PERFORMANCE EVALUATION OF ASPHALT BINDER USING WASTE PET AND RAP

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A thesis submitted to National University of Science and

Technology (NUST), Islamabad,

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in

Transportation Engineering

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THESIS ACCEPTANCE CERTIFICATE

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DEDICATION

Dedicated to my exceptional parents, husband, supportive siblings and adored children whose tremendous support and cooperation led me to this wonderful accomplishment.

ACKNOWLEDGEMENT

I am very thankful to ALLAH (S.W.T), Whom blessing helped me to complete my research.

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(Engr. Lubna Tabassum)

ABSTRACT

Roads are considered as the backbone in the economy of Pakistan as it dominates over the other two systems of transport i.e. rail transport and the air transportation. However due to heavy expenditure involved in expansion of projects and lack of resources even for regular and routine maintenance of existing network, recycling is only the best possible solution. In a recent survey, Pakistan has got the highest mismanaged plastic wastes in the region of South Asia and produces 87000 tons of solid waste per day. Waste is also produced in the form of Reclaimed Asphalt Pavement (RAP) from the road construction industries. So, in this study, an effort is made towards the study of use of Reclaimed Asphalt Pavement and waste PET obtained from waste drinking plastic bottles as a partial replacement of asphalt use in the construction of asphaltic pavements. To do so, waste plastic bottles (PET) were collected, cleaned and shredded to a size less than 0.5mm, then they were mixed in percentages (2%,3%,5%,7%,9%by weight of virgin bitumen) at a temperature of 250°C with high speed shear mixer at 170rpm and physical tested in unaged and aged conditions to find the optimum dosage of binder. Four different percentages (10%,20%, 30% and 40%) of RAP was blended with (optimum dosage of 5%) of waste PET modified binder by means of a high-shear mixer, and then it was aged in the laboratory following a Rolling Thin Film Oven Test (RTFO) and a pressure aging vessel (PAV) machine. Penetration, Ring and Ball test, ductility and Rotational viscosity tests were performed before and after short-term aging and long-term aging respectively. The chemical and morphological changes were observed using FTIR and SEM i.e. Fourier Transformed Infrared Microscopy and Scanning of Electron Microscopy. Results indicated improvements in the modified asphalt physical properties and then modified asphalt added with optimum dosage of modifier along with different concentrations of RAP binder even after the process of aging. Viscosity aging index was decreased which indicates that Waste-PETMB with RAP binder has better anti-aging property. Decrease in the index of sulfoxide and carbonyl reflects good resistance against oxidation of the modified asphalt samples. Morphological analysis also proved their better compatibility with asphalt binder.

Keywords: Reclaimed Asphalt Pavement(RAP),Viscosity ,PET, environment, aging, modified asphalt, Waste-PET MB

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List Of Abbreviations

ASTM	American Society of Testing Materials
ARL	Attock Refinery Limited
CPEC	China Pakistan Economic Corridor
FTIR	Fourier Transformed Infrared Spectroscopy
HMA	Hot Mix Asphalt
FTIR	Fourier Transformed Infrared Spectroscopy
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
NHA	National Highway Authority
OD	Optimum Dosage
OBC	Optimum Binder content
PARCO	Pak Arab Refinery Company Limited
RTFO	Rolling Thin Film Oven
PG	Performance Grade
W-PET	Waste Polyethylene terephthalate
W-PETMB	Waste Polyethylene Terephthalate Modified bitumen
RAP	Reclaimed asphalt Pavement
TRB	Transportation Research Board

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Roads make a vital contribution towards economic development and growth and also plays an increase in social benefits. To support sustained economic growth and increase competitiveness, Government of Pakistan (GOP) has lined up a strategic approach to transportation and has launched many initiatives to improve internal movement of goods to facilitate the people of Pakistan.

The total length of roads, which was calculated as 229,595 KM in the years 1996-97, has now increased to 263,775 KM by the years 2017-18 with an increment of 13.16 percent. This includes NHA’s network of approximately 12,743 km, which is only 4.81% of the road network overall and it takes about 80% of Pakistan’s freight traffic. National Highways Authority (NHA) is responsible to Plan, promote and organize programs for Construction, maintenance, Operation and Repairs for National Highways/ Expressways and Strategic Roads. Recent inception and implementation of China Pakistan Economic Corridor (CPEC) is one of the land marks in this context, so that access to international markets be made easier.

However, it is also a fact that with the outbreak of COVID -19 pandemic which has challenged, social, financial and economic structure of the whole world including developing countries like Pakistan. Pakistan’s current account has turned deficit in the year 2019-2020 which has been spurred by higher prices of import oil. In the scenario; where there is inflation in the prices of materials and lack of funds for the developing and maintenance projects, recycling of waste products from industries not only a viable option but it will also save the environment.

Along with challenges of economic stabilization, Pakistan is also facing the challenges of waste disposal. Pakistan has got the highest proportion of mismanaged plastic wastes in the region of South Asia. It is estimated that approximately 55 billion of garbage/shopping bags are manufactured in the country annually, most of them are to be destined for garbage dumps, landfill sites, or municipal sewers. About 30 million tons of solid wastes is produced every year, out of which 9% are found of plastics. This has resulted in an increase of plastic pollution in the country which of course has a detrimental effect on environment and in return to human health and marine life, and causing the environmental pollution. GOP calculated 87,000 tons of solid waste which is generated per day, majorly from metropolitan areas.

So, to counter the above challenges, recycling by means of waste materials can save the environment and contribute towards saving in economy. Recycling is gaining traction globally and most of the countries adopt ways to use waste products from industries in the construction of asphaltic pavements.

1.2 PROBLEM STATEMENT

For sustainable growth we need cost effective and efficient construction techniques. Recycling is not only a critical necessity to save the depleting resources of aggregates, but to replace the use of costly bitumen as 90-95% of the world transportation infrastructure system is paved with HMA.

At present, our Government is facing challenges of lack of funds for the rehabilitation, maintenance and construction of road network. On the other hand, it is also a need of an hour to grow and maintain road network to enhance trade between our neighboring countries. To mitigate these issues pavement recycling is the best option to construct the pavements by maintaining the desired volumetric. As motorways and national highways construction and rehabilitation has been introduced HIR and CIR technology at fewer lengths. Similarly, warm mix asphalt technology to enable us to consume more RAP at a comparatively reduced than conventional temperature in Asphalt mixes. By the use of waste PET in RAP recycled material we can make project more economical and saving in funds which can be utilized for preservation of longer length of road or for construction of new pavements. So there is a need to promote the pavement recycling approach in Pakistan. For which, this research has been planned to explore the physical/conventional and chemical/morphological properties along with aging resistance of binder with different percentages of RAP and waste PET as rejuvenating agent and to categorize any special attentions that must be met to consume the RAP binder.

1.3 RESEARCH OBJECTIVES

i. To assess the physical properties of Waste-PET modified asphalt binder along with RAP binder in aged and unaged conditions
ii. Determine the effect of W-PET and RAP binder on morphology and chemical composition of asphalt by conducting Fourier Transformed Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM).
iii. Evaluate the influence of RAP percentages on R-PET modified asphalt binder properties
iv. To assess the flow behavior of W-PET modified asphalt binder along with RAP binder
v. Cost analysis of asphalt containing Waste-PET modified bitumen and RAP binder

1.4 SCOPE OF THE THESIS:

In order to accomplish the above stipulated objectives, a research methodology has been planned and outline of the tasks of research is as hereunder:

- Literature review for the use of RAP binder and waste/R-PET modified binder have been studied and the previous findings on aging behavior using laboratory test and their procedures and interpretation of results. The study is focused on the use of waste polymer additives that add up to the anti-aging performance of asphalt binder and enhance the properties of asphalt binder.
- Laboratory characterization of Waste-PET modified binder by adding different content levels (2%,3%,5%, &7% by weight of virgin binder). Aging has been observed with RTFO and PAV.
- Determination of optimum dosage of R-PET to be used as modifier in virgin grade 80/100 asphalt binder
- Preparation of samples by adding different concentrations (10%,20%,30%,40%by weight of W-PETMB) of RAP binder in the R-PET modified binder and then physical and performance tests were performed in aged and unaged conditions
- Chemical and morphological analysis has also been carried out with SEM and FTIR techniques

- Carrying out cost analysis for determination of cost of asphalt binder containing R-PET and RAP binder

1.5 ORGANIZATION OF THESIS

Chapter 1: includes the background of asphalt binder, properties and its modification and use of waste PET (plastic bottles) as a rejuvenator of asphalt binder. Use of RAP binder, and its effect on the behavior of asphalt binder. It also discusses problem statement, the research objectives as well as objectives of the research.

Chapter 2: incorporates an overview of the previous researches and their findings related to modification of binder with waste materials and then effects of addition of RAP binder contents on physical properties of asphalt binder.

Chapter 3: explains about the materials used in the research and the research methodology adopted. The primary materials include 80/100 penetration grade asphalt binder, waste polymer Polyethylene terephthalate (PET obtained from crushing of waste plastic bottles) and RAP binder extracted using Abson method ASTM d-2172. The testing approach includes the physical properties, morphological properties and the viscoelastic parameters to be evaluated.

Chapter 4: includes results obtained after extensive laboratory testing i.e. physical morphological and performance tests. Analysis was performed using Microsoft Excel 2016.

Chapter 5: encompasses the findings obtained after performance evaluation of asphalt binder using waste PET and RAP binder, detailed comments conclusions drawn are presented and future recommendations and suggestions are made for more studies.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter includes a brief review of the theory and literature pertaining to effects on binder modified with polymers and containing on RAP and waste PET to the physical, chemical and performance properties related to aging resistance. It deals with the utilization of waste PET obtained from recycling of plastic bottles and RAP and previous researches carried out to predict aging resistance of binder modified with R-PET with different concentrations of RAP binder.

For looking forward to, sustainable and cost effective solution for modification of asphalt binder, waste PET obtained from waste plastic bottles have been worked out by many researchers in the recent past. Sojobi in his study found out that utilization of waste PET from waste plastic bottle wastes has a beneficial environmental and economic effect keeping in view its positive effects including removal of tons of waste PET from the dumping sites and the economical saving generated in the form of extended remaining service life of roads, lessening of road accidents, energy saving and natural resources, and income derived from the trade in those wastes[1]. RAP can be defined as the material which is produced/generated when the pavement is rehabilitated, resurfaced or when an access is made to the buried utilities. It is found that it contains well graded and better quality aggregates coated with asphalt binder.

2.2 ASPHALT PAVEMENT

Cross-section of a fully flexible pavement is as hereunder:

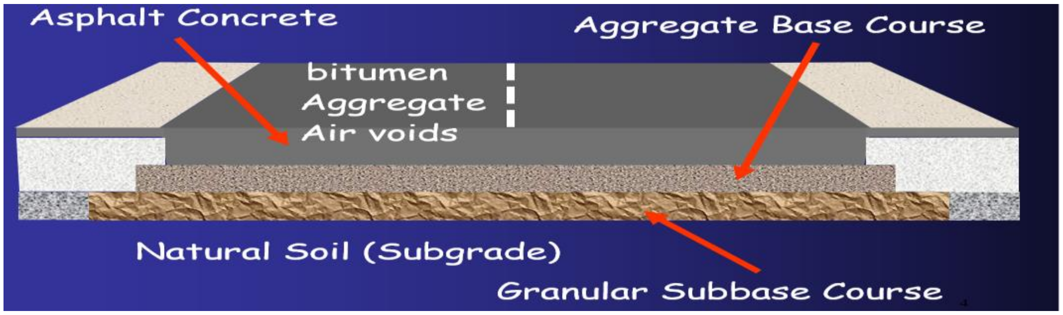


Figure 2.1: *Cross-section of fully flexible Pavement*

Asphaltic pavements are subjected to various stresses during the life of the pavement and these stresses causes defects in pavement like rutting, cracking, fatigue etc., if not treated timely lead to the reduced life of the pavement than design life. In Pakistan 90% of the roads are asphaltic roads and they are subjected to various distresses during the life of a pavement which needs urgent maintenance and rehabilitation involving finances from the Government. The major causes are:

i. Traffic volumes
ii. Axle loadings
iii. Tire pressures

Figure 2.2: Causes of deterioration – Overloading

It can be seen that the growth in traffic volume/axle load levels and inadequate / untimely maintenance are major contributing factors in deterioration of road network as shown in Figure 2.2. If not timely undertaken, then the pavement has to undergone through reconstruction which will be definitely costlier. So the extended service life of a pavement is achieved through timely maintenance as shown hereunder in Figure 2.3

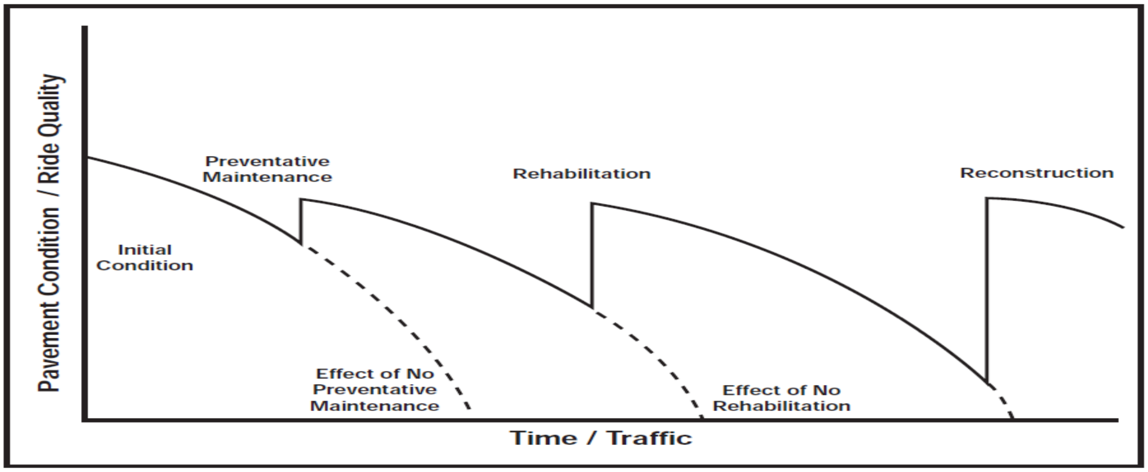


Figure 2.3:Pavement Deterioration Vs Time

With the growing current and future traffic loadings, conventional traditional pavement materials cannot fulfil the need. Therefore there is a dire need of better quality, environment friendly, safe and reliable pavement materials (R. Li *et al.*, 2017). Numerous types of modifiers and polymers are used in asphalt to improve its life and performance.

In Pakistan,90% of road network is asphaltic and road condition when survey was carried out on 10686Kms of length, on the national highway network was fair to poor as shown below.

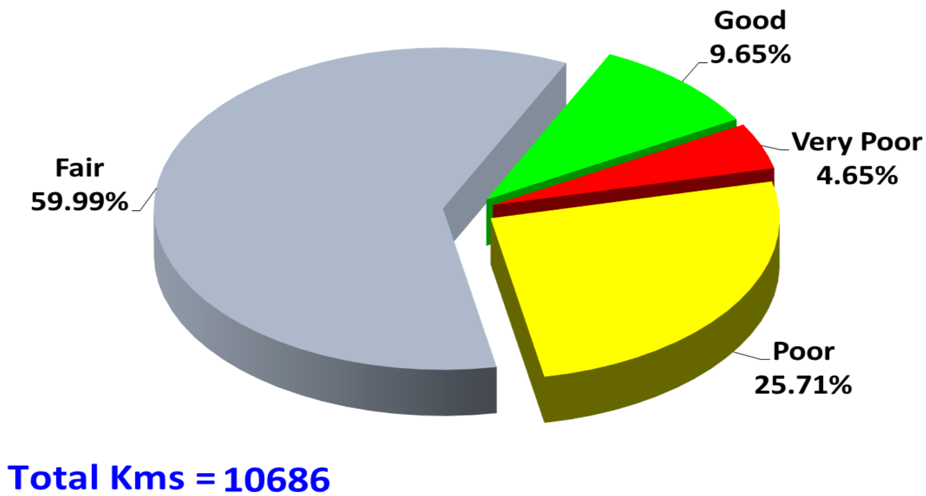
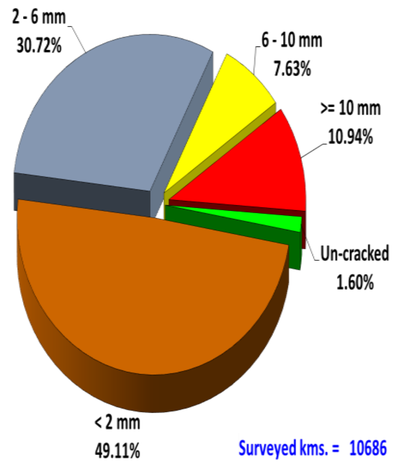


Figure 2.4:*REMAINING SERVICE LIFE (RSL)*



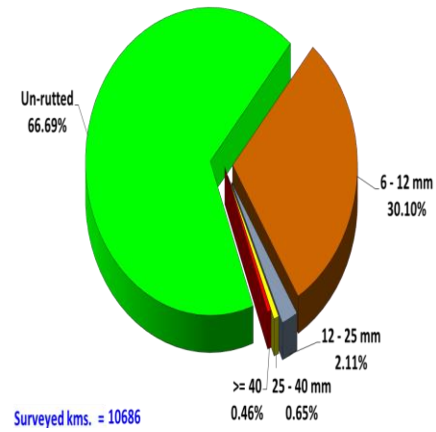


Figure 2.5:Cracking (Structural) (width)Figure 1.5Rutting (depth)

Studies have shown that mechanical, physical and rheological properties of the asphalt binder can be enhanced by the addition of waste polymer modifiers like plastic bottles, polythene bags, crumb rubber etc. They enhance the resistivity of asphalt binder against different distresses and pre-mature failures. Environmental and economic opinions/thoughts have encouraged the reuse of recycled aluminum, steel, plastic, rubber and many other waste materials. One of the mostly used recycling material in pavement is RAP.

2.3 ASPHALT BINDER HISTORY

Asphalt is manufactured from multistage fractional distillation process of crude oil. It can be said that "Bitumen is a Temperature and Load dependent material. Aging, temperature susceptibility and visco-elasticity are the three major properties of the asphalt binder that play a significant role in the performance of asphalt mixtures. Aging can be explained as the oxidation of lighter components in materials thatin return cause hardening of asphalt binder during construction and operation phase.

2.4 ASPHALT BINDER COMPOSITION

Bitumen is manufactured from multistage fractional distillation of crude oil and its chemical composition is as hereunder:

i. 82-88% Carbon
ii. 8-11% Hydrogen
iii. 0-6% Sulphur
iv. 0-1.5% Oxygen
v. 0-1% Nitrogen

Bitumen is mainly a thermoplastic and viscoelastic liquid which act as a glass-like elastic solid at low temperatures and at the time of rapid loading (short loading times) .It behaves as a consistent fluid at higher temperatures or during slow loading (long loading time).So "Bitumen is a Temperature and Load dependent material". Besides other reasons, primary cause of early deterioration of asphaltic pavement is found due to the aging of bitumen/binder. Performance of asphaltic mixture depends on three major factors; Aging effects, temperature susceptibility and viscoelasticity. Aging can be illustrated as the oxidation of lighter components of asphalt which resulted in hardening of asphalt binder at construction and service life of pavement. The primary cause of asphalt aging during service life time is the oxidation of molecules in atmosphere which results polar and strongly interacting functional groups containing oxygen Sirin, Paul [2].

Bitumen can be classified into two groups:

1. Asphaltenes 5-25% mass of bitumen
2. Maltenes: Resins (SOL, GEL)
   Aromatics 40-65%
   Saturates 5-20

Asphalt binder is a composed of very complex molecules that are the outcome of millions of years of intense heat, radiation and pressure acting on dead decaying,plant,animal ,and fish life. This process breaks down and indeed reforms very complex molecules to form this mixture of hydrocarbons that we call crude oil. The crude oil is then refined into its component parts, the heaviest and the most complex molecule of which is called an asphalt binder.

2.4.1 Elemental Composition

Composition of asphalt binder is as hereunder:

- 82-88% of Carbon

- 8-11% of Hydrogen
- 0-6% of Sulphur
- 0-1.5% of Oxygen
- 0-1% of Nitrogen

The presence of nitrogen in asphalt binder makes the complex constitution of asphalt binder. Many different chemicals present in the asphalt binder structure make its chemistry complex.Traces of some of the metals have also been found. The most frequent being vanadium and nickel.

2.4.2 Chemical Composition

The chemical composition of bitumen can be classified in to two main groups i.e. Asphaltenes(5-25%) and maltenes which further are composed of resins(SOL,GEL),aromatics(40-65%), and saturates(5-20%).Asphaltenes are the dispersing agents for maltenes.

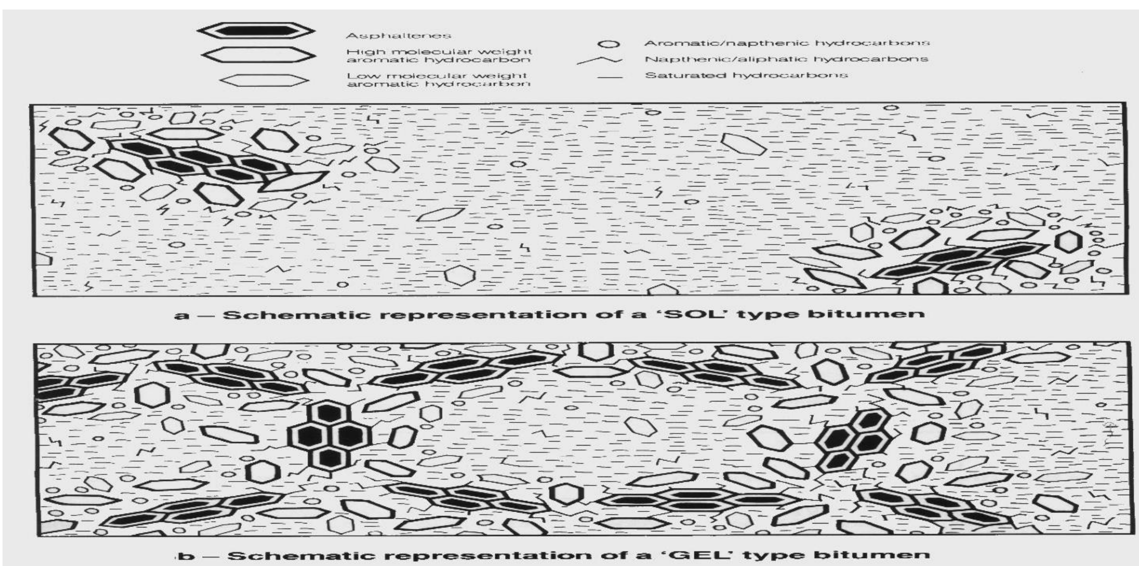


Figure 2.6:Schematic representation of SOL and GEL type asphalt binder

As shown in figure 2.3, i.e. The maltenes are the dispersing agents (peptisers) for asphaltenes, So balance of the SARA i.e. saturates, aromatics, resins and asphaltenes is very important for the behavior in service.

2.5 ASPHALT BINDER AGING

As stated by Apostolidis, aging is defined as the accretion of diverse harmful changes in molecular morphology with progressing age. Contrarily, its resistance is termed as "durability." However, asphalt binder should be protected against aging. He presented a review on antiaging techniques used to disallow or to rejuvenate aged asphalt kinetics of molecular geometry during aging are affected[3] .

It was defined by Wangas the asphalt binder has an exposure to oxygen and it is undergone to various temperatures on daily basis. The outcome is oxidation of its chemical composition, which leads towards the aging of the asphalt binder. The service life of asphalt binder affects by aging and therefore studies have been carried out pertaining to its chemical composition and performance properties[4].

Asphalt aging has a negative effect on the flexibility at the end of service life in field[5]. The progression of aging is also greatly reliant on the chemical structure of asphaltic mix[6].

Siddiqui and Ali in 1999 from their experimental studies stated that aging of the asphalt binder decreases the ductility and penetration values of binder while increases the softening point ignition temperature, which ultimately increases the binders viscosity making it more stiffer[7].

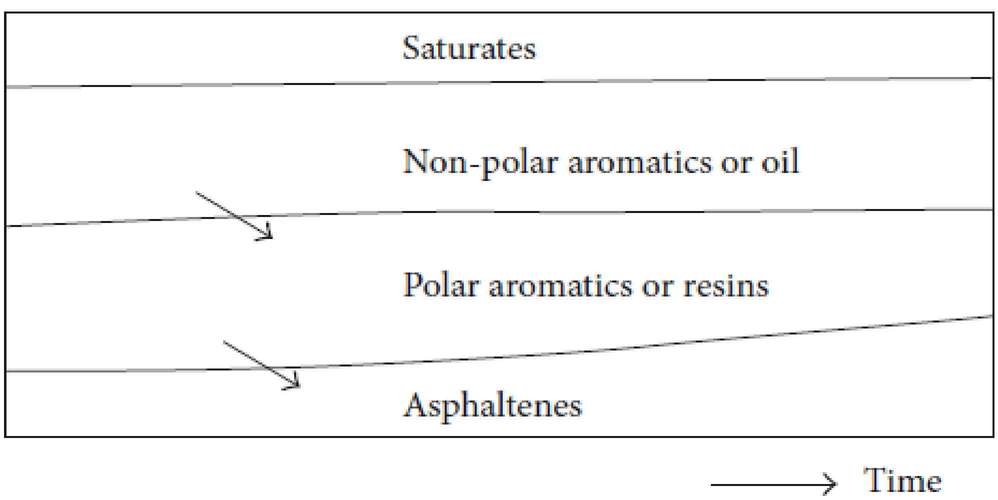


Figure 2.7: Aging effects on chemical composition of asphalt binder

Chemical composition of asphalt binder affected by aging is shown in the figure. Researchers indicate that the ratio of asphaltenes/maltenes changes due to aging which causes the increase in viscosity and make asphalt binder more hard and brittle [8]

2.5.1 Short Term Aging

As stated by Tian regarding short term aging that the thermal oxidation due to aging process into two stages. The first occurs during the construction period which is short-term aging , inclusive of mixing, transportation, paving, and compaction of asphalt mixture[9]. This phenomena take place when the asphalt binder material is mixed, transported, stored and compacted in the field[6]. Short term aging comprises almost 70% of total aging [10]. Rolling Thin Film Oven (RTFO) is normally used to stimulate it in laboratory conditions. Short-term aging temperature and added chemical type can affect the recovery phenomenon of asphalt binder[11]. Aging occurring within 2 to 3 years after the application of asphalt mixture in field also fall in the short term aging category.

2.5.2 Long Term Aging

As defined by Tauste, long term aging happens throughout the asphalt pavement service life due to exposure to sun and UV radiations[6]. Long term aging is a reversible process in which chemical composition of asphalt are changed while performance properties remain unchanged[12].

PAV i.e. Pressue aging vessel test is used in laboratories to simulate the effect of aging in the long term. The asphalt binder is exposed to increased temperature and high pressure for 20 hours.

Wang *et al.* 2019 analyzed the aging behavior of samples taken from different bituminous pavement structures. GPS, FTIR, DSR and fluorescence microscope (FM) were used as analytical tools to characterize the aging mechanism of different samples. It was found that degree of aging in the upper most layer of the pavement are more prominent, weak in the medium layer and weakest in the bottom layers. That’s why proper treatment of the pavement structures should be done considering the different impact of aging on different layers[13]

Effect of aging on asphalt binder can be studied by using following techniques i.e. Dynamic Shear Rheometer (DSR), Brookfield or rotational viscosity test, Softening Point Test, FTIR, AFM and Penetration Test [6]

2.6 ASPHALT BINDER MODIFICATION

To enhance the properties of bitumen many modifiers are used which are classified as hereunder:

i. Rubber
   a) Natural Rubber
   b) Styrene Butadiene Or Sbr
   c) Styrene Butadiene Styrene Or Sbs

ii. Reclaimed Rubber
   Crumb Rubber Modifier (Old Vehicle Tyres)

iii. Plastic
   a) Polyethylene/Polypropylene
   b) Ethylene Vinyl Acetate (Eva)
   c) Polyvinyl Chloride (Pvc)
   d) Polyethylene terephthalate (PET)

However due to heavy cost incurred on using these modifiers, agencies are restricted to keep the budget under control and use the conventional materials for construction of roads including surface layers. However utilizing waste material is the only viable option for modification. Properties of waste PET(plastic bottles) are as follows:

Table 2.1: Properties of Waste Pet

Chemical formula	**Melting point(°C)**	**Density(g/cm3)**	**Solubility**	**Water Absorption%**
C10H8O4	250	1.38	Insoluble in water	0.16

Waste plastic bottles contains polyethylene terephthalate (PET). Therefore, utilizing them i.e. waste PET as a source of modifier in asphalt mix has been found cost-effective and rational solution to this issue. After a number of researches, it was found that PET can be used to increase rutting resistance in asphalt mix design[14]

As per FHWA Publication No. FHWA-HRT-11-021 in April 2011, RAP is a cycle of utilizing the material which reduces the need of virgin material. RAP is a good substitute to new materials as it resulted in the reduction of need to use original aggregate. It also replaces the expensive asphalt quantity which is required in the production hot mix asphalt. The aforementioned report told researches regarding the utilization of RAP use in the United States as well as its use in asphalt paving mixtures. In the instant report it was concluded that RAP is a better and high-quality material which can replace costly aggregates and asphalt binders. The prominent and cost effective use of RAP is in asphalt mixtures[15].

Utilization of waste plastic bottles as a source of PET has been used modification and improvement of binder properties for decades in many countries like Australia, China, India, Malaysia, Hong Kong. Standards have also been developed for the use of waste plastics in road construction. Similarly, RAP recycling and its use has also gained popularity since 19^{th} century. So investigation should be carried out to use both waste PET modified binder with RAP binder which will serve as a step towards saving of energy and environment, consumption of waste thus making less costly and greener pavements.

Modification of bitumen has been done in the past decades. Several rejuvenating agents are utilized to enhance the properties of asphalt binder. Among these some of them are: Plastomeric Polymers like ethylene Vinyl Acetate (EVA), Polyethylene (PE) which primarily increase the stiffness of the bitumen. Secondly there are elastomeric Polymers like Styrene-butadiene-styrene (SBS). This develops multi-dimensional structure in the binder resulting in excellent elasticity and making it more strong in terms of cohesion.

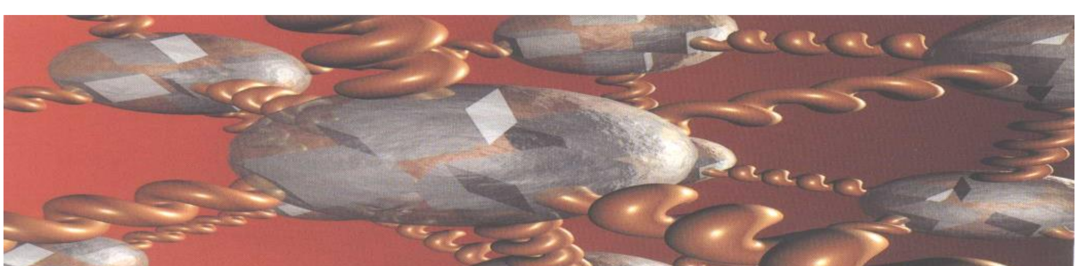


Figure 2.8: Bitumen Modification-Three Dimensional Network

Modifiers/additives used widely can be classified as follows:

i. Filler

   Crusher Fines, Lime, Portland Cement, Flyash & Carbon Black

ii. ExtenderS

   a. Sulphur
   b. Lignin

iii. Rubber

   a. Natural Rubber
   b. Styrene Butadiene Or Sbr
   c. Styrene Butadiene Styrene Or Sbs

iv. Reclaimed Rubber

   d. Crumb Rubber Modifier (Old Vehicle Tyres)

v. Plastic

   a. Polyethylene/Polypropylene
   b. Ethylene Vinyl Acetate (Eva)
   c. Polyvinyl Chloride (Pvc)
   d. Polyethylene tere phthalate

2.7 USE OF WASTE PLASTIC BOTTLES (PET)AS A MODIFIER

However due to increase in the prices of construction materials including asphalt binder and heavy cost involved in the utilization of the additives/modifiers to be used in the modification of binders , construction industries are restricted to prohibit the use of expensive modifiers.However by utilizing recycled or waste products for modification of binder,it not only enhance the properties of binder but it also save the environment and money.

2.7.1 Waste Cooking Oil

Researchers have used many recycled materials for modification e.g plastic bags,waste engine oil,bones of animals,plastic bottles,sugarcane residue etc.Azahar in his research stated that use of waste cooking oil can be used in modification of binder to make bio-asphalt is environment friendly and sustainable solution to reduce waste dumping while at the same time to replace the usage of natural resources[16].

2.7.2 Reclaimed Paper Based Asphalt Felt Material

Hu in his study used reclaimed paper made asphalt felt material which is utilized for water proofing in the modification of asphalt binder. He further found in his research that with the use of this material there is enhancement in the viscosity and performance of asphalt binders at high temperatures[17].

2.7.3 Waste Plastic Bottles(Pet)

PET has been found the mostly used polymer. It is an abbreviation for polyethylene terephthalate, which is a polymer .PET is a thermoplastic polyester which is formed by a polymerization reaction between an acid and alcohol. Itis not only easy to handle but its also proven to be strong and durable .It is thermally stable and chemically. Due to itsbetter properties, it has been widely in the form of the automobile part, food packaging , textile, power tools and other applications. 60% PET is obtained from plastic bottles[18].

Xiong Xu in his research has clearly stipulated that waste PET obtained from waste drinking bottles and tyres which completed their service life are solid wastes dumped and produced on daily basis.They are transported to the landfills and stockpiles which in turn occupymajor area of land and also cause serious hazard to environment. He studied to first convert waste PET into two value adeed additives under the chemical process of two amines, namely triethylenetetramine (TETA) and ethanolamine (EA), respectively, and then used them in combination with crumb rubber (CR) for modification of neat binder for preparation of different rubberized asphalt mixtures[19].

2.7.4 Findings On Waste PET

Sources of Waste PET may be classified into three main groups which are foils, bottle, and from tires. Ahmed further concluded in his research that utilization of waste PET can enhance the properties of asphaltic pavement for example an increase in stability,viscosity and stiffness.It can also modify the anti stipping,resist thermal cracking and fatigue damage and resistance against rutting [18].

The same findings were also incorporated in the research carried out by Gunartha.He studied that by using waste plastic i.e. waste PET as a modifier in bitumen improve the properties such as fracture resistance, rutting resistance and thermal stability of flexible pavements. Further, enhancement of viscosity due to waste plastic modification in bitumen resulted in poor workability as well as higher mixing and paving temperatures[20]

Use of waste plastic was also studied by Mashaan and he concluded that hat 6 to 8% is found to be ideal percentages of waste plastic PET, which can be used to improve the stiffness and elasticity characteristics of asphalt binders. Furthermore, 8% waste PET-in modified version of asphaltic mixture depicted improvement in the properties like stability and resistance against rutting[21]

Bashir.A.Alhamidi also studied in his research the effect of waste plastic modified binder on the properties, He found that there is improvement in the physical property by addition of waste PET in ACW-14 which act as a replacement for binder content compared to neat 80/100 binder physical and rheological behavior. He further concludes that 5.8% is the optimum percentage of waste PET to be used as modification of asphalt binder as it resulted in improvement in the performance characteristics of asphalt binder such as its stability ,stiffness, density and flow[22]

Xu recommended in his study that waste plastic(PET) can be used in rubber asphalt pavement keeping in view its benefits in extending service life of rubberized asphalt. The reusing of waste products in his study not only lessen the environmental damage but also adds in the durability of pavement[23]..

2.8 FINDINGS ON USING RAP AND ITS BENEFITS

A new asphalt binder selection and mix design practice is introduced in the asphalt paving industry resulted from Superpave mixture design procedure development (Asphalt Institute Superpave Mix Design). In Superpave there was no attention for recycled mixtures as initially it was established for virgin binder-aggregate mix. However, environmental and economic concerns prescribe the utilization of recycled materials in pavement.

As Government is intending to double the road density from 0.32 to 0.64Km/Km2, which is the need of an hour too, for the economic activity, development and prosperity.

However, the lack of funds faced by the Government is hindering the implementation of many planned project. In this scenario recycling or utilization of the waste material is only a viable option. Some of the advantages of recycling is as follows:

- Reduced construction cost
- Saving of aggregate and asphalt binders
- Environment preservation
- Energy saving
- Less user delay

In future, advancement in the recycling methods should be looked in to like Increased reuse of materials and modern equipment and modified mixtures and the vested interest in current technology and equipment should be analyzed.

Hussain endorses in his study that by increasing the quantity of RAP binder in asphalt increases the stiffness of the binder however it decreases with the increase in temperature. He further concludes that with the increase RAP binder contents, there is improvement in the properties of binder such as stiffness, viscosity and critical temperature[24].

It was stated in the report published by FHWA in April 2011 that the use of RAP also found beneficial in conservation of energy and costs along with preservation of resources other than sustainability of the asphalt pavement construction industry[15].

Hayat has also attempted to the use of RAP and waste PET as a solution to the waste disposal issue and utilization as a replacement of binder in HMA. He concluded in this study that 4% waste PET and 30% RAP binder is most suitable in enhancement of performance properties of asphaltic mixtures such as durability and stability other than environmental benefits[25].

Hettiarachchi et al evaluates and studied on the WMA technology, RAP mixtures and finally the utilization of RAP in WMA to have an understanding on performance aspects. He analyzed that the utilization of Rap in WMA can improve the properties of asphalt mixtures such as resistance to rutting, moisture susceptibility, and along with workability[26].

Shah, concluded in his study that 50% RAP can be used to design mixtures under the umbrella of Super pave, with a limitation that RAP aggregate quality and gradations were not compromised. Charts of linear binder blending were appropriate in most cases. In general, it was inferred that increase in RAP concentration resulted in improvement in properties of mixtures such as increase in its stiffness and decreased its shear strain, in return increase in rutting resistance if the neat binder grade was not changed[27].

Manke concluded in the research that asphalt mixtures encompassing 50% RAP and a bio-derived binder can be utilized for the performance criterion at low, intermediate, and high temperatures conditions without having use of neat binder **[28].**

Aurungzeb in his findings concluded that there is a considerable reduction in energy usage when RAP was applied in the mixtures.28% less energy was observed to be used GHG emissions in only binder course. Similarly, there is a reduction of energy of 26%, 33%, and 40% in feedstock was found for the mixtures with 30%, 40%, and 50% RAP material, respectively. Life cycle cost analysis when conducted for various scenarios also depicted the achievement of equal field performance for recycled mixtures in comparison to the neat mixtures[29].

2.9 LITERATURE RELATED TO FTIR AND SEM

Predicted the properties of asphalt binder with the help of Fourier transformed infrared spectroscopy (FTIR). 32 samples of different refineries and different viscosities and aging conditions were utilized to evaluate the physical and chemical properties based on FTIR results. It was concluded that the FTIR help in differentiating the source of binder. It also help in describing the chemical parameters. Rheological and conventional parameters including softening point, content of asphaltenes, log of penetration and log of phase angle and complex shear modulus at different aging levels[30].

Used FTIR and SEM to characterize the asphalt binder modified with e-plastic waste. FTIR spectra of modified binder showed the appearance of some new peaks while some peaks disappeared which were much stronger in the base binder’s spectra. This indicated the structural changes which occurred due to the addition of e-plastic. These changes add in the high performance of the e-PMB. SEM results showed the improved physical and engineering properties of the plastic waste modified binder as the results showed good homogeneity of the modifier in binder[31].

Fourier Transformed Infrared (FTIR) spectroscopy and high pressure gel permeation chromatography (HP-GPC) were utilized to evaluate the aging properties of zinc dialkyldithiophosphate modified asphalt by Ouyang et al. An increase in carbonyl group and molecular weight of asphalt was observed as a result of oxidative aging of base binder while the ZDDP modified binder after aging showed no change in molecular weight and restricted the formation of carbonyl group which indicate that ZDDP is a better modifier to add on the aging properties of asphalt binder[32].

Improvements in aging properties of asphalt binder were studied by using SBS and highly reclaimed (HRR). Physical characters, aging behavior of SBS modified asphalt (SBSMA), type and content of HRR were investigated. FTIR was used to determine major functional group of SBSMA before and after UV and thermal aging. Content of HRR affected the aging of SBSMA. It was found that HRR improved the physical properties and short term aging resistance of SBS modified asphalt. Morphological analysis done by SEM showed good compatibility between SBS and HRR[33].

Ouyang*et al.* 2006 used oil, zinc dibutyldithiocarbamate (ZDBC) and zinc dialkyldithiophosphate (ZDDP) to improve the aging resistance of base and SBS tri-block copolymer modified asphalt (PMA). FTIR was used to characterize the oxidation rates of asphalt binder. IR spectra showed a raise in carbonyl group in case of PMA after aging while the addition of antioxidants ZDDO or ZDBC in the PMA reduced the formation of carbonyls which indicate good aging resistance of the additives[34]

Lu *et al.*2008 compared the rheological and physical properties of laboratory aged and field aged samples of asphalt binder using DSR and FTIR. Laboratory aged samples produced a high amount of carbonyl group and low amount of sulfoxides while the formation of sulfoxides was much higher for the field aged asphalt binder samples. This might be owing to the fact that higher temperatures in laboratory aging produces higher level of carbonyls while longer duration in field generates sulfoxides. Such differences in the properties of aged binder suggest that the aging mechanism of the asphalt binder in the field might not be as same as done in the laboratory aging tests[35].

Improvement in short term aging resistance by using newly synthesized diethylene glycol based polyboron compound (DEGPB) was studies by Mustafa *et al.* 2018 Oxidation rates of the modified binder were examined through FTIR. DEGPB improved the physical characteristics in addition to short term aging resistance of the asphalt. Marshal stability of the bituminous mix was also improved[10].

2.10 CHAPTER SUMMARY

This chapter includes a brief introduction about the history of the pavements and different distresses associated with them which are more common in Pakistan. A brief history of asphalt binder, its chemical and elemental composition is discussed. Mechanism of aging and different methods for simulating aging effect in the laboratory has been discussed. SHRP Super pave criteria for different distresses i.e. rutting, fatigue is mentioned. And finally the methods for improving the aging properties of asphalt binder by its modification with polymers and other chemical additives has been discussed in the light of recent researches carried out on the same topic.

CHAPTER 3: RESEARCH AND TESTING THODOLOGY

3.1 GENERAL

This chapter of the thesis comprises the methodology of the planned research to accomplish the objectives of the study, which are collection of required material, preparation of samples, testing and analyzing the importance of several factors. Waste polyethylene terephthalate (PET) has been used to modify the asphalt and then it is mixed with different percentages of binder extracted from RAP. Their effect on physical, rheological and performance characters of asphalt binder are studied. In current chapter, in order to determine the optimum dosage of modifier i.e. waste PET different percentages of waste PET i.e. 0%, 2%, 3%,5% and 7% by weight of virgin asphalt binder i.e. 80/100 were used. The optimum dosage of PET is established by carrying out laboratory tests. The modified asphalt is then mixed with the bitumen extracted from RAP material. An Asphalt extraction procedure from RAP using ASTM D1856 which is a standard test method for recovery of Asphalt from solution using Abson method will be discussed. Then modified asphalt physical, rheological and aging behavior with various percentages of RAP binder i.e.0%,10%,20%,30% and 40% will also be discussed. The equipment used for laboratory testing, procedure adopted for preparation of test samples and input parameters of different tests have discussed in this section.

Different test procedures were adopted to check the behavior of neat asphalt binder and Waste PET modified asphalt binder along with RAP binder under similar experimental conditions.

3.2 MATERIALS SELECTION

The objective of this research is to improve the binder aging characteristics with waste material so for this purpose selection of modified alternative binder material is very crucial step. Materials are selected as per the availability and with a view to utilize the waste products. Following mixture of material were used for preparation of samples for different experimentation.

- 80/100 Asphalt binder

- Waste PolyethyleneTeraphthalet (PET) obtained from waste drinking plastic bottles
- RAP binder (RAB)

3.2.1 Reclaimed Asphalt Pavement and Asphalt binder

Reclaimed asphalt pavement was obtained from Lahore Islamabad Motorway M-2 near chakri.

Figure 3.1*: RAP Collection from M-2*

Binder was separated from RAP using trichloroethylene solution and then it is recovered by Abson method ASTM D-1856.Penetration value of the recovered binder was determined and its value came out as 62(Grade 60-70) so the base binder of Grade 80/100 pen grade asphalt binder was chosen as one grade up, it was supplied by PARCO sales office Rawalpindi. Table below shows the basic properties of base binder. According to the standards and specifications all the necessary tests were performed on acquired bitumen.

Table 3.1:Physical properties of base binder 80/100

S No.	Test Description	Specification	Results ARL 80/100
1	Penetration Test @ 25 (°C)	AASHTO T 94-03	87
2	Flash Point (°C)	AASHTO T 48-89	45
5	Softening Point (°C)	AASHTO T 53	45
6	Viscosity Test (Pa.sec)	AASHTO T 316	0.362
7	Ductility Test (cm)	AASHTO T 51	>100

3.2.2 Modifier

Waste Polyethylene terephthalate was obtained by collecting waste plastic drinking bottles and then these bottles were cleaned and dried ,then shredded into small pieces of 5 mm by 5 mm (Figure 2) pieces and kept in the oven for 3 hours at 180 °C. Polyethylene Terephthalate was then mixed in shear mixer at 170 rpm with the neat base binder

Figure3.2*: Shredded Plastic bottles*

Waste Polyethylene terephthalate (PET) is obtained by waste plastic bottles and is used this research is in liquid form. The main objective of this research is to investigate the effect of waste PET and reclaimed asphalt on improving the performance, chemical and physical properties of asphalt binder along with energy conservation. It also aims to measure the significant benefits of asphalt modification in the asphaltic pavement system using waste materials in terms of extended remaining service life of pavement structure. Physical properties of waste polyethylene terephthalate are given below in table 3.2.

Table 3.2: Physical properties of waste PET

Property		ASTM Method	Result
Density, Kg/m^3		ASTM (D-792)	1370
Melting point, °C		ASTM (D-3418)	260
Elongation		ASTM (D-638)	>500

3.3 MATERIAL TESTING

Physical and Performance testing were performed on virgin aged and un-aged and modified aged and unaged asphalt binder. Modified asphalt binder was obtained through extensive physical testing by determining an optimum content of Polyethylene terephthalate and then mixing it with different content levels(10%,20%,30% and 40%)of RAP binder. Physical and performance test results, which includes low temperature cracking, and resistance against fatigue of neat and modified asphalt binder were compared.

3.3.1 Recovery of Asphalt Binder from RAP

Bitumen is first distilled from aggregates using trichloroethylene in RAP material using extraction machine as per ASTM D-2172.

Figure 3.3: Extraction Unit

The distillation is carried out using the apparatus as shown in the figure below:

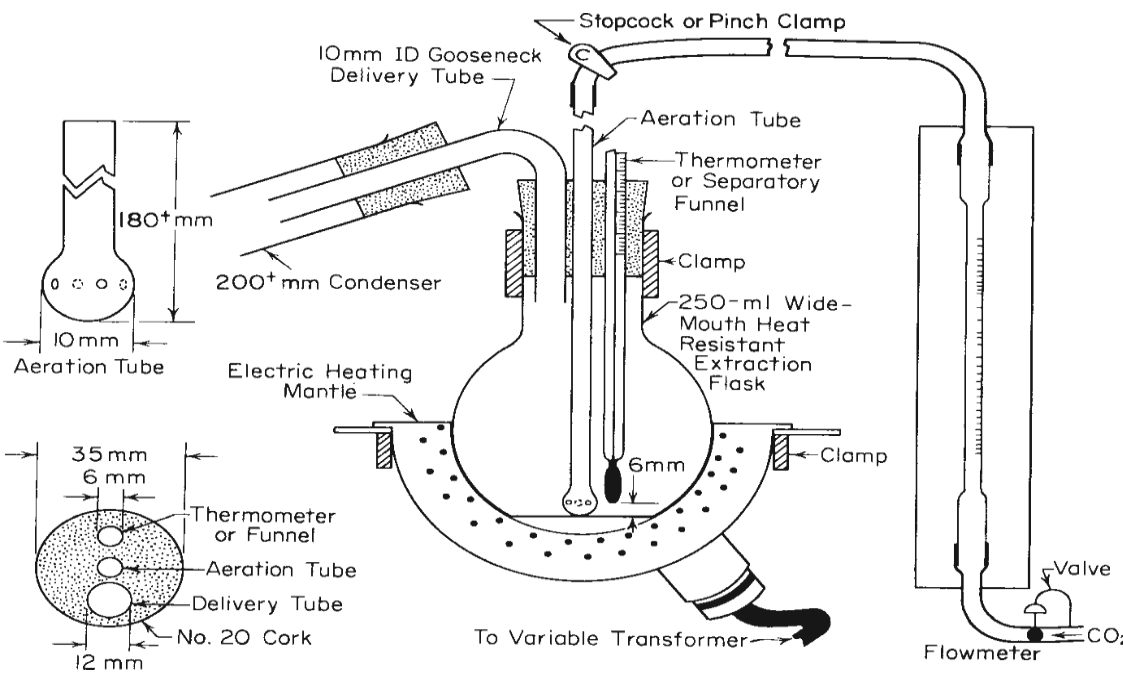


Figure 3.4: Distillation Assembly for Bitumen Recovery

Figure3.5*: Extraction and Recovery of RAP binder using Abson method*

3.3.2 Modification of Asphalt with Waste PET and RAP Binder

Polyethylene terephthalate was obtained from waste plastic bottles and then they were shredded in to small pieces 5mmX5mm with a help of crushing machine. It was placed in an oven at 170°C for 3 hours, it was then mixed with virgin binder with a shear mixer at the rate of 170rpm in concentrations of 2%,3%,5%, and 7% by weight of virgin binder. The physical, chemical and performance tests were performed, after that optimum dosage came out as 5%. Samples were prepared by adding different concentrations (10%,20%,30%,40%) of RAP binder after extraction by Abson method in Waste PET Modified Binder with the help shear mixer. Measured amount of Waste PET Modified binder(5%PET), was liquefied by heating at 150 °C. Then, the temperature was raised to 170°C and then premeasured weight of RAP binder was gradually added to the binder. High rate shear mixer was used for the mixing to get homogeneous blends.

Test matrix for the samples prepared are as hereunder:

Table 3.3: Test Matrix

Type of Sample	RAP content (% of bitumen)	R-PET content (% of bitumen)	PenetrationTest	SofteningPoint Test	Ductility Test	RVT(135 ^{0}C)	RVT(165 ^{0}C)	SEM	FTIR
Virgin Asphalt binder (ARL) (80/100)	-	0	3	3	3	3	3	-	-
	-	2	3	3	3	3	3	-	-
	-	3	3	3	3	3	3	-	-
	-	5	3	3	3	3	3	3	3
	-	7	3	3	3	3	3	-	-
Modified Asphalt binder + RAP	10	OD	3	3	3	3	3	-	-
	20	OD	3	3	3	3	3	-	-
	30	OD	3	3	3	3	3	3	3
	40	OD	3	3	3	3	3	-	-
	50	OD	3	3	3	3	3	-	-
Total	-	-	30	30	30	30	30	06	06

Research methodology is shown in the Figure below:

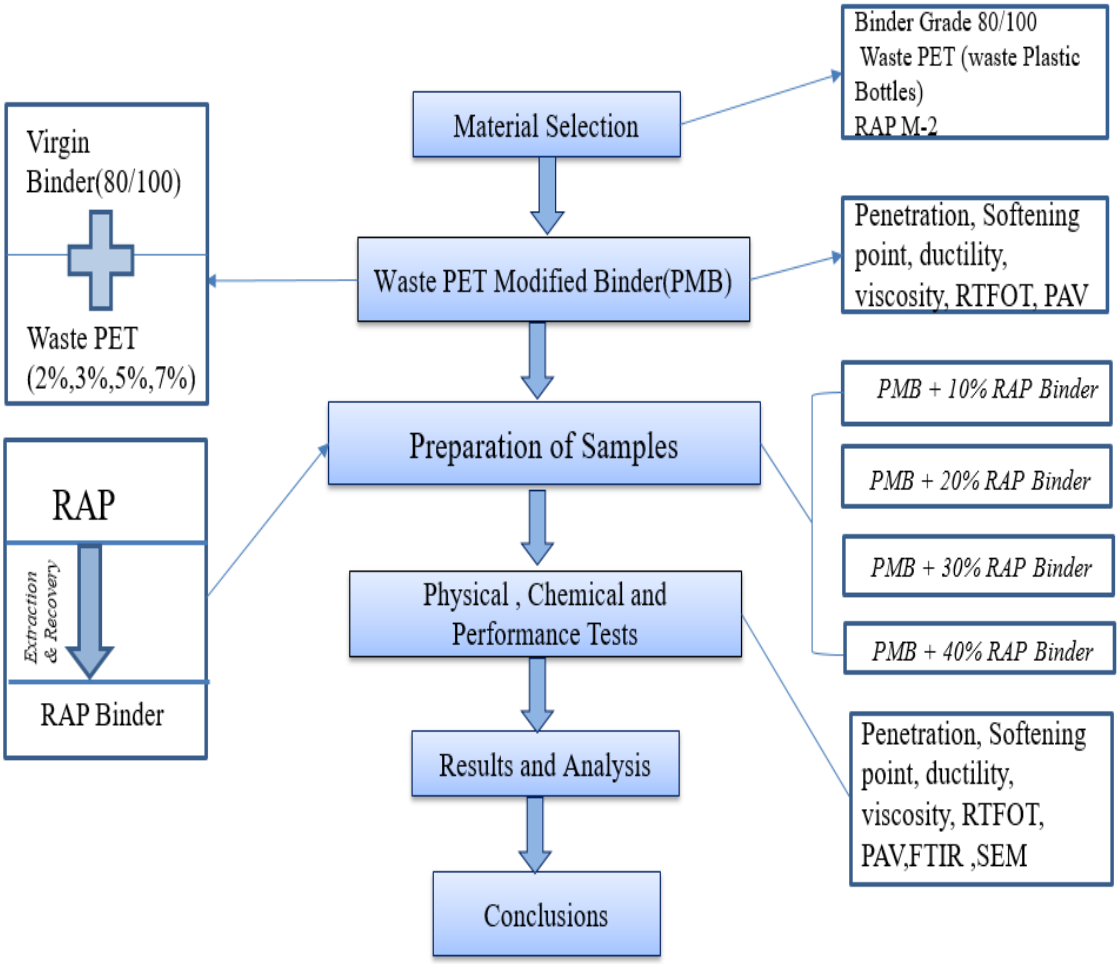


Figure3.6: *Research Methodology Adopted*

3.3.3 Aging

Short term and long term aging tests were used to evaluate the performance of asphalt binder

3.3.3.1. Short Term Aging

After short term aging of asphalt binder, evaluation of its rheological properties is very important to assess the quality of asphalt binder. Mixing, spreading, storage and compaction of asphalt bindercause its short term aging. In laboratory, the effect of short term aging was stimulated by RTFO. Asphalt in RTFO is aged by introducing heating and blowing of hot air at about 163ºC for a period of 80 minutes. Short term aging is loss of volatile in an asphalt binder when it is heated at asphalt plant and subsequently laid at site. This procedure is described by ASTM D2872.

Apparatus include the following

- Glass bottles
- Balance
- Back for bottles.
- Oven equipped with carousal which exhibit circular motion and a nozzle for hot air.

Figure 3.7:Glass Bottles used in RTFOT   *Figure 3.8: Rolling Thin Film Oven*

3.3.3.2 Long Term Aging

Exposure to heat and Ultra violet radiation during its life span cause long term aging of asphalt pavement. Pressure Aging Vessel (PAV) was used for simulation of the effect of long term aging in the laboratory. The binder was exposed to higher temperature and pressure for about 20 hours to have a simulation of aging during service life of asphalt binder. This procedure is described by ASTM D6521.

Apparatus includes the following.

- Sample Pan/trays
- PAV
- Vacuum oven

Figure3.9:Pressure Aging Vessel

Figure3.10:PAV Samples

3.4 PHYSICAL TESTING

Penetration, softening point and Ductility Tests were done for physical testing.

3.4.1 Penetration

To measure the consistency of asphalt binder at a room temperature, penetration test is used. In this test, a standard loaded needle is vertically penetrated in the sample of asphalt binder under standard condition and its penetration depth is measure up to tenths of a millimeter. Softer binder have higher values of penetration. According to AASHTO T49-03 standard temperature was used as 25°C, load of 100 grams, and time for the test equal to about 5 seconds. Using PARCO 60/70 specimen, three values from each specimen were taken after performing penetration tests. All values obtained fulfilled the required criteria of penetration test as per specification.

Following are the apparatus that is use in penetration test.

- Penetrometer
- Digital timer
- Water bath
- Penetration cup

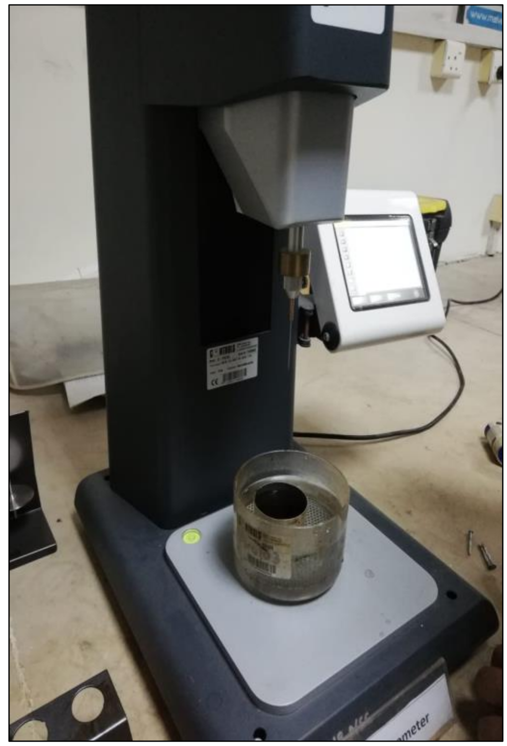
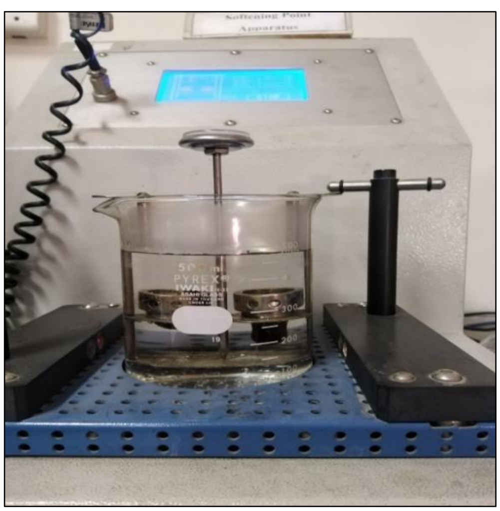


Figure 3.11:Penetrometer *Figure3.12:Samples for Penetration*

3.4.2 Softening Point

It is the mean temperature at which the asphalt binder in the rings becomes soft and fall to a distance measuring 25mm because of the mass of a steel ball lying upon asphalt binder. Test was performed as per ASTM D36.



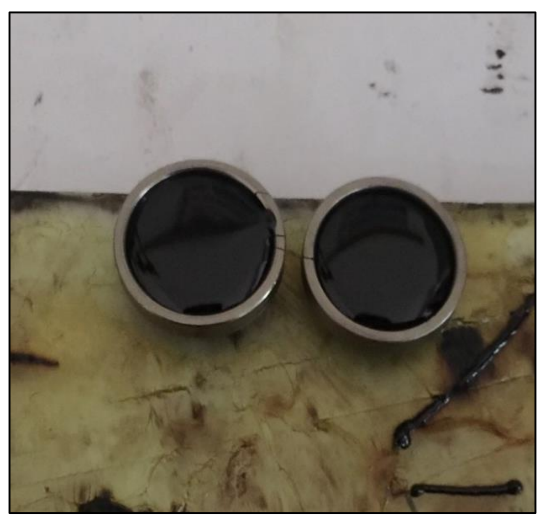


Figure3.13:Ring and Ball Apparatus *Figure 3.14:Samples for Softening Point*

3.4.3 Penetration index

Penetration index can be defined as quantitative measure of the asphalt binder in reaction to the variation in temperature as explained by Pfeiffer and Van Doormaal[36]. By means of PI the behavior of asphalt binder in an application can be predicted. Moreover the type of binder can be described based on the deviation of its behavior from Newtonian to non-Newtonian. The range of PI values is from about -3 for highly temperature susceptible asphalt binder to around +7 for low temperature susceptible asphalt binder and highly blown asphalt binder. Generally, for construction of pavement, asphalt binder has PI between -2 to +2. Asphalt binder having PI values smaller than-2 shows Newtonian behavior with brittleness at lower value and those greater than +2 are less stiffer, indicating high elastic properties under higher strains.

With the help of Penetration value and SP, variation in the thermal sensitivity of asphalt binder can be calculated by using Penetration Index. Penetration Index (PI) can be calculated using following equation[36]

$$PI = \frac{20 * T_{R\&B} + 500 * \log pen - 1952}{T_{R\&B} - 50 * \log pen + 120}$$

Where:

Pen= penetration at 25°C

Table3.4: Penetration index for different types of asphalt binder

Asphalt binder Type	PI
Blown asphalt binder	>2
Conventional paving asphalt binder	-2 to +2
Temperature susceptible asphalt binder (Tars)	<-2

It is generally known that a high value of PI indicates lower temperature susceptibility. The binder is considered high susceptible to temperature if it has Penetration

Index value smaller than -2. The binder will behave more brittle at lower ranges of temperature and it will undergo transverse cracking in colder regions.

3.4.4 Ductility

Ductility depicts material's ability to withstand tensile stresses. The ductility of a asphalt binder is measured by the distance in "cm" up to which it tends to elongate before breaking when a standard specimen briquette of the material is pulled apart at a quantified speed and a specified temperature. Test was performed as per ASTM D113-17.

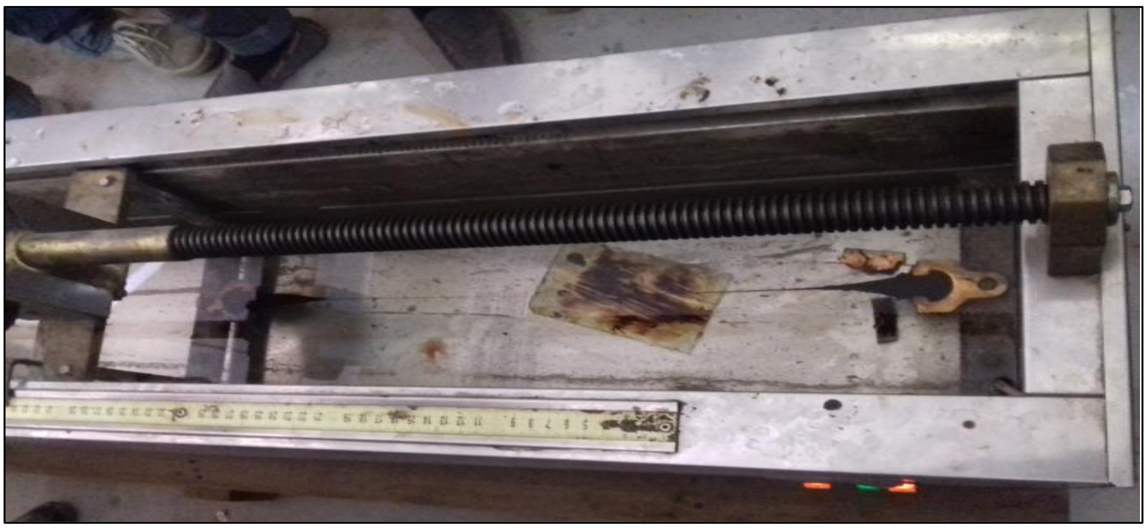


Figure 3.15:Ductilometer

Figure3.16:Ductility test sample

3.4.5 Aging Index*:*

To evaluate the temperature sensitivity of the bituminous binder, different physical/rheological aging indices are used. Aging index is defined as the ratio of physical/rheological property of aged bitumen to that property of unaged bitumen. Physical aging index used in this research are penetration aging ratio (PAR), softening point increment (SPI) and ductility retained ratio (DRR). These indices are calculated by formulae given below:

$$\text{Penetration Aging Ration (PAR)} = \frac{\text{Aged Penetration Value}}{\text{Unaged Penetration Value}} \times 100$$

$$\text{Softening Point Increment (SPI)} = \frac{\text{Aged Softening Point}}{\text{Unaged Softening Point}} \times 100$$

$$\text{Ductility Retained Ration (DRR)} = \frac{\text{Aged Ductility Value}}{\text{Unaged Ductility Value}} \times 100$$

3.5 ROTATIONAL VISCOSITY

Rotational Viscometer is used to determine bitumen viscosity at increased temperature ranges. We can conduct rotational viscosity at different temperatures, but since production temperatures are similar irrespective of the environmental conditions, the test for Super pave performance grade bitumen description is always carried out at 135°C and 160°C.Rotational viscometer has been used to find viscosity of bitumen according to AASHTO T 316.

Figure3.17:Rotational Viscosity test

3.6 SCANNING ELECTRON MICROSCOPE(SEM)

"Morphology is a branch of science to study the intermolecular structural form of a material using advanced microscope instrument especially scanning electron microscope (SEM) for a very high zoom". In SEM, an electron beam is subjected on the sample with high intensity and then the image of the surface of sample is taken with the help of reflected beam of electrons. In this research this technique was used to observe the homogeneity of the modifiers in the asphalt binder after its modification.

The test samples were prepared by placing a droplet of Waste PET and RAP modified asphalt binder on glass slide and then outspreaded so that asphalt binder uniformly distributed on the surface in thin layer to assess the dispersion of the modifiers in asphalt binder as shown in the Fig 3.19

Asphalt binder is a petroleum compound and contain volatile components in it. When bituminous samples are subjected to focus electron beam the volatile components of asphalt binder evaporate which contaminate the chamber of Scanning Electron Microscopy. To overcome this problem, the asphalt binder samples are first coated with a thin film of gold palladium. This process of placing thin film of gold palladium is known as sputtering. After preparing the samples and sputtering of samples SEM images were taken at different magnifications. It analyzed that whether modifiers were uniformly dispersed in asphalt binder or not.

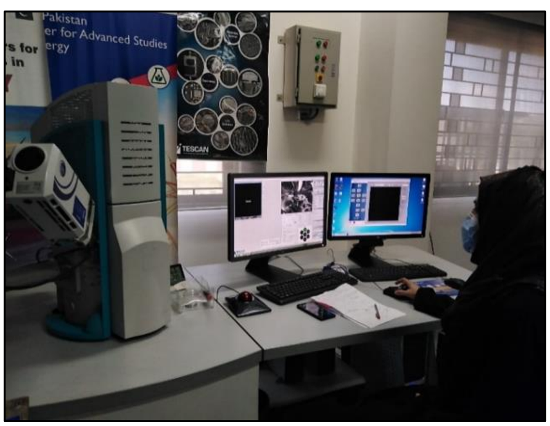


Figure 3.18:Scanning Electron Microscope

Figure 3.19: SEM Samples

3.7 FOURIER TRANSFORMED INFRARED SPECTROSCOPY

Fourier Transform infrared spectroscopy(FTIR) spectroscopy is a simple technique used to analyze the structural modification of different samples and determining the influence of aging on modified asphalt binder. In infrared spectroscopy, infrared radiations are passed through the sample. The wavelength ranges from 4000 cm^{-1} to 400cm^{-1}. Among these radiations some are been absorbed by the test sample and some transmitted. The resulting spectrum depicts the molecular absorption and transmission phenomenon, thereby creating a molecular finger print of the test sample. Thus FTIR makes a good tool for chemical identification.

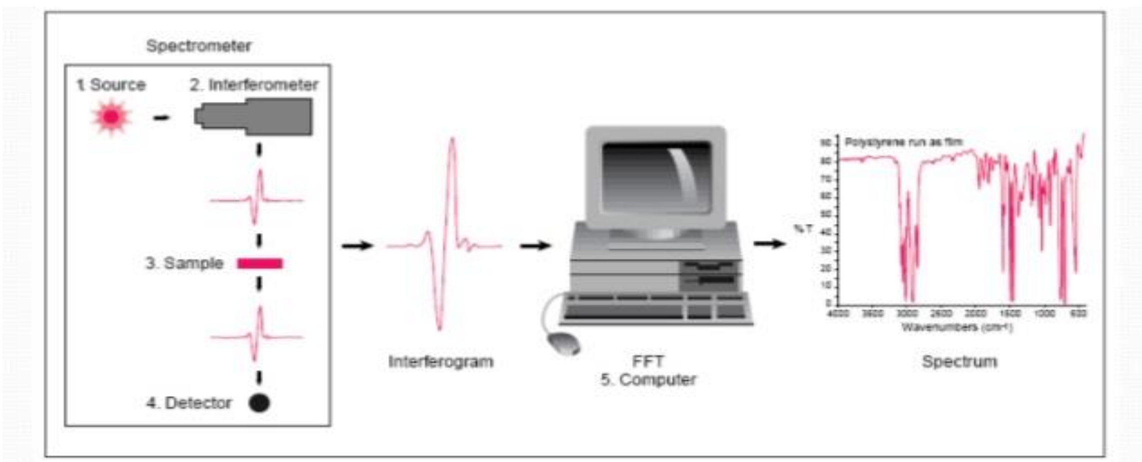


Figure3.20:Fourier Transformed Infrared Spectroscopy Mechanism

Figure3.21:Fourier Transformed Infrared Spectroscopy

3.8 CHAPTER SUMMARY

This chapter is focused on the adopted methodology for the research study. Selection of material used in this research and their basic properties are mentioned. Conventional testing is done on the neat and modified samples which comprises of penetration test, ring and ball test, ductility test and viscosity test. Testing is done on the samples before aging and after RTFO and PAV aging and the results before and after aging are compared. Optimum percentage of the modified samples is determined based on the conventional test results. Optimum samples then mixed with different percentages of RAP bitumen and were then they are tested for their physical, chemical and morphological properties. SEM and FTIR are adopted to demonstrate the changes in the properties of modified binders before and after aging.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter covers the results acquired by performing Laboratory tests on PET modified bitumen using RAP are presented. Consistency analysis are done using results obtained by softening point, penetration test and penetration index(PI) is determined. Results before and after RTFO are compared to obtain the best possible blend of modifier, bitumen and Reclaimed asphalt bitumen. Chemical and morphological analysis are done using FTIR and SEM. Functional groups are assigned using relative IR spectra. In the end of this chapter, cost analysis for different mixtures has presented covering Waste PET and RAP modified bitumen.

4.2 PENETRATION

Penetration results for virgin asphalt binder and asphalt binder modified with Waste PET and RAP bitumen are presented in table 4.1 and 4.2 respectively. Penetration value is a measure of degree of stiffness and hardening of asphalt binder under the normal temperature conditions. Lower the penetration, stiffer and harder the binder will become. From table4.1, it can be observed that by increasing the concentration of Waste Polyethylene terephthalate 1% to 7%, the penetration value of asphalt binder decreased which shows increase in the stiffness and consistency of asphalt binder at normal temperature of 25°C.

Table 4.1:Penetration result for Waste-PETMB

	Penetration		
Additive rate %	**Unaged**	**RTFO aged**	**PAV aged**
0%	87	82	78
2%	83	77	71
3%	76	68	60
5%	69	62	52
7%	61	50	40

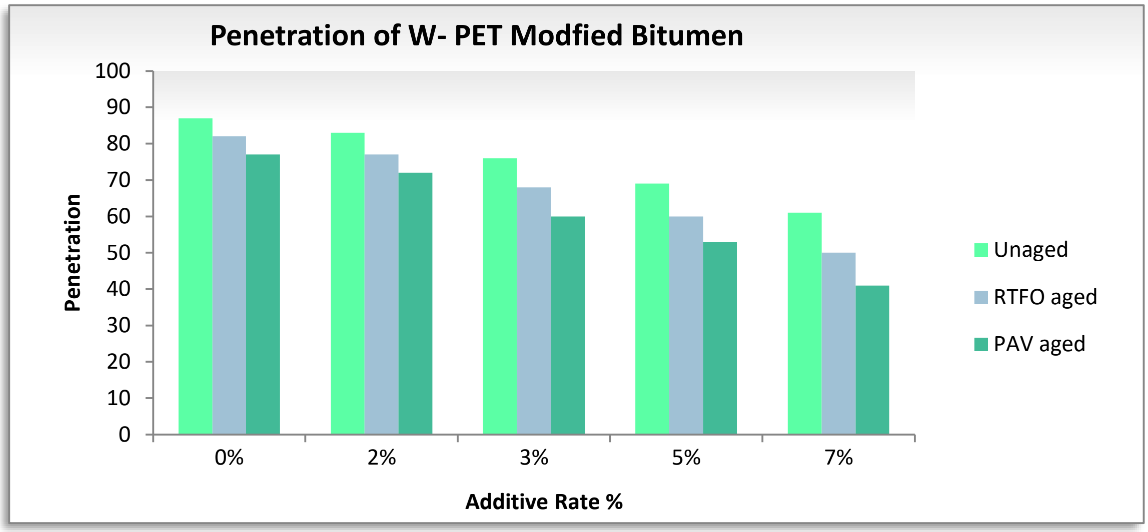


Figure 4.1:Results of PAR for Waste PET modified binder after short and long term aging

Figure 4.1 represents the results of PAR for unmodified and Waste PET modified binder after short and long term aging. It is evident from the results that the penetration of unmodified and modified asphalt binder decreased after the two different aging. Moreover, higher the PET content lower the value of penetration aging ratio which leads to reducing the degree of aging of PET modified binder. Therefore, Waste polyethylene terephthalate PET, addition improves the binder's resistance to oxidative aging.

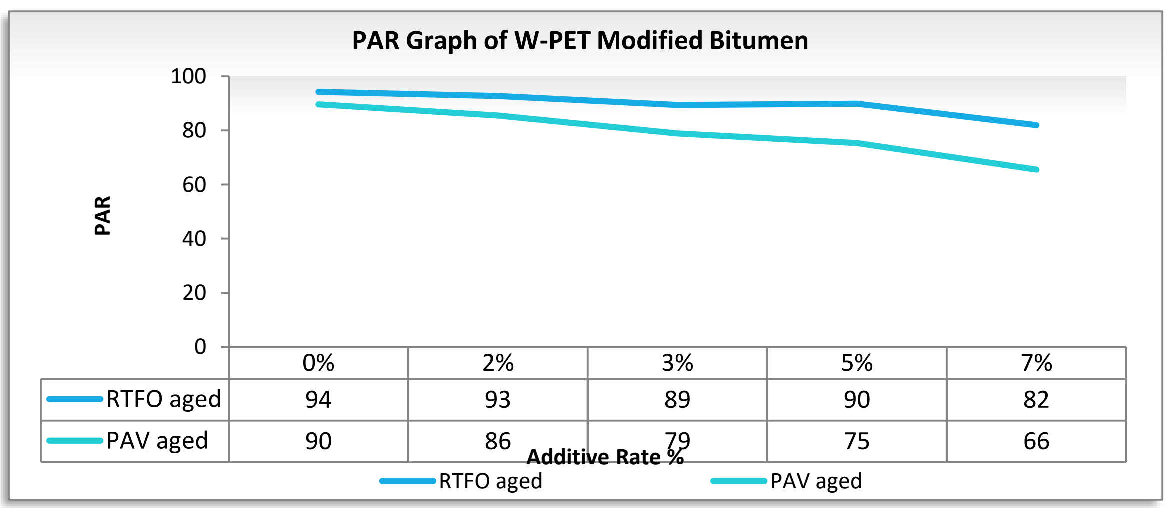


Figure 4.2:PAR graph for waste PET modified asphalt binder

By addition of 10% to 50% of RAP binder PET (optimum dosage) modified binder the penetration value decreases significantly. It indicates that by increasing the content level of RAP increases the stiffness of asphalt binder. This result is in correspondence with the study of[24] for the effect of RAP on the properties of asphalt binder of reclaimed modification.

Table 4.2:Penetration values for PET modified bitumen with RAP binder

PMB+RAP binder	**Penetration**		
RAP Binder content %	**Unaged**	**RTFO aged**	**PAV aged**
PMB+10%	79	75	72
PMB+20%	72	70	67
PMB+30%	69	65	59
PMB+40%	63	57	51
PMB+50%	56	50	43

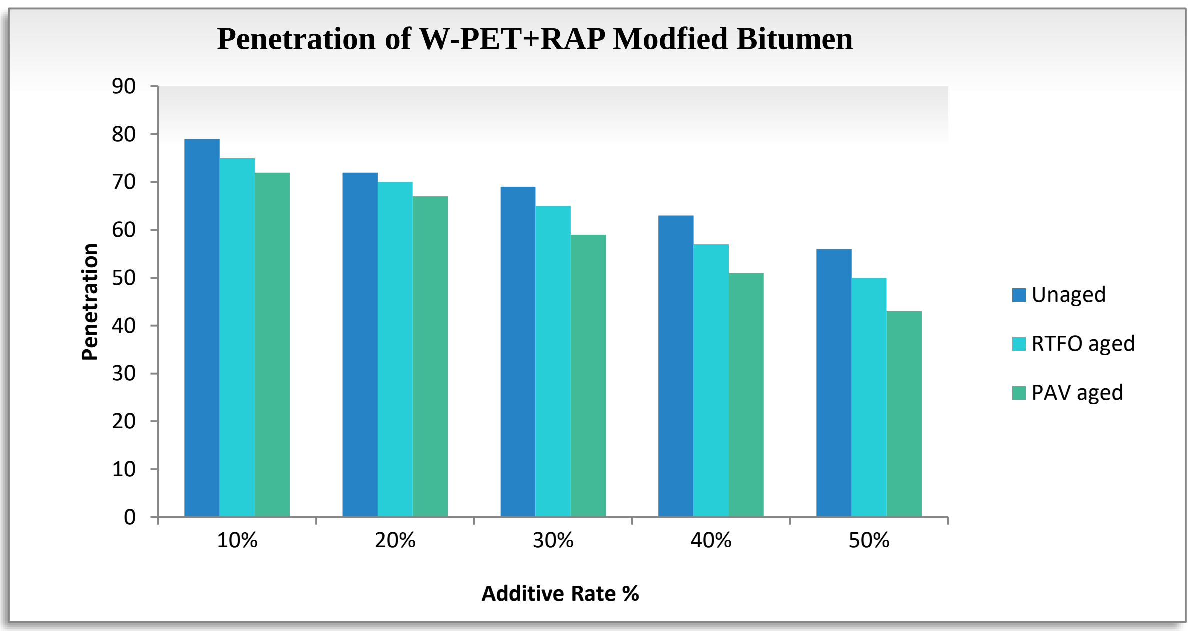


Figure 4.3:PAR of the waste PET modified binder along with RAP binder

PAR of the waste PET modified binder alongwith RAP binderas shown in figure 4.3 has been reduced significantly which is indicative of the result that the modified binder is more resistant towards aging susceptibility than the neat asphalt binder.

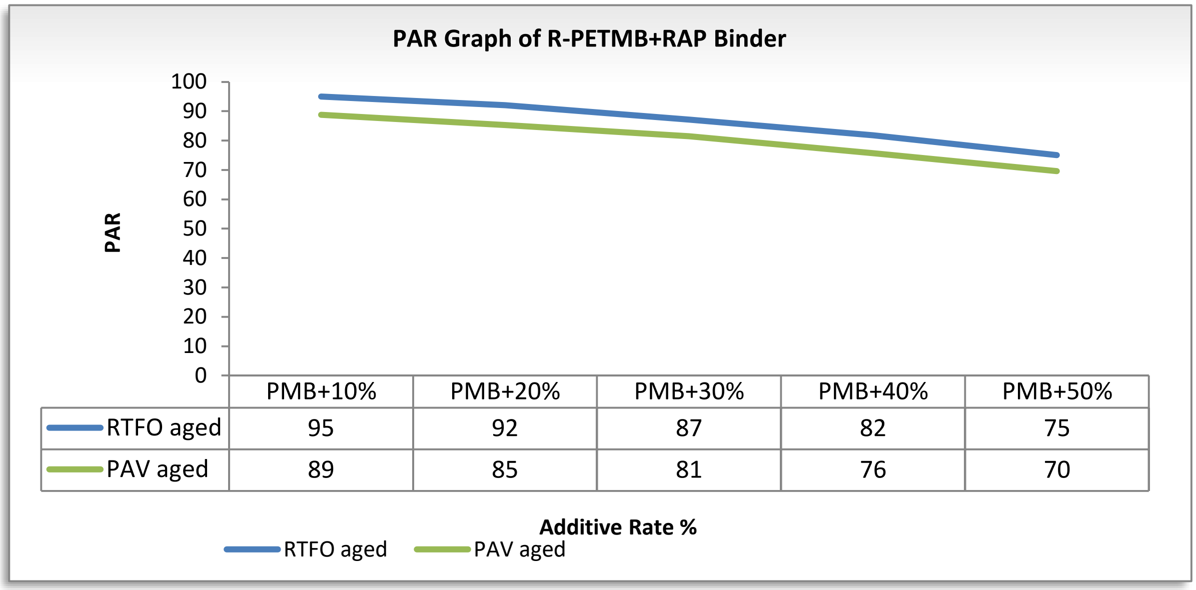


Figure 4.4:PAR for PET modified (Optimum dosage of PET) binder and RAP binder

It can be seen from the above graphs that by modifying the asphalt binder with waste PET the penetration and PAR values decreases .Then by adding the different contents(10%,20%,30%,40%,50%) of RAP binder in R-PET modified(optimum dosage i.e. 5%) bitumen further decreases PAR values thereby causing an increase in the stiffness of asphalt binder, which reduces the rutting and shoving and making in return the pavement more durable[37].

4.3 SOFTENING POINT

Softening point test is generally used to describe an approximate limit between viscous and viscoelastic behavior of asphalt binder, and it represents the degree of resistance of asphalt binder against permanent deformation. By addition of percentages from0% to 7% of waste PET into the virgin binder, softening point of the modified asphalt binder increased. 2% addition of PET resulted in 2% increase in the temperature of softening point. Also after aging, with the increase in the additive percentage there is improvement in the high temperature stability of the binder. The effect of aging on the virgin and modified binder can be viewed in the form of softening point increment in figure4.5 and 4.6. It is generally concluded that with addition of Waste PET made the asphalt binder more stable against flowing when subjected to high temperatures, which depicts that Waste PET modified binder has a better resistance against rutting at high temperature.

Table 4.3:Softening point results for Waste PET modified asphalt binder

	Softening Point		
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	45	45	47
2%	46	48	49
3%	47	48	50
5%	49	51	54
7%	52	55	57

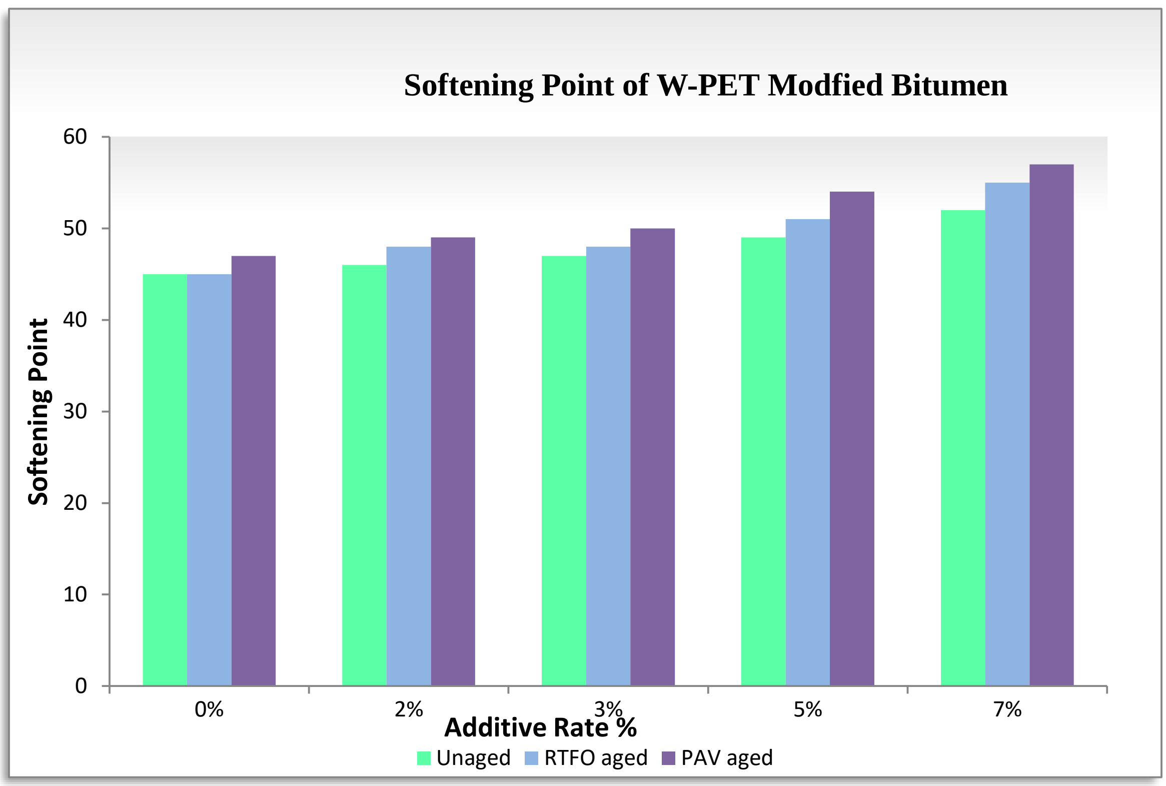


Figure 4.5:Softening Point of W- PET modified Asphalt binder

Similar trends are obtained for the softening point temperature of Waste PET modified binder mixed with different content levels of RAP binder. It is generally known that a higher value of softening point is representative of lower temperature susceptibility. Waste PET modified asphalt samples along with RAP binder depicted a constant increase in the softening point in the unaged conditions which supports the past findings inferred by penetration test that asphalt binder becomes stiffer on the augmentation of different content levels of RAP binder. After the short and long term aging the hardening level of modified asphalt binder with RAP binder has also continues to increase. This can be observed by the constant increment in softening temperature after these two aging processes. A softening point of higher values in asphalt binder is generally preferred in hot regions.

Table 4.4:Softening point result for PET modified binder and RAP binder

PET(OD)+RAP Binder	**Softening Point**		
RAP Bitumen Rate %	**Unaged**	**RTFO aged**	**PAV aged**
PMB+10%	50	52	55
PMB+20%	51	52.5	55.5
PMB+30%	53	54	57
PMB+40%	53.5	55	58
PMB+50%	55	56	59

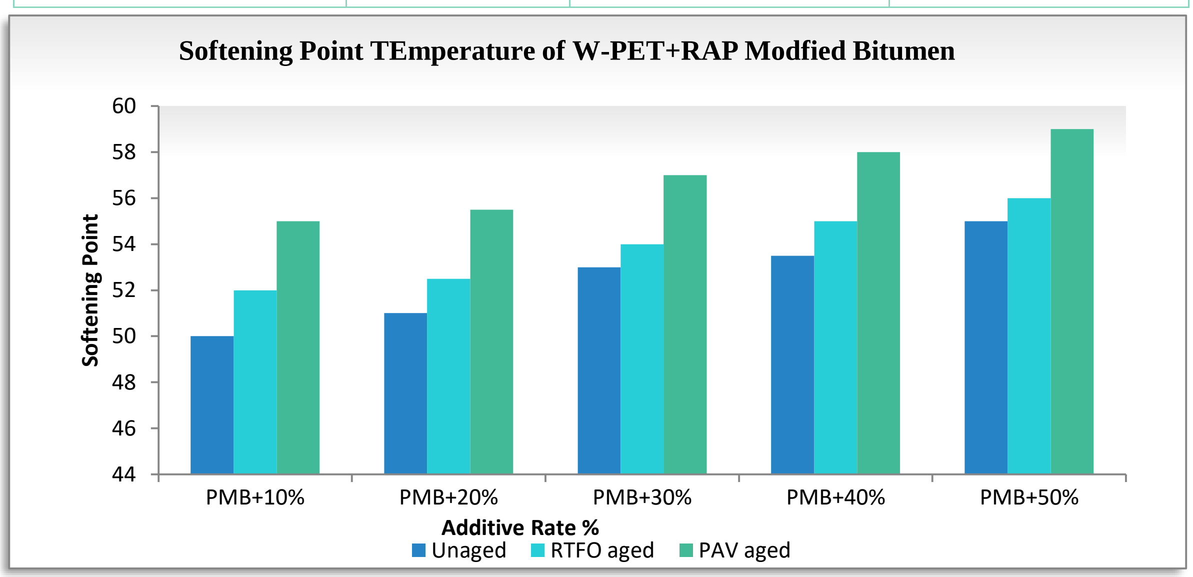


Figure 4.6:Softening point result of R-PET modified asphalt binder and RAP binder

4.4 PENETRATION INDEX

It is generally known that a high value of PI indicates lower temperature susceptibility. The binder is considered high susceptible to temperature if it has Penetration Index value smaller than -2. The binder will behave more brittle at lower ranges of temperature and it will undergo transverse cracking in colder regions.

All the PI values obtained in our case are within the normal range of -2 to +2 for pavement construction requirements and shown in table 4.5 and 4.6. The value for neat binder is more towards down side of the criteria i.e. -2 which means the binder is more susceptible to temperature variations. But with the addition of polyethylene terephthalate (PET) and then the PI value increased which indicated the lower temperature susceptibility of the modified binders. With the increasing percentages of PET and PETMB and RAP binder S i.e. 2%, 3%, and 5%,7% and Waste PET Modified Binder (optimum dosage of 5% along with content levels(10%,20%,30%,40%) the PI value also increased indicating the better aging resistance of modified binders. The results obtained after long term and short term aging showed more improvement in temperature susceptibility as the PI values moved towards the upper side. Higher PI values indicate higher temperature resistance. (Ali, Mashaan, & Karim, 2013)

At 3% addition of PE into base asphalt binder, PI increased by 10% with respect to base binder and the addition of 2% S by weight of asphalt binder resulted in 36% increase in the penetration index. This increase in the PI in turn result in improved resistance against thermal cracking of pavement at low temperatures, and lower plastic deformation at higher temperatures.

Table 4.5:Penetration index for Waste PET Modified binder

	Penetration Index		
Additive rate %	**Unaged**	**RTFO aged**	**PAV aged**
0%	-1.21	-1.37	-0.91
2%	-1.03	-0.66	-0.61
3%	-0.98	-0.99	-0.78
5%	-0.68	-0.44	-0.16
7%	-0.23	-0.03	-0.11

Table 4.6:Penetration index for Waste PET Modified Binder with RAP binder

	Penetration Index		
W-PETMB +RAP%	**Unaged**	**RTFO aged**	**PAV aged**
10%	-1.27	-1.07	-0.98
20%	-1.10	-1.17	-0.88
30%	-1.09	-0.99	-0.52
40%	-0.80	-0.40	-0.45

Moreover, when we compare the PI results of waste polyethylene terephthalate (PET) and waste PET (optimum dosage) modified binder with reclaimed asphalt binder (RAP binder) as shown in figure4.7, waste PET modified binder showed higher values of PI which means higher resistance to thermal susceptibility, lower brittleness and better elastic properties under higher strains.

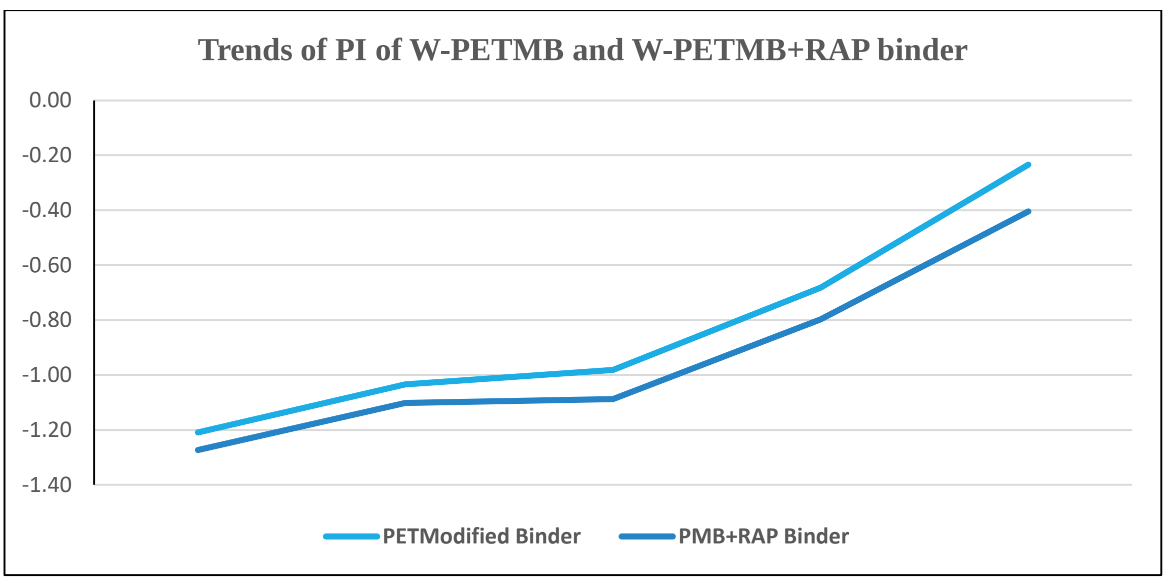


Figure 4.7:Penetration Index of PETMB and PETMB+RAP Binder

4.5 DUCTILITY

Table 4.7 and 4.8 shows the ductility test results of waste PET modified binder and Waste PET modified asphalt binder with different content levels of RAP binder respectively. Decrease in ductility was observed in case of waste Polyethylene terephthalate(PET) modified asphalt binder. When 3% waste PET is added in the neat binder the ductility value reduced from 108 to 94 causing a decrease of13% w.r.t base asphalt binder of grade 80/100. This reduction in ductility indicate the stiffening effect of asphalt binder after the addition of waste PET. While addition of different content levels of RAP binder in the Waste PET modified binder with optimum dosage, there is further reduction in ductility. These results are in consistent with the previous findings that PET modified binder along with RAP binder acts more like a plastic material rather than a viscous material. However, the results after short term and long term aging showed a constant decrease in the ductility indicating that aging makes the binder stiffer.

Table 4.7:Ductility values for Waste-PET modified binder

	Ductility		
Additive rate %	**Unaged**	**RTFO aged**	**PAV aged**
0%	108	98	88
2%	100	94	85
3%	94	90	83
5%	86	82	77
7%	78	74	70

The ductility value is decreasing with the increase in content level of waste- PET and RAP binder but the DRR is increase which depicts that by addition of Waste- PET and

RAP binder can deterioration in ductility of asphalt binder is reduced during aging.

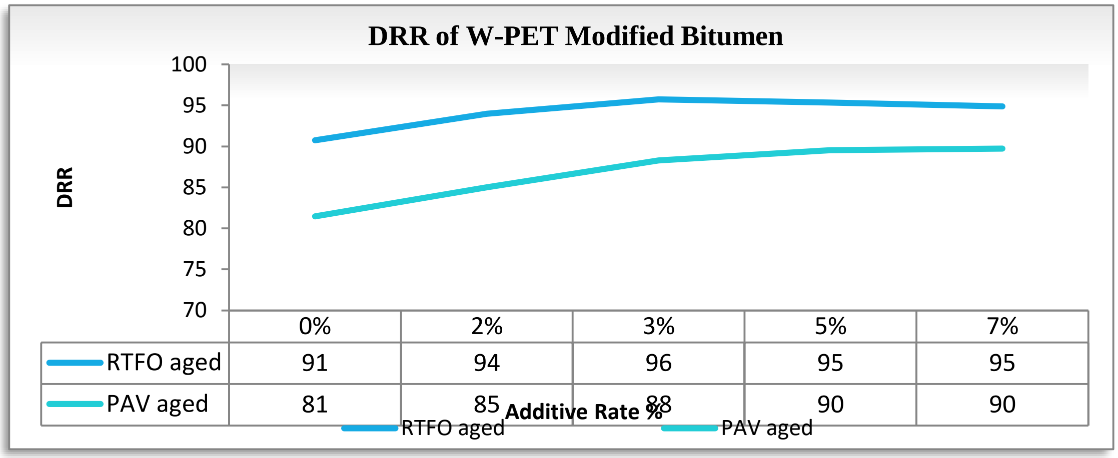


Figure 4.8:variation in Ductility Retained Ratio for Waste-Polyethylene terephthalate

Table 4.8:Ductility results for Waste-PET modified binder with RAP binder

	Ductility		
Additive rate %	**Unaged**	**RTFO aged**	**PAV Aged**
PMB+10%	97	85	80
PMB+20%	92	85	80
PMB+30%	86	82	78
PMB+40%	81	78	74
PMB+50%	73	71	68

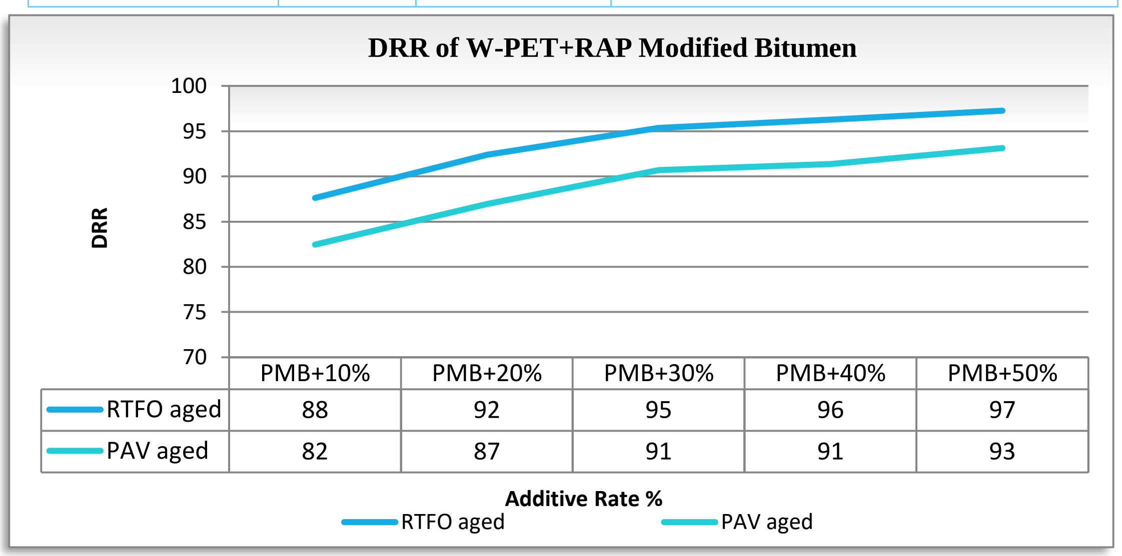


Figure 4.9:Ductility retained ratio of PET+RAP modified binder

It can be seen the values of DRR in the W-PMB increases up to 5% and then the values remain constant .So 5% is the optimum dosage of waste PET [38].

4.6 ROTATIONAL VISCOSITY TEST

The rotational viscosity is done to determine the viscosity of bitumen at high temperatures i.e. during compaction and mixing phases i.e. at 135° and 165°respectively.

Table 4.9:Viscosity values for Waste-PET modified binder

Viscosity Pa s						
Additive rate %	**Unaged (135ºC)**	**Unaged (165ºC)**	**RTFO aged (135ºC)**	**RTFO aged (165ºC)**	**PAV aged (135ºC)**	**PAV aged (165ºC)**
0%	0.4	0.1	0.7	0.2	0.8	0.2
2%	0.5	0.2	0.8	0.2	0.9	0.3
3%	0.9	0.2	1.3	0.3	1.5	0.3
5%	1.3	0.3	1.7	0.4	1.9	0.4
7%	1.7	0.4	2.1	0.5	2.3	0.5

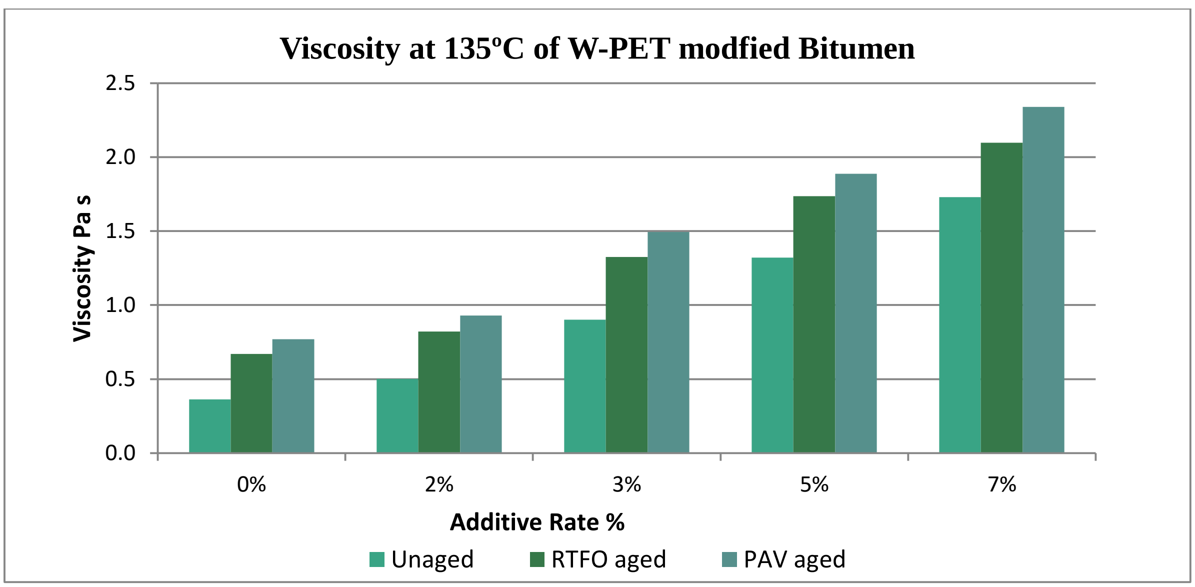


Figure 4.10:Viscosity of waste PET Modified binder

Figure 4.10 above shows the viscosity values PET modified binder at percentages from 0% to 7%. It can be seen that viscosity values increase with the addition of waste PET.The modified binders are more viscous than un modified binders[39].

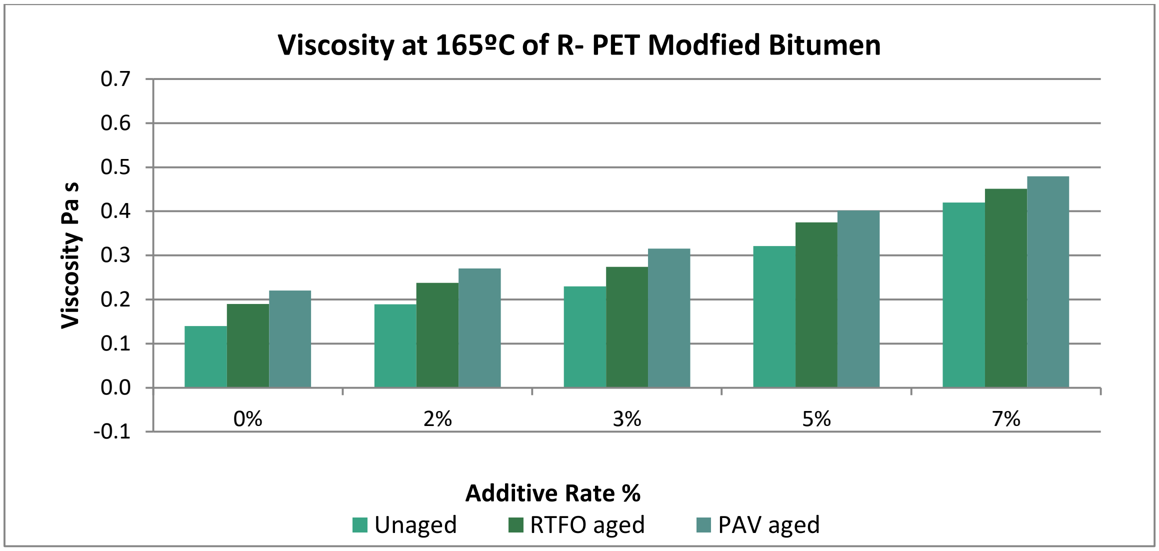
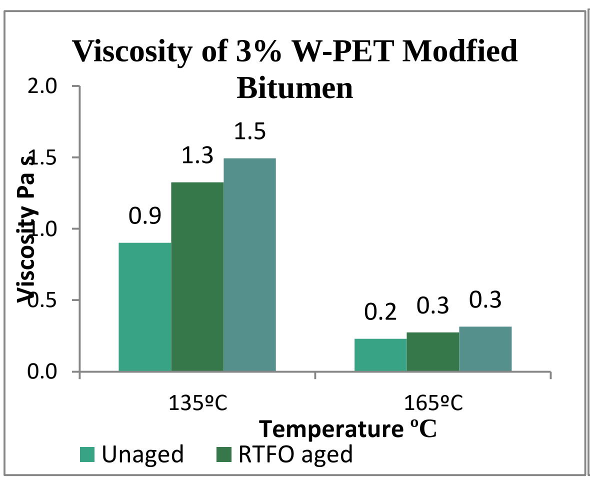


Figure 4.11:Viscosity of waster R- PET Modified binder

Figure 4.10 and 4.11 also shows that with the gradual increase of waste PET viscosity increases. In other words viscosity of waste PET modified bitumen increases with aging.



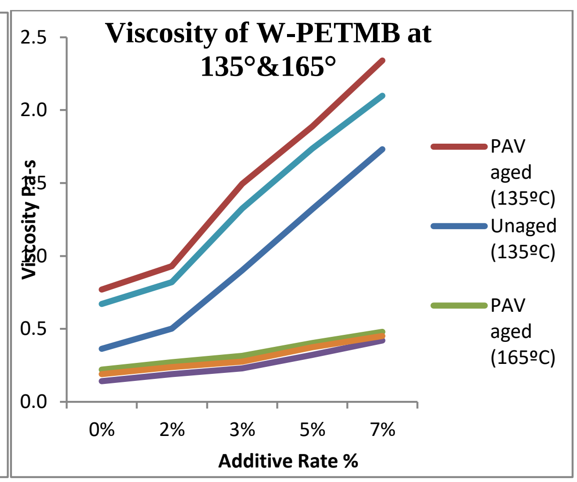


Figure 4.12:Viscosity of R-PETMB *Figure 4.13:Viscosity of R-PETMB*

Similarly, we can see that viscosity increase when we add different concentrations of RAP binder in W-PETMB

Table 4.10:Viscosity values for R-PETMB along with RAP binder

	Viscosity Pa s						
R-PET + RAP	**Additive rate %**	**Unaged (135°C)**	**Unaged (165°C)**	**RTFO aged (135°C)**	**RTFO aged (165°C)**	**PAV aged (135°C)**	**PAV aged (165°C)**
	10%	0.9	0.2	1.3	0.3	1.4	0.3
	20%	1.1	0.3	1.6	0.3	1.8	0.4
	30%	1.5	0.3	1.9	0.4	2.2	0.4
	40%	1.6	0.4	2.1	0.5	2.4	0.5
	50%	1.9	0.5	2.4	0.5	2.8	0.5

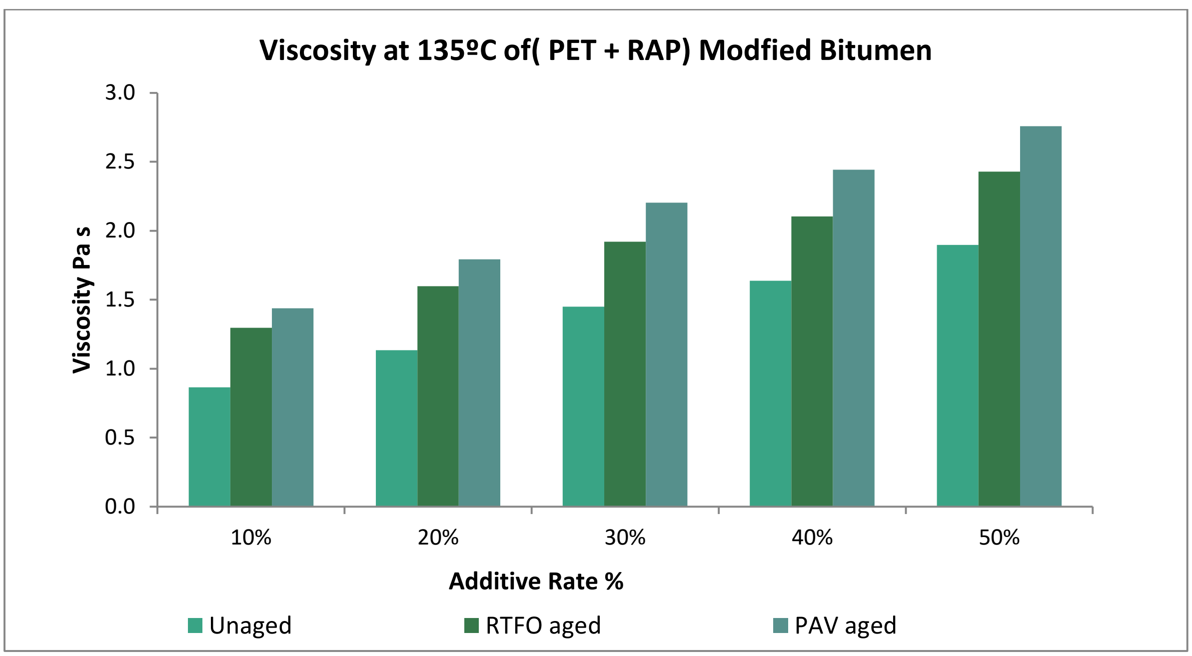


Figure 4.14:Viscosity of R-PETMB +RAP binder

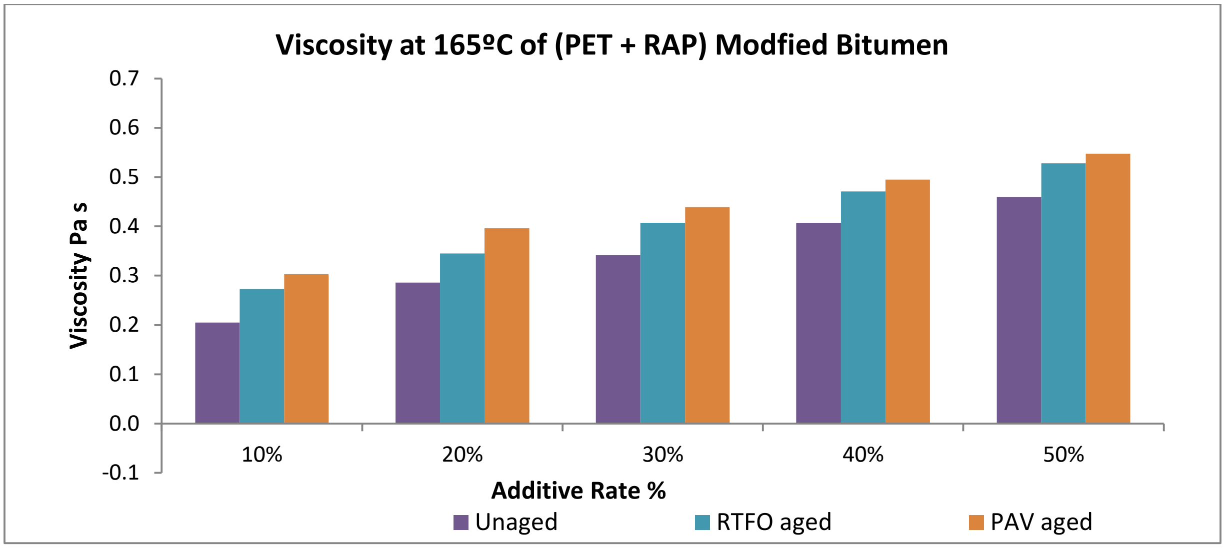
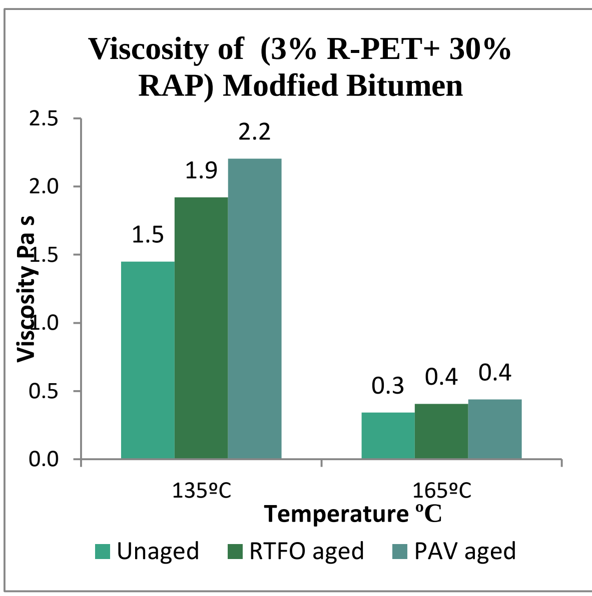


Figure 4.15: Viscosity of R-PETMB +RAP binder



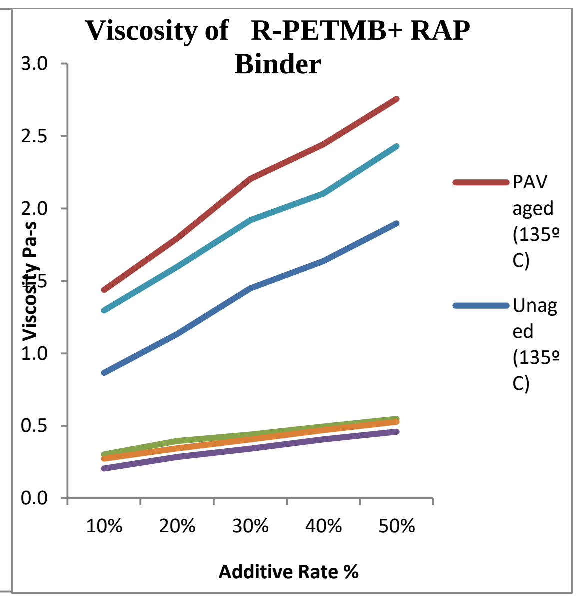


Figure 4.16:Viscosity of 3% R-PETMB +RAP *Figure 4.17:Viscosity of W-PETMB +RAP binder*

Table 4.10 and Figures 4.13,4.14 and 4.15 clearly depicts that the viscosity of waste PET modified (optimum dosage i.e.5%) binder increases with the increase in concentration of RAP binder. Figure 40 & 41 shows that viscosity of aged W-PETMB along with RAP binder is more as compared to the unaged sample of W-PETMB and RAP binder. These viscosity values are also higher than the aged W-PETMB in Figure35. This result occurs because the sample i.e. W-PETMB and RAP binder possess recovered asphalt binder which increases the value of viscosity. When the W-PETMB and RAP binder is subjected to the conditions of short-term aging , symbiotic effects of the recovered binder which is currently present in the binder mixes and the short-term aging process combined together to have an increase in the asphalt binder viscosity[40].

Viscosity Aging index (VAI))can be calculated from the following formula:

$$VAI = \frac{\text{Viscosity of unaged binder}}{\text{Viscosity of aged binder}}$$

It is one of the important index for analyzing the ageing resistance properties of bitumen.

Table 4.11:Viscosity Aging Indices (VAIs) for W-PET modified binder

VAI			
RTFO aged (135°C)	**RTFO aged (165°C)**	**PAV aged (135°C)**	**PAV aged (165°C)**
1.85	1.36	2.12	1.57
1.64	1.26	1.86	1.43
1.47	1.19	1.66	1.37
1.31	1.17	1.43	1.25
1.21	1.07	1.35	1.14

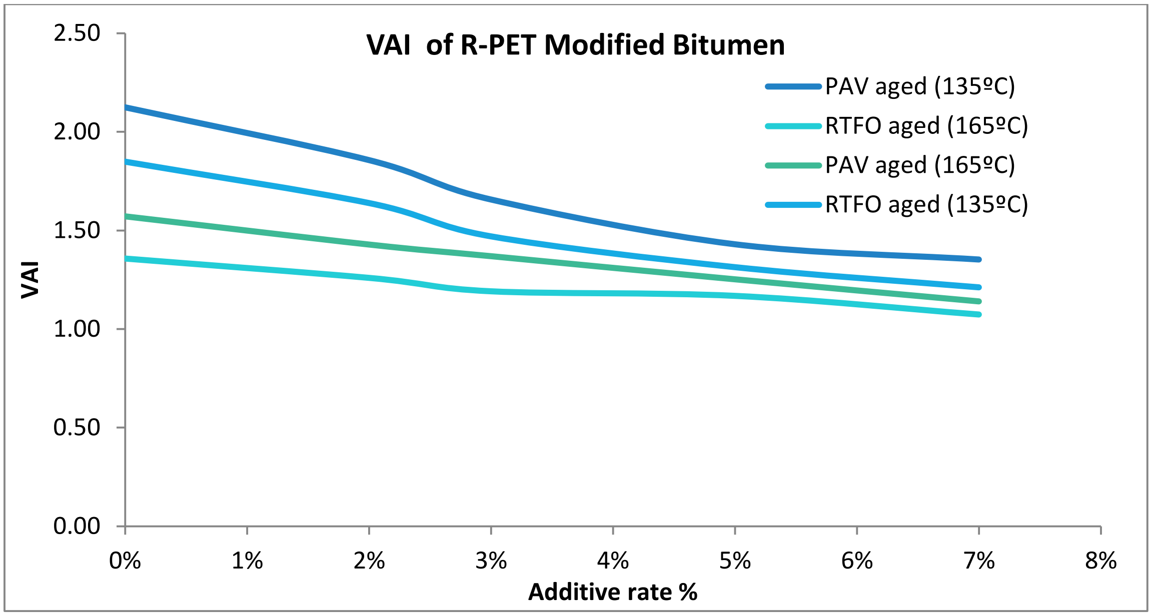


Figure 4.18:VAI of W-PET Modified binder

Table 4.11 and Figure 4.16 shows that viscosity aging index value decreases with the increase in the concentration of modifier i.e. waste polyethylene terephthalate(PET).It means that increase in the quantity of waste polyethylene terephthalate in asphalt reduce the effect of ageing on viscosities of asphalt. The lower the VAI is, better the antiaging property is (Cheng, 2015).

Table 4.12:Viscosity Indices (VAIs) for W-PETMB+RAPbinder

VAI			
RTFO aged (135°C)	**RTFO aged (165°C)**	**PAV aged (135°C)**	**PAV aged (165°C)**
33.3	24.9	39.8	32.3
29.0	17.1	36.8	27.8
24.5	16.0	34.2	22.1
22.2	13.6	33.0	17.8
21.9	12.9	31.2	15.9

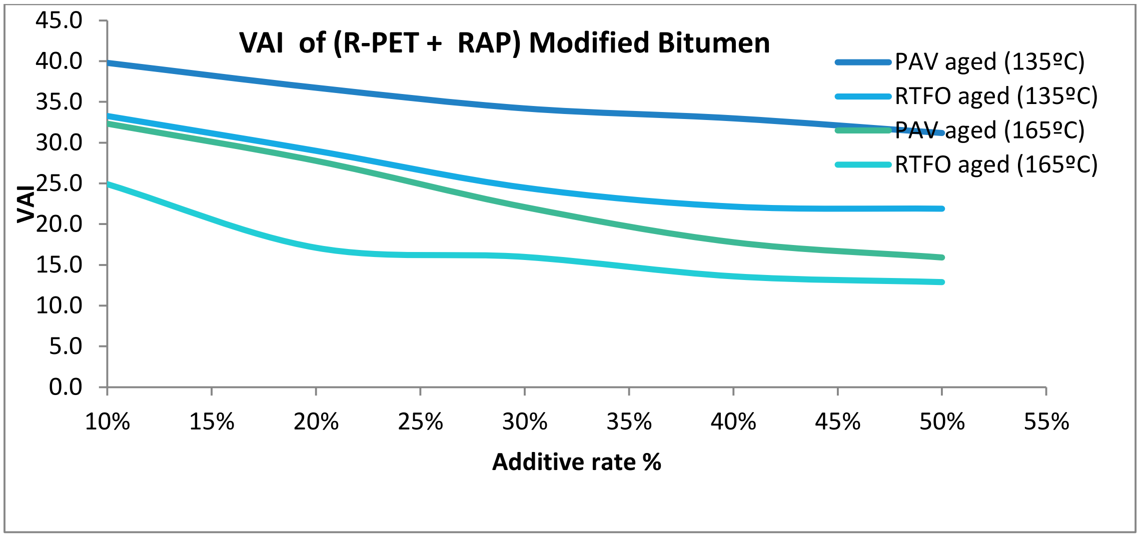


Figure 4.19:ViscosityAging Index,VAI of W-PETMB + RAP binder

Figure 4.19 shows that Viscosity ageing index decreases with the addition of RAP binder in the Waste PET modified binder.

4.7 FOURIER TRANSFORMED INFRARED SPECTROSCOPY

Figure 4.20 and 4.21 shows the IR spectra of neat asphalt binder and asphalt binder modified with Waste Polyethylene terephthalate PET and then WPET Modified binder along with different content levels of RAP binder. While looking at the spectrum of virgin binder we can see the peak in the area of 3100 to 3500 which indicates that there is OH stretching of alcohol group. There are peaks observed in the region at 2919 and 2848refers to the stretching of C-H aliphatic alkanes while peak at 1615corresponds to C=C stretching of aromatic. Peaks in the region of 1720-1750 shows the C=O functional group of Carbonyl. Peak at 1453 and 1102 depicts C-H bending group pertaining to alkane and C-O stretching of secondary group of alcohol respectively. The area between 1072-1035shows the strong S=O stretching of sulfoxide related group. Peaks in the region between 887 and 817 mention to C=C bending of alkene group and peak at 775 indicates C-S or C-H bending. While looking at the IR spectra of Waste PET modified binder with RAPasphalt binder, small or no noticeable change of peaks has been observed. It validates that the modification of asphalt binder with Waste PETthen with Waste PET modified binder with RAP binder is entirely physical in manneras chemical arrangement remain constant.

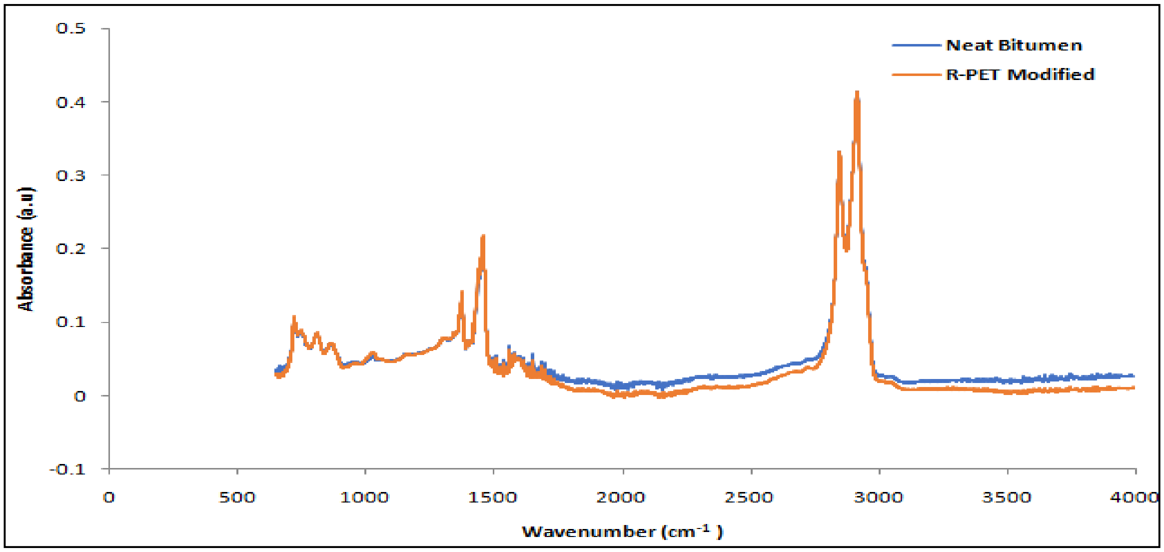


Figure 4.20:IR Spectra of Neat and W-PET modified Asphalt binder

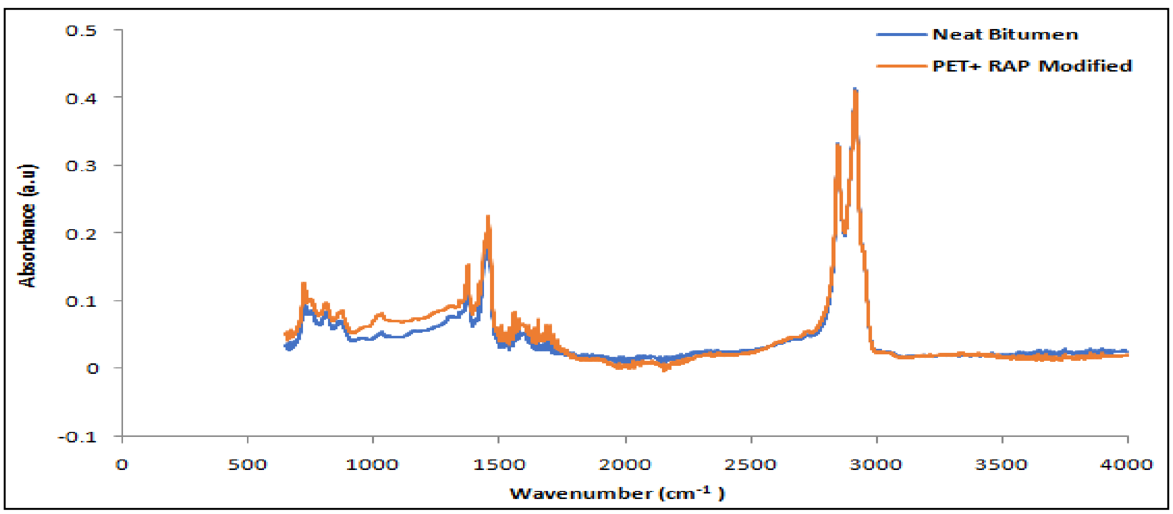


Figure 4.21:IR Spectra of Neat and W-PETMB+RAP binder

Now when we compare the spectrum of neat and modified asphalt binder after aging, we can clearly see that the addition of Waste PET and PMB with reclaimed asphalt pavement binder hinders the oxidation rate which can be seen as the reduction in carbonyl and sulfoxide regions of two modified samples of asphalt binders with respect to original binders in figure 4.21. It is also studied from the previous literature view that S=O and C=O are mainly two functional groups which are responsible for asphalt binder hardening. From the results obtained in the FTIR spectroscopy of modified binders it is concluded that the wastePET and RAP binder are good additives to have improvement in the anti-aging properties of asphalt binder.

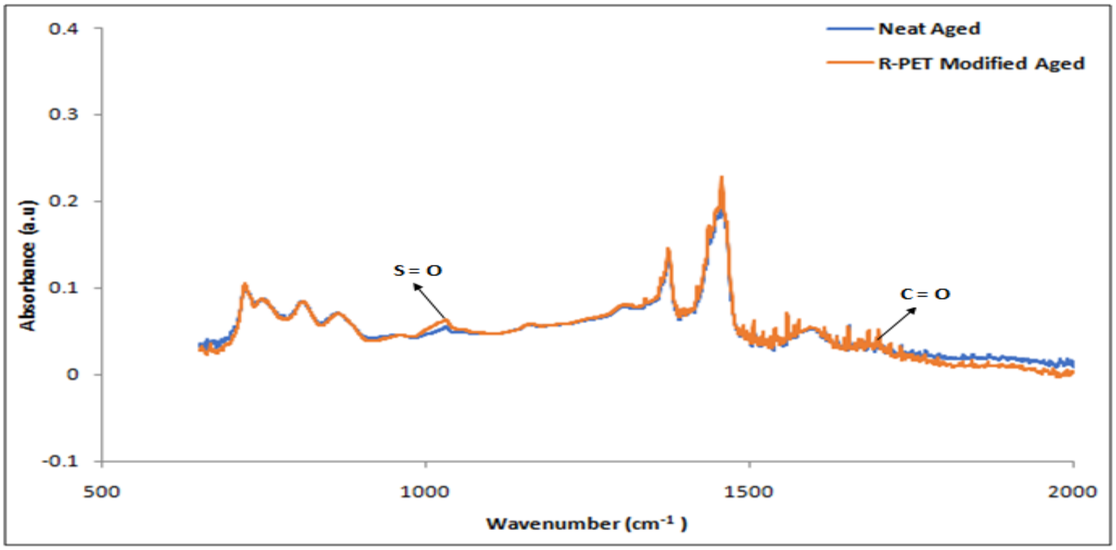


Figure 4.22:IR Spectra of Neat and W-PETMB after RTFO

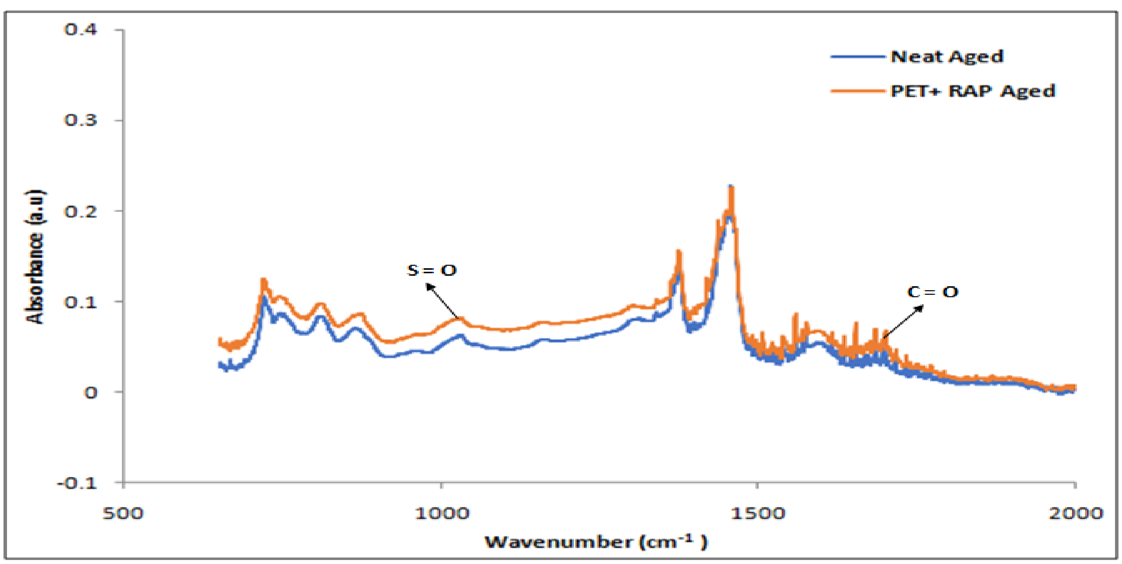


Figure 4.23:IR Spectra of Neat and W-PETMB +RAP binder after RTFO

Lamontagne computed structural index by summation of peak of targeted functional group numerically and then dividing it by entire region between 600 cm-1 to 2000 cm-1. Carbonyl and sulfoxide can be calculated by using the following formula[41].

$$\text{Carbonyl Index} = \frac{A_{1750}}{\sum A}$$

$$\text{Sulfoxide Index} = \frac{A_{1030}}{\sum A}$$

Structural index after the RTFO aging are presented in table 4.13 and figure 4.24. Carbonyl and sulfoxide index of the Waste PET and RAP modified binders decreased in comparison to virgin binder. Carbonyl index decreased by 16% in case of 5% W-PET modified binder however it decreased by 12% with introduction of RAP Binder. Similarly, sulfoxide index has been decreased by 33% and 30% in case of W-PET and RAP binder respectively. This decrease in the structural index indicate the higher capability of the additives for resistance against oxidation in asphalt binder.

Table 4.13:Structural Index after RTFO aging

STRUCTURAL INDEX		
Sample	**Carbonyl Index**	**Sulfoxide Index**
Virgin 80/100	0.050	0.054
Virgin + 5% PET	0.042	0.036
WPMB+30%RAP	0.044	0.038

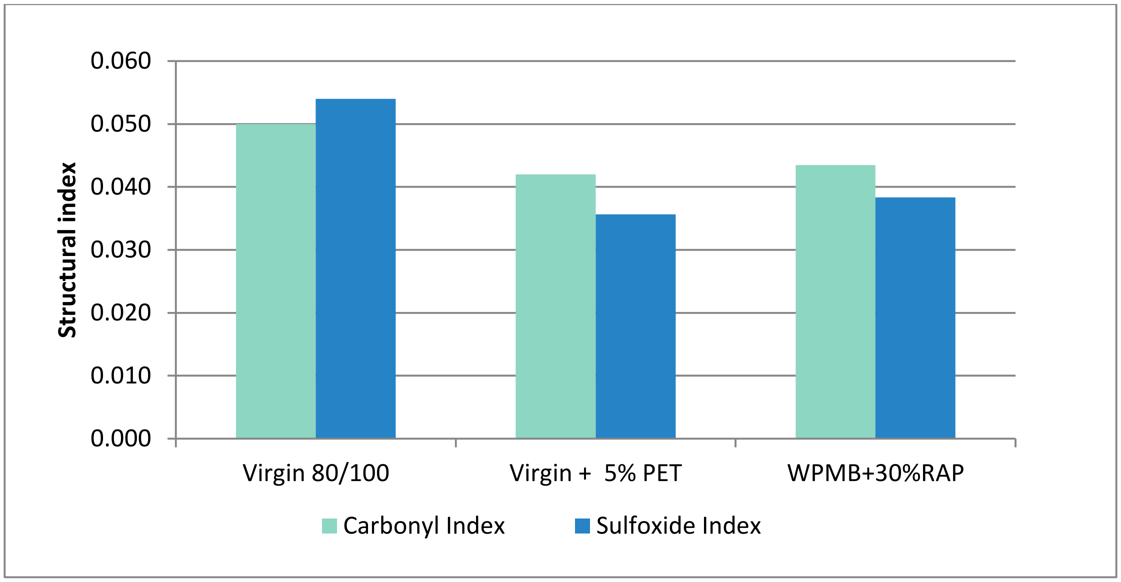
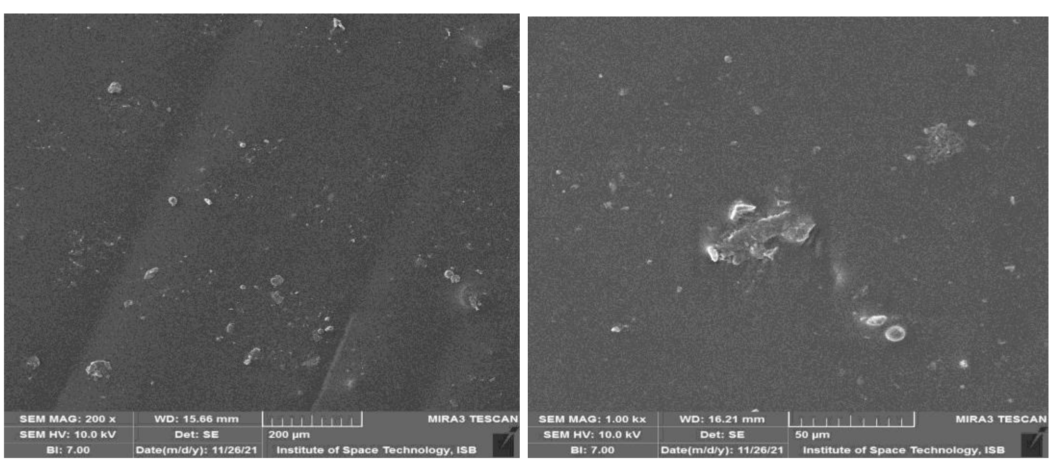


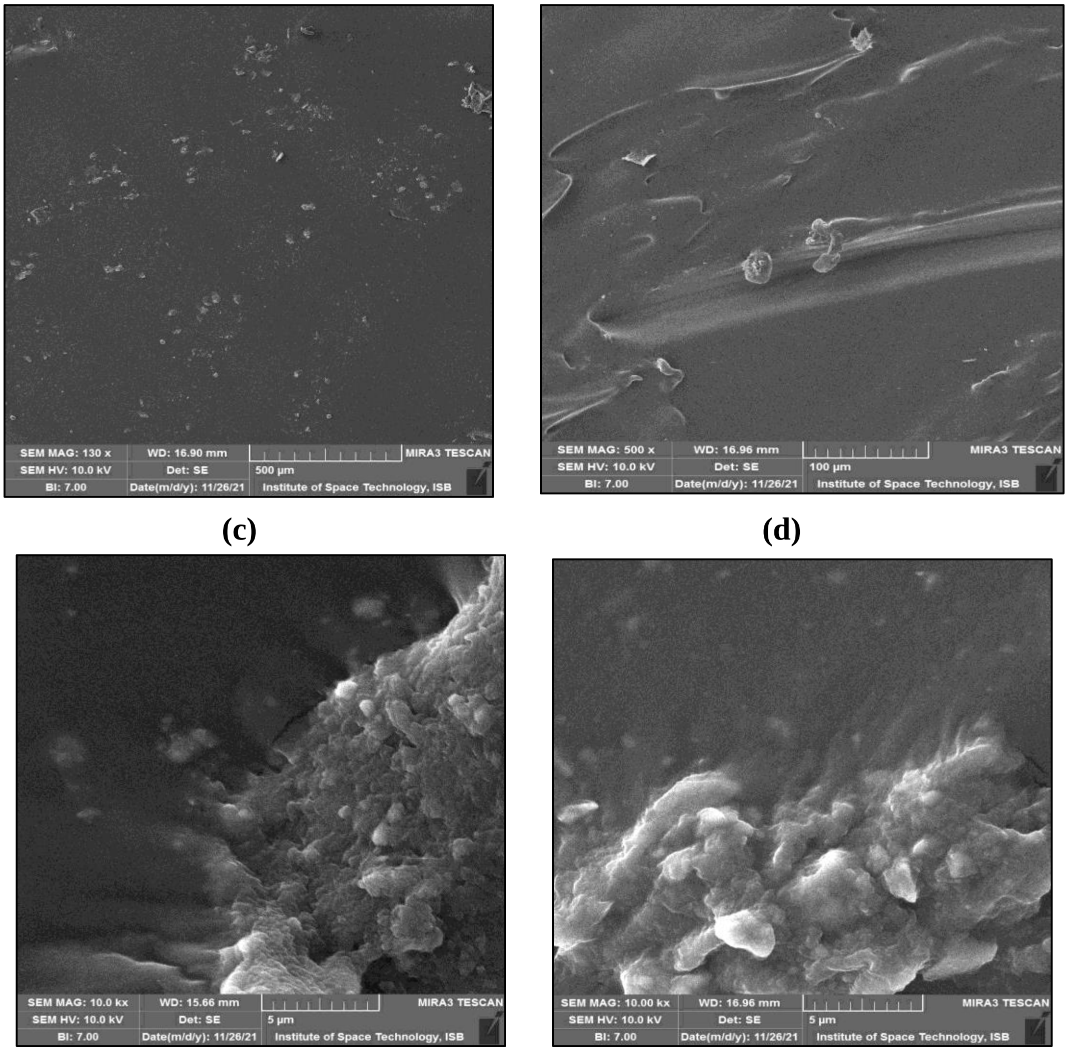
Figure 4.24:Structural index of neat and modified binders after RTFO

4.8 SCANNING ELECTRON MICROSCOPE(SEM)

SEM was performed to check the changes in chemical structure and homogenous dispersion of additives introduced in asphalt binder. As PET is a polar polymer, its dispersion in asphalt binder is purely physical in nature. Asphalt binder basically has black color while white spots show the presence of additives i.e. Waste PET and RAP binder. It is clear from the SEM images in figure 4.25 that with the addition in content of Waste polyethylene terephthalate and RAP binder, the white area is increasing.



(a) **(b)**



(c) **(d)**

(e) **(f)**

Figure 4.25:SEM images(a) 5% PET unaged, (b) 5% PET aged, (c) 30% RAPunaged, (d) 30% RAP aged, (e) 5% PET 5µm, (f) 30% RAP 5µm

It can be seen in the above images that surface of both waste PET modified asphalt binder RAP modified asphalt binder is rough. Tiny particles of PET and RAP binder either enflamed or dispersed in the base asphalt binder can be viewed in SEM images of 5%PET modified binder and 30%RAPasphalt binder. These imageries also depict that that asphalt binder is uniform thus it represents the compatibility of additives with asphalt binder.

At the same rate of additives, normally the surface area of both PET modified asphalt binder and then PET modified binder with RAP binder with different content levels, is rough. The particle size of both waste PET modified binder and then PET modified binder along with RAP binder is almost the same and during the blending the particles of PET modified binder and W-PET modified Binder with RAP surface has been observed with small irregularities. So, it can be determined that PET modified binder and RAP binder are compatible with each other.

4.9 COST COMPARISON

One kilometer of road section is assumed for the cost comparison of virgin mix and modified mixture containing 30% RAP binder and 5% W-PET binder. Standard lane width of 3.65 meters was assumed here with thickness of 50 mm. Cost for the lower layers i.e. base and subbase and then cost of the subgrade was completely ignored as they were assumed of having same properties for both the mixtures. Cost of filler material, aggregates water and furnace oil is assumed to be constant as we have only evaluated the binder properties. Moreover, cost of only HMA surface course is reflected in this comparison. NHA class A asphaltic concrete has been taken in this comparison. Volume of mix of HMA surface course required for 1Km in Punjab region as per NHA CSR 2014 is 188 cubic meter. For estimation of cost, quantities and rates given in Composite Schedule Rates (CSR2014) of NHA is used.

4.9.1 Cost Estimation

Cost Estimation was done for virgin and modified HMA.

4.9.1.1 Virgin HMA

Volume of Mixture required for 1Km road section=188CM

Table 4.14:Cost Estimation of 1Km road section

ITEMS					Amount(Rs)
Manpower charges for laying of 1 Km HMA					**23,075.20**
Material					
Code	**Description**	**Unit**	**Quantity**	**Rate(Rs.)**	**Amount(Rs.)**
2024	**AGGREGATE1.1/2"-3/4"**	CM	28.88	920.95	26,597.04
2025	**AGGREGATE3/4"-3/8"**	CM	86.63	1119.62	96,992.68
2026	**AGGREGATE3/8"-No.4**	CM	57.75	744.35	42,986.21
2027	**AGGREGATENO.4-NO.200**	CM	96.60	597.77	57,744.58
2028	**FILLERMATERIAL**	CM	18.90	608.37	11,498.19
2041	**ASPHALTGRADE 80/100**	CM	20.19	83967.89	1,695,311.70

2065	**WATER**	1000LIT	4.00	100.00	400.00
2116	**FURNACE OIL**	LIT	5400.00	79.44	428,976.00
					2,360,506.40
Equipment Charges					**529,219.08**
Overhead Charges					3,873.41
	Total				**2,912,800.6832**

4.9.1.2 Modified HMA (30%RAP binder and 5%W-PET)

Volume of Mixture required for 1Km road section=188CM

Table 4.15:Cost Estimation of 1Km road section modified with W-PET and RAP binder

ITEMS					**Amount(Rs)**
Manpower charges for laying of 1 Km HMA					**23,075.20**
Material					
Code	**Description**	**Unit**	**Quantity**	**Rate(Rs.)**	**Amount(Rs.)**
2024	**AGGREGATE1.1/2"-3/4"**	CM	28.88	920.95	26,597.04
2025	**AGGREGATE3/4"-3/8"**	CM	86.63	1119.62	96,992.68
2026	**AGGREGATE3/8"-No.4**	CM	57.75	744.35	42,986.21
2027	**AGGREGATENO.4-NO.200**	CM	96.60	597.77	57,744.58
2028	**FILLERMATERIAL**	CM	18.90	608.37	11,498.19
2041	**ASPHALTGRADE 80/100**	CM	13.123	83967.89	1,101,658.72
2065	WATER	1000LIT	4.00	100.00	400.00
2116	FURNACE OIL	LIT	5400.00	79.44	428,976.00
					2,360,506.40
Equipment Charges					**529,219.08**
Overhead Charges					3,873.41
Crushing of plastic bottles(Waste PET)					4000
Recovery of Asphalt from RAP					100000
Transportation charges of RAP					**3000**
	Total				**2,430,021.1109**

The difference between the construction cost of both virgin HMA and HMA modified with RAP binder and waste PET per kilometer per lane (3.65 m) for 5 cm thickness of road section is presented in Figure4-26which shows that HMA will result in the cost saving of approximately16.55 %, that is only the monetary advantage during construction besides other environmental benefits and enhanced/improved properties.

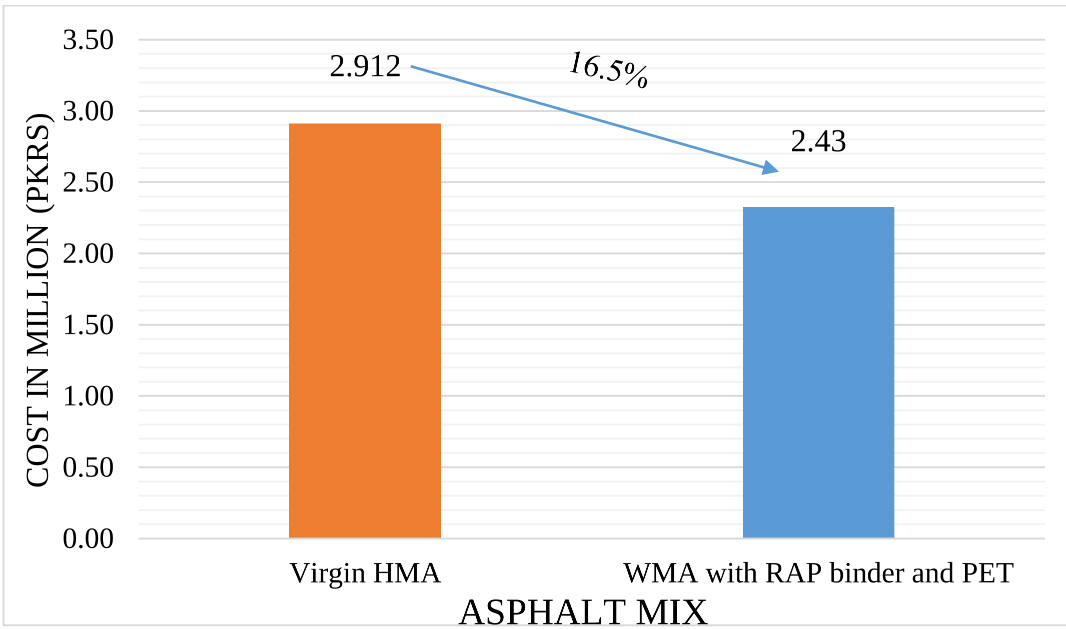


Figure 4.26: Cost Comparison

4.10 CHAPTER SUMMARY

This chapter is comprised of results of this study presented in the form of table and figures. Consistency analysis is done based on the results of penetration and softening point, penetration index (PI) is established. Ductility test was performed and DRR was determined. Viscosity test was also performed to obtain Viscosity ageing index. Results before and after RTFO are compared to obtain the best possible blend of modifier and asphalt binder. Chemical and morphological analysis is done using FTIR and SEM. Functional groups are assigned to relative peaks from IR spectra. Morphological analysis shows good compatibility of Waste PET and RAP binder with asphalt binder.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

Present study was conducted to determine the effect of Waste polyethylene terephthalate and reclaimed asphalt binder effect on the physical, chemical and performance properties of PARCO 80/100 grade asphalt binder. Increase in the performance properties of Asphalt binder increases the service life of roads. To analyze the effect of Waste PET and RAP binder on the Performance Grade of Asphalt binder, performance testing of modified and unmodified asphalt binder were carried out. The key findings based on the performed laboratory testing are concluded in this chapter.

5.2 CONCLUSIONS

After successful completion of extensive lab testing, carried out in an effort to obtain the targeted objectives of this research work, following conclusions can be drawn based on lab test result and logical observations.

- Results indicate that the addition of waste polyethylene terephthalate and RAP binder improved the physical properties of binder for both unaged and aged conditions.
- Penetration value of the W-PET modified binder decreased and softening point increased which indicate high resistance of the modified binder against rutting.
- W-PET modified binder along with RAP binder showed a considerable increase in the penetration value and decrease in the softening point. This depicts the plastic behavior of modified asphalt along with RAP binder. However, after the aging, the binder behaved more like a stiffer material in comparison with the neat binder and hence high temperature cracking resistance of the W-PET modified binder along with RAP binder increased.
- Penetration aging ratio decreased by 13% for W-polyethylene terephthalate Modified Binder and 21% for W-PET modified Binder along with RAP binder after the short term aging which indicate binders improved resistance to oxidative aging.

- Penetration index of all modified binder before and after aging is within the permissible limit of -2 to +2 for road paving applications. Moreover, PI of all modified binder is greater than the neat asphalt binder which indicate improved temperature susceptibility of the modified binders.
- Ductility value is decreased with the increase in percentage of waste PET and RAP binder but the DRR increased which represented that the addition of PET and RAP binder can reduce deterioration in ductility of asphalt during aging.
- Viscosity increases with the increase in the percentage of W-PET. Viscosity of W-PMB along with RAP binder also increases with the increase in the concentration of RAP binder
- Viscosity aging index of W-PETM binder and W-PETMB along with RAP binder decreases with the increase in W-PET and RAP binder respectively which indicate that they have better antiaging property
- FTIR results show that the addition of W-PET and RAP binder into neat binder is purely physical in nature.
- Results indicate decrease in carbonyl and sulfoxide index with respect to neat binder after the RTFO which indicate improvement in aging resistance.
- Morphological analysis carried out by SEM shows the compatibility of the Waste PET and RAP binder with the neat asphalt binder.
- Cost analysis of HMA with virgin binder and when quantity of binder in HMA is replaced with 5%PET and 30% RAP binder shows cost saving of approximately 16.5% which is monetary benefit besides other.

5.3 RECOMMENDATIONS

- This research is limited to only binder related study, more work has to be carried out to evaluate RAP and waste PET in asphalt mixture studies to establish their suitability for field tests
- More work should be done in carrying out performance testing such as Rutting, Fatigue, Marshall Stability, wheel tracking test etc.

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