a valuable opportunity to utilize RAP and PET in road construction, allowing the country to fully harness the potential of combining HMA technology with waste materials. The main objective of this study was to replace conventional aggregates with RAP and PET in asphalt pavements, aiming to reduce indirect construction costs and mitigate the environmental impact. By embracing RAP technology instead of traditional methods, the research seeks to introduce a sustainable solution that effectively utilizes RAP and PET materials. This approach not only promotes environmentally friendly practices but also enhances the overall performance of asphalt pavements. Through exploring the potential of integrating RAP and PET materials with HMA technology, this research aims to contribute to sustainable waste management practices, optimize construction costs, and protect the environment. The use of RAP and PET materials as replacements for aggregates represents an innovative approach to road construction in Pakistan, facilitating the country's transition towards a more sustainable and efficient infrastructure development model.

1.4 Research Objectives:

The main objectives of this study included:

1. Determination of Moisture Susceptibility of RAP infused with PET plastics.
2. Evaluation of Rutting Resistance of RAP integrated with PET plastic.
3. Evaluation of Economic and Economical Benefits of Reclaimed Asphalt with PET additives.

1.5 Thesis Organization:

This thesis consists of five chapters that cover various aspects of the research conducted on the utilization of RAP and PET in pavement construction, incorporating Hot Mix Asphalt (HMA) technology.

Chapter 1 provides an overview of the issues related to the generation of RAP and PET waste materials and their potential application in pavement construction. It also highlights the advantages and benefits of using HMA technology in the road construction industry, emphasizing its relevance to the research study.

Chapter 2 includes a thorough literature review that examines transportation needs and challenges, previous studies conducted on the utilization of RAP and PET in pavement construction, and the associated problems encountered.

Chapter 3 explains the methodology employed in this research. It describes the systematic collection of RAP and PET materials, followed by laboratory characterization to assess their properties. The chapter also outlines the Marshal Mix design process used and the performance testing procedures conducted.

Chapter 4 presents the compilation of results obtained from laboratory characterization, Marshal Mix design, and performance testing. It analyzes the collected data to draw meaningful conclusions and provide insights into the performance of asphalt pavements using RAP and PET.

Chapter 5 serves as a comprehensive summary of the entire research study. It summarizes the key findings, draws conclusions based on the results, and offers recommendations for future research in the same field. The chapter aims to provide a concise yet comprehensive understanding of the research outcomes while suggesting potential areas for further exploration.

Overall, this thesis encompasses a systematic investigation into the utilization of RAP and PET in pavement construction, incorporating HMA technology. It aims to contribute to the understanding of the performance and feasibility of using these materials, while also providing valuable insights for future research and development in this area.

Chapter 2: Literature Review

2.1 Introduction:

This chapter provides a concise literature review and theoretical background related to the response of asphalt mixes that incorporate RAP (Reclaimed Asphalt Pavement) and PET (Polyethylene Terephthalate) in two specific tests: the Hamburg Wheel Tracker test, which assesses permanent deformation, and the Indirect Tensile Strength test, which evaluates moisture damage. The primary focus of this chapter is to explore the utilization of RAP and PET in asphalt mixes and their impact on various performance properties. Additionally, it examines previous research studies that have investigated the prediction of permanent deformation and moisture damage in asphalt mixes using the Hamburg Wheel Tracker test and Indirect Tensile Strength test.

2.2 Transportation: A Critical Need

The establishment of a well-developed and interconnected transportation network is crucial for the progress and prosperity of any country. In the case of Pakistan, the importance of highways and motorways is particularly significant due to the limited effectiveness of alternative modes of transportation like railways. To address this need, Pakistan has been actively engaged in the construction of a major trade route known as the China Pakistan Economic Corridor (CPEC), with substantial support from China. The CPEC involves the development of a 1,100-kilometer motorway that will connect Karachi and Lahore. Furthermore, the completion of the Karakoram Highway, which connects the Khunjerab China border with Rawalpindi, is on the horizon. These infrastructure projects aim to enhance transportation efficiency and promote economic growth within the country.

2.3 RAP and PET as Materials

RAP, derived from reclaimed asphalt pavements, and PET, a type of plastic made from polyethylene terephthalate, are valuable resources that have been explored in various applications. Previous research papers have investigated the utilization of RAP and PET in hot mix asphalt (HMA) pavements, examining their effects on properties such as stiffness modulus, fatigue life, and resistance against rutting. Noteworthy studies in this field include the works of Nur Izzi and Md Yosaff (2018), Ghasemi and Marandi (2003), Sahar Mohsenian and Hadad Amlashi (2015), Y. Issa (2016), Modarres and Hamedi (2014), Holtz and Eighmy (2000), Hoppe et al. (2015), Kalantar et al. (2011), and Taher Baghaee Moghaddam (2012). These studies have provided insights into the impact of incorporating RAP and PET on asphalt mixture properties. Addressing the challenges associated with incorporating glass particles in asphalt mixtures, Airey et al. emphasized the importance of using anti-stripping agents to improve the bond between glass and binder. Su and Chen proposed adding 2% lime to enhance the bond between glass particles and asphalt binder. Arabani et al. found that angular glass particles can enhance interlocking between asphalt mixture constituents, leading to improved fatigue life. However, excessive use of glass particles or larger particle sizes may result in inadequate friction and bonding strength. Navarro et al. demonstrated that replacing sand with waste glass in moderate proportions (around 8%) can yield asphalt mixtures with suitable mechanical properties for surface courses. Other studies have suggested that incorporating 4% waste recycled glass and 1% plastic can yield optimal results. These studies collectively contribute to our understanding of the benefits and challenges associated with incorporating RAP, PET, and glass particles in asphalt mixtures, offering valuable insights for the development of sustainable and high-performing pavement materials.

Table 2.1: Literature Review

S/No.	Year	Title	Objectives	Materials/Methods	Results/Conclusion	Locality
1	2022	Mechanical properties evaluation of asphalt mixtures with variable contents of reclaimed asphalt pavement (RAP)	This research paper aims to evaluate the performance of hot asphalt mixes containing reclaimed asphalt pavement (RAP) at	Bitumen, Aggregate RAP Marshall Stability Tests	An improvement in the stability values was observed with the increase of the RAP content from 3.5% to 4.5%, then, for the 25% and 50% RAP content at 5% and 5.5% asphalt cement ratios, the stability decreased, respectively,	Jordan

			different percentages.		compared to the control mix.	
2	2021	EVALUATING RECYCLED WASTE PLASTIC MODIFICATION AND EXTENSION OF BITUMINOUS BINDER FOR ASPHALT	This research evaluates three different commercial recycled plastic products in the laboratory.	60/70 penetration grade bitumen For the present study different domestic plastic waste such as PET (in plastic bottles) and HDPE (in plastic bags) were used.	The three recycled plastic modified binders improved the deformation resistance and structural contribution of the SMA.	Australia
3	2021	Using Waste Plastics as Asphalt Modifier: A Review	The use of recycled waste plastic in asphalt binders	Waste LDPE Waste HDPE Waste PP Waste PVC Waste PET Waste PS Waste EVA Waste ABS	The use of waste plastic as an asphalt modifier expands the application field of waste plastic and avoids the waste of resources	China

4	2020	USE OF PLASTIC WASTES AND RECLAIMED ASPHALT FOR SUSTAINABLE DEVELOPMENT	Sustainable use of wastes in pavements	Plastic Waste RAP Bitumen Performance Tests	Resistance to rutting Resistance to fatigue Improved Marshal Stability	Pakistan
5	2020	A REVIEW OF THE USE OF RECLAIMED ASPHALT PAVEMENT FOR ROAD PAVING APPLICATIONS	Reuse of reclaimed asphalt to minimize waste	Cold Center Plant Recycling (CCPR) Full Depth Reclamation (FDR)	Based on the advantages and disadvantages discussed, it is apparent that RAP methods have the advantage of minimizing maintenance and rehabilitation costs as well as environmental impact since these methods used recycled asphalt pavement which contributes to reducing wastes.	Malaysia

Chapter 3: Research Methodology and Testing

3.1 Introduction

This chapter provides an overview of the methodology employed to achieve the research objectives, including material acquisition, experimentation on the acquired materials, specimen preparation, and testing. The study involved conducting experiments on both control samples and specimens containing different percentages of PET Plastic with RAP in Hot Mix Asphalt (HMA). Specifically, two combinations were examined: 10% PET Plastic with 20% RAP and 10% PET Plastic with 40% RAP.

The primary tests conducted were the evaluation of Optimum Bitumen Content (OBC) for various RAP percentages, the Hamburg Wheel Tracker (HWT) test, and the Indirect Tensile Strength (ITS) test. This chapter also describes the equipment used, the procedure for specimen preparation, and the input parameters utilized during the different tests.

3.2 Research Methodology

For this research project, we obtained coarse and fine aggregates from the Margalla quarry. The bitumen used was of penetration grade 60/70, which was sourced from PARCO. Grade 60/70 was chosen due to its widespread usage in Pakistan and its suitability for the local climate conditions. The Reclaimed Asphalt Pavement (RAP) was collected from the IJP road during its rehabilitation process, while the PET waste plastic was collected from the hostels of NUST.

In the hot mix asphalt (HMA) mixture, the aggregate structure plays a crucial role in providing maximum resistance to permanent deformation, accounting for about 95% of the resistance. The remaining 5% is contributed by the bitumen binder. The properties of the HMA are significantly influenced by the gradation, surface texture, and shape of the aggregates. The strength properties of the aggregate are also influenced by its texture and shape. Aggregates with a more regular and rougher texture exhibit greater resistance against stresses caused by temperature changes and traffic loads.

To assess the properties of the aggregates that affect pavement performance, several tests were conducted following the standards outlined by ASTM and BS. These tests aimed to evaluate the gradation, surface texture, shape, and other relevant properties of the aggregates.

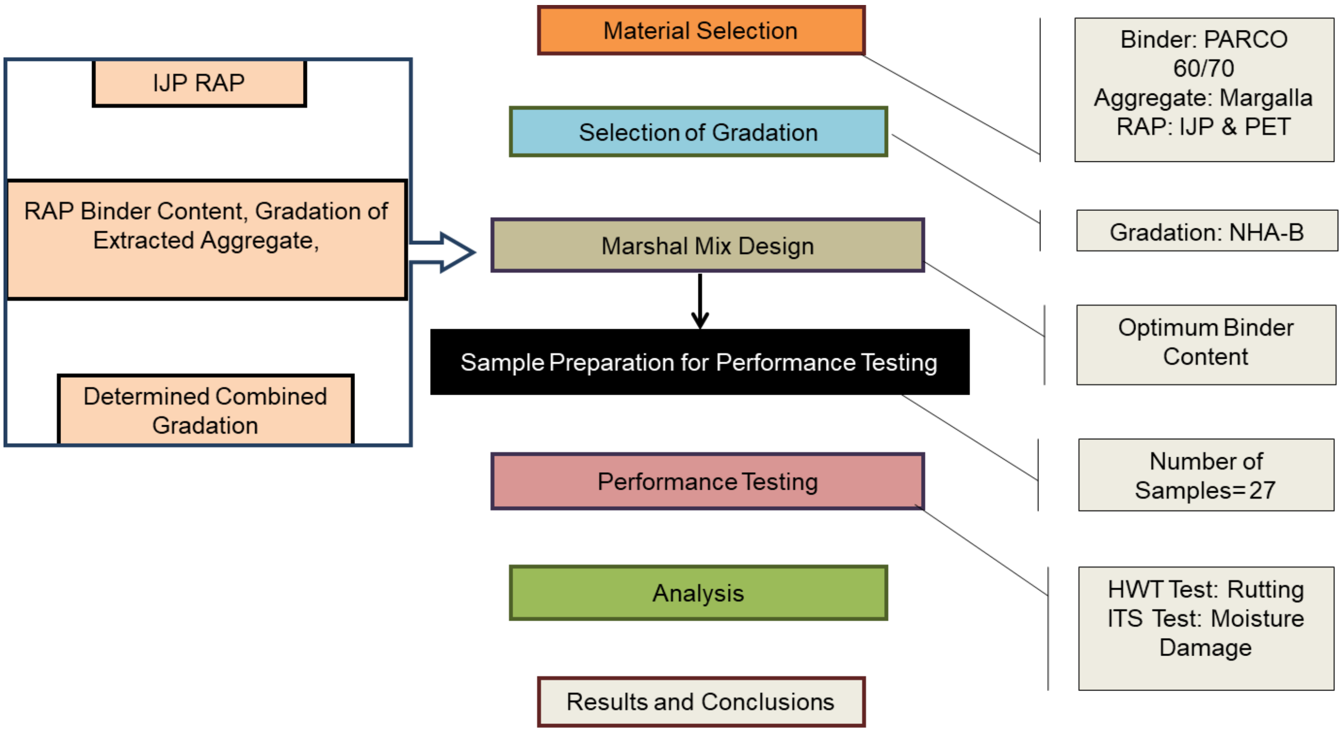

Figure 3.1: Research Methodology

3.2.1 Material Characterization

3.2.1.1 Aggregate Tests

The aggregate skeleton is a crucial component of the asphalt concrete mix, providing the primary resistance to permanent deformation under various stresses. To ensure the suitability of aggregates for the mix, it is important to consider factors such as texture, toughness, strength, durability, absorption indexes, and shape. To assess the quality of the selected aggregates and their adherence to the required criteria, several aggregate quality control tests were conducted. These tests included the Impact Value Test, Aggregate Shape Test, Specific Gravity, and Water Absorption Test, and Los Angeles Abrasion Test.

In each test, three samples were taken, and the average value of the three samples was used to minimize errors and obtain a representative result. These quality control tests were performed to evaluate the aggregates' properties and ascertain their compatibility with the asphalt concrete mix.

3.2.1.1.1 Shape Test of Aggregates (ASTM D 4791-99)

The shape of aggregates plays a significant role in determining the strength and workability of the asphalt mixture. It also influences the ease of compaction required to achieve the desired density. According to ASTM D4791, aggregates are categorized as flaky when their dimensions are less than 0.6 of their mean sieve size. Flaky and elongated aggregates are prone to breaking more easily under repeated traffic loads. On the other hand, angular aggregates are preferred as they offer better interlocking properties and greater resistance under various loading conditions.

To assess the shape characteristics of aggregates, the flakiness index and elongation index are commonly measured. It is recommended for both indices to be less than 15%. These indices provide valuable information about the proportion of flat and elongated particles in the aggregate, helping to ensure that the aggregates used in the asphalt mixture possess favorable shape qualities for optimal performance.

Figure 3.2: Flakiness Sieve

Figure 3.3:Elongation Sieve

3.2.1.1.2 Specific Gravity Test of Aggregates (ASTM C 127 & ASTM C 128)

The specific gravity of aggregates provides information about their weight and volume characteristics. It is calculated by dividing the weight of a given volume of aggregate by the weight of an equal volume of water at 25°C. The specific gravity test for coarse aggregates was conducted following ASTM C 127-88 standards. The test involved determining three weights: the oven dry weight, the weight of the sample when submerged in water, and the saturated surface dry weight of the aggregate. For fine aggregate, the specific gravity test was carried out according to ASTM C 128. The absorption of aggregates, which measures the amount of water that can penetrate the pores of the aggregate, is crucial for several reasons. High absorption indicates that a large quantity of asphalt binder may enter the aggregate pores, potentially reducing the strength of the mixture. It can also lead to non-durability of the asphalt mix. It is recommended for the absorption value to be less than 3%. To determine the saturated surface dry weight and submerged weight, a sample of the aggregate was taken and weighed. The sample was then immersed in water for 24 hours, allowing the pores of the aggregate to fill with water. After that, the sample was removed and dried from the surface, and the weight was measured to obtain the saturated surface dry weight.

Figure 3.4: Specific Gravity Test Apparatus

3.2.1.1.3 Impact Value Test of Aggregates (BS 812)

The impact value test for aggregates was conducted following the **BS 812** standard. This test measures the aggregate's resistance to impact load, which is different from progressive compressive load. Toughness, a material property that describes its ability to withstand impact, is crucial for aggregates as they are subjected to impact loads from traffic and need to have sufficient strength to withstand it.

The method used for the impact value test involved the following equipment and materials:

- Impact testing machine
- Sieves of sizes 1/2", 3/8", and #8 (2.36mm)

- Tamping rod
- Approximately 350g of aggregate passing through the 1/2" sieve and retained on the 3/8" sieve

The test procedure included filling a mold with the aggregate sample in three layers, with each layer being tamped 25 times using the tamping rod. The sample was then transferred to the larger mold of the impact testing machine. A hammer weighing between 13.5 to 14 kg was used to deliver 15 blows from a height of 38 cm to the aggregate sample. After the impact, the resulting material was passed through the #8 sieve. The impact value was determined by calculating the percentage of material passing through the sieve. It should be noted that the impact value test provides information on the aggregate's resistance against sudden shocks and helps assess its suitability for withstanding impact loads experienced in real-world scenarios, such as traffic conditions.8.

Figure 3.5: Impact Value Test Hammer

3.2.1.1.4 Los Angeles Abrasion Test of Aggregates (ASTM C 535)

The abrasion value test is conducted to determine the hardness and toughness of aggregates, ensuring that they can withstand the wear and tear caused by heavy traffic loads. The following apparatus was used for this test:

- Los Angeles abrasion machine

- Balance

- Set of sieves

- Steel balls

For the test, 2500 g of aggregate retained on the 1/2" and 3/8" sieves, totaling 5000 g (W1), along with 11 steel balls, were placed in the Los Angeles machine. The machine was then rotated at a speed of 33 rpm for 500 revolutions. After completing the revolutions, the material from the machine was sieved through a 1.7mm sieve. The weight of the sample passing through this sieve was recorded as (W2). The abrasion value, indicating the resistance of the aggregate to abrasion, was determined using the formula W2/W1*100, where W2 represents the weight of the sample passing through the sieve, and W1 represents the initial weight of the aggregate. It is important to note that the abrasion value test provides valuable information about the durability and performance of aggregates under repeated abrasion, simulating the conditions experienced by aggregates in real-world scenarios.

Table 3.1: Aggregate Test Results

Test Description	Specification Reference		Result	Limits
Elongation Index (EI)	ASTM D 4791		3.578 %	≤ 15 %
Flakiness Index (FI)	ASTM D4791		12.9 %	≤ 15 %
Aggregate Absorption	Fine Agg:	ASTM C 127	2.45 %	≤ 3 %
	Coarse Agg:		0.73 %	≤ 3 %
Impact Value	BS 812		17 %	≤ 30 %
Los Angles Abrasion	AASHTO T96		22%	≤ 45 %
Specific Gravity	Fine Agg:	ASTM C 128	2.61	-
	Coarse Agg:	ASTM C127	2.63	-

3.2.1.2 Bitumen Tests

Bitumen is a crucial component in the asphalt mixture as it provides the necessary binding properties. It is essential that the bitumen used is safe, pure, and consistent, as stated in the Asphalt Institute MS-2 manual. The consistency of bitumen can vary with temperature, so it is important to measure it at a standardized temperature for accurate assessment. Various tests were conducted to ensure the quality of the bitumen used in this research. These tests include:

- Penetration test of bitumen
- Flash and fire point test
- Ductility test
- Softening point of bitumen test

3.2.1.2.1 Penetration test of bitumen (AASHTO T49-03)

This test was done according to **AASHTO T49-03** standard . This test is used to measure the hardness and softness of bitumen by a standard needle in five seconds while maintaining bitumen temperature at 25̊ C. Three penetration values were taken, and they all passed the required specifications as described in the manual.

Figure 3.6: Bitumen Penetration Test Apparatus

3.2.1.2.2 Flash and fire point test (D 3143/D 3143M-13)

This test was done according to **D 3143/D 3143M-13** standard. This tells us that how much temperature is safe to which bitumen is exposed.

Figure 3.7: Flash and Fire Point Apparatus

3.2.1.2.3 Ductility test (AASHTO T 51-00)

This test was conducted according to **AASHTO T 51-00** standard. Ductility shows asphalt behavior with changes in temperature. According to specifications in manual ductility is the distance to which a standard specimen of bitumen lengthens without breaking when its two ends are pulled away from each other at a speed of 5 cm/min and at a temperature of 25 C. Three samples were taken and all satisfied the 100 mm criteria.

Figure 3.8: Ductility Test Apparatus

3.2.1.2.4 Softening point of bitumen test (AASHTO-T-53)

softening point of bitumen was found according to **AASHTO-T-53** standard. Bitumen is a visco-elastic material, and it loses its viscosity with an increase in temperature.AASHTO-T-53 ring, and ball apparatus were used to find softening point of bitumen. The temperature at which a sample of bitumen of standard size cannot hold a steel ball of 3.5 gm and the ball falls 25mm by passing through bitumen is called softening point of that bitumen sample.

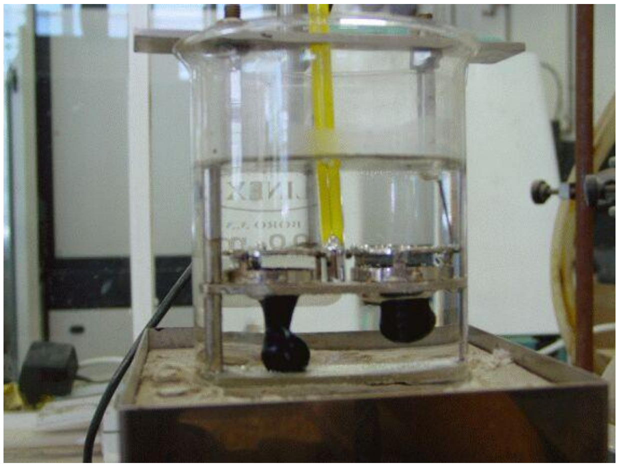

Figure 3.9: Softening Point Test Apparatus

Table 3.2: Bitumen Test Results

Test Description	Specification	Result
Penetration Test @ 25 (°C)	AASHTO T49-03	66
Flash Point (°C)	ASTM D 92	235
Fire Point (°C)	ASTM D 92	251
Specific gravity	ASTM D 70	1.03
Softening Point (°C)	AASHTO T-53	48.2
Ductility Test (cm)	AASHTO T51-00	> 100

3.2.2 Gradation Selection

Aggregate gradation of NHA Class B for asphalt wearing course was selected. The nominal maximum aggregate size selected for NHA class B was 19mm which is a standard according to the Marshall mix design.

Table 3.3: NHA Gradation B

S/ No.	Sieve Size (mm)	NHA Specification Range (% Passing)	Our Selection (% 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

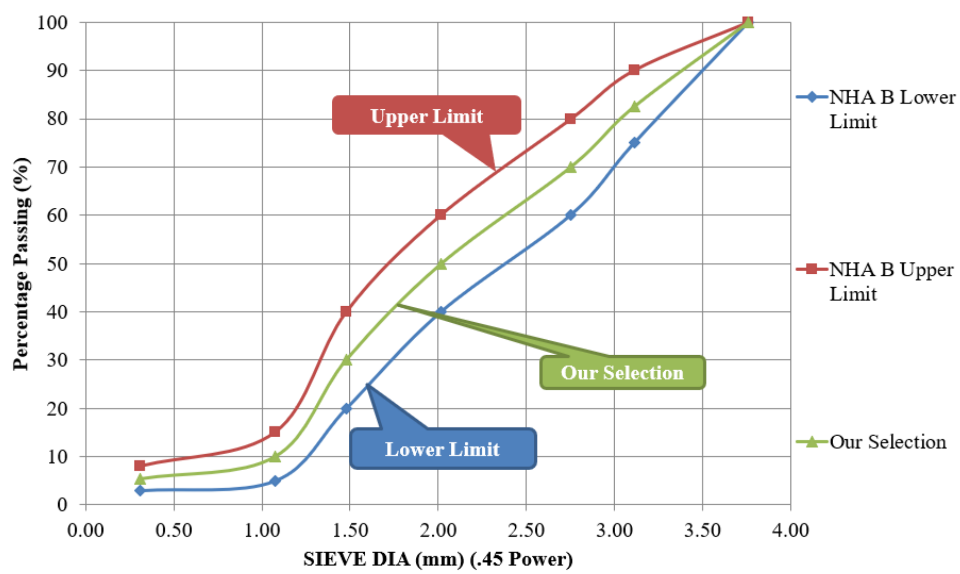

Figure 3.10: NHA Gradation B

3.2.3 Asphalt Mixture Preparation

Two types of samples were prepared. One is controlled samples having virgin aggregates and bitumen and the other one is samples containing 20 % RAP with 10 % PET Plastic and 40 % RAP with 10 % PET Plastic respectively. The samples were prepared according to the Marshall mix design procedure. Samples were prepared to determine OBC for both types. After OBC determination, volumetric properties were tabulated, and further samples were prepared for performance testing.

3.2.3.1 Preparation of Aggregates and Bitumen

After sieving aggregates according to selected gradation, they were oven dried at 110˚ C. The weight of the Marshall mix sample was 1200 gm. Bitumen weight varies according to its percentage from 3.5% to 5% of the mix. While preparation of samples containing RAP and PET same procedure was followed only the weight of bitumen was replaced by the weight of PET and also the weight of the mix was replaced by RAP depending upon the percentages of PET and RAP used in the sample. RAP percentage is taken of the weight of the sample. The weight of bitumen in samples can be obtained as:

$$Wt = Wa + Wb$$

$$Wb = \frac{X}{100} * Wt$$

Where:

Wt= Total sample weight

Wb= Bitumen weight

Wa= aggregate weight

X=Bitumen percentage used in the sample

3.2.3.2 Mixing of Aggregate, RAP, PET Plastic, and Bitumen

For controlled samples bitumen is heated at 160˚C and then oven-dried aggregates are added to it and thoroughly mixed until a homogenous mix is formed. For samples containing masks, first PET is melted (at 260˚C), bitumen is heated to 160˚C, and then aggregates and RAP are added to it. As plastic melts so it would assist bitumen in binding aggregate and make a homogenous mixture.

3.2.3.3 Compaction of the Specimen

According to Marshall mix design criteria, there are three different criteria for compaction depending on the surface for which samples are being prepared. In our case, samples were prepared for wearing course so 75 blows should be given on either side of sample by placing filter paper on each side.

3.2.4 Determination of OBC

The optimum bitumen content is calculated depending on the volumetric properties of the sample. For volumetric properties, G_{mb} and G_{mm} were calculated by performing tests according to standards **ASTM D2736** and **ASTM D2041** respectively. For G_{mb} determination first weight of the sample in air is taken after which weight in water and SSD weight is taken. After this sample is transferred to the water for 30-40 mins at 60˚C . Then Stability and flow values are measured using Marshall equipment. The load is applied at a constant deformation rate of 5mm/min until the specimen fails. For a sample to pass design criteria it should have stability value greater than 8.006kN and the flow value should be between 2 to 3.5mm. For G_{mm} calculations, weigh the loose mix then determine the calibrated weight of the apparatus. After this mix is transferred to a vacuum chamber and a vacuum is applied. After removal of entrapped air in the chamber, weigh the chamber again containing the mix in it.

Three samples were prepared for each percentage of bitumen in controlled samples. For samples containing RAP and PET, three samples were prepared for each percentage of bitumen having corresponding percentages of RAP and PET. A total of 36 samples were prepared that are shown in following matrix.

Table 3.4: Test Matrix for Marshal Mix Design

Plastic Content(%)	RAP Content (%)	Bitumen Content (%)	No of Samples For Analysis
0	**0**	3.5	3
		4	3
		4.5	3
		5	3
10	**20**	3.5	3
		4	3
		4.5	3
		5	3
10	**40**	3.5	3
		4	3
		4.5	3
		5	3
Total			**36**

3.2.5 Determination of Flow and Volumetric Stability

After determining Gmb and Gmm we found volumetric parameters containing a percentage of air voids, voids in mineral aggregates (VMA), and voids filled with bitumen (VFA) using equations from the MS-2 design manual. The flow and Marshall stability for each sample were determined using the Marshal apparatus. Volumetric properties graphs and tables are represented below for virgin samples as well as for samples containing additive.

Graphs of Volumetric Properties of mix having 0 % Plastic and 0 % RAP

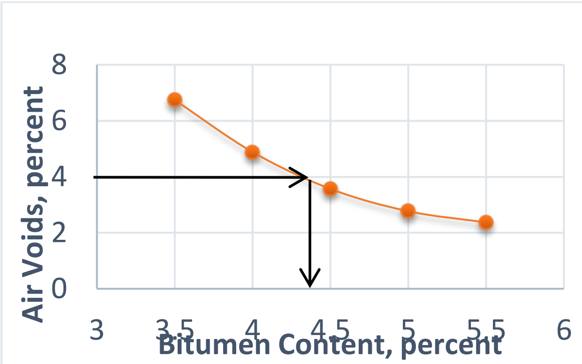

Figure 3.11: Air Voids vs Bitumen Content

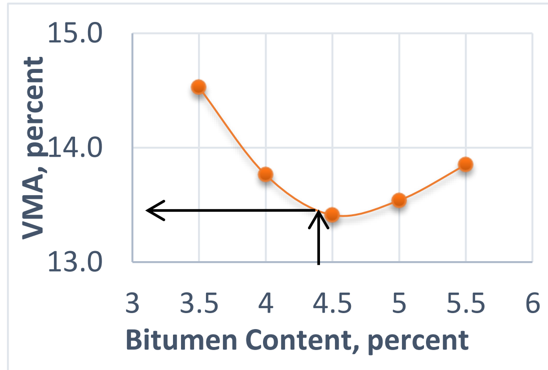

Figure 3.12: VMA vs Bitumen Content

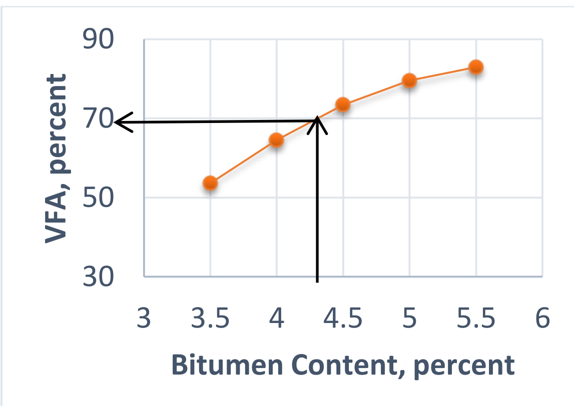

Figure 3.13: VFA vs Bitumen Content

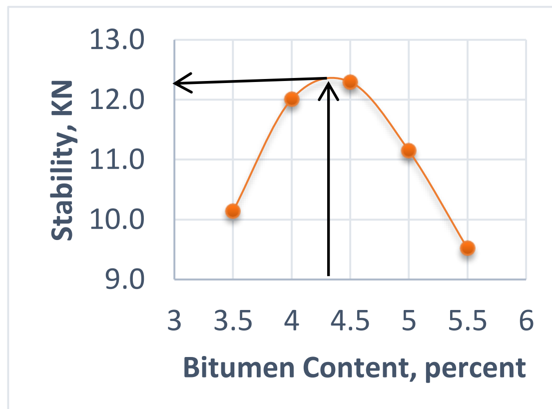

Figure 3.14:Stability vs Bitumen Content

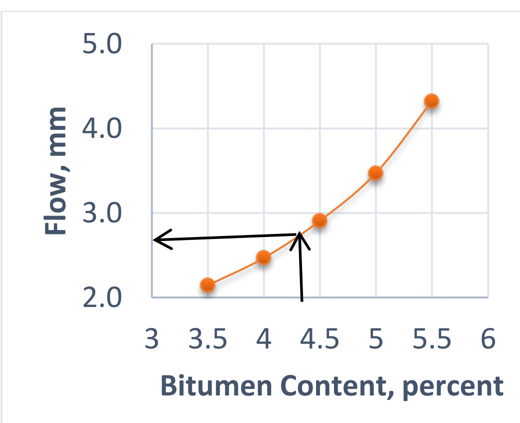

Figure 3.15: Flow vs Bitumen Content

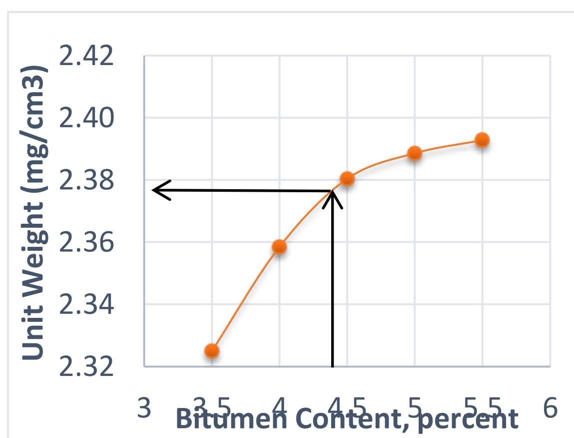

Figure 3.16: Unit Weight vs Bitumen Content

Table 3.5: Summary of Volumetric Properties of Mix Having 0 % RAP and 0 % Plastic

% AC	G_{mb}	G_{mm}	Unit wt(mg/cm^3)	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow(mm)
3.5	2.32	2.49	2.325	6.74	14.53	53.61	10.13	2.14
4	2.35	2.48	2.359	4.88	13.76	64.54	12.39	2.47
4.5	2.38	2.47	2.380	3.66	13.41	73.43	12.10	2.91
5	2.39	2.46	2.389	2.77	13.54	79.56	11.15	3.47
5.5	2.40	2.45	2.393	2.36	13.85	82.91	9.52	4.32

The asphalt content at 4 % air voids i.e., OBC of mix with 0 % RAP and PET Plastic came out to be **4.4 %**.

Graphs of Volumetric Properties of mix having 10 % Plastic and 20 % RAP

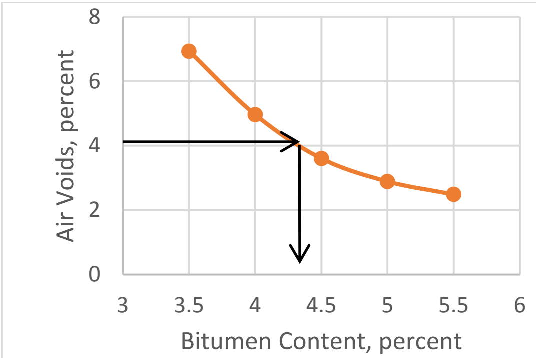

Figure 3.17: Air Voids vs Bitumen Content

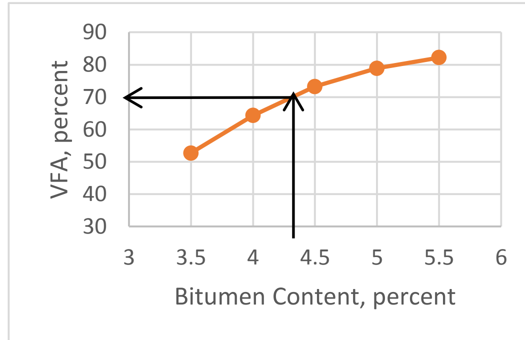

Figure 3.18: VFA vs Bitumen Content

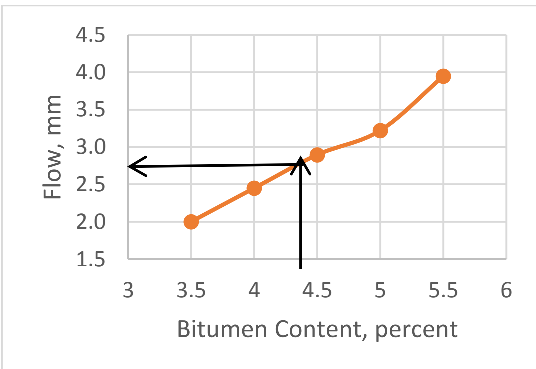

Figure 3.19: Flow vs Bitumen Content

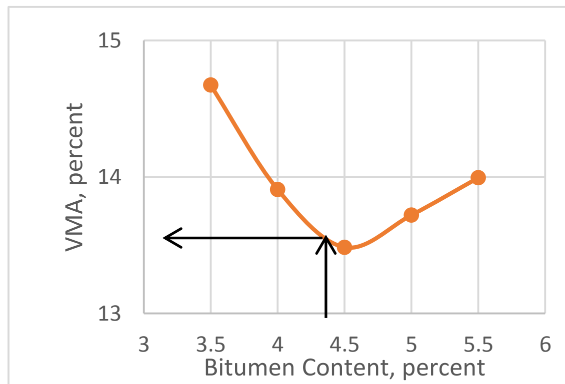

Figure 3.20: VMA vs Bitumen Content

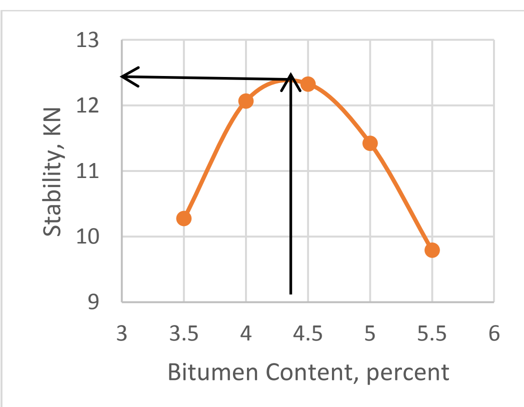

Figure 3.21: Stability vs Bitumen Content

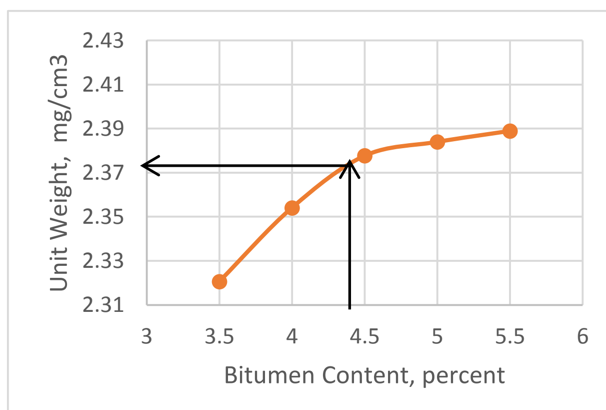

Figure 3.22: Unit Weight vs Bitumen Content

Table 3.6: Summary of Volumetric Properties of Mix Having 20 % RAP and 10 % Plastic

% AC	G_{mb}	G_{mm}	Unit wt(mg/cm^3)	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow(mm)
3.5	2.321	2.494	2.321	6.937	14.674	52.729	10.275	2.003
4	2.354	2.477	2.354	4.966	13.909	64.300	12.068	2.451
4.5	2.378	2.467	2.378	3.608	13.485	73.246	12.329	2.896
5	2.384	2.455	2.384	2.892	13.720	78.921	11.424	3.221
5.5	2.389	2.450	2.389	2.490	13.994	82.209	9.792	3.946

The asphalt content at 4 % air voids i.e., OBC of mix with 20 % RAP and 10 % PET Plastic came out to be **4.4 %**.

Graphs of Volumetric Properties of mix having 10 % Plastic and 40 % RAP

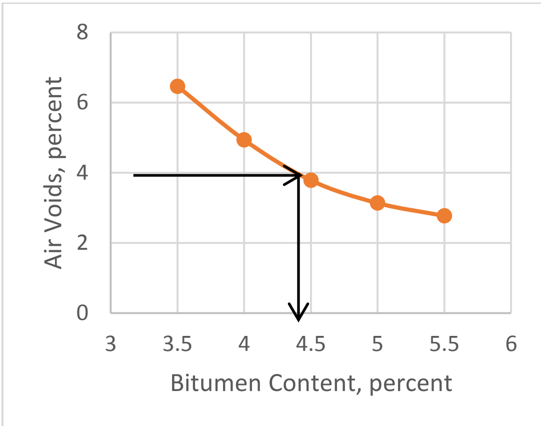

Figure 3.23: Air Voids vs Bitumen Content

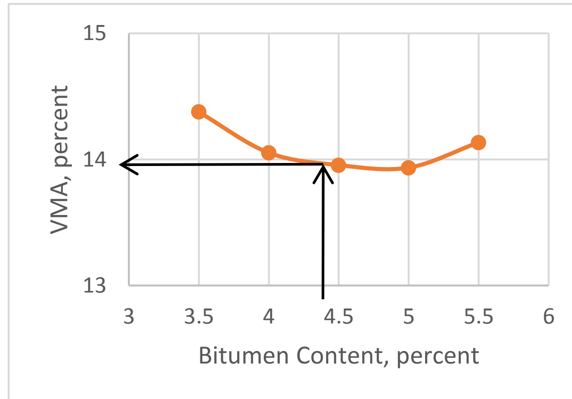

Figure 3.24: VMA vs Bitumen Content

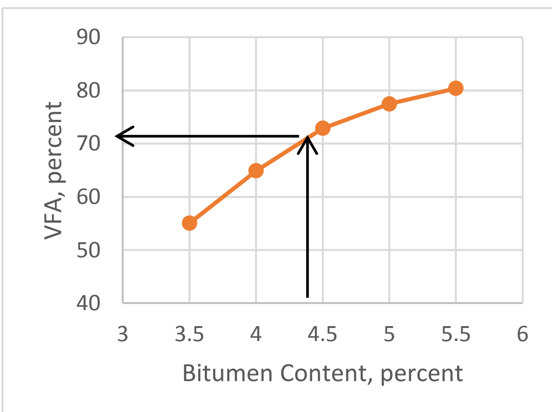

Figure 3.25: VFA vs Bitumen Content

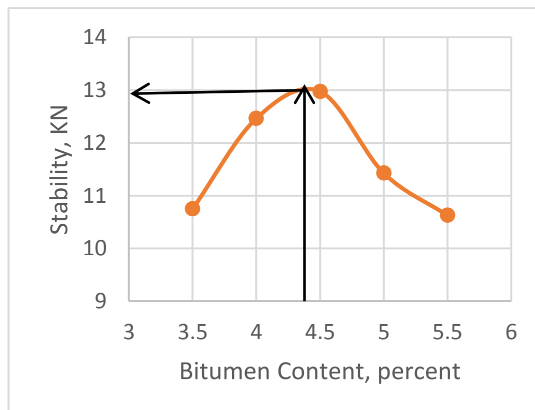

Figure 3.26:Stability vs Bitumen Content

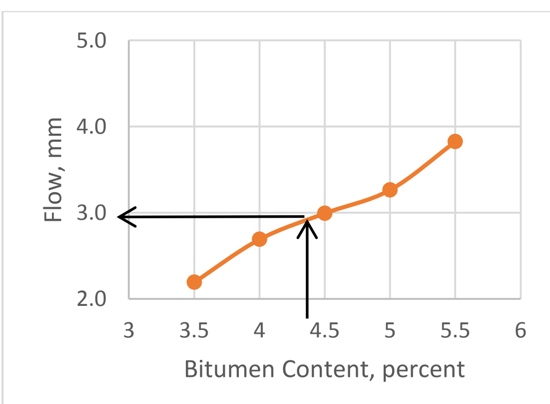

Figure 3.27: Flow vs Bitumen Content

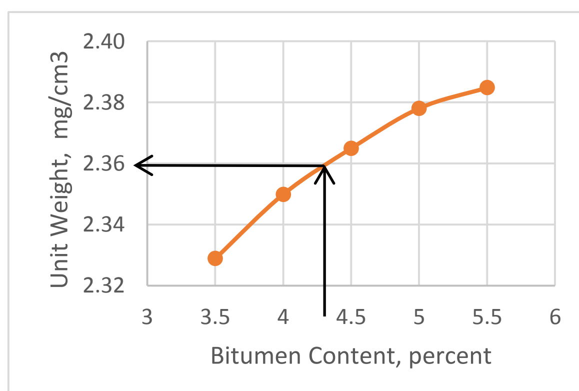

Figure 3.28: Unit Weight vs Bitumen Content

Table 3.7: Summary of Volumetric Properties of Mix Having 40 % RAP and 10 % Plastic

% AC	G_{mb}	G_{mm}	Unit wt (mg/cm^3)	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.329	2.490	2.329	6.466	14.377	55.027	10.753	2.193
4	2.350	2.472	2.350	4.935	14.053	64.880	12.46	2.69
4.5	2.365	2.458	2.365	3.784	13.955	72.887	12.97	2.99
5	2.378	2.455	2.378	3.136	13.935	77.492	11.43	3.27
5.5	2.385	2.453	2.385	2.772	14.136	80.389	10.63	3.83

The asphalt content at 4 % air voids i.e., OBC of mix with 40 % RAP and 10 % PET Plastic came out to be **4.4 %**.

3.2.6 Preparation of Samples for Performance Tests

After OBC determination of virgin samples and samples containing waste, samples were prepared for performance tests. The parameters for which asphalt study is done in this research are :-

- Resistance against rutting
- Moisture susceptibility

For these parameters two tests were performed which were

Hamburg Wheel Tracker Test (ASTM 324)

Indirect Tensile Strength Test (ASTM D 6931-07)

For indirect tensile strength test total of 18 samples were prepared. Six samples were of virgin asphalt concrete while 12 samples contained waste. Also, 9 samples were conditioned i.e., placed in water for 24 hours and other 9 samples were unconditioned.

Figure 3.29: ITS Test Apparatus

For Hamburg Wheel Tracker Test, total of 9 samples were prepared each of 6kg. Diamond cutter was used to cut the samples according to dimensions of machine. 5000 cycles were selected as per standard and samples were tested under room temperature. Rut depth of any sample should not exceed 12mm according to TEXAS department of transportation.

Figure 3.30: Hamburg Wheel Tracker Test Ongoing

3.3 BIM-Based Studies:

First, a BIM model was prepared for the NUST University in Autodesk Infraworks. The model was developed up to LOD 300 for effective quantity estimation processes. The model was fed with the transportation routes of NUST, and their data was integrated with it. The thickness of wearing course and base course of Asphalt was set at 8 inches.

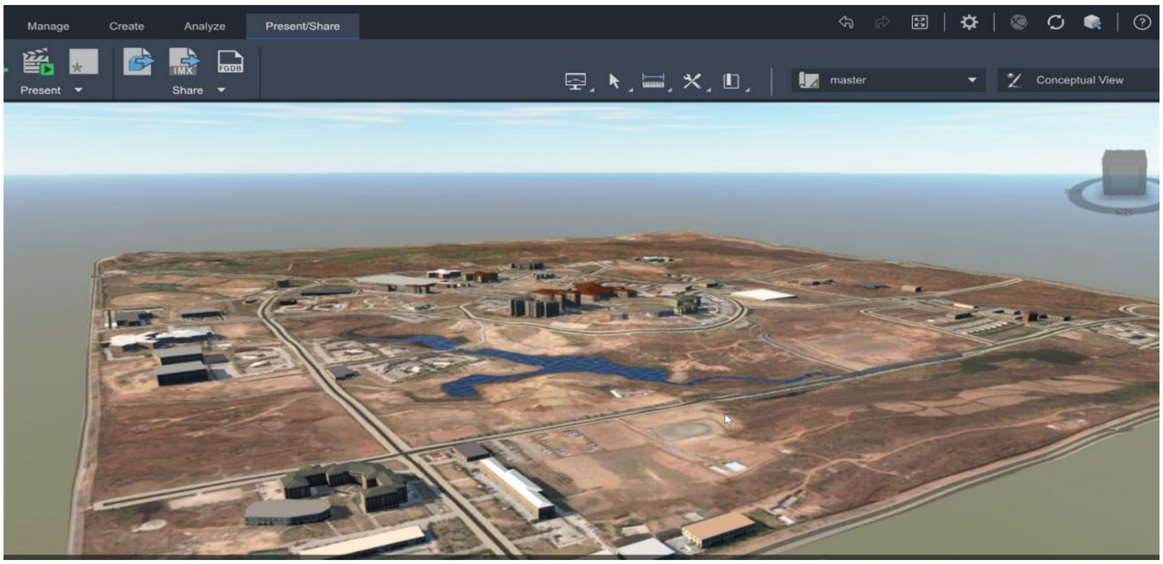

Figure 3.31: Infraworks Model of NUST

Using the model developed in Autodesk Infraworks, quantity of Asphalt to be used was calculated for Base course and Wearing Course.

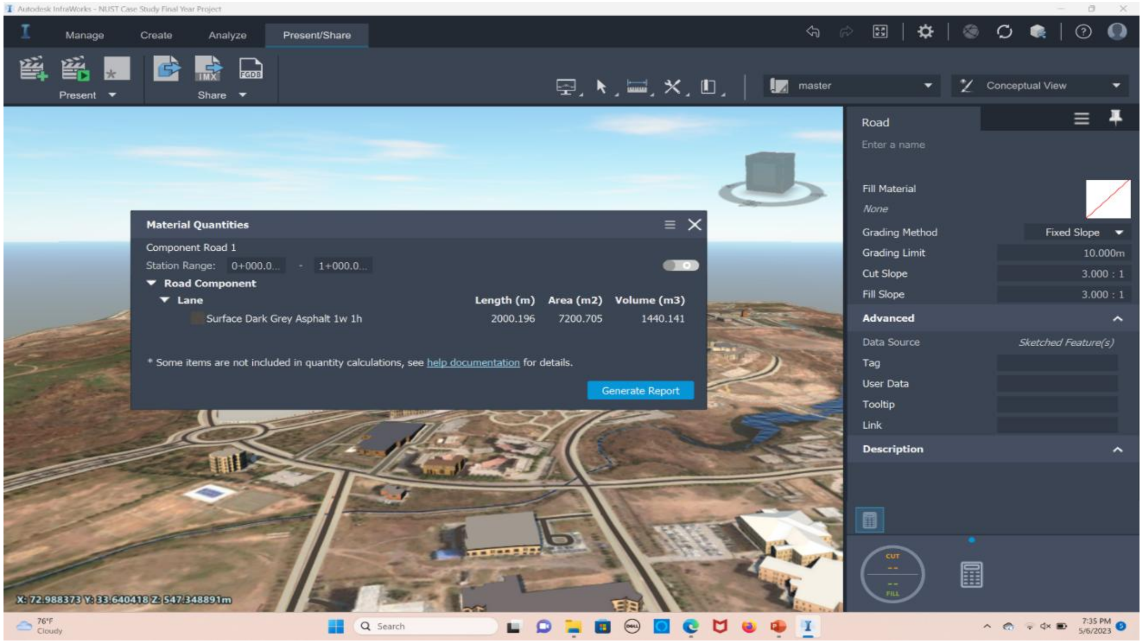

Figure 3.32: Infraworks Calculation of Volume of a road of 1 km

Then, the quantity of materials was used to perform Cost-Benefit analysis in MS Excel and Environmental Impact analysis using One Click LCA.

3.3.1 Cost-Benefit Analysis:

The costs incurred during the paving of Fresh Asphalt and Reclaimed Asphalt were identified. The cash flow developed for fresh asphalt and RAP were developed based upon the costs incurred during these processes. The cashflows for Virgin Asphalt and RAP are given as:

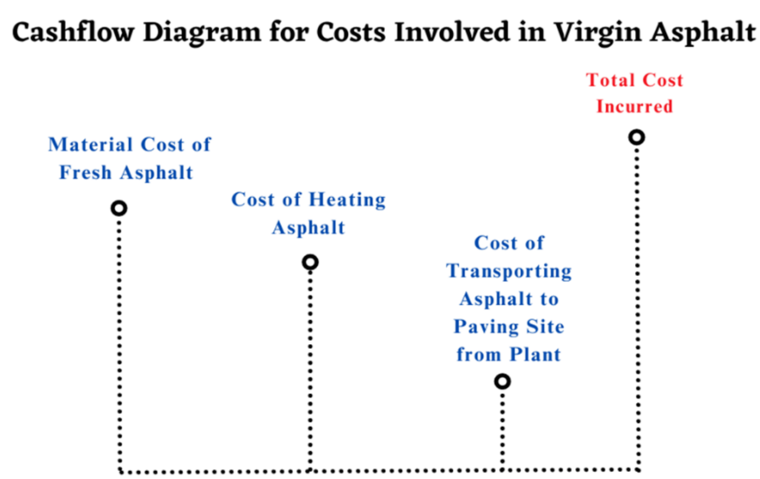

Figure 3.33: Cashflow Diagram for Costs Involved in Virgin Asphalt

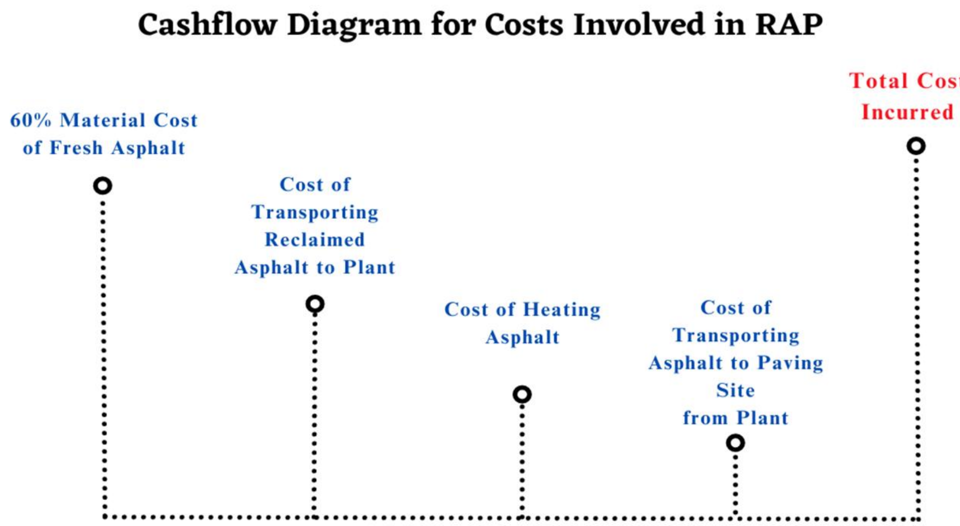

Figure 3.34: Cashflow Diagram for Costs Involved in RAP

3.3.2 Environmental Impact Assessment:

The materials under study were traced in the Material Library of One Click LCA, which is an online BIM based platform that is used for Environmental Impact Assessments. Then, the Quantity of materials calculated from Infraworks was imported and used in One Click LCA. The assessment was done using LEED standard for energy and environment. The assessments were conducted for **Carbon Emission**, **Acidification Potential** and **Eutrophication potential** of RAP and Virgin Asphalt in order to evaluate the Environmental Sustainability of Reclaimed Asphalt. The calculations were conducted for a lifetime of 20 years for Pavements.

Chapter 4: Results and Analysis

4.1 Introduction

This research project focuses on investigating the impact of incorporating Recycled Asphalt Pavement (RAP) and Polyethylene Terephthalate (PET) as substitutes for aggregates in Hot Mix Asphalt (HMA) mixtures. The RAP and PET materials used in the study were obtained from Multan, Pakistan. To determine the Optimum Bitumen Content (OBC), samples were prepared with different percentages of RAP and PET. The NHA class B gradation was utilized for the mixtures. This chapter presents and analyzes the results of the Wheel Tracking (Rutting) and Indirect Tensile Strength (ITS) tests. A comprehensive discussion of these tests can be found in Chapter 3. The outcomes of these tests are compared to those of the control samples to evaluate the effects of RAP and PET on tensile strength and rutting behavior.

4.1.1 Hamburg Wheel Tracker (Rutting) Test

The purpose of the Hamburg Wheel Tracker (Rutting) test was to assess the resistance of the specimens to rutting. Dry conditions were selected for conducting the test. A total of 9 samples were prepared, including control samples and samples with varying proportions of RAP and PET. Each sample was carefully cut using a diamond cutter to match the required dimensions for the test assembly. The sample was then divided into two equal parts, and both parts were placed inside the assembly. To ensure accuracy, the average rut depth readings from both specimens were recorded to minimize any potential errors. The test was carried out under dry conditions at a temperature of 25°C, with a total of 10,000 passes applied to the specimens. The failure criteria were determined based on rut depth values exceeding the specified cutoff value of 12mm.

Table 4.1: Test Matrix for Performance Evaluation Tests:

Sr. No.	Plastic (%)	RAP (%)	Indirect Tensile Strength Test		Hamburg Wheel Tracker Test
			Conditioned	Unconditioned	
1	0	0	3	3	3
2	10	20	3	3	3
3	10	40	3	3	3

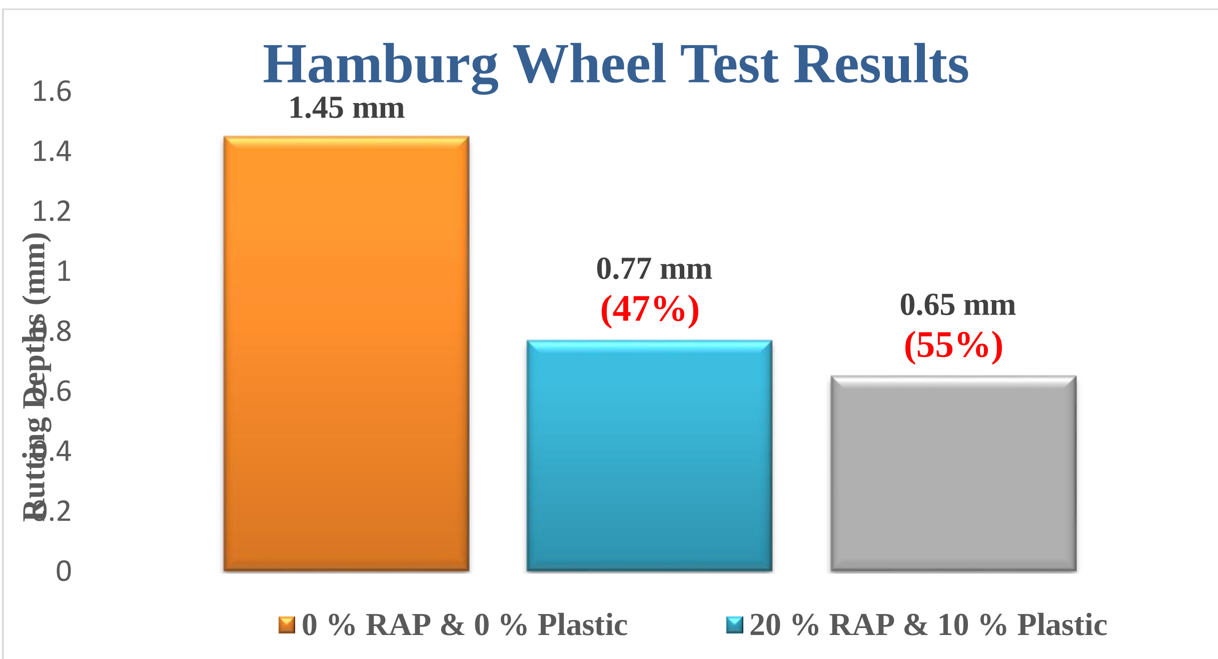

Figure 4.1: Hamburg Wheel Tracker Test Results

The results indicate that the HMA samples containing RAP and PET exhibited superior resistance to deformation and rutting.

4.1.2 MOISTURE DAMAGE (ITS TEST RESULTS)

After finalizing the mix design, the asphalt concrete samples underwent a moisture susceptibility test following ASTM D 6931-07 guidelines. The samples were conditioned according to ALDOT 361 procedures. A total of 18 samples were prepared, targeting 4% air voids, and subjected to the Moisture Susceptibility Test. Among these samples, 9 were tested in an unconditioned state, while the remaining 9 were tested after conditioning. The strength values of both conditioned and unconditioned samples were recorded and analyzed. The results revealed that the samples incorporating RAP and PET exhibited enhanced performance compared to the control (virgin) samples. This indicates the improved moisture resistance of the RAP and PET modified mixtures.

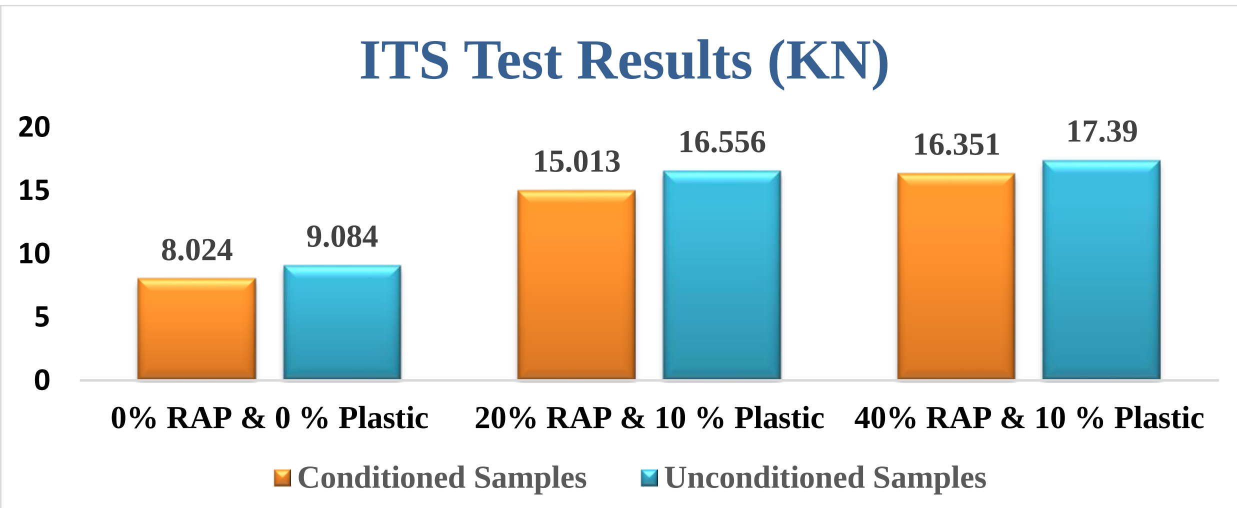

Figure 4.2: ITS Test Results

The following figures illustrate the trends of the ITS test results along with the Tensile Strength Ratio (TSR). According to Superpave criteria, the TSR should be a minimum of 80%. The calculated TSRs for all the samples exceeded 80 percent.

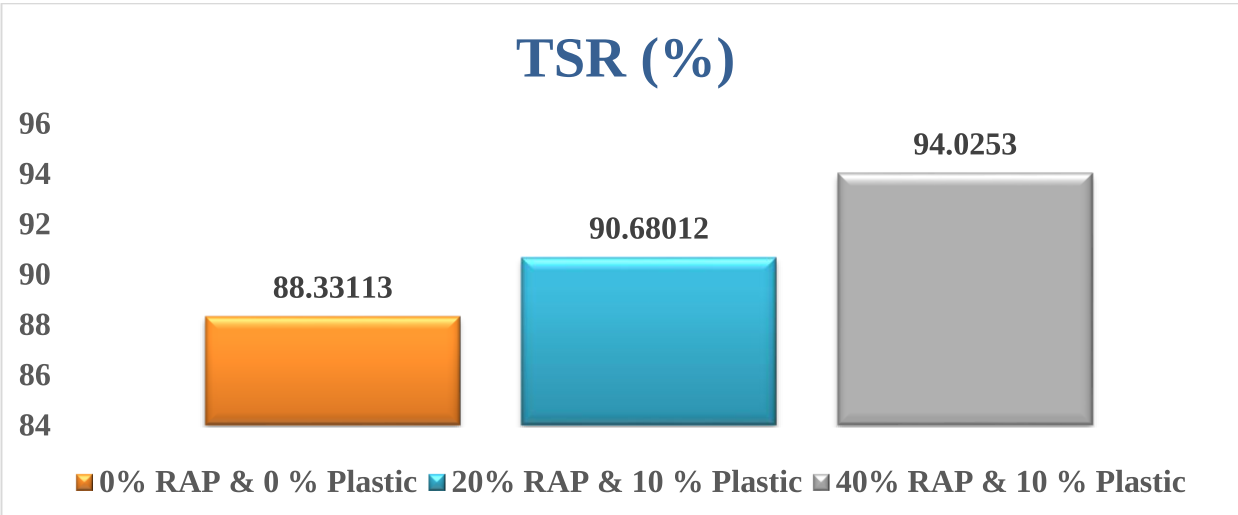

Figure 4.3: Tensile Strength Ratio Results

The cost incurred during paving was calculated using the quantities pulled from Infraworks. The unit prices of materials were obtained from online resources. The cost for each component of Cash flows was calculated and at the end comparison was drawn for both materials. The first Iteration was performed for a hauling distance of 5km from asphalt plant to the Paving site.

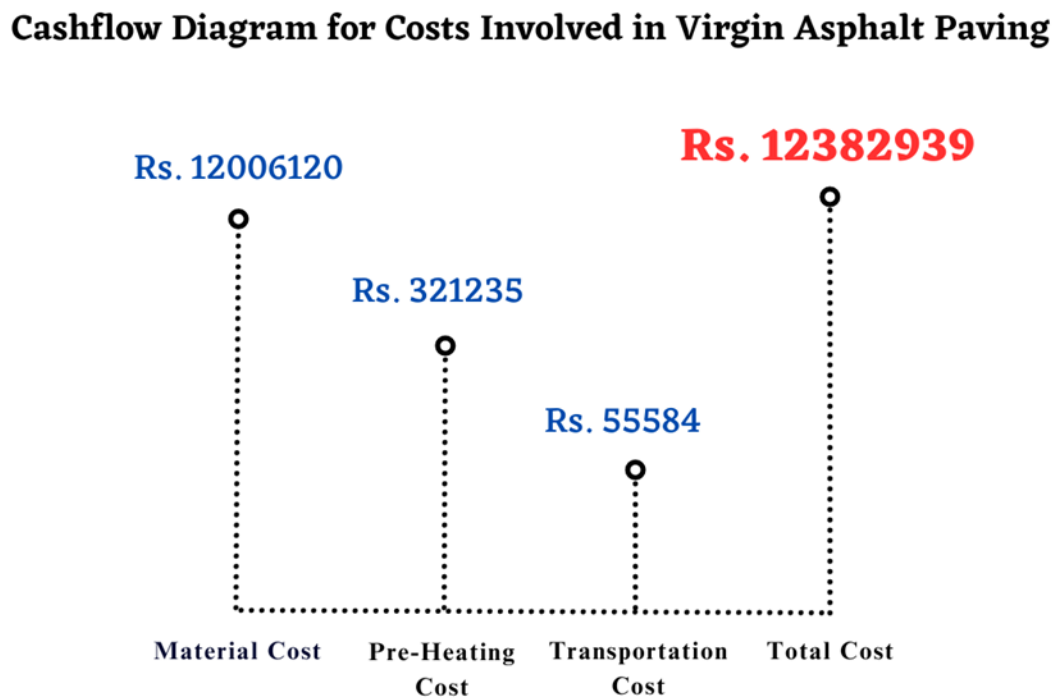

Figure 4.4: Cashflow Diagram for Costs Involved in Virgin Asphalt Paving

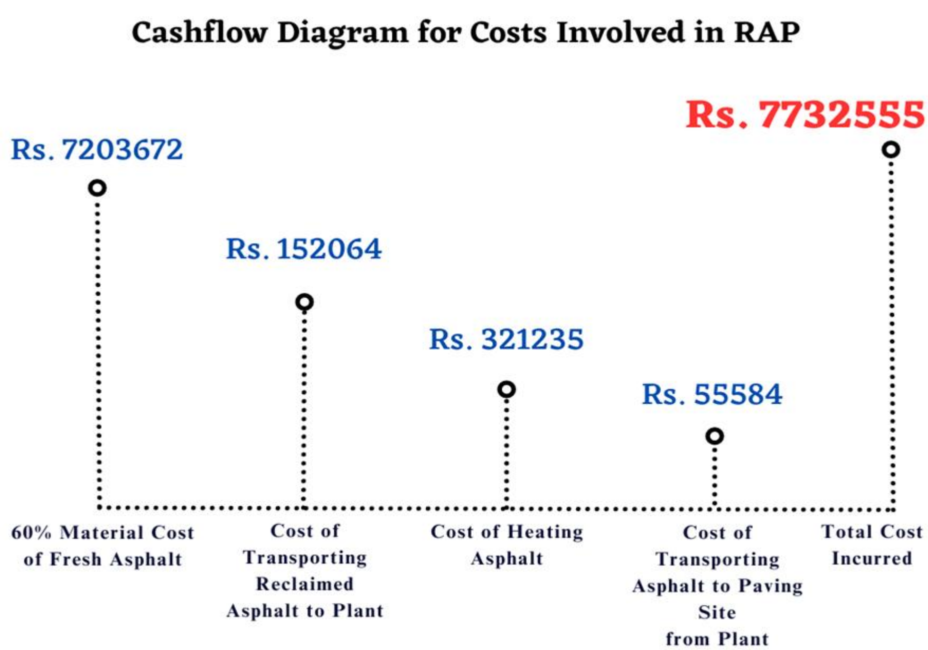

Figure 4.5: Cashflow Diagram for Costs Involved in RAP

For 5 km hauling distance, we can observe a cost reduction of up to 33% by means of using 40% RAP in place of Fresh Asphalt. The same calculation was performed for hauling distance ranging up to 30 Km and cost reductions were calculated:

Table 4.2: Cost Reduction for different haul distances

Haul Distance Kilometers	Fresh Asphalt Overall Cost (Rs)	Reclaimed Asphalt Cost (Rs)	Cost Reduction Using RAP (%)
10 km	12,438,235	7937282	31%
15 km	12493675	8147419	29%
20 km	12549115	8355292	27%
30 km	12659995	8756643	25%

The results for these Environmental Impact Factors along with explanation are given below:

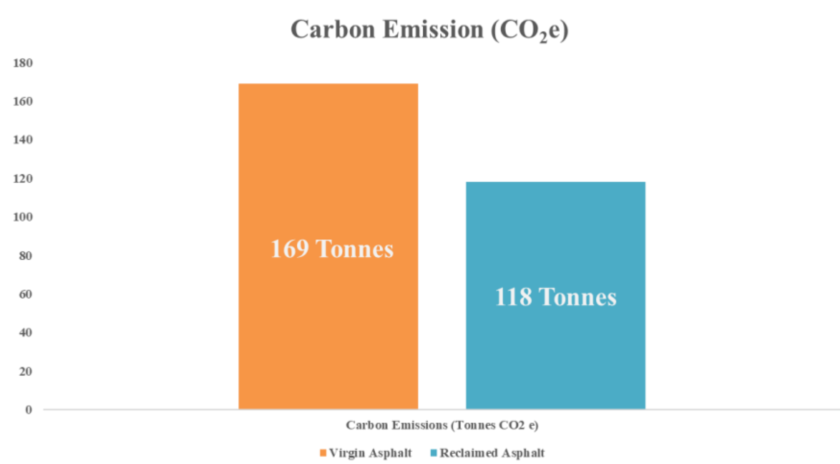

Figure 4.6: Carbon Emission

The Carbon Footprint of RAP is less as compared to that of Fresh Asphalt as lots of fossil fuels must be burnt to produce Fresh Asphalt as it is a Petroleum based product. However, it is not the case for RAP. RAP does not require burning of new fossil fuels for production which accounts for its lower Carbon Emission.

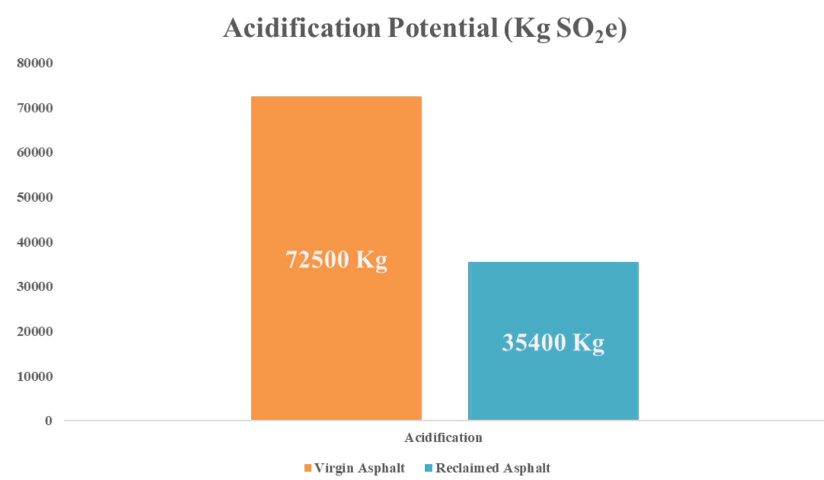

Figure 4.7: Acidification Potential

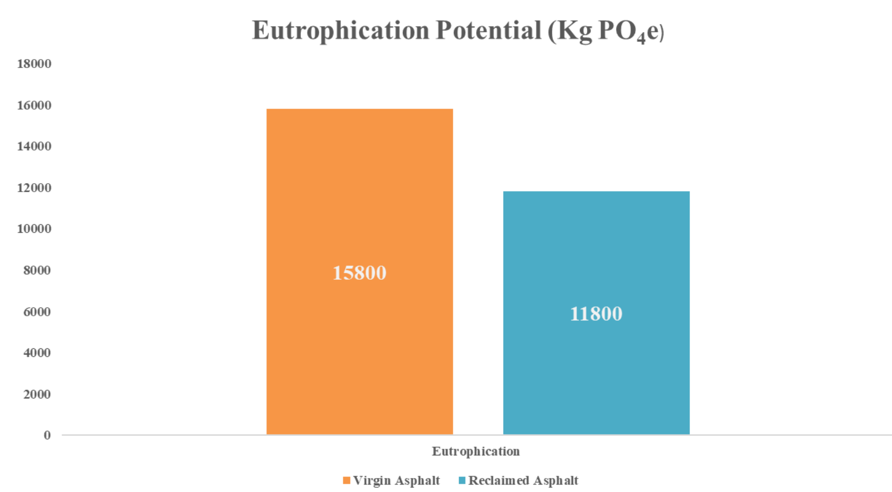

Figure 4.8: Eutrophication Potential

The low Acidification Potential and Eutrophication Potential of RAP as opposed to Fresh Asphalt is owing to the depletion of pH reducing chemicals and other nutrients of Reclaimed Asphalt during its first lifecycle of 20 years. Therefore, during its second lifecycle, it does not release as many chemicals in the environment as Fresh Asphalt.

Chapter 5: Conclusions and Recommendations

5.1 Summary:

The main aim of this research study was to evaluate the performance of Hot Mix Asphalt (HMA) by incorporating Reclaimed Asphalt Pavement (RAP) as substitute for conventional aggregates and Polyethylene Terephthalate (PET) as a bitumen modifier. The objective was to develop an environmentally friendly asphalt pavement that surpasses the properties of traditional asphalt mixes. The research focused on comparing the performance of fresh asphalt with RAP as aggregate replacement and PET as a bitumen modifier, with a specific emphasis on two crucial factors: resistance to rutting and moisture susceptibility. Rutting and moisture damage are significant concerns observed in flexible pavements. To investigate these factors, two performance-based tests were selected for evaluation: Hamburg Wheel Tracker Test: This test employed specialized equipment to assess the potential for rutting in the asphalt concrete samples. The samples were subjected to 10,000 passes of loading under dry conditions using a steel wheel. Indirect Tensile Strength (ITS) Test: This test evaluated the susceptibility of the asphalt mixture to moisture damage. Both conditioned and unconditioned samples were examined. The selected aggregate gradation adhered to the NHA CLASS-B Mid Gradation specification. The bitumen used was sourced from PARCO and had a penetration grade of 60/70. PET, which served as a warm mix asphalt additive, was procured from NUST Hostels. The percentage of PET used was limited to 10% based on the Optimum Bitumen Content (OBC) by weight. The Marshall Mix design procedure was employed to determine the OBC for the virgin samples and various proportions of RAP and PET. Subsequently, samples were prepared for the Hamburg Wheel Tracker Test, which involved subjecting them to 10,000 cyclic loading repetitions under dry conditions using a steel wheel. Moisture susceptibility was assessed for both conditioned and unconditioned samples. In summary, this section provides the key findings of the performance-based tests conducted and presents the corresponding conclusions.

5.2 Conclusions:

Based on the analysis of the conducted tests described in the previous chapter regarding the utilization of RAP and PET in HMA technology, the following conclusions can be drawn:

1. The incorporation of RAP and PET in HMA technology provides several advantages, including reduced indirect costs, improved pavement performance and longevity, and the conservation of natural resources. Additionally, using waste materials like RAP and PET promotes a more sustainable and environmentally friendly approach.

2. As the proportion of waste materials (RAP and PET) increased, the Optimum Bitumen Content (OBC) of the asphalt concrete samples decreased.

3. The samples produced using RAP technology exhibited enhanced resistance against moisture damage, as indicated by their Total Resilient Strain (TRS) values, compared to samples produced using Fresh Asphalt.

4. The TSR of the HMA samples increased by approximately 8-10%, demonstrating improved moisture resistance.

5. Among the samples containing different proportions of waste materials, those with 10% PET and 40% RAP, produced using HMA technology, displayed higher TSR values.

6. The rut depth of the samples produced with HMA technology exhibited increased resistance against rutting.

7. The rut depth of the RAP-PET samples improved by approximately 47-55%, indicating significant enhancement in rutting resistance.

8. The samples containing waste materials, specifically 10% PET and 40% RAP, and produced using HMA technology, demonstrated the least rut depth, highlighting their superior performance.

9. The inclusion of PET in the mixture contributed to improved workability characteristics.

10. Overall, the project costs were reduced by 33% for haul distances of 5 km, with substantial cost savings observed for distances up to 30 km.

In summary, the utilization of RAP and PET in HMA technology yielded positive outcomes, including improved performance, increased resistance against rutting and moisture damage, and the potential for cost savings.

5.3 Recommendations:

Based on the findings of this study, the following recommendations are proposed:

1. Further investigation: As Warm Mix Asphalt (WMA) technology is still evolving, there is a need for additional research to explore other parameters. Conducting tests such as creep, fatigue analysis, and dynamic modulus would provide a more comprehensive understanding of WMA properties.

2. Variation in percentages: It is recommended to experiment with different proportions of RAP and PET to assess their impact on performance. By adjusting the percentages, a more detailed analysis can be conducted to optimize the blend and achieve desired outcomes.

3. Higher percentage of PET: To examine changes in performance and durability, it is advisable to test the blend with a higher percentage of PET, exceeding the previously used 10% limit.

4. Alternative plastic types: In addition to PET bottles, other types of plastic can be explored to evaluate their suitability and influence when incorporated into the asphalt mixture.

5. Construction of a trial section: To validate the performance of the RAP and PET blend under specific temperature and traffic conditions in Pakistan, it is recommended to construct a trial section. This practical implementation will provide valuable insights into the real-world behavior and performance of the blend.

6. Further research areas: Investigating the self-healing properties of WMA with RAP and PET, as well as exploring porous asphalt pavement, are recommended research directions. These areas of study can contribute to advancements in sustainable transportation infrastructure.

7. In-situ RAP paving studies: Conducting studies on in-situ RAP paving, including its applications, impacts, and implications on cost, environment, performance, and society, would provide valuable insights for future projects.

Based on the outcomes of this study, it is confidently recommended that the utilization of RAP and PET in WMA shows promise for future applications. The blend meets the desired volumetric and performance criteria and outperforms conventional Hot Mix Asphalt (HMA). By incorporating RAP and PET, valuable resources can be conserved, and sustainability can be promoted within Pakistan's transportation industry.

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